2.0 State of the Bay—Ecosystem Resources

The structure and function of the San Diego Bay ecosystem and what we do and do not understand about its condition are the subjects of this Chapter. Component by component, the elements that make up the ecosystem are discussed—climate, hydrology, water, sediment, then habitats and the communities that inhabit them. Finally, the state of the ecosystem as a functional whole is presented, along with an assessment of the gaps in our understanding about the state of the Bay.

Photo 2-1. South Bay Mudflat Adjoining Northernmost Levee of Salt Works.

2.1 Ecoregional Setting

A natural, nearly enclosed embayment, San Diego Bay is an exceptional harbor because of its deep entrance and protected conditions. It originated from alluvial plains of the Otay, Sweetwater, and San Diego Rivers. Southern California bays and estuaries are small compared to those along the east coast and elsewhere. San Diego Bay is unusual among the world's river-dominated estuaries because it receives minimal freshwater input and has a high evaporation rate, similar to estuaries of South Africa (J. Largier, Scripps Institute of Oceanography, pers. comm.).

- The Bight is a very diverse and productive ecological region, where temperate and tropical species overlap.

The Bay is part of the Southern California Bight (SCB or "the Bight"), a curve in the southwestern California coastline that extends from Point Conception to just south of the Mexican border (Map 1-1). This ecological region is very productive and diverse for several reasons. First, for marine animals, this area represents the northern end of the range of many tropical species, and the southern end for many temperate species. Point Conception marks a sharp break in sea temperatures. Points north are cooler and just south of the Mexican border temperatures become warmer.

Second, the Bight is the landfall terminus of the very complex, Pacific Ocean underwater topography—especially when compared to the long, flat shelf extending seaward from the south Atlantic coast. A system of thirteen large and nineteen smaller submarine canyons, as well as offshore islands, provides habitat for a full range of species with different depth and temperature preferences. Special communities such as kelp beds add habitat structure in shallow water, fostering a rich species assemblage.

- Embayments in the Bight contain intertidal habitat required by a number of species. This habitat is scarce in southern California.

Third, the SCB contains both cool and warm water due to ocean currents mixing from subarctic and equatorial regions. Sea temperatures fluctuate regularly due to the changing strengths of these currents. These changes are reflected most by plankton and to a varying degree are transferred up the food chain.

Finally, the Bight's embayments, including San Diego Bay, contain intertidal habitat required by a number of species, and which is naturally scarce in southern California (compared to the east and gulf coasts, for example). These ecological "edges" are even more limited today due to commercial development in other harbors and estuaries of the Bight, such as the largest one at San Pedro.

2.2 Physical Conditions

2.2.1 Climate and Hydrography

San Diego Bay experiences an average annual rainfall of about 10 inches (in) (25 centimeters [cm]), occurring mostly from November through March. Evaporation exceeds rainfall throughout most of the year. The regional climate is classified as semiarid, Mediterranean.

Winds over the Bay are usually breezy (about 10 knots [kn]), but these have some strong seasonal and diurnal cycles. Throughout most of the year, westerly winds pick up in the afternoon as cool air moves inland; evening and early morning easterly winds occur primarily in winter and are less than 10 kn (Wang *et al.* 1998). Stronger winds may occur in winter, associated with cold fronts moving through the region. Easterly Santa Ana winds may be quite strong in the fall, driven by high pressure over inland deserts. Winds are generally greater south of the Coronado Bridge than north of it, with greatest wind speeds in central south Bay, west of Sweetwater Channel (Lapota *et al.* 1993).

- Productivity of the Bay is dependent upon the source and vertical stratification of nutrients and the attenuation of light with depth.

The combination of nutrient sources, vertical nutrient gradients, warm spring–summer temperatures, and the attenuation of light with depth in San Diego Bay is fundamental to its productivity.

The Bay is 15 miles (mi) (24 kilometers [km]) long and varies from 0.2 to 3.6 mi (0.4 to 5.8 km) in width. It is about 17 square miles (mi^2) (43 square km [km^2]) in area at mean lower low water (MLLW) (Wang *et al.* 1998). A sand spit, deposited by a northward-bound eddy of the coastal current on the west, separates the Bay from the sea. Historically, the sand transported in this way was laid down from deposition emanating from the Tijuana River. However, since the damming of the river in 1937, the sand supply has been cut off and northern beaches have undergone severe erosion (Peeling 1975). Zuniga Jetty, which runs parallel to Point Loma at the Bay's inlet, was built to control erosion near the inlet, changing the Bay's hydrodynamic characteristics by diverting both northward-bound sediment and currents (Wang *et al.* 1998). Broad lowlands extend about 1.5 mi (2.4 km) south and east from the bay, before rising up into the coastal terrace, or mesa, that supports urban San Diego. Rugged Point Loma hooks around the north side, cutting off the ancient floodplain of the San Diego River, which throughout its evolution alternatively drained into San Diego or Mission Bays.

- The Bay has always had a narrow, natural channel deepening at the mouth. Its area has been reduced and depth increased over the past century due to dredging and filling.

With a water volume of about 230,000 cubic meters (m^3) (Peeling 1975), the Bay's depth ranges from 59 feet (ft) (18 meters [m]) near the mouth to less than 3 ft (1 m) at the south end. It has an average depth of 21 ft (6.5 m) measured from mean sea level (Wang *et al.* 1998). There has always been a narrow, natural channel deepening at the mouth, possibly cut by river floods at a time when sea level was much lower (Peeling 1975). This channel has been and continues to be deepened by dredging for safe passage of ships seeking sheltered anchorage at port. Prior to major filling activities, which began in 1888 and intensified just before and during World War II, the Bay had an area of 21 to 22 mi^2 (54 to 57 km^2), as defined by the mean high tide line of 1918. About 6 mi^2 (15.5 km^2) of the Bay has been filled based on this high tide line, or about 27% (Smith 1976). Map 2-1 shows the recent topography of the Bay floor, while Map 3-1 shows the historic habitat breakdown, based on an 1859 chart. Note the natural channel in Map 3-1. Map 2-2 shows the cumulative history of dredge and fill activity. Only 17 to 18% of the original Bay floor remains undisturbed by dredge or fill (Smith 1976).

- Inflow of fresh water into the Bay estuary comes from seven streams and surface drainage. Historically intermittent, streams now have about 3/4 of their flow diverted before reaching the Bay.

Freshwater contribution comes primarily from the Otay and Sweetwater Rivers, but also Telegraph Canyon (south of Sweetwater River Basin), Chollas (north end of Naval Depot south of NASSCO), Switzer (Tenth Ave. Marine Terminal [north end]), Paleta (7th Street Channel, south of Naval Repair Base), and Paradise (south of Paleta) Creeks, as well as some minor drainage groups (Map 1-3). The first major reduction of freshwater input occurred when the USACOE diverted the San Diego River to Mission Bay in 1875. Later construction of dams and extensive groundwater use in the Sweetwater and Otay drainages reduced the already ephemeral input from those rivers by 76% (US Army Corps of Engineers 1973). Freshwater input is now limited to surface drainage from urban areas and intermittent flows from several rivers and creeks after storms. For about nine months of the year, the Bay receives no significant amount of fresh water. Evaporation approximately balances the freshwater input from all sources over the course of the entire year (Lackey and Clendenning 1965). During the summer, however, the evaporation rate of 62.7 in (159 cm)/year in south Bay is higher than precipitation and freshwater inflow (Peeling 1975; Lenz 1976). This can cause south Bay to become hypersaline, or saltier than seawater, in excess of 35% in dry seasons (Wang *et al.* 1998).

2.2.2 Sediment

Physical parameters, such as characteristics of the sediment, can explain the distribution and abundance of organisms, and sometimes changes in biotic populations that are closely tied to substrate. Sediment characteristics reflect hydrodynamic regimes and can also explain the fate and loading of contaminants. Map 2-3 shows percent fine sediments (silt and clay) on the Bay floor (593 data points compiled by Space and Naval Warfare Command [SPAWAR] from several sources).

Without human intervention, San Diego Bay would have eventually, in geologic time, filled up with sediment delivered by the San Diego, Otay, and Sweetwater Rivers. In addition, it is likely that the northward drift of beach sand that connected Coronado Island with the mainland, and Coronado and North Islands together, eventually would have blocked or nearly blocked the harbor entrance. Breakwaters, channel maintenance, and tidal action prevent this from occurring (Norris and Webb 1990).

- Mud layers on top of sand and sandy-silt along the eastern margins are removed during dredging, causing the sandier layers to be exposed.

Historically, the Bay floor and margins were characterized by sand, silt, clay, mud (silt and clay less than 62 microns in diameter), and mudstone. Sands were most common at the mouth and along the western margins, while finer mud deposits characterized the eastern margins and southern extremity of the Bay (Peeling 1975). According to studies in 1980 by the San Diego Gas & Electric Company (SDG&E), thickness of Bay floor muds average 0 to 7.8 ft (0 to 2.4 m). The mud sets upon layers of sand and sandy-silt, then on older semiconsolidated sediments. Dredging exposes these sandier layers.

- The diversion of the San Diego River and the damming of the Sweetwater and Otay Rivers has significantly reduced sedimentation sources into the Bay.

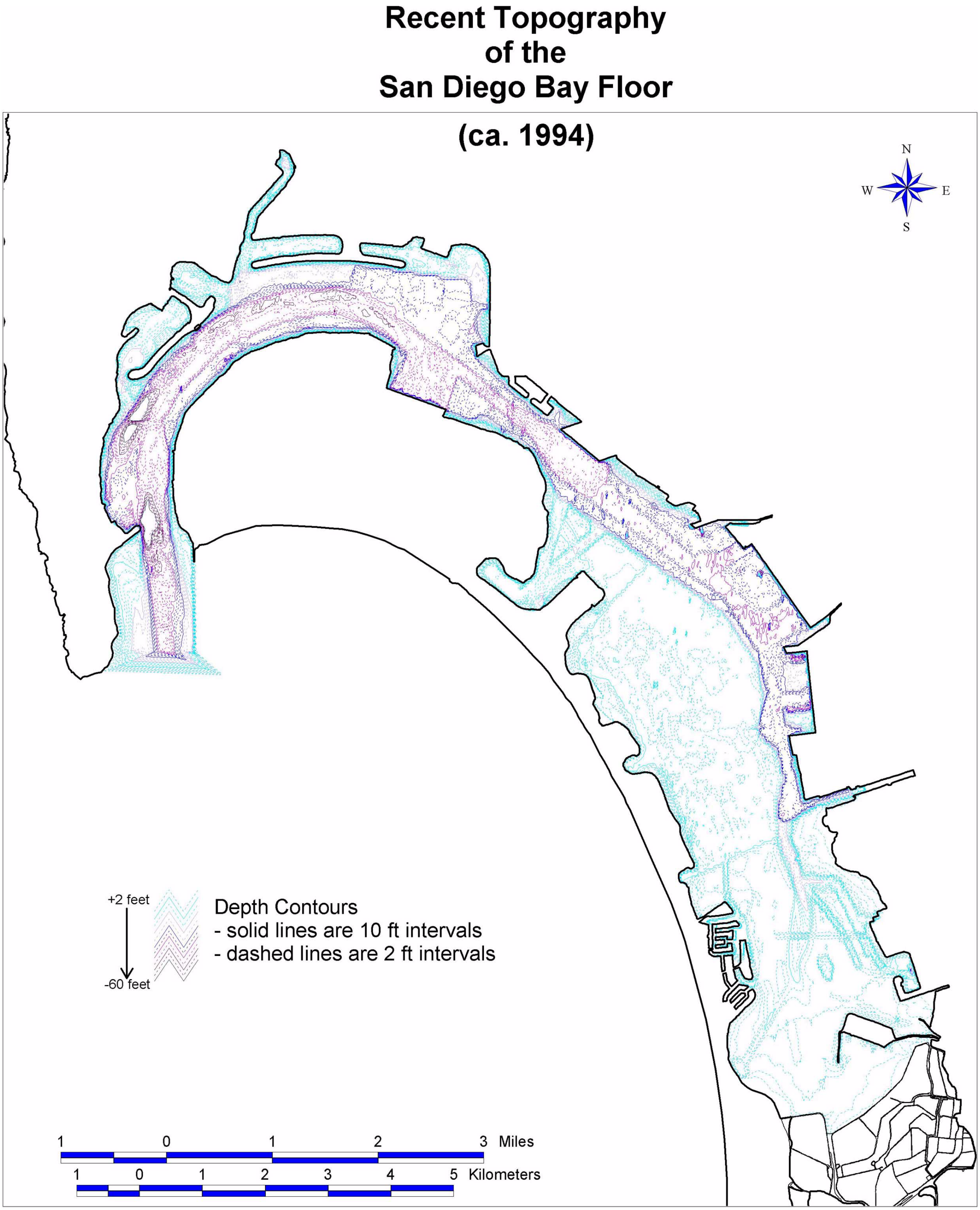
Present contribution of sediment from all potential sources is minimal. As described above for freshwater inflow, the major historic contribution of sediment was from the three major rivers plus smaller streams, which drained an area of about 900 mi^2 (2330 km^2). The current drainage area is 433 mi^2 (1122 km^2), since diversion of the San Diego River (Table 2-1). The total fluvial sediment delivered to the Bay was on the order of 0.8 to 1.1 x $10^6 m^3$ per year (Smith 1976). The San Diego River, alone, was estimated to have delivered about 3.8 to 5.3 x $10^5 m^3$ to the Bay annually (Smith 1976). As evidenced from the prominence of the San Diego River and other deltas, fluvial sediment was gradually filling the Bay until the late 1800s. The diversion of the San Diego River ended all sediment deposition from that river, and damming of the Sweetwater and Otay Rivers reduced sediment delivery by 75% (Smith 1976). The present-day sediment contribution from the undammed portions of the remaining drainages is estimated to be about 1.4 to 1.9 x $10^5 m^3$ per year (Smith 1976).

Table 2-1. Estimated trends in total fluvial sediment delivery to San Diego Bay (Smith 1976).

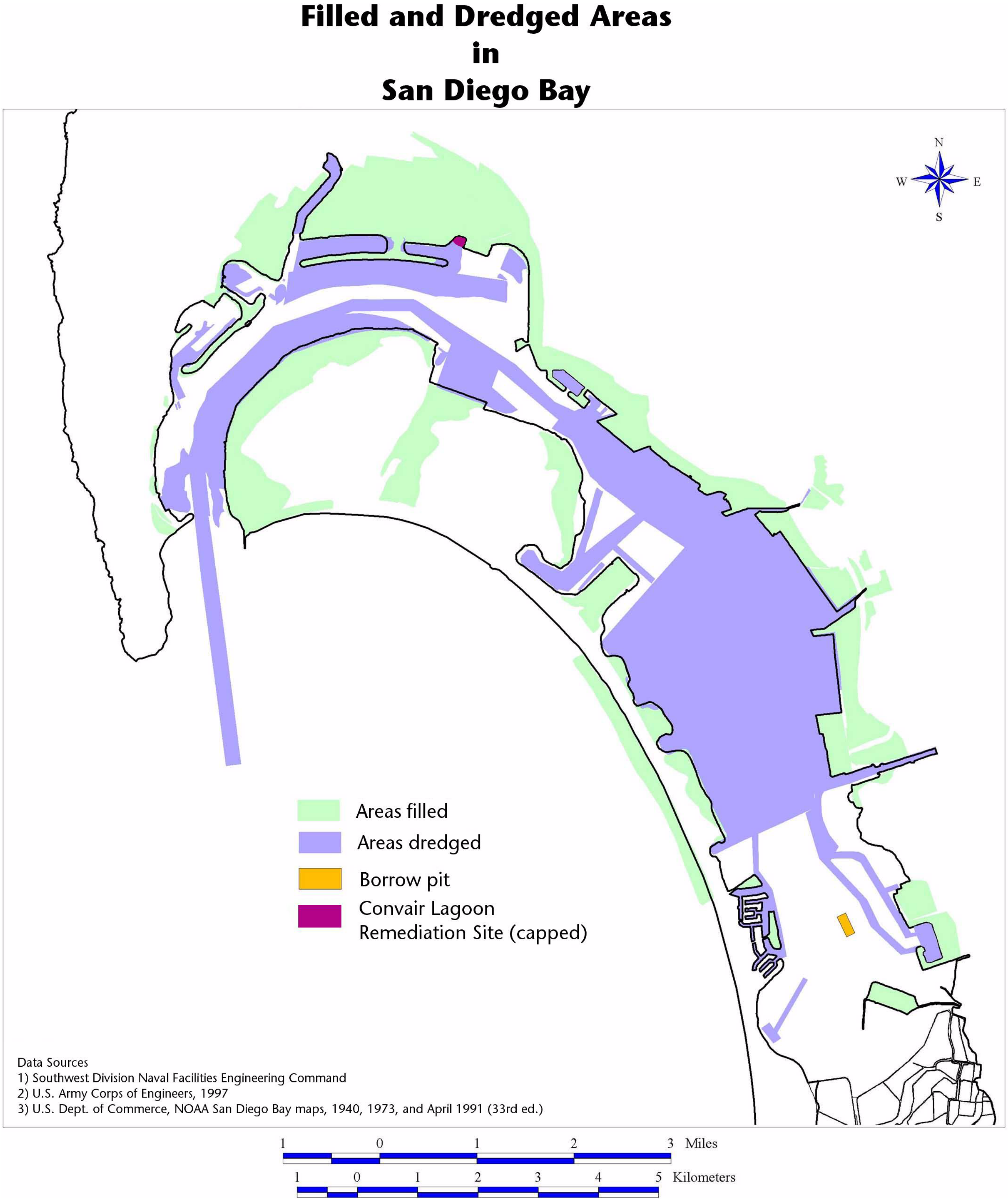
Drainage Extent	Drainage Area (km^2)	Annual Volume of Sediment Delivery (m^3)
Original	2330	800,000–1,100,000
Current (with San Diego River diverted, dams on Sweetwater, Otay, and other drainages)	1122	140,000–190,000

- Shoreline erosion is a minimal contributor of sediment to the Bay because of the amount of mooring and low potential for erosion of the remaining sites.

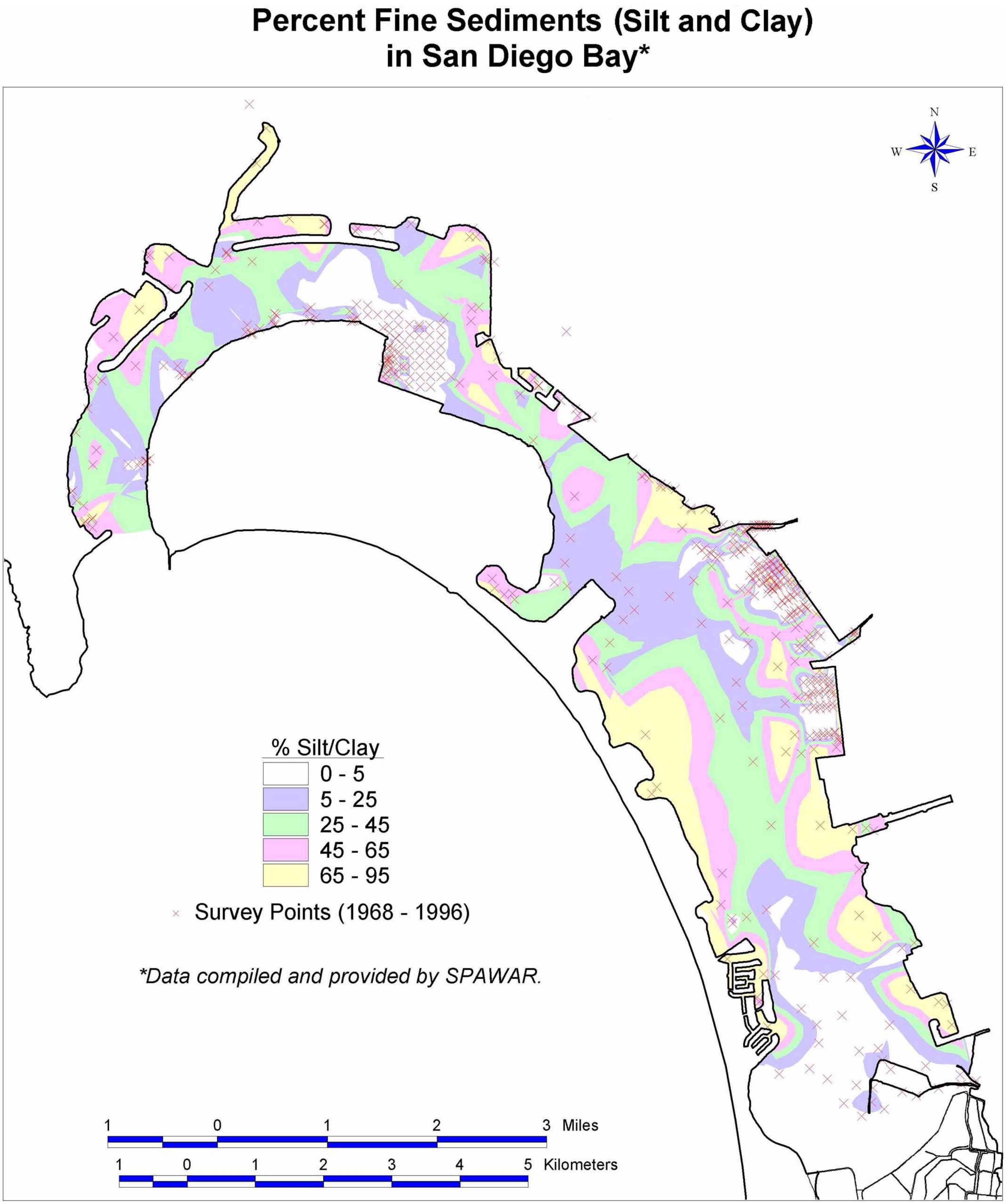
Some sedimentation would be expected from wave erosion of the Bay's shorelines. However, well over half of the shoreline is protected by piers, docks, bulkheads, revetments, and riprap. The remaining unprotected shoreline is predominantly on the lee side of prevailing winds (the western shoreline). As a result, only about 18 to 20% of the unprotected shoreline and 7% of the overall Bay shoreline appears subject to significant erosion; therefore, unprotected shoreline is a minimal potential contributor of sediment to the Bay (Smith 1976).



Map 2-1. Recent Topography of San Diego Bay Floor.



Map 2-2. Cumulative History of Dredge and Fill Activity in San Diego Bay.



Map 2-3. Percent Fine Sediments (Silt and Clay) on the Bay Floor.

- Maintenance dredging needs are relatively low due to the severely reduced sediment input to the Bay.

During the century prior to the 1960s, when more rigorous regulation went into effect, the annual dredging rate averaged 3.3 to 4.7 x $10^6 m^3$, which is three to six times the former yearly sediment input. This annual dredging rate is roughly seventeen to 34 times the current yearly sediment input to the Bay. The severely reduced sediment input to the Bay is further confirmed by the unusually low volume of maintenance dredging conducted in interior channel areas (Smith 1976).

2.2.3 Water

2.2.3.1 Turbidity

Waters of the Bay become more turbid, or less transparent, as distance increases from the entrance. In the shallow, wider south end of the Bay, where a longer fetch is possible, persistent wind and wave action cause a marked increase in turbidity during the winter and early spring. The wind is able to scour up the finer sediments of this region at that time of year. Water is then clearer in the fall months (Lapota *et al.* 1993).

2.2.3.2 Circulation, Temperature, and Salinity

Circulation of ocean currents outside the Bay affects organisms having access and entry to the Bay. The ebb and flood of tides within the Bay circulate and mix ocean and Bay waters, and also transport organisms, especially plankton, in and out of the entrance. Tides produce currents, induce changes in salinity, and alternately expose wet portions of the shoreline. Tidal flushing and mixing are important for dispersing pollutants, maintaining water quality for marine life, and moderating water temperature that has been affected by exchange with the atmosphere or heating, such as by the south Bay power plant.

- Tidal exchange in the Bay exerts control over the flushing of contaminants, transport of aquatic larvae, salt and heat balance, and residence time of water.

Bay circulation may be driven by wind, tides, temperature, and density gradients associated with seasonal, tidal, and diurnal cycles. In San Diego Bay, circulation is primarily related to tides, because winds are of mild magnitude and there is a low fetch area (Wang *et al.* 1998). Tidal patterns off this coast are mixed, with two unequal highs and lows each day. The diurnal difference in the high mean higher high water (MHHW) and low MLLW tides is 5.6 ft (1.7 m), with extremes of 9.8 ft (3 m) (Largier 1997). The tidal prism, or the volume of water contained between the tides, is about 73 x 10^6 m^3 (Gautier 1972). Highest tides are in January and June. Tidal exchange in the Bay exerts control over the flushing of contaminants, transport of aquatic larvae, salt and heat balance, and residence time of water (Chadwick 1997).

- Tidal velocity decreases with distance from the Bay's mouth.

Tidal current velocities range from 0.6 to 2.7 ft/sec (0.2 to 0.8 m/sec) at the mouth (Gartner *et al.* 1994) to much lower in central and south Bay. Velocities at depth lead velocities at the surface during flood tides by 30 to 90 minutes (Chadwick *et al.* 1996). Variations in velocity are due to variations in depth and width of the Bay as the tidal prism moves southward, the presence of side traps such as marinas and basins, and the general reduction in velocity with distance from the entrance (Largier 1997). Longitudinal tidal currents will still, however, exceed the strength of wind and wave action, except during periods of high winds (Falter 1971; SDG&E 1980).

- Thermal gradients are common in the summer but absent in the winter due to wind and cooling.

Temperature and density gradients, both with depth and along a longitudinal cross-section of the Bay, drive tidal exchange of Bay and ocean water beginning in the spring and continuing into fall. The seasonal thermal cycle has an amplitude of about 46 to 48° F (8 to 9° C) (Smith 1972). Maximum water temperatures occur in July and August, and minimums in January and February. In the winter, thermal gradients are absent, with cooler air temperatures and higher winds causing the Bay to be nearly isothermal (Smith 1972). During 1993 surveys, the warmest temperature was 84.7° F (29.3° C) in south Bay, and the coolest temperature, 59.2° F (15.1° C), was just north of the Coronado Bridge in January (Lapota *et al.* 1993). The average surface temperature is estimated to be 63.3° F (17.4° C) (Smith 1972). Smith (1972) also found maximum vertical temperature gradients of about 0.3° F/ft (0.5° C/m) during the summer. Typical longitudinal temperature range is about 45 to 50° F (7 to 10° C) (about 0.3 to 0.5° C/km) over the length of the Bay (Largier 1995) during the summer. Temperature inversions also occur diurnally due to night cooling.

- Salinities in south Bay are greater than in the ocean in late summer, but can be lower in the winter following rain and runoff.

Salinities near the Bay entrance approach those of the nearby open ocean (31.2 to 31.4 practical salinity units [psu] [Largier 1997]). In contrast, south Bay evaporation and poor flushing produce salinities as high as 37 psu in late summer (Ford 1968; Ford and Chambers 1973), decreasing to lows of 22 psu following heavy rains (Largier 1997). This summer occurrence of hypersalinity in south Bay may lead to stratified, density-driven flushing in the fall. This process moderates the build up of hypersaline conditions in south Bay (Largier 1997).

Within tidal cycles, the temperature stratification builds up during the flood tide and weakens with the ebb tide. The thermal exchange that occurs at the mouth of the Bay when sea water is mixed with warmer Bay water is complicated by salt gradient-driven flows of south Bay water seaward, beneath the less dense water of the surface. As described above, the importance of this stratification depends on the state of the tide, the strength of the wind, and time of year. Estimates of the tidal exchange ratio at the Bay entrance (the proportion of water coming in the Bay with the flood tide that is new oceanic water versus recycled Bay water) range from 0.5 to 0.7 (Fischer *et al.* 1979; Largier 1995; Chadwick and Largier 1997).

- The Bay's flushing rate has been reduced due to the reduction in the tidal prism volume and increased depth.

The marked reduction in area of the Bay from its historical dimensions has reduced the volume of the tidal prism by roughly 25%, and it is probably this reduction combined with increased depth that has reduced the flushing rate (Smith 1976). Another estimate of this reduction is 30% (Browning *et al.* 1973), while Largier (1997) places it as 33% the volume of the tidal prism. It is also likely that the Bay's circulation pattern has been modified by this change in geometry (Smith 1976).

2.2.3.3 Residence Time of Water

Flushing rates change drastically as one moves away from the Bay entrance. Longest residence times are observed in the summer, apparently related to the density stratification of the Bay at that time (Chadwick 1997). The amplitude of the tidal cycle also affects the flushing rate. During a *strong* tidal cycle, up to 40% of the mean volume of the Bay passes Ballast Point during the ebb flow, at least temporarily residing outside the Bay. During an *average* tidal cycle, the volume of water leaving the Bay is about 13%. This Bay water mixes with ocean water. During the next flood tide, this mix gets pulled back into the Bay. While the residence time of water near the northern inlet of the Bay is short, it can take from ten to 100 days for water in the Bay as a whole to be exchanged, depending on the tidal amplitude. Residence times in south Bay may be twenty to 300 days (Chadwick 1997).

- During an average tidal cycle, about 13% of the Bay's water leaves the Bay and mixes with ocean water before returning on the next tide.

Taking into account this mixing, Map 2-4 shows the half-life of water residing in the Bay with different tidal amplitudes. The actual process is somewhat more complicated, with warm, less dense water moving out of the Bay as a jet near the surface. Colder, denser water moves in as a front at greater depths. The data are based on a two-dimensional hydrodynamic model (depth is not considered), validated with salinity and temperature correlations (data and graphics provided by Don Sutton and John Helly of the San Diego Supercomputer Center).

2.2.3.4 Hydrodynamic Regions of the Bay

Based on the factors described above, Largier (1996, 1997) described four hydrodynamic regions of the Bay:

1. **Marine Region.** Circulation in the marine region is dominated by tidal exchange with the ocean. In San Diego Bay, this area of efficient flushing is within perhaps 3 to 4 mi (5 to 6 km) of the entrance, reaching almost to downtown. Residence time of Bay water is just a few days. The net result of these circulation patterns in the Bay is the presence of cold, clean ocean water at depth, explaining the Mussel Watch Project result that mussels at the mouth of the Bay are the cleanest in the county (Largier 1996, 1997). (See Section 2.8.2 "What We Currently Understand About Bay Ecosystem Health" for more on Mussel Watch.)
2. **Thermal Region.** In the thermal region, still in north Bay but extending to approximately Glorietta Bay, currents are driven primarily by surface heating. The vertical exchange of water results from entry of a cold, oceanic plug at depth with the flood tide, then the receding of warm, Bay surface water with the ebb tide.
3. **Seasonally Hypersaline Region.** Between about Glorietta Bay and SMNWR is a seasonally hypersaline region. Water is stratified by salinity gradients induced by evaporation.
4. **Estuarine Region.** South of the SMNWR is an estuarine region where occasional inputs of freshwater discharge from the mouth of the Otay and Sweetwater Rivers. Residence time of Bay water can exceed one month and may approach much longer times in this region.

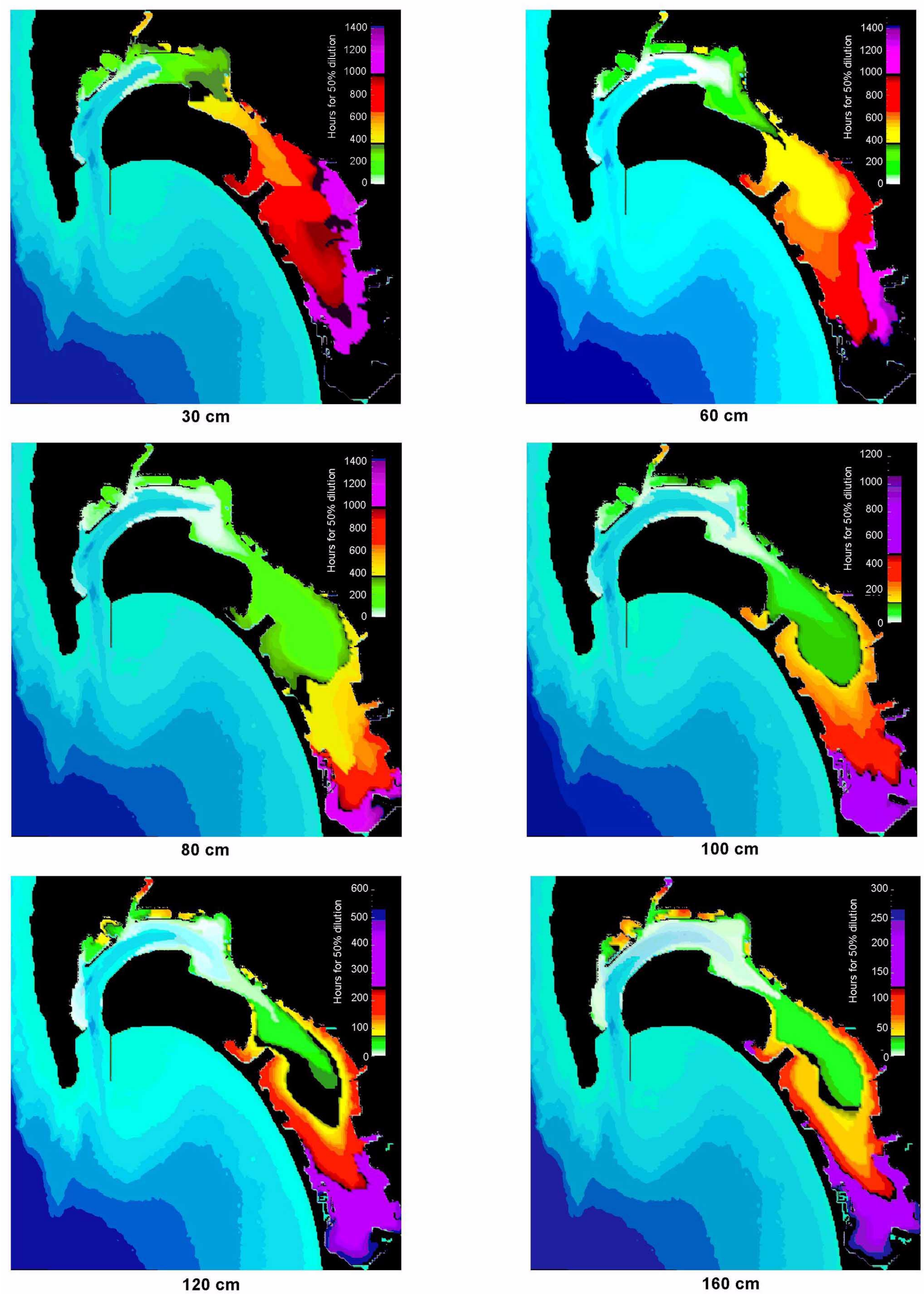
2.3 Water and Sediment Quality

San Diego Bay's water and sediment quality represents the ecosystem's chemical and physical properties that reflect the effects of external or human influences. How this quality has changed over time, what the current quality is, and the ecological effects of this change, are the topics of this section.

2.3.1 Historical Conditions

Excellent, detailed accounts of the Bay's historical water quality problems and changes can be found in reports by Macdonald *et al.* 1990 and San Diego Unified Port District 1995.

San Diego Bay's water quality impacts most likely began upon its becoming a harbor in the late 1700s. Until the mid-20th century, its waters were seen as the solution for the disposing of bilge water, garbage, and sewage. Waste disposal of collected sewage into the Bay was first attempted in 1887–1888 when the City's population was less than 16,000 (San Diego Regional Water Pollution Control Board 1952). Industrial wastes were mainly from the food processing industry in the early part of this century. In 1924, high bacterial levels (ten *E. coli* organisms



Map 2-4. Half-life of Water residing in the Bay with Varying Tidal Amplitudes, taking into Account mixing of Bay Water with Ocean Water during Tidal Cycles. The Data are based on a Two-Dimensional Hydrodynamic Model (depth not considered), validated with Salinity and Temperature Correlations. Data and Graphics provided by Don Sutton and John Helly of the San Diego Supercomputer Center. Legend on Graph says "Hours for 50% dilution."

per milliliter [ml] or greater) were detected in a zone near the city sewer outfalls but did not extend beyond the pier head into the navigation channel. Before the first sewage treatment plant was constructed by the City of San Diego in 1940, high coliform counts indicated sewage contamination in all parts of the Bay. However, rapid population growth during and after World War II overwhelmed the capacity of the few sewage plants, which used primary treatment and usually no chlorination.

- Until 1952, the Bay was thought capable of absorbing all untreated sewage and industrial wastes.

By 1952, at least 50 million gallons of sewage and industrial wastes were disposed of daily into San Diego Bay. Large sections of the Bay were reaching waste loading capacities and the Bay was being doubted as "a satisfactory and economical solution to the metropolitan sewage disposal problem" (San Diego Regional Water Pollution Control Board 1952). The San Diego Regional Water Pollution Control Board (SDRWPCB), a newly formed state agency at that time, undertook a comprehensive pollution survey of the Bay that was the first one of its kind on the west coast (Delaney 1966). It identified principal waste discharges to be from three municipal sewage plants' primary effluent, four industrial sources of untreated wastes, and two military sources of crude sewage. In addition, 4,000 vessels used the harbor every month.

- Sewage solids were commonly found along Coronado's bayside shore, with the east and central bays exceeding state health standards in the early 1950s.

Water quality conditions in the early 1950s were indicative of such a large waste loading (San Diego Regional Water Pollution Control Board 1952). Visually, the color of the Bay's water varied from green to brown, with widespread oil slicks commonly found, and transparency as low as 2.5 to 5.9 ft (0.76 to 1.8 m) at the industrial east shore. Solid wastes dumped into the south Bay were deposited by wind onto western beaches of the Bay and sewage solids were frequently observed along Coronado's bayside shore. Coliform bacteria densities were 70 mpn (most probable number)/ml along the east shore and 24 to 70 in (70 to 178 cm) in the central Bay, exceeding California Department of Public Health (CDPH) standards; all recreational areas had high bacterial densities. Dissolved oxygen levels were frequently found to be under 5.0 parts per million (ppm) over most of the south and central areas of the Bay, approaching the then minimum allowable level of 4.0 ppm.

- A large area devoid of bottom living organisms was found along the eastern shore due to thick sludge deposits.

Benthic animal life was almost completely absent from a zone 27,001 ft (8,230 m) by 600 ft (183 m) between the USCG station and the south end of the US Naval Supply Base due to the lethal effect of up to 3 ft (1 m) of sludge deposits on marine invertebrates. Toxic wastes were not measured at the time, though industrial operations were known to discharge cyanide, chromium, and other toxic materials and had probably caused a die-off of some birds and cockles in the south Bay in spring 1952. Hydrogen sulfide was dominant in and around Los Chollas Creek, symptomatic of depleted oxygen levels.

- A quarantine was placed on the central Bay beaches by the state in 1955. By 1964, all domestic sewage was taken to a new sewage treatment plant at Point Loma and discharged offshore.

By 1955, the CDPH found that the waters of the central portion of the Bay had deteriorated since 1951 and were now "sufficiently contaminated by sewage wastes to be hazardous to public health," particularly for recreational uses (California Department of Public Health 1955). In December, CDPH placed a quarantine on the beaches and shorelines in the central Bay area (San Diego Unified Port District 1995). The SDRWPCB adopted its first water quality criteria for San Diego Bay that same year. By 1963, dissolved oxygen levels had dropped to 4.0 ppm in all parts of the Bay except at the entrance, with some samples recording 1.0 ppm (Terzich 1965). Finally, in August 1963, the San Diego Metropolitan Sewerage System went into operation and by February 1964, all domestic sewage discharges and those from the Naval Amphibious Base (NAB) were connected (Delaney 1966). Treated effluent from this system was, and continues to be, discharged through an ocean outfall off of Point Loma.

- Improvements in water clarity and marine life became apparent almost immediately.

Once the sewage discharges stopped, water clarity improved to 15 ft (5 m) by March 1964 (San Diego Unified Port District 1995). By 1966, SDRWPCB staff were noticing large schools of fish and occasionally seals in the central Bay (Delaney 1966). Through the return of dissolved oxygen levels in excess of 5 milligrams per liter (mg/l) throughout the Bay, agency staff claimed that about 9,600 acres (3,885 hectares [ha]) or 80% of the Bay had returned to being suitable habitat for marine life. Sportfishing and clamming were once again a popular activity. Sludge deposits over 11.8 in (30 cm) deep were seldom found in the original "dead zone," then shrunken to about 8,999 ft (2,743 m) by 299 ft (91 m) in size. Only a few sites had coliform densities occasionally approaching 10 mpn/ml. The biological oxygen demand, suspended solids, phosphate, and nitrogen loadings showed great improvement due to the significant decline in wastes discharged into the Bay, as shown in Table 2-2 below (Delaney 1966).

Table 2-2. Comparison of Known Wastes Discharged into San Diego Bay, 1955 and 1966.

Year	Volume (million gallons /day)	Biological Oxygen Demand (kg/day)	Suspended Solids (kg/day)	Phosphate (kg/day)	Nitrogen (kg/day)
1955	44.28	35,834	45,995	6,305	7,394
1966	2.87	16,352	22,770	240	576
% reduction	93.5	54.5	50.5	96.2	92.2

- The mid-1960s focused on addressing vessel and industrial pollution sources.

After this success, attention became focused on the impacts of wastes discharged from vessels and from industrial sources (Terzich 1965; Delaney 1966; US Federal Water Pollution Control Administration 1969). Vessel discharges from the Bay's commercial and government ships, as well as party boats and pleasure craft, were specifically evaluated in a comprehensive federal study, which determined that their wastes created conditions "hazardous to health, aesthetically offensive and damaging to ecological balances in San Diego Bay" (US Federal Water Pollution Control Administration 1969). The Naval Station (NAVSTA) area had the highest coliform levels in the Bay, which were twice the standard. Oil spills, primarily from Naval fueling and fuel transfer operations, were noted as another problem. After 1967, industrial dischargers were required to reduce the amount of biological oxygen demand and settleable solids to meet SDRWPCB discharge requirements. Storm drains were also identified as sources of chemical and bacteriological contaminants to the Bay in 1965, but no estimate was made of their discharge volume or content.

- The Navy had stopped all vessel and industrial discharges to the Bay by 1980.

By 1969, water quality conditions for turbidity, salinity, transparency, nutrients, and associated plankton populations were generally within the limits set forth by the State-Federal Water Quality Standards in most parts of the Bay (US Federal Water Pollution Control Administration 1969). In 1971, San Diego Bay was reportedly considered "one of the world's cleanest metropolitan bays" (San Diego Unified Port District 1995). The Navy began eliminating vessel discharges in the early 1970s and ceased all ship sewage and industrial waste discharges into the Bay by 1980 (San Diego Unified Port District 1995).

- Contamination from heavy metals and toxicants started gaining attention in the 1970s.

San Diego Bay's bacterial contamination from sewage discharges overshadowed the issue of other possible contaminants for decades. In the 1970s, staff from the RWQCB, San Diego Region, began to take notice of industrial wastes and high levels of heavy metals and toxicants within the Bay (Mathewson 1972; California Regional Water Quality Control Board 1972). Much of the chemical pollution was found in the Bay's sediment rather than in the water column. A series of studies showed San Diego Bay to have serious problems with chemical pollution, even though the conditions were similar to other urbanized bays (California State Water Resources Control Board 1976; California Regional Water Quality Control Board 1985; Kennish 1997).

- High levels of copper, TBT, PCBs, and PAHs were detected in the Bay's sediments in the 1980s.

Copper ore spills and associated discharges at a copper loading facility at the 24th Street Marine Terminal caused concentrations in bottom sediments in the spill area to be 25 times higher in the mid-1980s than prespill levels (California Regional Water Quality Control Board 1985). In that same decade, tributyltin (TBT) levels were found to be very high in marinas and commercial and Naval ship basins where antifouling hull paints were concentrated (Valkirs *et al.* 1991). In the 1984 National Status and Trends Program (NS&T) for Marine Environmental Quality measured polychlorinated biphenyls (PCBs) at 422.10 parts per billion (ppb) in San Diego Harbor and 6.74 ppb in San Diego Bay, while polycyclic aromatic hydrocarbons (PAHs) measured 5000.00 ppb near Harbor Island and 0.00 at the Coronado Bridge (National Oceanic and Atmospheric Administration 1987 in Kennish 1997). Overall, San Diego Bay was ranked 5th in the nation for total PCBs in mussels and 10th for PAHs in mussels during the 1986–1988 national Mussel Watch Project out of about 145 in estuaries, embayments and open coastal sites (Kramer 1994; National Oceanic and Atmospheric Administration 1989 in Kennish 1997).

- San Diego Bay ranked 5th in the nation for total PCBs in mussels for the period 1986–1988.

Sediment quality had also changed due to the influx of upstream sediments from the Sweetwater and Otay Rivers during very large storm events. In the winter of 1980, a large amount of sediment was flushed into the south Bay because of spill-overs at upstream reservoirs. Total organic nitrogen concentrations generally decreased over the area's sediments, along with an increased coarseness in grain size (Lockheed 1981 in Macdonald *et al.* 1990).

2.3.2 Current Conditions

Present day water quality concerns for San Diego Bay focus mainly on the quantities of contaminants found in the sediments, shellfish, and other marine organisms (Lapota *et al.* 1993). Monitoring studies and research are continuing to seek answers to the many questions about the Bay's water and sediment quality condition. The entire San Diego Bay is listed as an impaired water body (under Clean Water Act (CWA) Sec. 303[d]) by the California State Water Resources Control Board (SWRCB) due to benthic community degradation and toxicity. Some ecological effects of impaired water quality are discussed in Section 2.3.4 "Ecological Effects".

2.3.2.1 Contaminants

Contaminants that are currently of concern in San Diego Bay include:

- chlordane (total)
- chromium
- copper
- mercury
- TBT
- zinc
- PAH compounds
- PCBs (total)

- A recent state assessment found the Bay to exceed threshold quality values for six constituents, and identified priority toxic sites.

As part of California's ongoing Bay Protection and Toxic Cleanup Program, San Diego Bay's sediment was evaluated for chemical and biological conditions between October 1992 and May 1994 (Fairey *et al.* 1996). Results indicated chemical pollution based on established sediment quality guidelines, developed by National Oceanic and Atmospheric Administration (NOAA) and the State of Florida and used as a substitute for absent US Environmental Protection Agency (EPA) and California guidelines. Major chemicals or chemical groups most often found to exceed threshold quality values were copper, mercury, zinc, total chlordane, total PCBs, and the PAH compounds. Seven stations (representing four sites) in this Program were given high priority ranking based on toxicity, chemical and benthic community data: Seventh Street channel area, two Naval installation areas near the Coronado Bridge, and the downtown Anchorage area west of the airport. Forty-three stations were given a moderate priority ranking, mostly commercial and Naval installation areas in the vicinity of the Coronado Bridge.

- PAHs may be the least understood organic compounds but are known to be long lived in marine sediments, becoming concentrated in the food chain.

PAH pollutants are organic compounds that are among the heaviest molecular fraction of petroleum hydrocarbons (Woodward-Clyde 1996). Because they are not very soluble in water and tend to accumulate as particulates in aquatic systems, they can become persistent as well as concentrated within the aquatic food chain. Commonly found at high levels in estuarine and marine sediments near industrial centers, they serve as a continual source of contamination for biotic communities (Kennish 1997). PAHs are released through fossil fuel combustion, asphalt production, leaching of creosote oil, and spills of oil, gasoline, diesel, and other petroleum products. An overall criticism of the available literature on PAHs is the absence of enough high quality data to estimate mass loadings. Ultra-low PAH detection methods are necessary, yet there is still a major void in knowledge on atmospheric fallout of pyrogenic PAHs and the pathways to receiving waters (P. Michael, California Regional Water Quality Control Board, pers. comm.).

- Bay sources of copper are mainly from the leaching or in-water cleaning of copper-containing antifouling paint on ship and boat hulls. PAHs in the Bay appear to primarily come from the leaching of creosote from pier pilings.

Recent studies evaluated the sources of two contaminants, copper and PAHs, for San Diego Bay (PRC 1996; Woodward-Clyde 1996). While not peer-reviewed, these studies suggest the relative amounts estimated to come from various sources (Figures 2-1 and 2-2). Copper's major origin appears to derive from ship and boat hulls (77%), with the leaching of copper-containing antifouling hull paints the primary cause and in-water hull cleaning the secondary cause. In contrast, PAH origins are the leaching of creosote from pier pilings in the Bay (61%), followed by in-place sediments introduced to the water column, mainly through dissolved molecules (27%).

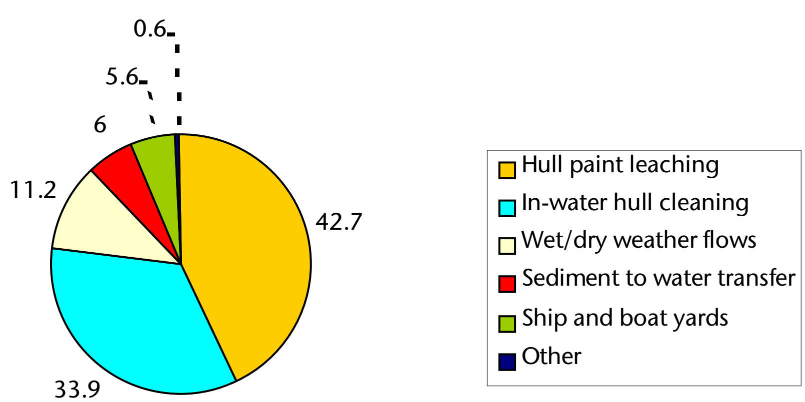


Figure 2-1. Percent Total Copper Loading to San Diego Bay.

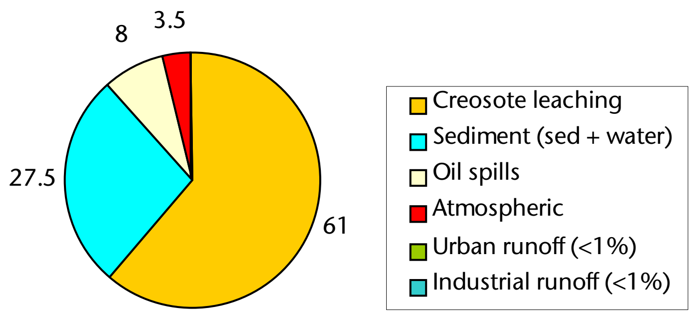


Figure 2-2. Percent Total PAH Loading to San Diego Bay.

- A 1997 survey revealed improved PAH levels in the Bay and significantly lower levels at the Naval Station. The Navy attributes the reduction to removal of creosote pilings and changes in bilge water operations.

The Navy measured PAH and copper concentrations in 1997 to assess the effects of its recent changes in bilge water operations and the removal of creosote impregnated pier pilings at NAVSTA (US Department of the Navy 1998). Total PAH concentrations ranged from 24 to 200 micrograms per liter (μg/l) during two surveys, reaching maximum levels near NAVSTA. Sources of PAH appeared to be from weathered creosote and fuel product sources. Copper concentrations ranged from 0.41 to 4.18 μg/l. Increased copper levels were found in semienclosed basins and at NAVSTA. PAH levels were the lowest measured in the Bay in the past eight years, and significantly lower by a factor of nine at NAVSTA sites, which was attributed to the operational changes by the Navy there. However, copper levels at NAVSTA were not significantly lower, though the remainder of the Bay had significantly lower copper concentrations.

- TBT levels in the Bay have declined since their restriction but chlorane levels have not. PCB pollution remains a prominent problem along the eastern and northern waterfront.

Levels of TBT, formerly a serious problem in the Bay's marinas, have decreased significantly since this component of antifouling paints was restricted to Navy ships in 1988 (Valkirs *et al.* 1991). TBT also naturally degrades to tin. However, TBT still remains a serious concern in areas of high vessel density and low hydrologic flushing (California Regional Water Quality Control Board 1994). Sediment concentrations at commercial and Naval basin areas have declined but are still higher than other areas in the Bay (Fairey *et al.* 1996).

PCBs are extremely persistent in the environment and can cause various carcinogenic and adverse effects to marine life and people. Total PCB pollution was most prominent in sediments along the Naval installation waterfront as well as several locations along the downtown waterfront and small boat harbors.

Chlordane, an insecticide discontinued in the mid-1970s, has caused extensive contamination along the north shore of the Bay and in areas receiving storm runoff (Fairey *et al.* 1996).

- Bioconcentration of certain contaminants in the tissues of marine species is a real concern and needs additional study.

Since several pollutants are known to bioaccumulate in the tissues of marine species, a tissue contamination study was recommended for PCBs, chlordane, and possibly methylmercury to determine potential human health problems associated with consuming resident species of finfish and shellfish (Fairey *et al.* 1996). Contaminants of uncertain concern in regard to bioaccumulation include tin, cadmium, silver, lead, and organotin. Of these, tin, cadmium, and lead have all been detected at elevated levels in San Diego Bay's sediments (Mearns 1992). PAHs are known to be absorbed and to accumulate in marine organisms and have the potential to cause cancer, mutations, and abnormal growth (Kennish 1997).

- Contaminated sites are being cleaned up through remediation projects throughout the Bay.

Contaminant levels are being reduced through sediment remediation projects at priority sites. Since 1990, the Port has removed contaminated marine sediments from Tenth Avenue Marine Terminal (TAMT), National City Marine Terminal (NCMT), America's Cup Harbor (ACH), and East Harbor Lagoon (San Diego Unified Port District 1995). Regional Board Cleanup and Abatement Orders require that remaining sediments in boatyards achieve a copper level below 530 ppm and a mercury level below 4.8 ppm. According to the RWQCB, San Diego Region, the following sites have been cleaned up as of September 1998:

- PACO Terminals at 24th St. Marine Terminal (copper)
- Kettenburg boatyard (copper, mercury, TBT)
- Bay City Marine boatyard (copper, mercury, TBT)
- Driscoll boatyard (copper, mercury, TBT)
- Mauricio boatyard (copper, mercury, TBT)

The following sites have cleanup agreements with RWQCB:

- Campbell Marine shipyard,
- National Steel and Shipbuilding shipyard, and
- Southwest Marine shipyard.

The following sites were capped:

- Teledyne Ryan Aeronautical storm drains (PCBs)
- Stennis Ocean Control Carrier (CVN) site (PCBs, copper, zinc).

2.3.2.2 Coliform Contamination

Coliform contamination of the Bay can become a problem near stormwater outfalls and streams following rain storms. The first major rainfall of the season contributes high levels (Macdonald *et al.* 1990; San Diego Unified Port District 1995). High levels of bacteria were measured in the 1993–1994 wet weather season at the receiving waters of Chollas and Switzer Creeks (San Diego Unified Port District 1995). Sources of this contamination most likely include leaking or broken sewer lines, illegal dumping of sewage, and domestic animal feces. The County of San Diego has monitored recreational sites in the Bay for indicator bacteria for several years, with many exceedances of state recreational water contact standards near storm drains and in poor circulation areas (San Diego Bay Interagency Water Quality Panel 1998).

- Coliform bacteria contaminate recreational sites during episodes of sewage spills and stormwater runoff. Pleasure boats also can dump sewage.

The City of San Diego's Public Health Department has had to close beaches in recent years due to sewage spills ranging from 1,300 to 3,000 gal (Rodgers 1997). Sewage from broken lines enters storm drains and contaminates the Bay during dry weather as well as wet. Another source of coliform contamination is illegal dumping of sewage from recreational boats and live-aboard boats.

2.3.2.3 Other Water Quality Conditions

Nutrient levels compared favorably in 1993 to those from 1980 (Lane 1980; Lapota *et al.* 1993). January had the highest concentrations of phosphate (0.2 to 3.1 μg technical atmosphere per liter [at/l], nitrate (12.0 to 31.9 μg-at/l), and ammonia (3.5 to 9.3 μg-at/l). Chlorophyll concentrations ranged from 1.8 to 18.9 μg/l at their highest in January. These levels correlate with maximum algal production that month, with measured nutrients higher in south Bay than north Bay. High chlorophyll levels in 1993 were thought to be the result of increased nutrient loading from the freshwater runoff into the Bay.

- The Bay's watershed contributes pollution that causes sediment contamination adverse to aquatic life.

With its large watershed, the Bay receives drainage from the cities of San Diego, National City, Chula Vista, Lemon Grove, El Cajon, Bonita, Imperial Beach, and Coronado, and from surrounding communities as far east as the Cuyamaca Mountains (San Diego Unified Port District 1995). Storm drains and streams deliver pollution from many nonpoint sources: automobile oil and grease that build up on roads and parking lots, fertilizer runoff from lawns, illegal dumping of chemicals, yard debris, garbage, and soil erosion. San Diego Bay's watershed was identified as an Area of Probable Concern by the National Sediment Quality Survey in 1997 because 32 sampling stations showed sediment contamination where associated adverse effects to aquatic life were probable (Tier 1) (US Environmental Protection Agency 1997).

2.3.3 Regional Comparisons

Within the Bight, a review of the long-term findings reveals that most contaminants increased during the 1950s and 1960s, but decreased during the 1970s and 1980s (Mearns 1992). Metals in fish have not elevated and have not changed, despite significant pollution controls. Pesticide levels are 100 times lower today. Overall, the levels of most pollutants in the open coastal zone are now declining compared to their levels of 30 to 40 years ago. However, sediments of bays and harbors are more contaminated than the open coast. Major gaps are evident in trend monitoring for bays and harbors where "long-term monitoring has been virtually nonexistent," according to Mearns (1992).

- San Diego Bay continues to rank among the highest bodies of water for contaminated sediments in California.

In a 1987 regional survey, PAHs in sediments collected at southern California stations between Santa Monica Bay and San Diego Bay found the Seventh Street (Paleta Creek) and Chollas Creek stations to contain the highest levels of these hydrocarbons of all stations sampled (Anderson and Gossett 1987). Comparing ten coastal sites in southern California, a 1988 study revealed samples from San Diego Bay to have the highest concentrations of metals, PAHs, and hydrocarbons of all stations sampled and were the most toxic in two out of three toxicity tests used (Anderson *et al.* 1988). The 1997 National Sediment Quality Survey determined that San Diego Bay, San Francisco Bay, and offshore areas around San Diego and Los Angeles appear to have the most significant sediment contamination in the EPA's Region 9 (US Environmental Protection Agency 1997).

- SCCWRP should provide comparable data among southern California bays and ports in a few years.

The Southern California Coastal Water Research Project (SCCWRP) regional monitoring effort should be able to provide some valuable comparable data among the various southern California bays and ports in a few years (P. Michael, pers. comm.).

2.3.4 Ecological Effects

The effects of the historically high sewage pollution levels on the Bay's flora and fauna were partially documented in the 1950s and 1960s (San Diego Regional Water Pollution Control Board 1952; Terzich 1965). The CDFG and the Federated Sportsmen of San Diego County reported great changes in the numbers and types of fish and wildlife using the Bay. By 1952, the Bay only supported a few of the "particularly sturdy rough fish," with no evidence of croaker, corvina, sand bass, halibut, or sea trout and few bait fish. Razor clams, cockles, and scallops had disappeared and migrating waterfowl only used the Bay occasionally for a brief stopover. A die-off of hundreds of ducks, gallinules, cormorants and other shorebirds, and large numbers of cockle clams and fish in the south Bay in the spring of 1952 was attributed to the discharge of toxic metal processing wastes (San Diego Regional Water Pollution Control Board 1952). A zone of about 373 acres (151 ha) on the east shore was devoid of benthic invertebrates due to the toxic effects of thick sludge deposits. Laboratory tests by CDFG showed that crabs were more susceptible to the toxic effects than molluscs or worms.

- Sewage pollution devastated the fish and wildlife populations of the Bay by the 1950s, but their populations rebounded rapidly upon improvements in the water quality in the 1960s.

After the regional sewage treatment plant, with its ocean disposal outfall, became operational in 1963, the effect of improved water quality on fish and wildlife in the Bay became apparent almost immediately. Observers noted in April 1964 the return to its waters of sculpin, sole, sand bass, octopus, shark, seal, porpoise, bonito, and other fish while returning birds included cormorants, "bluebills," scoters, and mergansers (Terzich 1965). A 1968 study described the south Bay as supporting a diversity of marine species representative of the inner sections of relatively undisturbed bays and estuaries in California and Baja California (Ford 1968). However, central Bay and its shoreline still showed the ecological effects of sludge deposits with bottom organisms reduced to only a few of the most pollution tolerant species; a polluted site was indicated by less than five kinds of organisms or more than 200 polychaete worms per square foot (Parrish and Mackenthun 1968).

- Healthy fish and invertebrate populations were noted in 1973 and undesirable algal mats had greatly reduced.

By 1973, the CDFG noted that "healthy fish and invertebrate populations again flourish in many areas," with eelgrass beds becoming reestablished on dredged sites and ecologically desirable marine plants beginning to grow on pilings and rock structures (Browning *et al.* 1973). The "ecologically undesirable" algal mats that had previously covered the bottom of portions of the central and south Bay areas were also greatly reduced.

- Thermal effluent from the south Bay power plant causes a decrease in the number of species within the cooling channel during late summer. On the plus side, the warmed water increases biomass for some organisms and provides year-round habitat for the endangered green sea turtle.

Thermal pollution from the SDG&E south Bay power plant's discharge was found to cause adverse effects on marine life within 1,801 to 3,901 ft (549 to 1,189 m) of the discharge point (Ford *et al.* 1970). Only marine invertebrate and algae species tolerant of the temperature conditions were found in this zone, although adverse effects to the Bay outside the cooling channel were determined to be minimal, mainly affecting decapod crustaceans and gastropod molluscs. Impacts were apparently greatest from the late summer cooling water discharge, with additional species occupying the channel area during cooler periods. Beneficial effects of the thermal plume included significant biomass increases for several major groups and the creation of favorable year-round habitat for the endangered green sea turtle (Macdonald *et al.* 1990). Ecological effects of the thermal effluent on certain marine species at the site were also studied in several master's theses at San Diego State University (SDSU) (Kellogg 1975; McGowen 1977; Merino 1981).

High winter runoff in 1980 caused sediment changes of increased grain size and decreased total organic nitrogen levels in the south Bay. The species composition and benthic community structure of infaunal invertebrates remained very similar to prestorm conditions (Lockheed 1981).

- High copper levels in the Bay reduced phytoplankton diversity but have no effect on biomass or productivity.

The effects of high (>3.0 ppb) and low (<1.0 ppb) copper levels on phytoplankton communities in San Diego Bay were studied for one year (Lane 1980). Phytoplankton samples taken from high copper level areas showed less species diversity but maintained high biomass and productivity. The effects of excessive copper levels have been evaluated nationally for various marine organisms: sea anemones, mussels, softshell clams, snails, zooplankton, amphipods, crabs, sandworms, algae, and topsmelt (*Atherinops affinis*). As a result, copper criteria to protect marine life and human health are proposed in a new federal review of copper hazards (Eisler 1998).

- Certain sportfish species in the Bay are known to accumulate PCBs and mercury at levels that could pose health risks for consumers.

Bioaccumulation of potentially toxic chemicals by organisms in the food chain is a concern that is still being studied. One study compared the Bay to nonurban sites and found high concentrations of PCBs in liver tissues of white croaker (*Genyonemus lineatus)*, barred sand bass (*Paralabrax nebulifer)*, and black croaker (*Cheilotrema saturnum)* from several sites (McCain *et al.* 1992). Barred sand bass showed symptoms of fin erosion. A health risk study of the Bay in 1990 determined that mercury and PCB levels in selected fish species could pose a limited health risk, if significant quantities of fish were consumed. San Diego Bay posed less of a risk than Santa Monica Bay (San Diego County Department of Health Services 1990).

The relative quality of the Bay's benthic invertebrate community was analyzed from 1992–1994 as an indicator of sediment quality and toxicity (Fairey *et al.* 1996). The results of this study are shown in Map 2-5. The Degradation Index reflects the level of species diversity and the occurrence of opportunistic species that are more tolerant of high pollution levels. These data, combined with toxicity and chemical data, were used to recommend priority areas for more intense evaluation.

2.4 Bay Habitats

- The water column as a habitat is treated under Deep Water, although the water column extends to shallower depths. Also, the benthos as a habitat is discussed under Unvegetated Shallow Subtidal, even though it extends to deeper depths.

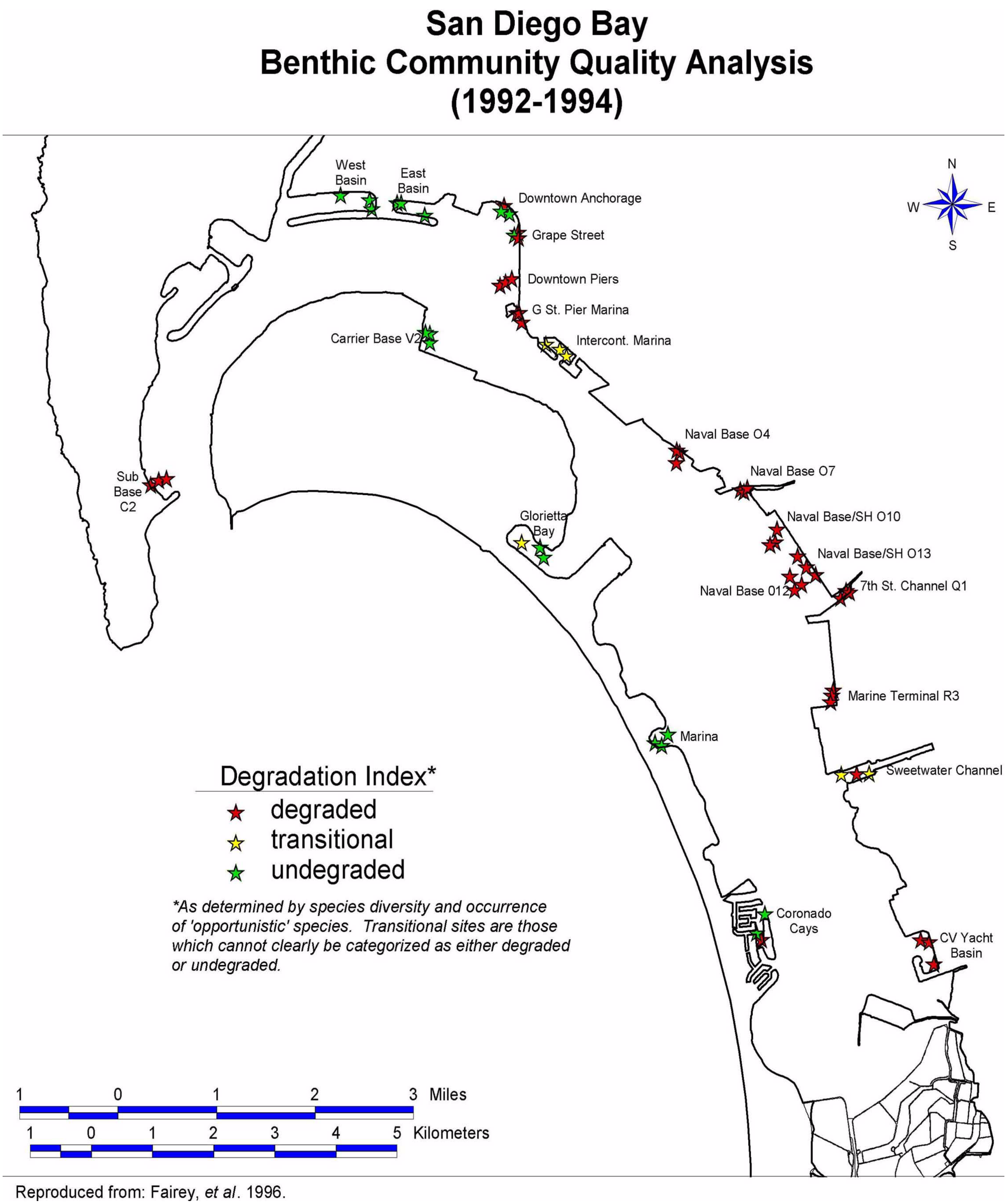
Habitats of the Bay are arranged by depth with respect to the tides, then by substrate, water clarity, and other factors. Figure 2-3 depicts approximate positioning of the habitats, defined in this Plan, in relation to tidal elevation, using Broadway Pier as a reference point. Map C-1 shows the two-dimensional distribution of these habitats as they occur today. These habitats are linked together ecologically by the transport of energy and other resources. These relationships are discussed in Section 2.7 "The Ecosystem as a Functional Whole." The water column as a habitat is treated under Deep Water, although the water column extends to shallower depths. Also, the benthos as a habitat is discussed under Unvegetated Shallow Subtidal, even though it extends to deeper depths.

The shallower habitats and the Bay's natural shoreline have been severely depleted or modified, beginning with the first pier at the end of Market Street in 1850, and the first dredging in 1914. Table 2-3 shows the habitat losses, comparing an 1859 geodetic chart and a 1995 aerial photo.

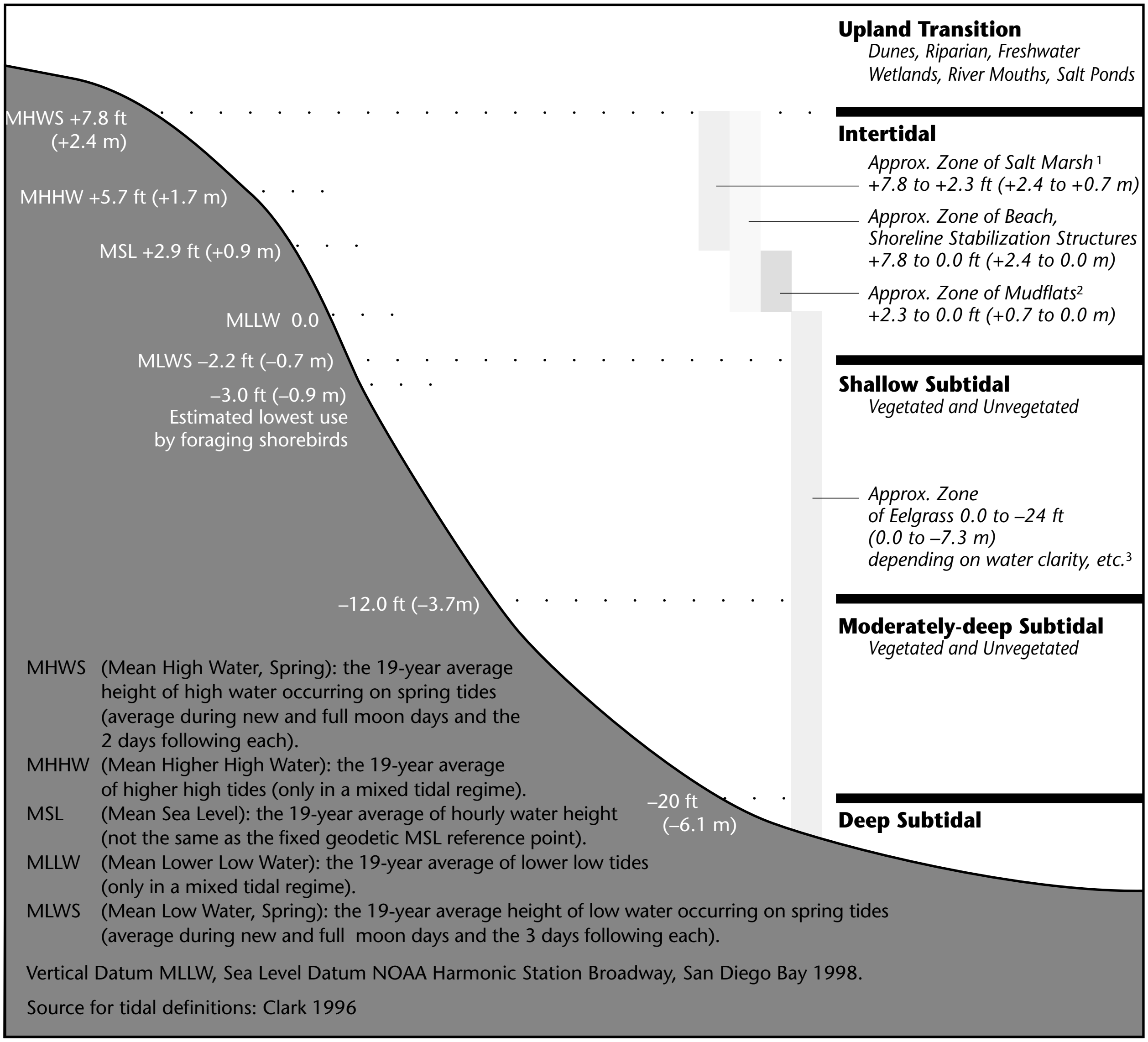
2.4.1 Deep Subtidal (>–20 ft [–6 m] MLLW)

Habitat Description

Deep subtidal habitat includes the surface water, water column and sediments for areas greater than 20 ft (6 m) in depth, constituting about 4,440 acres (1,797 ha) (34%) of Bay surface area. It is associated primarily with navigational channels. Except for a few areas in north Bay that have no dredging record, all deep subtidal habitat has been dredged since the 1940s; most was dredged in the 1960s or more recently.



Map 2-5. San Diego Bay Benthic Community Quality Analysis.



[1] Lower limit of salt marsh is defined by lower limit of cordgrass (*Spartina foliosa*). These tidal elevations are estimated based on salt marshes neighboring those of San Diego Bay. This is as low as +2.3 ft (0.7 m) MLLW in Mission Bay (Levin *et al.* unpubl. data). In Tijuana Estuary and Anaheim Bay, lower limits range from +3.5 to +5.25 ft (+1.1 to +1.6 m) MLLW (Zedler *et al.* 1992; Massay and Zembal 1979).

[2] Mudflat zone derived from lower limit of cordgrass to upper limit of eelgrass (0.0).

[3] In San Diego Bay, depth of eelgrass varies with Bay regions as follows: south Bay 0.0 to –7 ft (0.0 to –2 m) MLLW; central Bay 0.0 to –8 ft (0.0 to –2.4 m) MLLW; north Bay 0.0 to –13 ft (0.0 to –4 m) MLLW. Near the mouth in north Bay, there is a different form (wider blades) that extends down to –18 to –24 ft (–5.5 to –7.3 m) (Hoffman, pers. comm.)

Figure 2-3. Habitat Definitions Used in this Plan in Relation to Tidal Elevation.

Table 2-3. San Diego Bay: Comparison of Current and Historic[1] Habitat Acreages

Habitat (depths in feet)[2]	Current Acres/Hectares (% of total)		1859 Acres/Hectares (% of total)	Percent Loss or Gain
Deep Subtidal (>–20)	4443 / 1798	(28%)	2212 / 895 (12%)	+100%
Moderately Deep Subtidal (–12 to –20)	2219 / 898	(14%)	954 / 386 (5%)	+133%
Shallow Subtidal (–2.2 to –12)	3734 / 1511	(24%)	6400 / 2590 (35%)	–42%
Vegetated Shallow Subtidal[3]	1065 / 431	(7%)	Unknown	Unknown
Intertidal excluding Salt Marsh (+2 to –2.2 in Map C-1, high tide line to –3 on 1859 coverage)	979 / 396	(6%)	6148 / 2488 (33%)	–84%
Artificial hard substrate [4,5] (riprap and seawall; piers, wharves)	45.4 mi / 73.1 km		0	+74% of shoreline
Salt Marsh	823 / 333	(5%)	2785 / 1127 (15%)	–70%
Upland Transition	2313 / 936	(15%)	Unknown	Unknown
Riparian	7 / 3	(<1%)	Unknown	Unknown
Freshwater Marsh	1 / 0.4	(<1%)	Unknown	Unknown
Salt Works				
Crystallizer	121 / 49		N/A	N/A
Pickling	59 / 24		N/A	N/A
Primary	462 / 187		N/A	N/A
Primary/Intertidal	106 / 43		N/A	N/A
Secondary	366 / 148		N/A	N/A
Dikes	62 / 25		N/A	N/A
Total	15694 / 6351		18500 / 7487	**–15%**

1. Historic figures are based on an 1859 chart. Current figures are based on a 1995 aerial photo taken at Mean Lower Low Water and bathymetry from 1859 versus current chart.

2. All depths based on MLLW.

3. Vegetated shallows is a subset of shallow subtidal, so is not included in the totals.

4. Plus 131 acres (53 ha) horizontal surface structures (piers, etc.).

5. Artificial hard substrate is a subset of subtidal and intertidal habitats, so is not included in the totals.

Use of the Habitat

- Except for a few areas in north Bay that have no dredging record, all deep water areas have been dredged since the 1940s; most were dredged in the 1960s or more recently.

Deep subtidal habitat is used by a wide variety of vertebrate and invertebrate species. Some specifically inhabit the open water areas, some spend only part of their life cycle in the open water, and others use the open water to access coastal areas. Within the water column are microscopic species of phytoplankton and zooplankton (see also Section 2.5.1 "Plankton"). Their movement and distribution are completely dependent on currents and they are continually flushed out to sea by tides. Phytoplankton are an important primary producer in the Bay. Their bloom appears to be driven seasonally by stormwater runoff, peaking in January (Lapota *et al.* 1993). Feeding on the phytoplankton and with a potentially completely different seasonal cycle are the zooplankton, including abundant meroplankton or "temporary plankton," the larval forms of invertebrates that later settle to the bottom and become benthic juveniles and adults. These forms occur together with species called holoplankton, which are zooplankton that spend their entire lives in the open water environment in planktonic form. The density and diversity of holoplankton are greater in north Bay, which is closer to coastal ocean water (Ford 1968). Some zooplankton migrate vertically through the water column from day to night, as well as horizontally with tidal movement.

- Waterbirds use deep water habitat of the Bay, as do fish, sea lions, and dolphins. Occasionally, gray whales visit in the deep water near the Bay mouth.

Photo 2-2. Sea Lions Napping on Buoy.

Bay fish surveys found that fish inhabiting open water had numerical and biomass densities which were the lowest of all sampled habitats (Allen 1999). The most common species were the round stingray (*Urolophus halleri*), California halibut (*Paralichthys californicus*), and barred sand bass. Bird abundance and diversity also appears lower in deep water habitats than in shallower ones (US Fish and Wildlife Service 1995a; Ogden 1995). However, many different waterbirds use the open water for feeding and resting. The California least tern (*Sterna antillarum browni*) and the California brown pelican (*Pelecanus occidentalis californicus*), both federally listed endangered species, forage in the open water, but especially along the Bay margins where schooling fish concentrate. In addition to foraging, brown pelicans use these areas for staging fall migration, roosting, and for juvenile pelicans to scatter in search of new territory (US Fish and Wildlife Service 1997). Ogden (1994) reported many elegant and other terns using the open water habitat. Surf scoter (*Melanitta perspicillata*) make more use of deep water than other birds (Ogden 1995). California sea lions (*Zalophus californianus*) use buoys in deep water areas for hauling out, and California bottlenose dolphins (*Tursiops truncatus*) may be seen regularly in the deep water of north Bay. Occasionally, visiting gray whales (*Eschrichtius robustus*) visit near the Bay mouth.

Organisms that live in the deep water benthos have a patchy distribution due to changes in sediment particle size on the Bay floor and to their own reproduction and dispersal mechanisms which have a clumped pattern.

Function

An important function of the deep water environment is the transport of plankton into and out of the Bay for coastal species that depend on access to the warm, sheltered, shallow waters during early life cycle stages. This includes the larvae of many fishes and crustaceans.

The food web in deep water is dependent upon detrital "rain" from sunlit surface waters. Fungi, bacteria, and protozoans of the benthos help break down coarser organic matter, making it available to higher organisms. As this organic matter is progressively consumed by larger and larger organisms, protein becomes increasingly concentrated up the food chain, creating higher quality food. While most of the deep water benthic habitat is not accessible to birds, benthic organisms do provide forage to rays and flatfishes. They also release planktonic larvae, which frequently undergo diurnal vertical migrations.

2.4.2 Moderately Deep Subtidal (–12 to –20 ft [–4 to –6 m] MLLW)

Habitat Description

Approximately 2,219 acres (898 ha) (17%) of Bay surface area falls into the moderately deep category, primarily in south-central Bay off the coast of the NAB and in inlets of north Bay. The habitat extends from the approximate lower depth of most eelgrass to the approximate edge of the shipping channel. It represents areas that generally have been dredged in the past but are not maintained as navigational channels. The most recent dredging record at these depths off of NAB is dated 1941–1945. Sediment texture varies widely, from 5 to 95% fines.

- Due to their potential for enhancement, moderately deep water habitats are distinguished from deep water in this Plan.

While it generally supports similar communities to deeper habitat, moderately deep water habitat is distinguished in this Plan because it represents potential enhancement sites for shoring up to shallower depths, which are more representative of historical habitat conditions.

Use of the Habitat

Allen's sampling scheme for fish abundance and distribution (see also Section 2.5.4 "Fishes") does not allow quantification of use for moderately deep water habitats with the definition used in this Plan (deep, moderately deep, and one shallow area were lumped by Allen into a single "channel" category). Allen's open water and offshore sampling locations fell into three depth categories using the definitions of this Plan: deep (north and north-central Bay), shallow (south-central Bay), and moderately deep (south Bay). The moderately deep, south Bay region is dominated by round stingray, spotted sand bass (*Paralabrax maculatofasciatus*), California halibut, and barred sand bass.

Use for resting by bottom feeding diving birds, especially rafting surf scoter, scaup, and bufflehead (*Bucephala albeola*), and plunge divers, like terns and brown pelicans, in moderately deep water is higher compared to other Bay locations (US Fish and Wildlife Service 1995a; Ogden 1995). Surf scoter and scaup have been declining in San Diego Bay (Macdonald *et al.* 1990). The endangered California least tern and brown pelican forage in these areas.

No information specific to this intermediate depth exists for invertebrates or plankton.

Function

Other than the fact that these areas have been left undisturbed by dredging for longer periods than deeper water, any ecological differences between deep and moderately deep habitats have not been quantified.

Photo © 1998 Tom Upton.

Photo 2-3. Birds Rafting.

2.4.3 Shallow Subtidal (–2.2 to –12 ft [–0.7 to –4 m] MLLW)

- About 3,734 acres (1,511 ha) (28%) of shallow subtidal presently dominate south Bay, portions of south-central Bay, and narrow strips along the shoreline of north and north-central Bay. This represents an overall loss of 41% from historic proportions.
- Waterbirds and fishes are more abundant in shallow waters close to the shoreline.

Continually submerged, these shallow habitats extend from the low tide zone (2.2 to –12 ft/0.7 to –4 m MLLW). Shallow, soft bottom areas, with their associated fauna and flora, were the primary subtidal habitat in San Diego Bay prior to its development. About 3,734 acres (1,511 ha) (28%) presently dominate south Bay, portions of south-central Bay, and narrow strips along the shoreline of north and north-central Bay. This represents an overall loss of 41% from historic proportions due to filling in of the Bay margins and dredging to deeper depths. South Bay has comparatively little disturbance from dredging, having last been dredged off NAB in 1941–1945. Exceptions are the Emory Cove channel, Chula Vista Marina and the navigation channel leading to this marina. Sediment grain sizes tend to be very coarse (0 to 5% fines) to coarse (5 to 25% fines), except off the coast of NAB where fine sediments (up to 95% fines) accumulate.

The abundance and biomass of fishes is much higher in shallow waters (Allen 1999). Bird abundance and diversity is also higher at these depths, possibly due to the higher abundance of fish (Ogden 1994; US Fish and Wildlife Service 1995a). Shallow waters support many thousands of resident and migratory birds every year for foraging and resting. While all waterbirds are more abundant in shallow waters close to the shoreline, the groups that appear to use these areas preferentially are bottom feeding divers such as scoter and scaup, dabbling brant (*Branta bernicla*), plunge divers such as terns, and the surface-foraging black skimmer (*Rynchops niger niger*) (Ogden 1994; US Fish and Wildlife Service 1994a).

2.4.3.1 Unvegetated Shallow Soft Bottom

Habitat Description

Soft bottoms of unconsolidated sediment are unstable and shift in response to tides, wind, waves, currents, human activity, or biological activity such as feeding by bottom fishes, or bat rays (*Myliobatis californica*) excavating pits to reach buried clams. Few plants and animals have adapted to this instability—eelgrass is one of the few. Because animals and plants lack attachment sites in this environment, they must burrow into the substrate to prevent from being washed away by currents, and so are called "infauna." Competition for space is ameliorated partly by organisms occupying various depths within the substrate. Invertebrates such as sponges, gastropod molluscs, and some larger crustaceans and tunicates live on the surface.

Photo © 1999 San Diego Unified Port District.

Photo 2-4. Ray on soft bottom sediment.

- Deposit feeding species tend to predominate in soft bottom sediment areas, where they glean live and dead plankton.

Different areas within this habitat have different species composition and abundance, generally depending on time since last disturbance and composition of the substrate. Deposit feeding species, those that glean detritus once it has settled, tend to predominate in soft bottom sediment areas with large amounts of silt and clay. The main reason for this relationship is that more detritus accumulates in the interstitial spaces among fine sediment particles than among those of larger grain size. In contrast, suspension feeders, those that filter material from the water column, are more common in areas where sandy sediments predominate, such as in portions of north Bay.

- Underwater observations indicate that algal mats provide cover from predators for many species of motile invertebrates and fishes, much like marsh vegetation does for birds.

An important structural component of unvegetated shallows is the presence of extensive masses or mats of living algal material interspersed with areas of exposed sediment that may extend into the intertidal zone (Ford 1968; Ford and Chambers 1974). The dense, heavily branched red alga *Gracilaria verrucosa* forms the bulk of this mat, which also includes the red algae *Hypnea valentiae* and *Griffithsia pacifica*. Some of these plants are loosely anchored in the sediment, while others drift just above the bottom. Mats can be 1 to 2 ft (0.3 to 0.6 m) thick during the warmest months of the year. Underwater observations indicate that these algal mats are an important microhabitat feature, because they provide cover or refuge from predators for many species of motile invertebrates and fishes, much like marsh vegetation does for birds. The algae also appear to serve as a food source for some invertebrates. The living plant material and detritus constitute a primary food source for California killifish (*Fundulus parvipinnis*) and other fish, crabs, isopods, gastropod molluscs, and some aquatic birds (Macdonald *et al.* 1990).

Use of the Habitat

- Demersal fishes of unvegetated shallow areas of soft sediment feed on benthic invertebrates.

Unvegetated shallows support species assemblages of benthic invertebrates and demersal fishes that are distinct from vegetated shallows (Kramer 1990; Takahashi 1992a; Allen 1997). Many of these invertebrates serve as food sources for the demersal fishes that are restricted to or occur primarily in these unvegetated shallow areas of soft sediment. An important example is the California halibut, a flatfish species of commercial and recreational value. The small juvenile halibut are restricted primarily to unvegetated shallows of unconsolidated sediment in bays and estuaries (Allen 1982; Kramer 1990), where they feed on invertebrate fauna (Drawbridge 1990). Unvegetated shallows therefore provide an important nursery for halibut.

Other species of demersal fishes that appear to depend primarily on invertebrates of unvegetated shallows as their food source include the diamond turbot (*Hypsopsetta guttulata)*, round stingray, and several species of gobies. In addition, many fishes that also occur in eelgrass and other vegetated shallow habitats feed both there and in unvegetated areas, as documented by the recent work of Allen (1998).

Not surprisingly, studies in south Bay have shown that many of the fishes that occur in shallow subtidal habitats of south Bay also occur intertidally (Ford and Chambers 1973, 1974). Sediment characteristics at a given location are much the same both intertidally and subtidally. However, the number of intertidal species present generally appears to be much smaller than the number of subtidal species (Ford and Chambers 1973, 1974; Macdonald *et al.* 1990).

Factors Affecting Composition and Stability of the Soft Bottom Community

As in the deeper water environment, benthic organisms in shallow areas have very patchy distribution in space and time due to such variables as sediment composition, environmental disturbances, the nonrandom settlement and growth of larvae, productivity of the overlying water in terms of phytoplankton, life history strategies of organisms, competitive strategies, and predation by larger, active predators such as the round stingray and flatfishes.

The stability of the soft bottom community depends upon the relative importance of physical factors versus biological ones in structuring it. The major physical and chemical factors that determine the structure of a soft bottom community and affect the population dynamics of its epifaunal and infaunal species involve a variety of characteristics of the sediment. They include grain size distribution, degree of grain compaction and porosity, water content, drainage (that is, whether it is stagnant or flushed at low tide), dissolved oxygen levels, levels of suspended and deposited organic material, and the short-term and long-term stability of the sediment. These characteristics are affected by depth, slope of the bottom, wave action, currents, and other physical and chemical characteristics of the water above the bottom.

- A stable, healthy community will support larger infauna and a greater diversity of infaunal life-styles.

Biological activity can also dominate community structure. For example, a relatively long-lived species, such as a sea cucumber, can dominate a shallow-water benthic community partly by modifying its physical environment through a series of stable mounds and unstable intermediate areas to favor organisms compatible with itself. In that way, the sea cucumber-based community can remain stable for years. A stable, healthy community will tend to support larger infauna (ghost shrimp, clams, etc.), and a diversity of infaunal life-styles such as suspension feeders, burrowers, tube builders etc. (L. Levin, Scripps Institute of Oceanography, pers. comm.). Invasion of a community by exotic species can completely change the relative dominance of species. Sometimes, physical and biological factors alternate in controlling residents in an area, such as before and after storms (Nybakken 1997).

Function

- Invertebrate fauna of unvegetated shallows in San Diego Bay is important to ecological functioning of the Bay, both because it serves as the main food source for a wide variety of demersal fishes that occur in this habitat, and because it is a major species assemblage in its own right.

The invertebrate fauna of unvegetated shallow habitats in San Diego Bay is important to ecological functioning of the Bay, both because it serves as the main food source for a wide variety of demersal fishes that occur in this habitat, and because it is a major species assemblage in its own right.

Feeding by nematode and polychaete worms, gastropod molluscs, brittlestars, crabs, isopods, and a wide variety of smaller crustaceans serves to transform detritus and small invertebrates into usable food for larger invertebrates and fishes; the latter, in turn, are eaten by other large fishes and aquatic birds, many of which are of sport fishing value or esthetic value. Bivalve molluscs and other suspension feeders serve a similar function in transforming plankton and suspended detrital material into food for fishes and birds.

The benthos provides other functional roles besides serving as a prey base for fish and birds. The less conspicuous molluscs, polychaete worms, small crustaceans, and other invertebrates living at the bottom of the Bay mineralize organic wastes as it accumulates, consume macroalgae, and return essential chemicals and organic matter to the water column.

2.4.3.2 Vegetated Shallow Subtidal

Habitat Description

A very important and productive benthic habitat in San Diego Bay is formed by beds of eelgrass, *Zostera marina*, a type of seagrass and a marine angiosperm. Eelgrass habitats rank among the most productive habitats in the ocean (Nybakken 1997). As has occurred in bays and estuaries all along the Pacific coast and elsewhere in the world, eelgrass beds in San Diego Bay have suffered substantial losses and impacts due to their location in sheltered waters where human activity is concentrated. In San Diego Bay, these beds extend from zero MLLW to depths of at least 23 ft (7 m) below MLLW, depending on levels of light and water turbidity. In south Bay the range is from 0 to –7 ft (0 to –2 m) MLLW, central Bay 0 to –10 ft (0 to –3 m) MLLW, and north Bay 0 to –13 ft (0 to –4 m) MLLW. Near the mouth in north Bay, a different form of eelgrass (wider blades) grows from –16 to –23 ft (–5 to –7 m) MLLW (R. Hoffman, National Marine Fisheries Service, pers. comm.).

The plant density and biomass of eelgrass beds in San Diego Bay and elsewhere can vary widely from one season to another (Marsh 1973; Takahashi 1992a). The main factors responsible appear to be depth, sediment grain size distribution, nutrients, light levels, temperature, and salinity (Phillips and Lewis 1984). Distribution and abundance of eelgrass in San Diego Bay have changed significantly over time, declining and improving along with the water quality condition in the Bay (Ford and Chambers 1974; Lockheed 1979; Hoffman 1986). Black brant (*Branta bernicla nigricans)*, a goose that uses eelgrass as its predominant food item, has been an indicator of eelgrass abundance in the Bay since the 1880s. Reports of 50,000 to 100,000 brant in Spanish Bight alone (an inlet between Coronado and North Islands that was filled in 1941) suggest abundant eelgrass beds during that period. In 1941 there were reports of the complete loss of all eelgrass beds due to marine pollution, which peaked in the late 1950s and early 1960s. Reports of brant in 1942 totaled 1,100 individuals for the entire Bay (US Fish and Wildlife Service 1995a). Since the elimination of sewage deposition into Bay waters in 1963, eel-

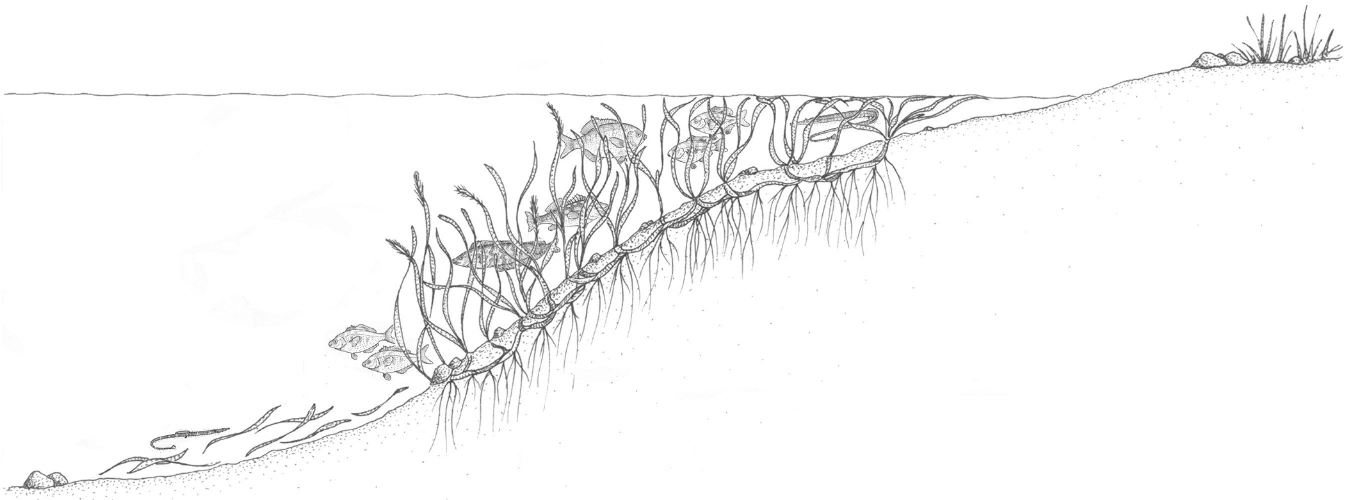


Figure 2-4. Eelgrass Bed.

grass appears to grow naturally or as a result of revegetation throughout the Bay wherever it can grow. Shallow subtidal areas that remain unvegetated may remain so due to turbidity or unknown reasons (R. Hoffman, pers. comm.).

Use of the Habitat

Eelgrass has an extremely rapid growth rate, high net productivity, and a very high level of biomass (McRoy and McMillan 1977). Its importance as habitat is evident both from the great diversity of its associated invertebrate and fish faunas (Phillips 1984; Hoffman 1986; Takahashi 1992a).

Photo © 1999 US Navy Southwest Division.

Photo 2-5. Eelgrass bed.

Because of their heterogeneous structure, eelgrass beds provide microhabitats for a wide variety of invertebrates and small fishes, primarily by increasing the available substrate surface and by providing effective refugia. Phillips (1984) and Takahashi (1992a) reported the following four functional groupings of animals living within the bed:

1. Epifauna living on the eelgrass blades and using them as a substrate for attachment.
2. Epifauna living on the surface of the sediment, sometimes also moving onto the eelgrass blades.
3. Infauna living in the sediment of the bed, with some of these moving onto the blades during the eelgrass growing season.
4. Invertebrates and fishes living in or above the eelgrass canopy. This last group involves animals that move easily in and out of the bed at different times of day or on a seasonal basis.

Function

- Eelgrass beds are the most productive areas on the soft bottom.

Eelgrass beds are the most productive areas on the soft bottom. Roots and rhizomes help stabilize the unconsolidated substrate by forming an interlocking matrix that inhibits erosion. The plants themselves keep water clearer by trapping fine sediments and preventing their resuspension (Takahashi 1992a). Leaves cut down wave action and currents; the resulting decrease in turbulence causes more fine sediment to be deposited. Abundant algae and invertebrates that grow on the leaf blades provide primary and secondary productivity for consumption by larval and juvenile fish. Sediments within eelgrass beds are loaded with detrital leaves, rhizomes, and nutrients that fuel infaunal invertebrates. These provide food for fishes and sometimes birds including the endangered California least tern. When epibenthic invertebrate abundances are low, this indicates impaired food chain support functions (Rutherford 1989).

- Algae and invertebrates that grow on the leaf blades of eelgrass provide primary and secondary productivity for consumption by larval and juvenile fish. Sediments are loaded with nutrients that fuel infaunal invertebrates.

Eelgrass beds are an important component of the San Diego Bay food web. Much of the eelgrass primary productivity enters the food web as detritus. Fish and invertebrates use eelgrass beds to escape from predators, as a food source, and as a nursery. Eelgrass plants provide surfaces for egg attachment and sheltered locations for juveniles to hide and feed. Fish produced from these beds are consumed by fish-eating birds, including the California least tern. Waterfowl, especially surf scoter, scaup, and brant are present in high numbers in late fall and winter. Black brant, in particular, rely heavily on eelgrass of central and south Bay as they are one of the few birds that consume it directly. A small population of the federally endangered green sea turtle (*Chelonia mydas*) feeds on eelgrass growing in several beds near the SDG&E power plant channel in south Bay (US Fish and Wildlife Service 1997).

2.4.4 Intertidal (+7.8 to –2.2 ft [+2.4 to –0.7 m] MLLW)

- Losses in the intertidal zone have been the most severe of all habitats, with the greatest decrease in north and central Bay (over 90%). Some of this occurred when the San Diego River was diverted and its tidal flats and salt marsh filled.

The intertidal habitat encompasses the area between high and low tides and is subject to varying degrees of tidal submergence. Losses in this zone have been the most severe of all Bay habitats, with the greatest decrease in north and central Bay (over 90%). Some of this occurred when the San Diego River was diverted and its tidal flats and salt marsh filled in. Intertidal areas currently constitute about 976 acres (395 ha), or 7% of the Bay. Most historic intertidal areas have been filled in on their landward edge and constricted on their Bay side due to dredging. Many sites are now mere slivers of their previous extent. Most of the remainder has been modified by structures for shoreline stabilization or access, with less than 15.8 mi (25.5 km) of soft shoreline left (26% of the total shoreline). "Hard" intertidal habitat (riprap and other structures) is plentiful but not natural to the Bay.

Despite its relatively small size, the intertidal zone has the greatest variability of any area in the Bay, and this variability can occur within centimeters. In part, this is due to the fact that the zone is exposed to air on a regular basis, and most physical factors show a wider range in air than in water (Nybakken 1997). Figure 2-5 describes the percent of time each tidal elevation is exposed above water in 1999 in the Bay. Organisms must adapt to extremes of temperature and desiccation, as well as salinity stress, mechanical wash, and backwash of waves. These extremes are more pronounced on sandy shores, where there is less animal life than on muddy shores. The abundance and diversity of fauna of a typical sand flat can also vary by orders of magnitude within and among years (Nybakken 1997).

- Shorebirds are the most visible species depending upon intertidal habitat for feeding, roosting and resting.

Shorebirds are the most visible species depending upon intertidal habitat for feeding, roosting, and resting. Both Boland (1981) and Kus and Ashfield (1989) observed shorebirds in the nearby Tijuana Estuary in a wide variety of habitats, and noted that nearly every species they studied made use of intertidal areas at some time. Boland (1981) consistently found the highest densities of nearly all shorebirds in intertidal flats and channels; likewise, Kus and Ashfield (1989) observed that the majority of large and small waders seen during low-tide surveys occurred in those habitats (citations from Zedler *et al.* 1992).

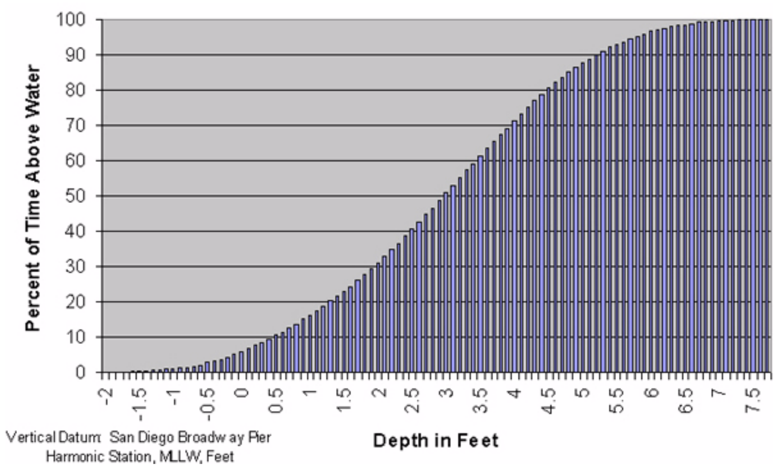


Figure 2-5. Intertidal Area Exposed Annually in San Diego Bay (1999).

2.4.4.1 Intertidal Flats

Habitat Description

Intertidal flats of San Diego Bay include mudflats, sand flats, and salt flats. They occur between the highest high and lowest low tide zones, or otherwise between the lowest cordgrass (beginning of the salt marsh) and highest eelgrass, approximately 3 to 0 ft (1 to 0 m) MLLW in the Bay. The zone normally lacks vegetation. The most extensive intertidal flats in the Bay are along the northern shore of the Salt Works, north of the northernmost levee; along other shorelines of south Bay; off the shore of North and South Delta beaches; and along the barrier edge of the power plant channel. Important, narrow intertidal flats also occur along the margins of tidal channels of the salt marshes of south Bay, which may be used for feeding areas by the light footed clapper rail (*Rallus longirostris levipes)* and Belding's savannah sparrow (*Ammodramus sandwichensis beldingi)*. Mudflats have been replaced by fill, concrete bulkheads, and a variety of other stabilization structures in the north Bay and the eastern shoreline of the central Bay to provide for recreational, commercial, industrial, and military uses.

A well-developed mudflat is anaerobic within the sediment and stable due to a lack of significant wave action. Sand flats remain aerobic and typically experience more turbulence from waves, preventing development of permanent burrows. Sandy beaches are more strongly zoned than mudflats (Castro and Huber 1997), because they tend to have a steeper gradient topographically and because coarse grain sizes allow for more rapid and differential drying. The upper beach is drier than the lower beach. Because water drains away from the upper beach more rapidly, it is drier than the lower beach. Beach hoppers, sand fleas and isopods may be expected there. On the lower beach, polychaetes, clams, and other animals predominate.

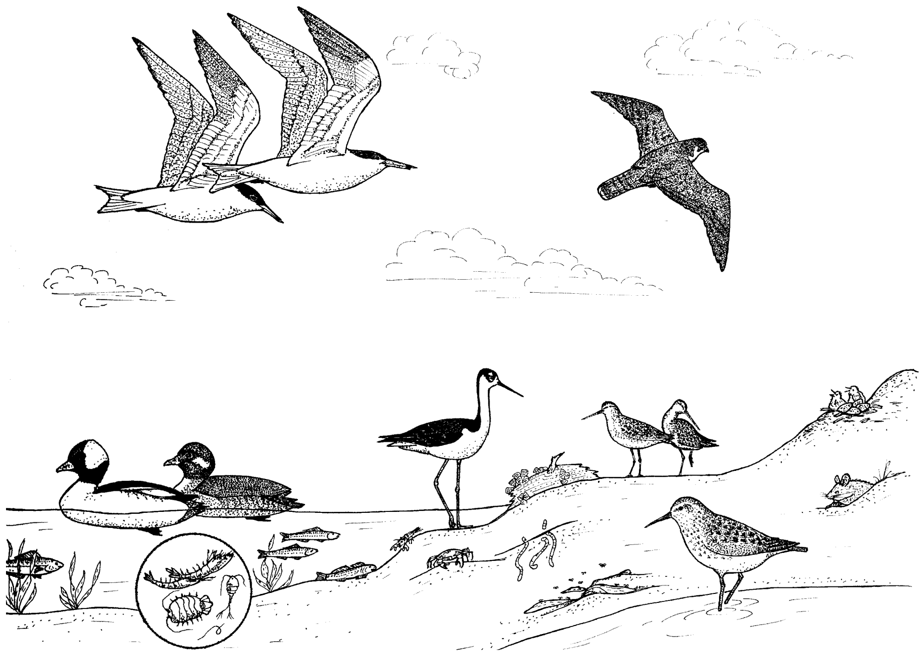


Figure 2-6. Intertidal Flat Community.

Use of the Habitat

- Intertidal flats contain abundant algae and detritus, which along with tiny benthic invertebrates are necessary to the food chain and mineral cycles of the Bay.

Mudflats contain abundant organic matter and microorganisms, but typically less so than eelgrass beds or salt marsh. Normally devoid of flowering plants, these areas may be covered with algae. Toward the uppermost elevations, green algae such as *Enteromorpha* sp., *Cladophora* sp. and *Ulva* spp. may form extensive mats (Mudie 1970). Burrows and siphon-holes of benthic invertebrates, tiny invertebrates that live among the grains of substrate (meiofauna), and algae and detritus fill the sediment with hidden activity, and are all necessary to support the food chain and mineral cycles of the Bay. Snails, crabs and polychaete worms (deposit feeders) glean the surface for detrital bits and algae. Filter-feeders such as clams, mussels, and small crustacean isopods and amphipods collect plankton, algae, and detritus as they wash by when the tide is in. The deposit and filter feeders together are extremely efficient processors of the living and dead plankton.

- Most mudflat fishes are tidal visitors, some remain at low tide in shallow drainage channels, and a short list of species are permanent residents.

When the tide comes in, numerous fishes, sharks, and rays move in to take advantage of the productivity of the flats. While most mudflat fishes are tidal visitors, and some remain at low tide in shallow drainage channels, a short list of species are full-time residents. These are commonly the ones that can live in the burrows of marine invertebrates (Moyle and Cech 1982). Other fishes are seasonal visitors during juvenile life stages: California halibut, California halfbeak (*Hyporhamphus rosae*), and striped mullet (*Mugil cephalus*) (Johnson 1999). Studies on tidal flats elsewhere have demonstrated that it is frequently only the juvenile decapod crustaceans such as shrimp, as well as demersal fish, that forage on tidal flats while the adults and pelagic larvae stay offshore. The tidal flats function as nurseries for the resident juveniles and the subadults, which migrate to the subtidal area to avoid low tide conditions on the flats. While relatively constant salinities and temperatures in offshore waters benefit larval development, these larvae eventually drift onto tidal flats so that the juvenile stages of these fish may take advantage of high temperatures, abundant food, and absence of large predators (Reise 1985).

Photo 2-6. Small Mudflat Adjacent to Delta Beach, Showing Sediment Churned Up At High Tide.

Topsmelt was the most abundant fish caught in Allen's (1998) intertidal habitat surveys in the Bay, for which sampling was only conducted in lower intertidal regions. The second most abundant was slough anchovy (*Anchoa delicatissima*). Other primary intertidal fishes observed by Allen were deepbody anchovy (*Anchoa compressa*), California killifish, and California halfbeak, as well as arrow goby (*Clevelandia ios*), shadow goby (*Quietula y-cauda*), cheekspot goby (*Ilypnus gilberti*), and yellowfin goby (*Acanthogobius flavimanus*). Young-of-year halibut and diamond turbot use intertidal flat. They are even commonly found in the high intertidal salt marsh, while older juveniles and young adults are in the shallow subtidal areas (Nordby 1982; Drawbridge 1990; Johnson 1999).

- Shorebirds congregate sometimes by the thousands to consume invertebrate prey that becomes available when the tide recedes.

When the tide recedes, biodiversity in the mudflat becomes much more visible to even the casual observer. Shorebirds congregate sometimes by the thousands to consume invertebrate prey. Each species specializes in a certain zone, evident by the length of its bill and feeding behaviors that help access the different lifestyles and niches of mud-dwelling species. In the flats that adjoin the salt ponds of south Bay, the USFWS made 50,000 bird observations of 67 species, primarily sea birds and shorebirds, during year-long, weekly surveys in 1993–1994 (US Fish and Wildlife Service 1995a). The threatened western snowy plover (*Charadrius alexandrinus nivosus)* and western sandpiper (*Calidris mauri*) forage on the mudflats during low tide. The endangered California least tern, other terns, and black skimmer forage in the waters over submerged mudflats during high tide (US Fish and Wildlife Service 1995a).

Function

The effects of the severe reduction of intertidal flat habitat from historic proportions have not been characterized for the Bay. It is possible that their own productivity may be limited by reduced sources of detritus they receive due to loss of eelgrass and salt marsh from the historic Bay. It may also be that an impaired nutrient supply function of intertidal flats is affecting nearby habitats. Finally, there appear to be significant subsets of mudflat habitat that provide important functions, but these have not been described. For example, birds use narrow versus broad intertidal flats differently, as well as coarse-grained versus fine-grained. For some birds, this may limit their ability to use intertidal flats of the Bay.

Photo © 1999 Tom Upton.

Photo 2-7. Mudflat of South Bay.

2.4.4.2 Salt Marsh

- Southern California salt marshes differ from east and south coastal marshes in part because of contrasting rainfall and tidal regimes.

Salt marsh is the driest intertidal habitat, occurring in the upper intertidal zone above the mudflats. It is regularly wetted by tidal water and always exposed at least once every 24 hours. Since the climate is semiarid with little rainfall for much of the year, uninterrupted tidal circulation is the most important source for water, nutrients, and oxygen (Macdonald *et al*. 1990). This contrasts with marshes from the east and south coasts. Southern California salt marshes differ from eastern and southern coastal marshes in other ways. The rate of primary productivity for vascular plants is lower in southern California, while productivity for epibenthic algae underneath the open canopy is higher (Zedler 1992a). Annual productivity of dense algal mats beneath the marsh canopy could match or exceed that of vascular plants in local marshes. These differences between marshes of southern California and elsewhere suggest that what drives and regulates marsh function, and how the marsh relates to other habitats, may also differ here.

Habitat Description

- In 1859, there were 642 acres (260 ha) of salt marsh in north San Diego Bay and 420 acres (170 ha) in central Bay. South San Diego Bay had over 1,700 acres (688 ha). Baywide, 88% of salt marsh habitat has been lost.

Salt marsh habitat has been severely reduced by urban development and only remains in south San Diego Bay. It previously existed at the mouths of seven drainages. In 1859, there were 642 acres (260 ha) of salt marsh in north San Diego Bay and 420 acres (170 ha) in central Bay. South San Diego Bay had over 1,700 acres (688 ha). Baywide, 88% of salt marsh habitat has been lost. The problem is not just loss of acreage, however, but fragmentation and isolation of the remaining parcels, which may cause them to lack long-term sustainability. This plant community is also considered to be scarce in southern California as a whole. Estimates of the amount of salt marsh habitats that have been destroyed in southern California range from 75 to 90% (Zedler 1996).

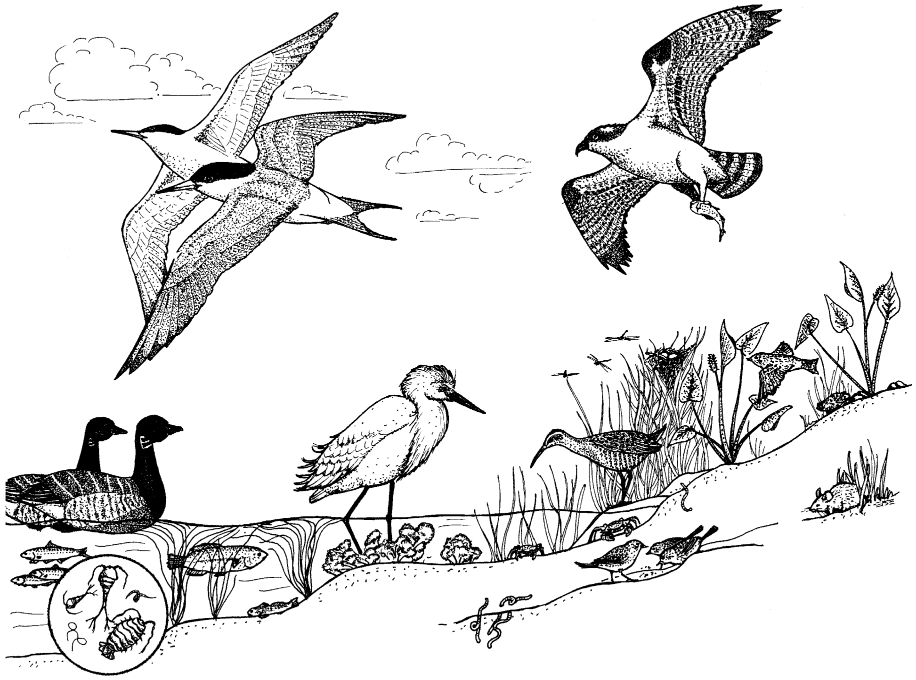
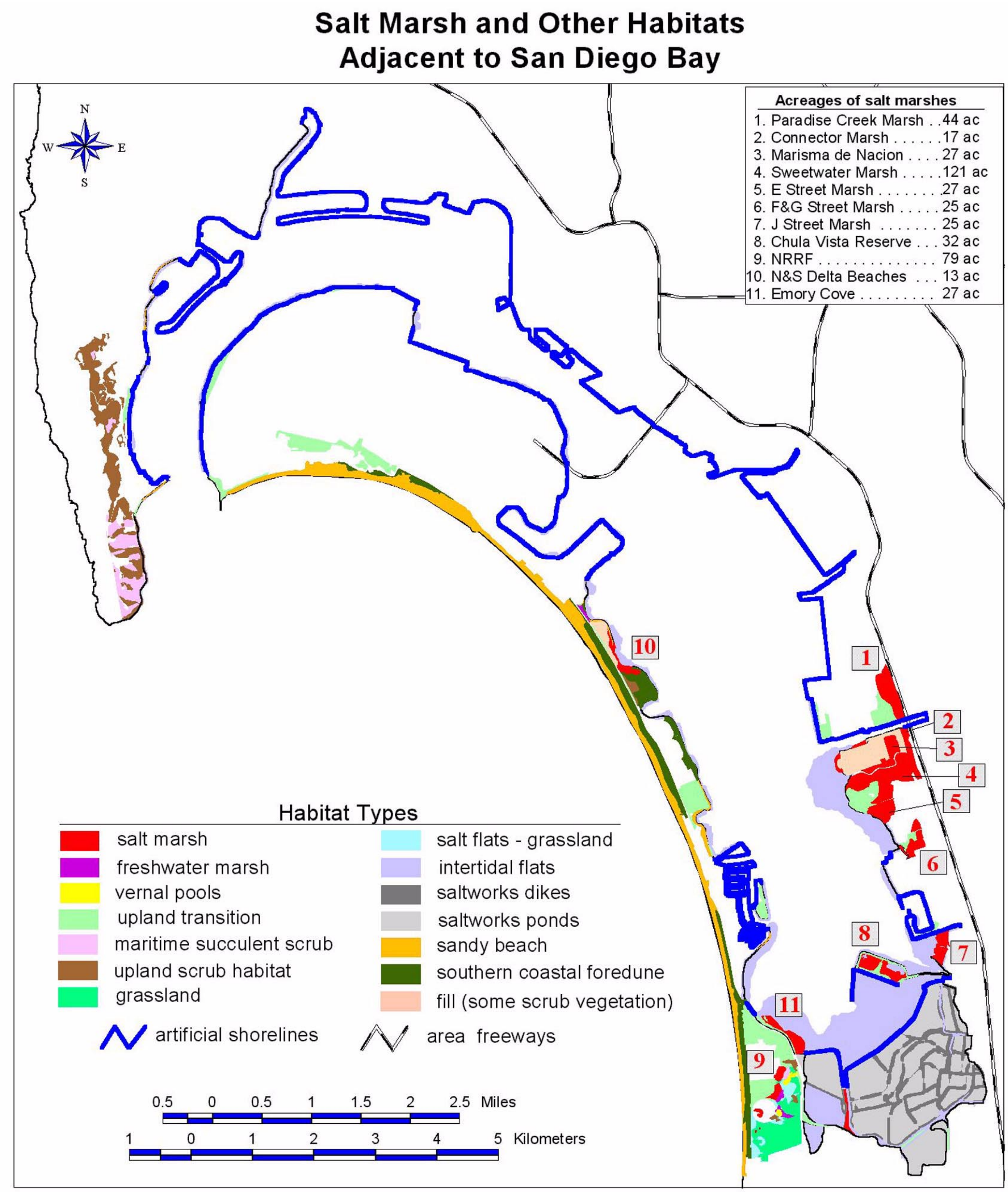


Figure 2-7. Intertidal Salt Marsh—Subtidal Interface.

- Important salt marsh fragments for some birds occur along dikes in the salt ponds and along portions of the Otay River. The primary marsh complex is at the SMNWR.

Today, the primary marsh complex is on the eastern shores of south Bay at the SMNWR. The individual parcels are (Map 2-6) Sweetwater River (121 acres/49 ha), Paradise Creek (44 acres/18 ha), Marisma de Nacion (27 acres/11 ha, excavated from the D-Street Fill in 1990), Connector (17 acres/7 ha constructed as a hydrologic link between Paradise Creek and the SMNWR), E St. (about 27 acres/11 ha), F and G Streets (25 acres/10 ha), and J Street (25 acres/10 ha) marshes. There is also the Chula Vista Wildlife Reserve (CVWR) (32 acres/13 ha of dredge fill constructed in 1987), the marsh at the south end of Emory Cove (about 27 acres/11 ha) and between North and South Delta Beaches (about 12 acres/5 ha). Portions of the marsh at the Naval Radio Receiving Facility (NRRF) no longer function as marsh land since they are no longer tidally influenced. Marshes support federal and state endangered salt marsh bird's beak (*Cordylanthus maritimus maritimus*). Important salt marsh acreage for birds occurs in long, narrow strips along some of the dikes in the salt ponds and along the tidally influenced portions of the Otay River.



Map 2-6. Salt Marsh and Upland Transition Adjacent to San Diego Bay.

Coastal salt marshes can be divided into more or less distinctive zones based upon vegetation patterns. These patterns are related to elevation and degree of inundation, and may be termed Lower, Middle, and Upper Marsh, and Upland Transition (Figure 2-8) (Zedler *et al.* 1992). The plant communities of each of these zones are described below.

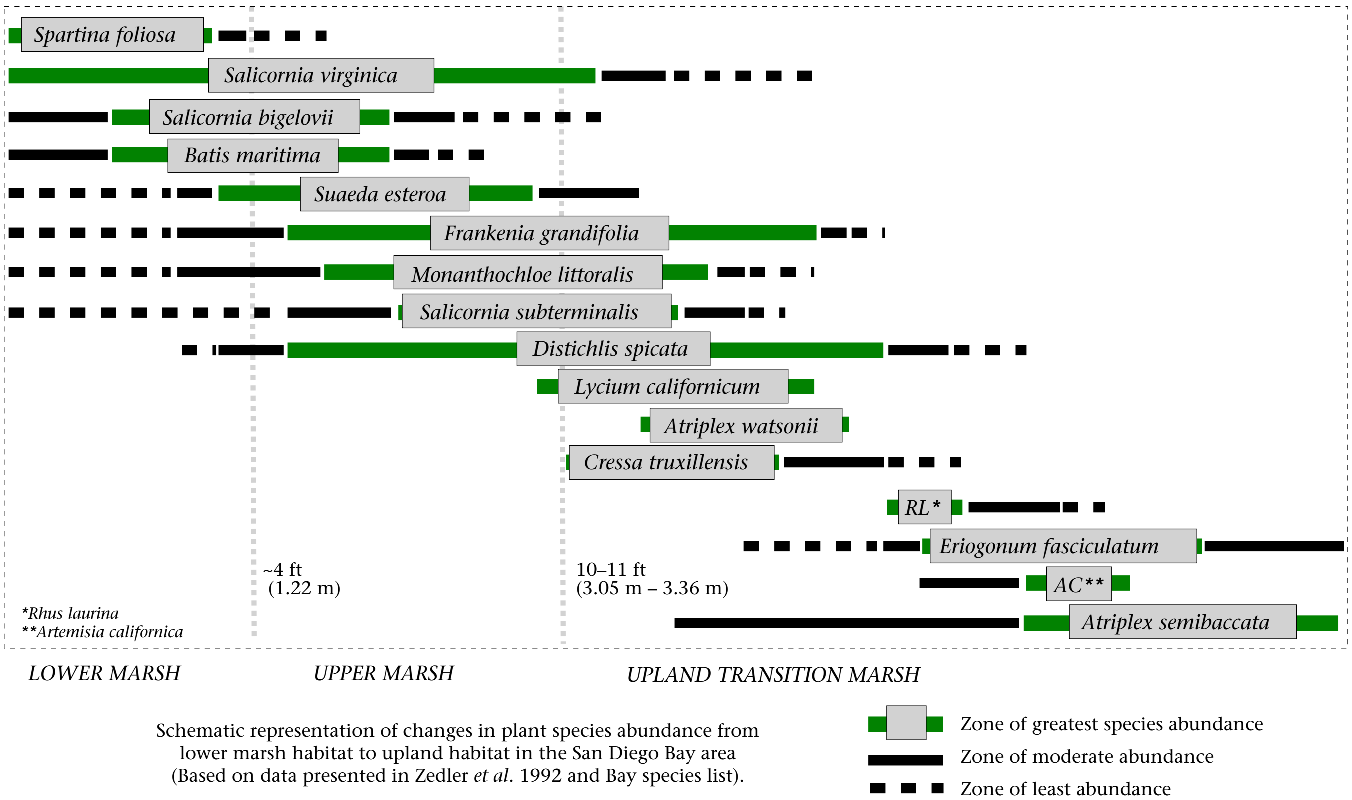


Figure 2-8. Vegetation Patterns in Salt Marsh Habitats.

Lower Marsh

The lower marsh is characterized by cordgrass (*Spartina foliosa*), grading into pickleweed (*Salicornia virginica* and *S. bigelovii*). Cordgrass, which may be up to 3 ft (1 m) tall and half submerged, spreads through the habitat with buried rhizomes, and less commonly from seed. Pickleweed occurs in areas that are inundated by only the highest tides (Zedler *et al.* 1992; Schoenherr 1992; Boyer *et al.* 1996b).

Middle Marsh

The middle marsh habitat is typified by the presence of saltwort (*Batis maritima*), pickleweed, sea blite (*Suaeda esteroa*), and arrow grass (*Triglochin concinna*) (not quantified by Zedler *et al.*, so not in Figure 2-8) (Zedler *et al.* 1992; Boyer *et al.* 1996b). Killifish and water boatmen typically inhabit pools of the middle marsh.

Upper Marsh

The upper marsh is characterized by golden bush (*Isocoma* spp.), prickly-pear (*Opuntia* spp.), glasswort (*Salicornia subterminalis*), sea blite, box thorn (*Lycium californicum*), salt grass (*Distichlis spicata*), and shore grass (*Monanthochloe littoralis*) (Zedler *et al.* 1992; Boyer *et al.* 1996a). Salt marsh bird's beak, a federal and state endangered species, occurs in the upper marsh zone. A small population of salt marsh bird's beak at the E Street Marsh in Chula Vista is one of only two known populations in San Diego County, with the second occurring at the Tijuana Estuary. Other populations are known from as far north as San Luis Obispo County and south into Baja California.

Upland Transition Marsh

The upland transition zone is not a distinct community in and of itself, but represents a gradient between the upper marsh and coastal scrub community (Zedler *et al.* 1992). The lower end of the transitional zone is characterized by *Salicornia*, *Distichlis*, *Monanthochloe*, *Frankenia*, and *Cressa* species, while the upper transition zone is characterized by *Atriplex*, *Eriogonum*, *Rhus*, *Salvia*, and *Artemisia* species (Zedler *et al.* 1992; Holland and Keil 1995). *Frankenia palmeri* is a California Native Plant Society (CNPS) List 2 species.

Use of the Habitat

A number of marine fish inhabit the Bay's salt marshes. Topsmelt, arrow goby, California killifish, and longjaw mudsucker (*Gillichthys mirabilis)* are most abundant at SMNWR (Johnson 1999). Young round stingray and California halibut also occur. Two exotic fishes that are present and could become a nuisance include the yellowfin goby and the sailfin molly (*Poecilia latipinna*). The former was probably introduced in ship bilge water, while the molly was likely introduced through the aquarium trade (Boyer *et al.* 1996a).

Function

- Birds that depend on marshes are concentrated on parcels that retain salient features. Not all marshes in the Bay attract birds.

A well-functioning salt marsh habitat provides nesting, feeding, and a high-water escape area for many species of birds, as well as food and cover for fish and invertebrates. Not all marshes in the Bay have the salient features to attract birds, so those that depend on the marsh are concentrated on the parcels that retain such features. The Belding's savannah sparrow nests in patches of pickleweed or boxthorn in some areas of Bay salt marshes, and forages in salt marsh and intertidal flats. Where it is found in the Bay, the light footed clapper rail depends entirely on salt marsh habitat for feeding, resting, and nesting. Cordgrass thickets, in particular, are an important component of the marsh for nesting by the rail. Cordgrass stabilizes the low elevation salt marsh within a narrow range that is dependent on tidal flushing (Zedler 1992b). It also lines the edges of tidal channels. Since cordgrass is linked by tidal flows to the mudflats on a daily basis, mobile animals are able to move into the marsh at high tide to feed. Detritus and algae float out from the marsh into channel waters (Zedler 1992b). The plants and productive algal mats that occur within the marsh support detritus- and grazer-based food chains.

- There is tremendous variability over time in the processes that determine the fate of carbon, detritus, and nitrogen in the system present in southern California.

There has been some difficulty characterizing the function of salt marshes of southern California because the systems are not stable long enough to quantify energy flow and nutrient cycling (Zedler *et al.* 1992). Investigators of southern California and east coast marshes have concluded that the traditional view that salt marshes are net exporters of productivity that subsidize waters nearby is not necessarily true. It may be different in each individual case. In southern California, there is tremendous variability over time in the processes that determine the fate of carbon, detritus, and nitrogen in the system. Rare events dominate the structure and function of the marsh (Zedler and Onuf 1984). Scientists have examined such patterns on nitrogen fluxes and productivity in the nearby Tijuana Estuary. Their results may not be transferable to San Diego Bay, however, because the Tijuana system experiences occasional sewage spills from Mexico and has experienced historical seasonal closures at the mouth that reduced tidal influence. The Tijuana Estuary no longer experiences seasonal closure—the last one was in 1983–1984. The mouth does become constricted from time to time, but the time of year is variable. Currently, the mouth is ready to be excavated immediately upon closure (B. Collins, US Fish and Wildlife Service, pers. comm.).

- Productivity rates in the marsh peaked in very open canopies during warm periods at sites that were frequently inundated, conditions where algae on the marsh soil surface could flourish.

Some patterns in the mechanisms behind salt marsh structure and function have been teased out of the natural and human-related variability in work conducted both in San Diego Bay and in the Tijuana Estuary (summarized in Zedler *et al.* 1992). When soil salinities were measured six times in Sweetwater marshes in late 1995 through 1996, lowest salinities were found in the winter following rains (Boyer *et al.* 1996a). High marsh locations have higher peaks in soil salinity, with salinities at the lower elevation being moderated by frequent inundation (Boyer *et al.* 1996a). In tidal creeks of the Tijuana Estuary, algae in phytoplankton blooms peaked in areas with the lowest tidal circulation, with seasonal peaks in spring when weather was warm and tidal action minimal due to estuary closure. This suggests that phytoplankton accumulate when water currents are reduced and nutrients are plentiful (Fong 1986). Rudnicki (1986) found maximum volume of macroalgae where circulation was reduced and where prevailing winds moved the floating mats. Salinity affected the growth of both phytoplankton and macroalgae. Lower salinity delayed phytoplankton blooms, and the species composition became more dominated by blue-green types. In manipulative experiments at the Tijuana site, productivity rates in the marsh peaked in very open canopies during warm periods at sites that were frequently inundated, conditions where epibenthic algae could flourish (Rudnicki 1986; Fong 1986). Algae blooms (based on chlorophyll concentrations and cell counts) occur during nontidal periods (Fong 1986).

- There is some evidence that nitrogen may be limiting to constructed Bay marshes. Studies of the Sweetwater complex show peaks in water nutrient levels in January.

While salt marshes are considered productive habitats due to plant and algal photosynthesis and access to nutrients from nitrogen fixing bacteria and blue-green algae and from flood tides, there is some evidence that nitrogen may be limiting to Bay marshes, at least in constructed marshes. The cordgrass marsh of the Bay is nitrogen limited and receives this nutrient in pulses from freshwater systems or slowly by trapping inorganics from tidal water (Zedler 1992b). Low nitrogen pools reflect low tidal import and infrequent streamflow influxes (Langis *et al.* 1991). A one-year study at the SMNWR showed nitrogen fixation rates (as measured by acetylene reduction) to be very low (Zalejko 1989). Studies of marshes in the Sweetwater complex show peaks in water nutrient levels in January, presumably related to nutrient inputs from runoff during winter storms (Boyer *et al.* 1996a). Most organic matter and runoff is trapped behind reservoirs on the Sweetwater River, which only overflow during extreme storms, approximately once per decade.

- Freshwater increases to the salt marsh system can cause conversion to brackish water, which quickly kills some species. Sufficient salinity conditions are necessary for the survival of marine fish and invertebrates.

There are several indicators that can reflect health of the salt marsh. One is loss of plant cover or density. Another is a change in plant composition towards species that tolerate brackish or fresh water. This can result from altered hydrology that decreases tidal influence, such as when fill is added to the marsh. The result is reduced flushing of the system so that sediment accumulates. This can also happen with increases in freshwater flow from urban runoff or imported water. Freshwater increases can cause conversion to cattail/bulrush vegetation and brackish water that may support different species. Most marine species have a low salinity tolerance range. If water becomes brackish, or if stagnant water becomes anoxic, such species are quickly killed (Zedler 1992a). A lack of marine fish and invertebrate species would indicate a lack of sufficient saline conditions for their survival. The presence of nonnative plants within the salt marsh could indicate reduced salinity levels, as could the presence of native upland plants.

2.4.4.3 Artificial Hard Substrate

Habitat Description

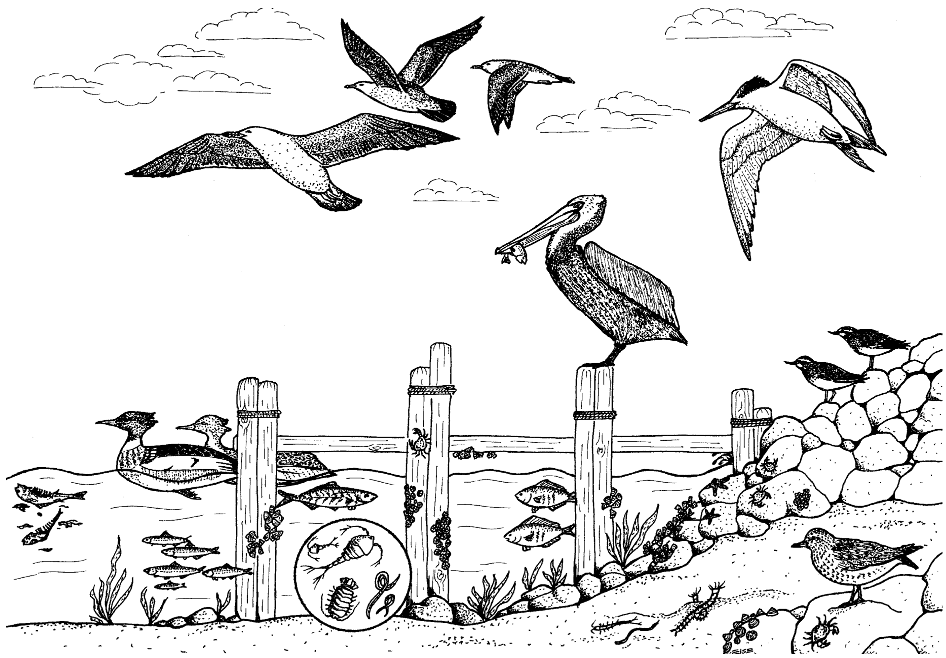


Figure 2-9. Artificial Shoreline Environment.

- This section and Section 4.2.1.7 "Artificial Hard Substrate" discuss artificial structures as habitat, while Section 5.1.3 "Shoreline Construction" addresses the building of these structures.

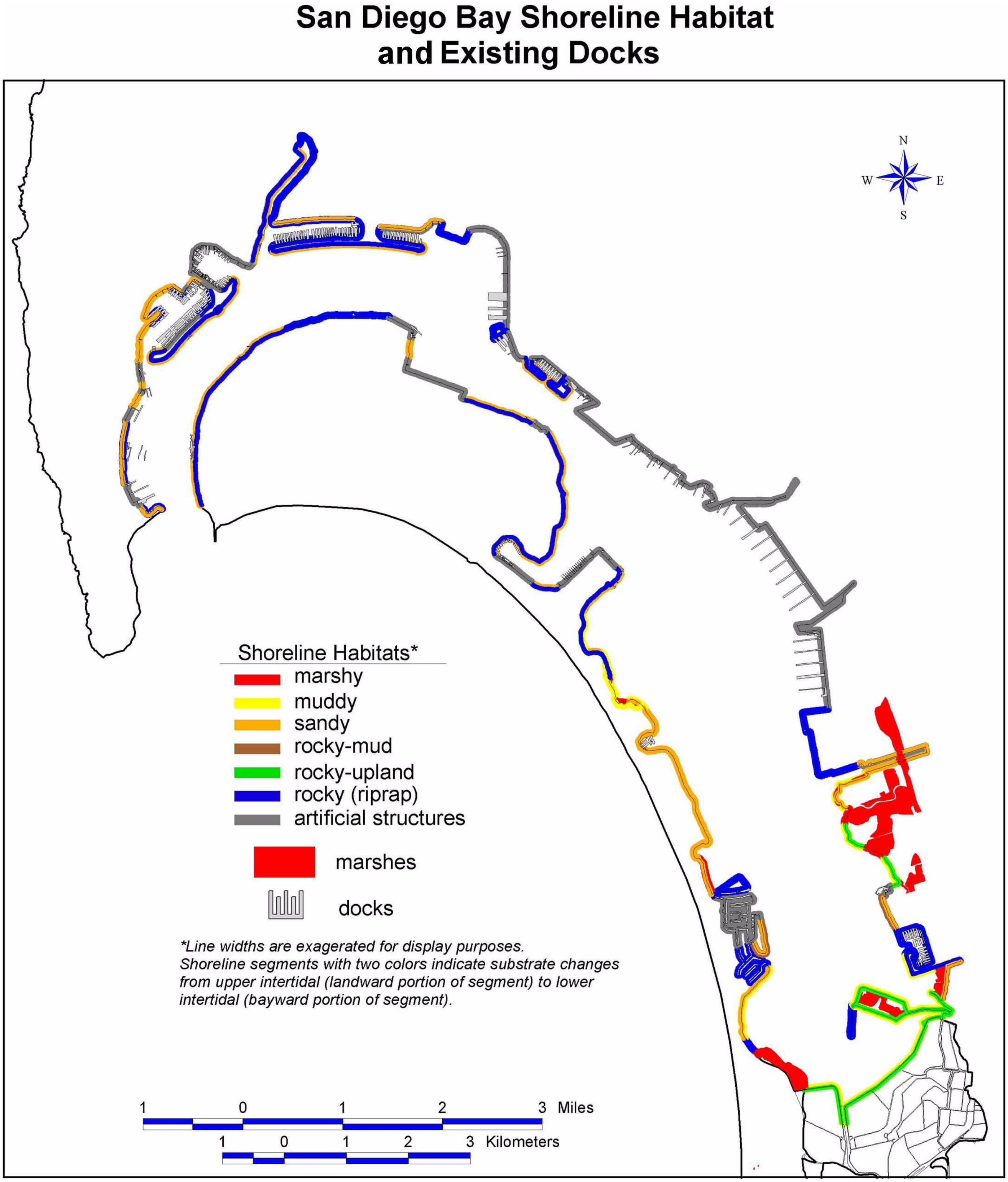
This section and Section 4.2.1.7 "Artificial Hard Substrate" discuss artificial structures as habitat, while Section 5.1.3 "Shoreline Construction" addresses the building of these structures and the permitting process and use of materials associated with this construction.

Unprotected shoreline sites will erode when exposed to tidal fluctuation, storm waves, storm surges, and surface runoff. Hard structures are used to protect developed sites along the Bay. Pier pilings, bulkheads, rock riprap, floating docks, sea walls, mooring systems, and derelict ships/ship parts form extensive artificial habitat in the northern and central portions of San Diego Bay and to a lesser extent in the southern Bay. San Diego Bay presently has 45.4 mi (73.1 km) of armored shoreline out of 64.4 mi (103.6 km) of shoreline, or 74% affected. There are also 131 acres (53 ha) of surface structures shading Bay waters, in both intertidal and subtidal habitats. See Map 2-7 to view the distribution of this habitat.

Use of the Habitat

- Man-made structures support invertebrates and seaweeds, including exotic species that have invaded the Bay. Floating structures are used by waterbirds and buoys by sea lions.

All of the man-made structures support a wealth of invertebrates and seaweeds, including many of the exotic species that have invaded the Bay. Native and non-native lobster, crabs, worms, mussels, barnacles, echinoderms (starfish, sea urchins), sponges, sea anemones, and tunicates (sea squirts) are all known to inhabit artificial structures. These areas may also provide refuge and feeding areas for certain juvenile and predator fishes, such as perches, basses, dogfish, opaleye, and croaker. Artificial habitats were not part of the fish sampling design conducted by Allen (1997) over the last several years. A hardened shoreline typically produces a very steep shore profile



Map 2-7. Shoreline Structures of San Diego Bay.

that can provide elevated roosting sites for Bay waterbirds to conserve energy and avoid harsh weather conditions (Ogden 1995). Floating structures in shallow water, which are relatively undisturbed by human activity, are used for roosting and foraging by waterbirds such as brown pelicans, cormorants, and gulls (Ogden 1995). Buoys in the Bay's deep water have long been used as haul out sites for sea lions.

Photo 2-8. Invertebrate in Riprap.

The diversity, abundance, and distribution of these artificial habitat organisms have not been characterized for San Diego Bay nor, apparently, for many other locations. Their strong seasonality and variation among years has also not been described. Other than for the limited scope of environmental impact assessments for specific projects, the only detailed, multiseason study of this kind was conducted on the concrete and wooden piling structures of the B Street, Broadway, and Navy piers during 1972–1973 (Ford *et al.* 1975). The results of this study are summarized in Section 2.5.3 "Invertebrates." More on piers and pilings is discussed in Section 5.1.3 "Shoreline Construction."

Function

- Habitat value of armored shoreline varies in structures around the Bay. Sea walls provide the poorest habitat because of a too-smooth surface and vertical angle, making it difficult for marine species to attach.

Habitat value of the armored shoreline is expected to vary according to material, construction, relief, and maintenance activities. The surface roughness and complexity of a structure can affect its ability to provide refuge niches and allow retention of water at low tides. A structure's elevation in relation to the tidal prism can also be important, with higher structures affecting less intertidal habitat. Many examples exist around the Bay of structures with clear differences in habitat value. For example, Shelter Island has better low tide habitat than Harbor Island where the structures and slope are too steep (R. Ford, San Diego State University, pers. comm.). Some riprap niches have been filled in with concrete, while others are filled with invertebrate fauna. Sea walls provide the poorest habitat for marine species, as their relatively smooth surfaces and vertical angles reduce suitable areas for attachment.

Research is also generally lacking by marine ecologists on creating higher habitat value out of such structures. A few innovative examples exist, such as experiments with docks (Russell *et al.* 1983; Hawkins *et al.* 1992) and littoral flat terraces that have been implanted in riprap-stabilized shorelines at the Port of Seattle (Simensted and Thom 1992). Figure 2-10 contrasts the lower diversity and abundance of life in riprap compared to a rocky tide pool to highlight the potential that exists for enhancement of these artificial shorelines.

2.4.5 Salt Works

- The nature of the salt extraction process has facilitated use of this artificial habitat by many shorebirds, sea birds, and waterfowl. It represents one of the few large feeding, roosting, and nesting areas remaining along the urbanized southern California coast. These values recently received long-term protection as the Port purchased this property and turned it over to USFWS for a wildlife refuge.

Habitat Description

Marsh lands around the mouth of the Otay River in the shallow, south end of San Diego Bay were converted to salt evaporation ponds in the early 1900s. In 1916, a major flooding of the Otay River washed out the levees. Between 1920 and 1933, new, diked ponds were constructed, creating over 899 acres (364 ha) of new habitat. The salt ponds consist of shallow, open water cells of different salinity levels interspersed with mudflats, dry dikes, and salt marsh. The nature of the salt extraction process has facilitated use of this artificial habitat by many shorebirds, sea birds, and waterfowl. It represents one of the few large feeding, roosting, and nesting areas remaining along the urbanized southern California coast. These values will soon receive long-term protection as the Port purchases this property and turns it over to USFWS for a wildlife refuge.

The Salt Works cover approximately 1,451 acres (587 ha), producing sodium chloride and magnesium chloride for industrial use. Primary ponds are approximately 3 ft (1 m) deep at their center, and are the least salty, representing the first stage of the extraction process. Secondary ponds are up to 5 ft (2 m) deep. These ponds are slightly more saline than sea water and are used for commercial brine shrimp production. Pickling ponds have the second-highest salinities. The final step in the extraction process occurs in crystallizer ponds, which support the highest salinity levels. The evaporation process takes 12 to 18 months, depending on rainfall, with each crystallization pond harvested once per year. Brine shrimp thrive in the secondary system; shrimp eggs hatch beginning in mid-May and mature shrimp are collected through mid-December. These are harvested commercially. Most birds use the southern side of these secondary ponds. Salinity in the salt ponds contributes to an abundance of brine flies, an important food for many birds (US Fish and Wildlife Service 1994a).

Use of the Habitat

The dikes and ponds provide an escape area from rising tides, as well as feeding and resting areas for shorebirds and waterfowl. Different bird species preferentially select different areas of levees by the amount or proximity of vegetation or bare ground, or some other unknown factor about the substrate (US Fish and Wildlife Service 1998). Dikes are quite variable, but are often comprised of compacted or soft powdery silt, with typically sparse vegetative cover. Gulls, terns, black skimmers, and pelicans, including the California brown pelican, use the dikes for evening roosts. Dikes separating the ponds support significant nesting colonies of western snowy plover, Belding's savannah sparrow, black-necked stilt (*Himantopus mexicanus mexicanus*), black skimmer, and Caspian, Forster's, gull-billed, royal, and California least terns (*Sterna* sp.). One of only two nesting colonies of elegant terns (*Sterna elegan)* in the United States can be found at the salt ponds.

The Draft Environmental Assessment and Land Protection Plan for the South Bay Refuge (US Fish and Wildlife Service 1998; Final February 1999 at http:www.rl.fws.gov/planning/plnhome.html) summarized use of the Salt

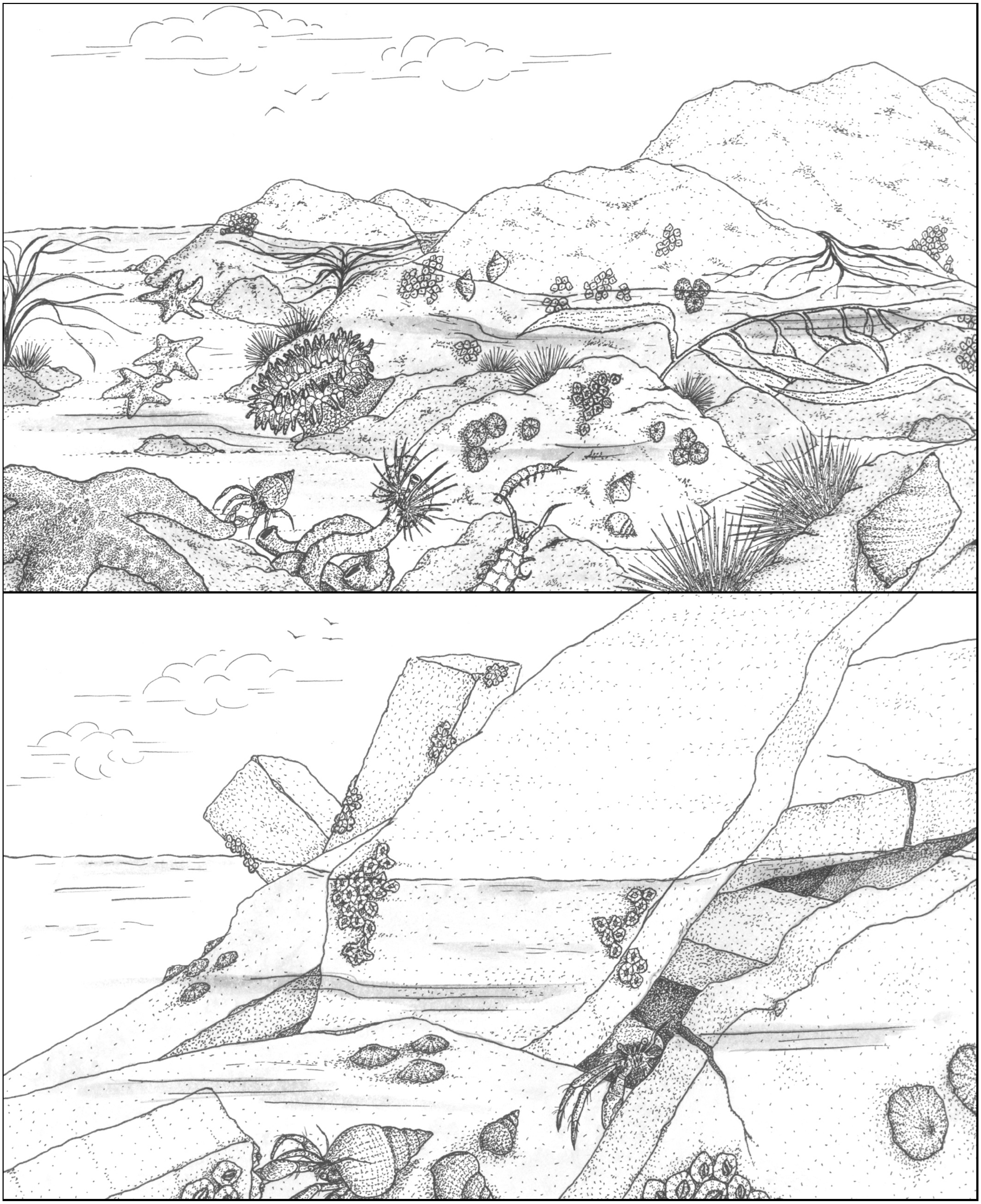


Figure 2-10. Typical Diversity and Abundance of Life in a Tide Pool (top) Compared to That of Life in Riprap (bottom).

Photo © 1998 US Navy Southwest Division.

Photo 2-9. Salt Works.

Works by sensitive birds. It is one of three primary locations in California where black skimmers nest (US Fish and Wildlife Service 1993). In 1993, double-crested cormorants (*Phalacrocorax auritus)* made 43 nests on an abandoned barge at the salt ponds; this increased to 47 in 1997 (US Fish and Wildlife Service 1993, 1998). In 1993, ten western snowy plover nests and 62 California least tern nests were initiated along the salt pond dikes (US Fish and Wildlife Service 1993). In 1995, eighteen California least tern nests were initiated (California Department of Fish and Game unpublished 1995). In 1993, breeding pairs of tern species were recorded as 312 elegant terns, ten royal terns (*Sterna maximus*), 280 Caspian terns (*Sterna caspia*), and ten gull-billed terns (*Sterna nilotica*). In 1994 these numbers were 80 elegant, no royal, 320 Caspian, and nine gull-billed terns. Elegant terns reproduced successfully in 1996 and 1997, but no numbers are available (J. Coatsworth, pers. comm.).

2.4.6 Upland Transitions

Terrestrial habitats along Bay margins include riparian regions, fallowed agricultural lands, sandy beaches, foredunes, backdunes, coastal scrub, and eucalyptus groves. Historically, a natural ecotone existed between the upper edge of tidal habitats and upland vegetation. This area has been almost completely replaced by urban development. Where it is present, it is disturbed and nonnative plant species are present. The tidal influence in this transition zone is limited to salt spray. Map 2-6 depicts some of the upland transition and salt marsh habitats around the Bay. Several wildlife and plant species of the upland transition areas are sensitive (see Section 2.6 "Sensitive Species" and the MSCP for San Diego County which is directed towards protection of these species).

Uplands that border the Bay are important as a buffer between the natural and constructed environment, and for the large number and diversity of avian species that use them as essential habitat for nesting, roosting, and refuge from high tides and adverse weather. Uplands may also be important for species that use a tidal habitat but do not live in it. For example, the bee pollinators of salt marsh bird's beak nest in upland areas. The western snowy plover prefers certain plants on southern foredunes or disturbed dunes outside its usual habitat affinity for sandy beaches. Yet, upland transition habitats are among the most threatened by development and management trends.

2.4.6.1 Beaches and Dunes

The shoreline is a stressful environment, subject to wind and wave turbulence, salt spray, shifting sands, high temperatures, and desiccation. Before development overcame the southern California coastline, dunes acted as a buffer in the unstable zone between the tidal and upland environments. A number of plants and animals have become adapted to this instability and are found only on dunes or beaches. However, many Bay beaches are subject to heavy recreational use. Others are used intermittently for military training. For example, North and South Delta beaches are not used for training April through September due to the presence of nesting California least terns and the beach near the Fuel Supply Pier at Point Loma is never used. Because of use patterns and because most of the habitat in southern California has already been destroyed (Holland 1986), dependent species are particularly vulnerable to extinction on a local scale.

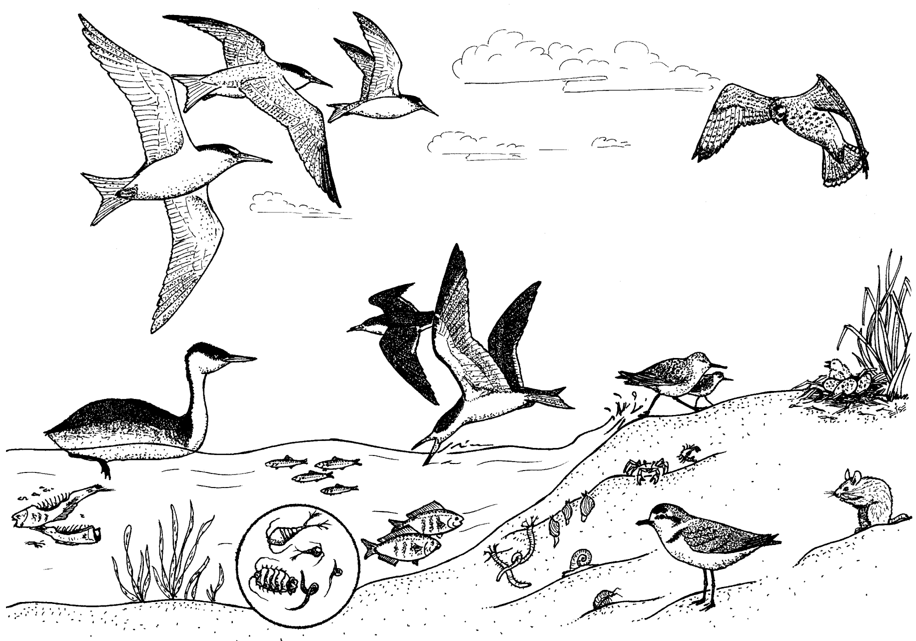


Figure 2-11. The Beach Environment.

Habitat Description

Plants of the coastal strand habitats, such as along the beaches and dunes of the Bay's relatively undeveloped west shore, are typically well adapted to the sandy soils that occur there, with low water-holding capacity, low fertility, low humus content, and high concentrations of sea salts (Schoenherr 1992; Holland and Keil 1995). Many have deep taproots, enabling them to reach fresh water deeper in the soils. They are also commonly prostrate, and many are succulent. Plants typical of coastal strand communities include beach sagewort (*Artemisia pycnocephala*), dune buckwheat (*Eriogonum parviflorum*), beach ragweed (*Ambrosia chamissonis*), red sand verbena (*Abronia maritima*), and beach evening primrose (*Camissonia chei-*

ranthifolia) (Schoenherr 1992; Holland and Keil 1995). Over time, wind-blown sand will accumulate under and around coastal strand vegetation, gradually building up distinctive sand hummocks and dunes (Photo 2-10).

- Invasive weeds and human use impact almost all remaining fragments of the sand dune habitat.

Several plant species are better adapted to the foredune areas of the coast, which are subject to the greatest amount of salt stress. Primary foredune species are *Abronia maritima*, Watson salt bush (*Atriplex watsonii)*, *Atriplex leucophylla*, and *Cakile maritima*. Plant species diversity tends to increase with distance from the beach, with less salt tolerant species becoming more abundant, particularly species of *Artemisia*, *Baccharis*, *Ericameria*, *Eriogonum*, *Lotus*, *Lupinus*, and *Salvia* (Holland and Keil 1995).

Photo © 1989 Scott Snover.

Photo 2-10. Sand Hummocks with Ambrosia Chamissonis.

Native plant cover is especially important to these habitats because it stabilizes the shifting substrate, which in turn protects the landward habitats from sea storms. Bayside portions of Silver Strand State Beach and dunes at NRRF contain examples of native dune plants such as beach evening primrose, sand verbena (*Abronia maritima* and *A. umbellata*), and beach-bur (*Ambrosia chamissonis*). Following human impacts, some native species declined, such as lemonade berry shrub (*Rhus integrifolia*), while several nonnatives, such as hottentot-fig (*Carpobrotus edulis*), sea rocket (*Cakile maritima*), and Australian saltbush (*Atriplex semibaccata)* invaded.

- The hottentot-fig is a noxious weed. It invades dunes and displaces native plants, which in turn influences development of the endemic insect community.

The life stages of some exotic plants differ from those of native plants and this may also affect native insects. The sea rocket is eaten by dune beetles, but the plant does not live long enough to support insect growth to maturity (Snover 1992). Hottentot-fig, a kind of iceplant, is a very invasive species that is sometimes planted for erosion control and on freeways. It displaces native plants (Williams and Williams 1984), and the animals that depend upon them. It provides little food or habitat for native insects (C. Nagano, US Fish and Wildlife Service, pers. comm., cited in Zedler 1992a; Snover 1992). Native dune beetles do not eat the hottentot-fig. In the field, dune beetles and other native insects are less abundant under exotic vegetation. Temperatures are cooler under the hottentot-fig than under the native vegetation, which may slow insect development (Snover 1992).

Photo 2-11. Dune Vegetation in Flower.

Use of the Habitat

Hottentot-fig dominates much of Silver Strand State Beach, which consists of 86 acres (35 ha). Forty acres (16 ha) are leased from the NAB by CDPR, and the balance is owned by CDPR. Only the leased portion is in this Plan's Functional Planning Zone. The area supports the wandering skipper *(Panoquina errans)*, a federal Species of Concern. This butterfly is associated with southern California coastal dune ecosystems where its host plant, salt grass, is present (US Fish and Wildlife Service 1998). Nuttall's lotus (*Lotus nuttallianus*), a sensitive species (CNPS List 1B) is present in the dunes at NRRF. Other sensitive plant and animal species of limited distribution that inhabit dune and beach areas of the Bay include coast woolly-heads (*Nemacaulis denudata denudata*, CNPS List 2), coast horned lizard, San Diego black-tailed jackrabbit (*Lepus californicus*), and coast horned lark (*Eremophila alpestris*). Dunes also provide habitat for the silvery legless lizard (*Anniella nigra argentea* [=*Anniella pulchra pulchra*]).

- Dunes and adjacent beaches support invertebrate fauna, which are food for Belding's savanna sparrow, among other species.

Dunes and the adjacent beaches support specialized invertebrate fauna, such as tiger beetles and the globose dune beetle (*Coelus globusus)*, sand spiders, robber flies, kelp flies, and ants. Beaches serve as important habitat for nesting, roosting, and foraging bird species, including the endangered California least tern and threatened snowy plover. The plover also uses coastal dunes for roosting outside of nesting season. Belding's savannah sparrow feeds on dune and beach insects.

2.4.6.2 Coastal Created Lands and Disturbed Uplands

Habitat Description

Disturbed uplands at NRRF are dominated by nonnative annual grass species such as foxtail chess (*Bromus madritensis rubens*), soft chess (*B. hordaceus*), ripgut grass (*B. diandrus*), and slender wild oat (*Avena barbata*). Other common plants include the nonnative hottentot-fig, Australian saltbush (*Atriplex semibaccata*), white-stemmed filaree (*Erodium cicutarium*), and native coast locoweed (*Astragalus trichopodus lonchus*). Areas of increased soil salinity support alkali weed (*Cressa truxillensis*), saltgrass, and glasswort where this community intergrades into upper salt marsh vegetation.

Created lands are formed by deposition of dredged sediments from other locations in the Bay. These areas may be devoid of vegetation, but may have wrack or debris washed up on the beach. Beach debris provides temporary shelter and sometimes food for shorebirds and small marine invertebrates such as crabs and amphipods. These lands are a mosaic of uplands and disturbed wetlands.

- Coastal created lands and disturbed uplands provide important habitat for listed species, migrating shorebirds, and nesting sea birds.

The largest parcel of created land is found at the D-Street fill partially within the SMNWR. Created land is also found at the CVWR, where dredged material was used to develop new habitat for wildlife that depend on mudflats and salt marsh. Other sites include the portions of Silver Strand State Beach, North and South Delta beaches, and along the Otay River.

Use of the Habitat

These lands provide important habitat for listed species, migrating shorebirds, nesting sea birds, and foraging raptors. Annually, USFWS or the Port grades portions of the D-Street Fill and the CVWR to enhance nesting substrate for the California least tern and the western snowy plover. The Navy grades areas of the Delta beaches used for nesting by California least terns. A large part of San Diego County's coastal burrowing owl population is located on uplands of the Bay. The sensitive plant, coast woolly heads, occurs on D-Street Fill as does Nuttal's lotus (B. Collins, pers. comm.).

The created lands at CVWR are used as feeding and resting areas by sea birds, migrating shorebirds, and wintering waterfowl. The Port removes vegetation both at this site and at Lindbergh Field to enhance its attractiveness for California least terns. The number of California least tern pairs nesting at the CVWR are as follows: 1988 (24), 1989 (28), 1990 (70), 1991 (1), 1992 (20), 1993 (52), 1994 (1), 1995–1997 (0), and 1998 (2).

2.4.6.3 Freshwater Wetlands and Riparian

Habitat Description

Freshwater wetlands and riparian areas are supported at the entry points of freshwater tributaries into San Diego Bay. They are nontidal. Freshwater marshes are generally contiguous with the upland side of the salt marshes and are occupied by cattails, rushes, and bulrushes. Freshwater riparian areas and wetlands adjacent to salt marshes have been severely impacted by development and reduced runoff from rivers and creeks.

Upstream from the mouth of the Otay River is riparian habitat (see also Photo 3-2 to compare how this area looked in 1928). The habitat is degraded and many of the trees are nonnative eucalyptus and California pepper tree. However, the riparian functions of providing habitat structure, shading some of the river, and buffering disturbances from nearby development are intact (US Fish and Wildlife Service 1998).

An area known as the Egger-Ghio parcel (formerly the MKEG/Fenton parcel), was recently purchased by the Coastal Conservancy. This property lies between the southernmost salt ponds and Interstate 5, consists of former wetlands that were diked and drained decades ago and mostly converted to agricultural use. (See the small parcel in the most southeastern corner of the Functional Planning Area in Map C-1 "San Diego Bay Habitats").

Use of the Habitat

- The Egger-Ghio parcel was recently purchased by the Coastal Conservancy.

Riparian vegetation established on the berms along the Otay River in the Egger-Ghio area supports several migratory songbird species. Although agriculture was discontinued in 1986, most of the area is occasionally disked to control weeds. The fallow agricultural land includes soils classed as prime farm land. There are wetlands, disturbed fields, and shrubby areas that support modest numbers of wildlife. No surveys or censuses of wildlife for the Egger-Ghio parcel are available. The Egger-Ghio parcel possesses high potential for wetland restoration by virtue of its low elevation, past history as tidal wetlands, and relatively undeveloped nature. The site is also suitable for other less intensive types of habitat enhancement measures using existing surface water patterns (US Fish and Wildlife Service 1998).

Function

Wildlife are attracted to riparian woodlands for the freshwater and the structural complexity that provides sites for shelter, refuge from predators, foraging, resting, and cooling. The riparian zone also serves as a natural corridor linking adjacent ecosystems and facilitating movement of animals between them. In these ways, the presence of riparian habitat significantly enriches regional biodiversity beyond what could otherwise be supported.

2.4.6.4 River Mouths

Seven intermittent stream systems and tidal influences created a shore lined with deltas, mudflats, and salt marshes before Europeans arrived to the embayment they later named San Diego. Waters of the San Diego River continued to flow over the delta to the Bay until the Derby Dike was built in 1853–1854, permanently diverting the river to Mission Bay. San Diego Bay was kept from further sedimentation while the character of the mudflat and salt marsh habitats around the former mouth of the river changed. Later, dams were built on the Sweetwater and Otay Rivers affecting pattern and quantity of freshwater inflow, as well as sedimentation. A flood in 1891 was followed by an eleven year drought (1895–1905). This periodic flooding and drought continues and has long been San Diego's pattern.

Photo © 1998 US Navy Southwest Division.

Photo 2-12. Sweetwater Channel.

■ River mouths no longer have a natural role. They are controlled by dams or diversion.

Today, streams are channelized or confined to storm drains and sometimes completely missing. They include the mouths of Paleta Creek and Chollas Creek at NAVSTA, the mouth of Switzer Creek at Tenth Avenue Marine Terminal, Sweetwater Channel and the mouth of the Otay at the Salt Works, Telegraph Canyon Creek between the Otay and Sweetwater, and small drainages in both north Bay and south Bay that drain directly into the Bay (Map 1-3). Dabbling ducks are found primarily in shallow brackish water near the mouths of drainages. Brackish water is hard to obtain for those that require it in San Diego Bay.

Stormwater outfalls provide some flows and nutrients to the Bay, but not with natural seasonality, timing, frequency, or content. Sedimentary organic matter is no longer provided to the system except what is available from below the dams on each stream system. How this has affected functioning of the Bay ecosystem has not been examined.

2.5 Species Assemblages

From plankton to mammals, most marine organisms have patchy distributions. They also vary diurnally, tidally, seasonally, and with climate cycles. Physical variables include sediment, wave action and currents, temperature and salinity. Biological factors include predation and competition. While many surveys have been conducted of species in San Diego Bay, they have been similarly patchy in time and space, so few "status and trend" conclusions are certain. The sections that follow summarize what is known.

2.5.1 Plankton

The nutritional base of any ecosystem is provided almost entirely by the "primary producer" organisms that use energy from sunlight to manufacture the biological chemicals needed for sustaining life. Other systems that obtain energy from sources other than sunlight are likely of minor consequence in the Bay. There are three principal groups of producers: vascular plants, simpler nonvascular plants, and the extremely simple algal forms typified by phytoplankton.

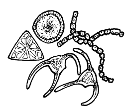
Plankton are organisms that drift in the water. Phytoplankton include tiny, single-celled plants or plants that are simple chains of cells, and other producers, such as diatoms and dinoflagellates, cyanobacteria (blue-green algae), protista (plant-like microalgae) and bacteria. Zooplankton includes tiny animals, such as protozoans, as well as the larvae of many invertebrates and fishes. Plankton are an extremely important component of bay and ocean ecosystems, both because they form a vital part of the food base for other species and they include the larval stages of many benthic species.

■ Despite some steps towards understanding plankton in San Diego Bay, there is scarcely any indication of long-term trends, nor understanding of what drives primary production. Also, plankton is well known to be patchy in both space and time; therefore, it is difficult to extrapolate meaningful management information from the sporadic studies that have been conducted.

There have been few studies of the phytoplankton and zooplankton inhabiting San Diego Bay, with most focus only on the south Bay region. The three primary investigations by Ford (1968), McGowen (1977, 1981) and San Diego Gas & Electric Company (1980) were concerned with characterizing different plankton groups of the south Bay and the possible effects on these organisms of heated water and entrainment caused by the South Bay Power Plant. Damon (1969), Krett (1979), and Krett-Lane (1980) have also described phytoplankton assemblages from central and north Bay sites, while Lapota *et al.* (1993) studied phytoplankton processes in relation to physical and chemical conditions throughout the Bay. These studies indicate that San Diego Bay supports plankton assemblages similar to those of other large bays in the temperate zone. Ford (1968) reported that the plankton of south San Diego Bay was similar to those of other southern California bays and estuaries, in that individuals are volumetrically quite abundant, but there are relatively few species.

Despite some steps towards understanding plankton in San Diego Bay, there is scarcely any indication of long-term trends, nor understanding of what drives primary production. Also, plankton is well known to be patchy in both space and time; therefore, it is difficult to extrapolate from the sporadic studies that have been conducted. Finally, changes in the Bay in the last twenty years may have altered plankton composition.

2.5.1.1 Phytoplankton



Dominant species of phytoplankton that Ford (1968) sampled in south San Diego Bay were pennate (linear-shaped) and chain-forming diatoms. These serve as food for a variety of zooplankton, as well as for filter feeding bivalve molluscs and other benthic invertebrates. They include the genera *Rhizosolenia, Chaetoceros, Biddulphia, Grammatophora, Fragilaria, Navicula, Gyrosigma, Pleurosigma, Nitzschia,* and *Suriella. Lingulodinium* was the only genus of dinoflagellate encountered. Unidentified tintinnids (ciliate protozoan that secretes vase-like cases) were another important component of the phytoplankton in south San Diego Bay (Ford 1968). The genera and species of phytoplankton reported to occur in San Diego Bay are listed in Table 2-4.

- Invertebrates and bacteria use organic detritus from dead phytoplankton and zooplankton in and on sediment.

In shallow marine waters such as those of San Diego Bay, the benthic animals and zooplankton utilize many of the same food resources (of which phytoplankton is a major component) to a much greater degree than in deeper water. Both dead phytoplankton and zooplankton contribute significantly to the organic detritus in and on the sediment. This material, in turn, is utilized by a wide variety of invertebrates and bacteria (see Figure 2-29).

Damon (1969) investigated the population dynamics of several of these species and of *Coenobiodiscus* in relation to nutrient cycling in San Diego Bay. A year-round study was conducted by Krett (1979) and Krett-Lane (1980) in 1978–1979 at sites inside the Shelter Island Yacht Basin, at a control location near the Shelter Island Public Fishing Pier, and at Pier 6 of the 32nd Street NAVSTA. The primary purpose of the study was to determine if natural phytoplankton assemblages are affected by elevated concentrations of copper in San Diego Bay, as evidenced by differences in their species composition, diversity (Hurlbert's PIE Index), biomass, and productivity. Measurements of chlorophyll *a* were also made. Field studies were accompanied by laboratory experiments conducted on these same phytoplankton species assemblages to assess effects of different copper concentrations.

Krett (1979) and Krett-Lane (1980) found that the major diatom genera were *Chaetoceros, Asterionella, Leptocylindrus, Nitzschia, Skeletonema,* and an unidentified pennate, chain-forming species. The major genera of dinoflagellates that were sampled in the central and north Bay were *Lingulodinium, Peridinium,* and *Prorocentrum.* Twenty-nine phytoplankton genera were at least moderately abundant members of the assemblages described. *Leptocylindricus* was frequently encountered during the fall, while *Chaetoceros* was the major genus encountered during the winter. Krett-Lane (1980) found that *Asterionella* was the numerically dominant form during February and March of 1979, when it represented more than 90% of the total phytoplankton cells present at the three sites. *Skeletonema* occurred throughout the entire year at these sites. *Nitzschia* was abundant during the spring.

Table 2-4. Genera and Species of Phytoplankton Reported in San Diego Bay.[1,2]

Dinoflagellates	Diatoms and Other Groups	
Ceratium	Achnanthes	Licomorpha
Dinophysis	Asterionella	Navicula
Lingulodinium	Biddulphia	Nitzschia
Gymnodinium oplendens	Ceratulina	Phaeodactylum tricornutum
Noctulica	Chaetoceros	Pleurosigma
Peridinium	Coenobiodiscus	Rhizosolenia
Prorocentrum	Coscinodiscus	Skeletonema
	Ditylum	Stephanophysix
	Dunaliella	Streptotheca
	Eucampia	Suriella
	Fragilaria	Thalassionema
	Grammatophora	Thalassiothrix
	Gyrosigma	other identified diatoms
	Leptocylindrus	unidentified tintinnids

1. This list is undoubtedly incomplete because of limited sampling.

2. By Ford (1968), Krett (1979), Krett-Lane (1980) and Salazar (1985).

- In January 1993, there was an increase in mean chlorophyll levels primarily in south Bay, as a result of stormwater runoff carrying high nutrient loads.

Lapota *et al.* (1993) conducted six survey cruises throughout San Diego Bay from November 1992 through September 1993 to evaluate seasonal differences and interrelationships in the physical, chemical, and phytoplankton characteristics of the Bay. These data were obtained using the Navy's survey vessel R/V ECOS and its associated sensor systems. The measurements included chlorophyll concentrations, water temperature, salinity, clarity, optical shifts in Bay color, pH, dissolved oxygen, oil fluorescence, and standard nutrient chemical concentrations of silicate, phosphate, nitrate, nitrite, and ammonia. Seawater clarity was highest in the fall and lowest in winter and early spring. Perhaps surprisingly, mean chlorophyll levels for the Bay as a whole did not show major changes seasonally. However, a relatively large increase in mean chlorophyll levels was measured in January, primarily in the south Bay. This increase clearly was the result of substantial stormwater runoff into the Bay at that time, which carried high nutrient chemical loads. The five nutrient chemicals measured had the highest concentrations throughout the Bay in January, which were also attributable to the effects of stormwater runoff from the surrounding watershed. The highest mean dissolved oxygen levels Baywide were measured in January, while the lowest levels were reported for night-time surveys in June and September.

Overall, Lapota *et al.* (1993) concluded that high chlorophyll concentrations in January, reflecting increased phytoplankton biomass, were probably the result of increased nutrient loading from freshwater runoff entering the Bay through the watershed. Seawater transmission and clarity also decreased because runoff and effects of wind generated turbulence in January. In addition, the pH of seawater became more basic at this time because carbonic acid was being removed by the higher rates of photosynthesis. Increased photosynthesis by phytoplankton in the Bay also caused greater oxygen production, leading to higher concentrations of dissolved oxygen in the seawater.

2.5.1.2 Zooplankton

Most of the limited research on zooplankton in San Diego Bay has been restricted to the south Bay. The invertebrate zooplankton inhabiting San Diego Bay include a high proportion of meroplankton, which are the ephemeral planktonic larval forms of invertebrates that later settle to the bottom and become benthic juveniles and adults. These forms occur together with species called holoplankton, which spend their entire lives in the open water environment in planktonic form.

Comparisons of zooplankton samples taken on the same dates in 1968 indicated that the numbers of species and the densities of many species were greater in north than south San Diego Bay locations (Ford 1968 and marine ecology class data, San Diego State University). These comparisons also indicated that zooplankton from the north Bay consisted of a higher proportion of holoplankton and a somewhat lower proportion of meroplankton. Both of these differences are expected, given the closer proximity of the north Bay to coastal ocean water, and the high density of invertebrates releasing meroplankton into the Bay. The relative importance of these groups could vary with location, season, lunar cycle, or tidal phase. In addition, Bay conditions have probably changed enough since 1968 to affect zooplankton relative abundances.

Common genera, species, and higher taxa of zooplankton and their rank abundances reported from San Diego Bay by Ford (1968) and San Diego Gas & Electric Company (1980) are listed in Table 2-5. Because of the limited sampling, except in the south Bay, this list is undoubtedly incomplete. Studies by Ford (1968) and San Diego Gas & Electric Company (1980) indicate that the major zooplankton of south San Diego Bay include species of calanoid copepods (a type of crustacean), of which *Acartia* spp. are the dominant forms. Also relatively dominant are the calanoid genera *Oithona, Paracalanus,* and *Pseudodiaptomus*. A large variety of harpacticoid copepods are also present in lower abundance. Most of the copepods feed on phytoplankton, while others rely to varying degrees on suspended detritus. Other presumed detrital feeders, the hypoplanktonic mysid crustaceans *Mysidopsis californica, Metamysidopsis elongata,* and *Acanthomysis macropsis*, are common at many south Bay locations (Ford 1968; San Diego Gas & Electric Company 1980). Other dominant crustacean zooplankton are cladocerans of the genus *Podon* and unidentified ostracods (bean clams). Meroplankton represent the most diverse and abundant zooplankton component of the south Bay. This is due in large part to the high density of adult benthic invertebrates releasing their meroplanktonic larvae into the Bay. In the samples analyzed by Ford (1968) and San Diego Gas & Electric Company (1980), these were primarily larval and post-larval stages of benthic polychaetes, molluscs, and crustaceans, which in adult stages inhabit the Bay floor. In addition, some of the meroplankton may be forms that are brought into the Bay by tidal action but do not successfully settle there.

Recent studies of decapod crustacean larvae conducted in the Bay (DiBacco, in progress) involve zooplankton sampling over complete tidal cycles at north, central, and south Bay locations. While this study focuses on decapod larvae, the samples represent a valuable record of zooplankton in San Diego Bay that might be processed and analyzed in the future to provide much needed baseline information.

2.5.1.3 Ichthyoplankton

Because of their importance and distinctive mode of life, planktonic larvae of fishes are considered as a separate category of plankton called ichthyoplankton. Ichthyoplankton have been studied extensively on a seasonal basis only in south San Diego Bay (McGowen 1977, 1981; San Diego Gas & Electric Company 1980).

Table 2-5. Rank Order of Abundance of Zooplankton.[1,2]

Taxa	Survey 04 (April)		Survey 08 (May)		Survey 12 (July)		Survey 16 (September)		Survey 20 (November)		Survey 24 (January)	
	Rank	Density	Rank	Density	Rank	Density	Rank	Density	Rank	Density	Rank	Density
Station 1 Featured Taxa												
Acartia spp. adults	1	71,896	1	1,450,125	1	80,704	5	1,436	4	5,462	2	473,583
Acartia spp. copepodites	2	27,223	3	200,786	2	16,750	11	419	1	86,591	1	559,689
Station 1 Nonfeatured Taxa												
Acartia clausi											4	8,611
Amphipoda–unident.			6.5	418	9	264			11	760		
Barnacle nauplii–unident.									9.5	951	12	1,545
Calanoid–unident.							8.5	531				
Caprellidea–unident.			6.5	418			3	1,699	15	190	13	926
Cladocera–unident.			10	209								
Corophium spp.			10	209								
Corophiidae–unident.									12.5	570		
Corycaeus spp.	3	2,946									5.5	7,718
Cyclopoid–unident.									5	3,802	9.5	3,088
Decapoda–megalops–unident.	11	39										
Decapoda–unident.	7	115			11	132	10	424	6	2,091	8	3,707
Harpacticoid–unident					4	5,940	2	3,716	7	1,901	5.5	7,718
Hyalidae–unident.					7.5	660	6	1,274				
Isopoda–unident.			13	105								
Leptocheila spp.					7.5	660	13.5	106	15	190	17	463
Natantia–unident.	5	1,683	4	1,464	5	1,980	4	1,486	8	1,521	11	1,853
Oikopleura spp.	11	39									17	463
Oithona spp.	11	39					8.5	531	3	5,704	3	16,987
Ostracoda–unident.					6	792	12	318	15	190		
Paracalanus spp.	4	2,104									14	772
Pinnixa spp.	11	39	8	314							17	463
Podocerus spp.			13	105	11	132	7	744			17	463
Podon spp.	6	1,262	5	1,046					9.5	951	7	6,178
Pseudodiaptomus spp.			2	202,934	3	7,260	1	12,740	2	8,556	9.5	3,088
Sagitta spp.	11	39									17	463
Squilla spp.			10	209	11	132	13.5	106				
Synchelidium spp.			13	105								
Taxea spp.	11	39										
Tunicate–unident.	11	39										
Station 7 Featured Taxa												
Acartia spp. adults	2	314,260	1	485,030	1	350,420	2	259,150	1	143,520	2	47,350
Acartia spp. copepodites	4	111,200	2	200,170	2	38,230	3	68,750	3	25,520	5	3,603
Acanthomysis macropsis									13.5	602		
Mysidopsis californica									13.5	602		
Station 7 Nonfeatured Taxa												
Acartia clausi	5	82,190	6	15,400			11	5,280			10	720
Barnacle nauplii–unident.	12.5	12,850			13.5	1,427	5	26,440	9.5	1,204		
Bivalve–unident.	18.5	2,140										

Table 2-5. Rank Order of Abundance of Zooplankton.[1,2]

Taxa	Survey 04 (April)		Survey 08 (May)		Survey 12 (July)		Survey 16 (September)		Survey 20 (November)		Survey 24 (January)	
	Rank	**Density**	**Rank**	**Density**	**Rank**	**Density**	**Rank**	**Density**	**Rank**	**Density**	**Rank**	**Density**
Caprellid–unident.					13.5	1,427						
Corycaeus spp.	12.5	12,850	10	5,574	4	18,550	7	17,630	5.5	7,220	4	5,070
Cyclopoid–unident.			16.5	1,858								
Cyphonautes–unident.			10	5,574								
Decapod–unident.	15.5	8,570	16.5	1,858	8	7,140	13	2,938			8	1,691
Euterpina spp.			16.5	1,858								
Gastropod–unident.	15.5	8,570			13.5	1,427						
Harpacticoid–unident	11	14,990										
Hydromedusae–unident.			12.5	3,716					13.5	602		
Labidocera spp.	8	25,700	10	5,574	6	9,990	10	8,810	13.5	602	6	3,382
Natantia–unident.	17	6,430	16.5	1,858	10.5	2,854			13.5	602		
Oikopleura spp.	14	10,710	8	7,430			12	3,525	4	13,250	8	1,691
Oithona spp.	1	417,650	4	52,030	8	7,140	7	17,630	7	3,612		
Paracalanus spp.	3	117,800	5	35,310	5	14,270	4	44,070	5.5	7,220	3	6,760
Pinnixa spp.	9.5	17,130	16.5	1,858	8	7,140			9.5	1,204	8	1,691
Podon spp.	6	44,980	3	128,220			1	405,470	2	33,110	1	74,410
Polychaete–unident.	9.5	17,130	16.5	1,858								
Sagitta spp.	7	27,840	7	11,150	3	29,970	9	12,340	8	1,806		
Squilla spp.					13.5	1,427						
Tunicate–unident.	18.5	2,140	12.5	3,176	10.5	2,854	7	17,630	13.5	602		

1. Based on Density Estimates (no. individuals/100 m^3) of all Zooplankton Collected During Tidal Surveys at Stations 1 and 7 at South Bay Power Plant, 1979–1980 (San Diego Gas & Electric Company 1980).

2. SDG&E examined selected plankton samples in detail to determine the rank order of abundance of all zooplankton species or taxa sampled (called "nonfeatured" taxa in this table). These ranks were used to define the nature of the general plankton assemblage with respect to both species composition and abundance. The samples used for this study were collected in middepth at night during tidal series surveys with nets of 663 ft (202 m) mesh size. The samples were selected because they represented both the near- and far-field areas, the time period when plankton were known to be abundant, and the depth stratum encompassing the largest portion of the water column. Adults of *Acartia* spp. were generally the most abundant group present in these zooplankton samples, ranking either first or second in abundance through most of the study. Other taxa that ranked as most abundant during at least one survey were *Acartia* spp. copepodites, the cyclopoid copepods *Oithona* and *Pseudodiaptomus*, and the cladoceran *Podon*. Many other zooplankton occurred at these stations in low densities. They were classified into general taxonomic groups, including polychaetes, gastropods, echinoderms, tunicates, amphipods, barnacle nauplii, harpacticoid copepods, and cyphonautes larvae.

One primary purpose of the study by San Diego Gas & Electric Company (1980) was to evaluate possible effects of entrainment in the cooling water system of the South Bay Power Plant on zooplankton. The specific objective of the South Bay Power Plant 316(b) field plankton studies (San Diego Gas & Electric Company 1980) was to characterize temporal and spatial patterns of plankton density in areas of San Diego Bay potentially affected by operation of the Plant. The study was designed to obtain estimates of the population size of featured taxa residing in the south Bay over different, representative time periods throughout the year. It was also designed to measure temporal (i.e. day/night, seasonal, tidal) and spatial (i.e. horizontal, vertical) distribution patterns for selected taxa. This was accomplished by using three types of sampling strategies: (1) day, (2) night, and (3) tidal series.

The natural patterns existing in the study area were described by examination of selected taxa of zooplankton. Those selected, called "featured" taxa, were the copepods *Acartia* spp. (adults), *Acartia* spp. (*copepodites*), three common mysid crustaceans (*Acanthomysis macropsis, Metamysidopsis elongata* and *Mysidopsis californica)*, and meroplanktonic larvae of the decapod crustaceans *Callianassa* spp. and *Cancer* spp. The basic method of field collection was the same for all three types of sampling strategies (day, night, and tidal series). Sampling was done at four stations, one near-field and three far-field, which were selected using information on the physical oceanographic characteristics of the area. The near-field station was located within the area influenced by the operation of the South Bay Power Plant, while the three far-field stations were located outside that area of influence. This array of stations was selected to provide data that would describe patterns of natural variability within the study area, as well as the relationships of the near-field and far-field stations.

Depth permitting, three strata were sampled at each station. Surface samples were taken with a manta neuston net (San Diego Gas & Electric Company 1980). The middepth stratum of the water column was sampled with a 20 in (50 cm) opening-closing bongo net using stepped, oblique tows at four levels. Bottom samples were collected using a 20 in (50 cm) opening-closing epibenthic bongo net (a bongo net with wheels). The bongo net systems used consisted of two paired, conical nets. Samples were collected with both 1,099 ft (335 m) and 663 ft (202 m) mesh nets in each sampling stratum. The larger mesh size retained virtually all fish eggs and larvae and the smaller mesh retained zooplankton between 0.02 and 0.04 in (0.5 and 1.0 millimeter [mm]) in length. Each replicate tow was made in each depth stratum for a duration of eight minutes in order to filter a relatively large volume of water and to minimize the effects of patchy plankton distribution. Towing speed was maintained at 1.5 to 2.0 kn to minimize damage to the organisms caught in the net.

Evidence presented in the report by SDG&E indicates that entrainment had no significant adverse effects on these featured taxa of zooplankton.

■ It appears that the value of south Bay for juvenile and adult fishes may be different from its value for fish eggs and larvae, when data from Allen (1998) are compared with limited plankton sampling in south Bay. This needs further investigation.

It appears that ichthyoplankton species composition and abundance may differ substantially from juvenile/adult fish composition and abundance of south San Diego Bay. This means the value of south Bay for juvenile and adult fishes is different from its value for fish eggs and larvae, when data from Allen (1998) (see Section 2.5.4 "Fishes") are compared with plankton sampling in south Bay. McGowen (1977, 1981) conducted a detailed seasonal study in which conical net tows were taken at eight south San Diego Bay stations every two to four weeks over a one-year period in 1972–1973. The primary purposes of this research were to describe and evaluate the species composition and seasonal dynamics of larval fishes in the area and to assess possible general effects on them from the South Bay Power Plant. McGowen identified the eggs and larvae of eighteen species of fishes from the study area. He found that the eggs of two species, the deepbody anchovy and the diamond turbot, accounted for over 97% of the planktonic eggs collected. These species are not dominant in juvenile and adult fish catches (Allen 1998). One taxon, consisting of the larvae of arrow, cheekspot and shadow gobies, accounted for over 87% of the fish larvae sampled during the one-year period. Atherinid larvae, consisting of the topsmelt and the jacksmelt (*Atherinopsis californiensis),* accounted for 8.5%, while the remaining 4.5% included representatives of ten other species or higher taxa. Several of these exhibited seasonal patterns of occurrence in the plankton. It was concluded that the ichthyoplankton assemblage of south San Diego Bay contained fewer species than occur in coastal waters at other locations studied along the Pacific Coast of the United States.

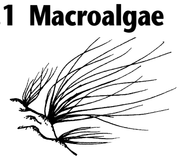
■ The results of a SDG&E study in 1980 indicated that operation of the South Bay Power Plant had no adverse ecological effects on icthyoplankton.

San Diego Gas & Electric Company (1980) conducted a one-year study that involved extensive net sampling at four south Bay stations designed to assess possible effects of the South Bay Power Plant on ichthyoplankton. The sampling design and methods were the same as those described in the previous section on zooplankton. This study was restricted primarily to consider selected important or "featured taxa" rather than all ichthyoplankton species. Based on several lines of evidence, the results of the study indicated that operation of the South Bay Power Plant had no significant adverse ecological effects on the ichthyoplankton of south San Diego Bay (San Diego Gas & Electric Company 1980).

2.5.2 Algae

With the exception of the algal forms living under the open canopy of salt marsh vegetation, the discussion on bacteria, cyanobacteria (blue-green algae), and protista (plant-like microalgae) is found under Section 2.5.1.1 "Phytoplankton."

2.5.2.1 Macroalgae



In the nearshore marine environments and in enclosed waters such as San Diego Bay, the contribution of the macroalgae (seaweeds) to overall productivity may be substantial. These larger algal species are described in this section.

Phylogenetic Description

In San Diego Bay, macroalgae belong to three different phyla, or divisions: the Chlorophyta (green algae), the Phaeophyta (brown algae), and the Rhodophyta (red algae). The differences among the algal phyla primarily relate to photosynthetic pigments, certain physiological processes, and reproductive/life history characteristics.

■ Macroalgae differ primarily by photosynthetic pigments, physiological processes, and reproductive/life history characteristics.

Chlorophyta: Of the close to 50 native macroalgal species present in the Bay (see Appendix D "Comprehensive Species List of San Diego Bay"), nine belong to the Chlorophyta. Most local green algal species are quite small.

Phaeophyta: There are twelve native species of brown algae that are consistently found in the Bay (see Appendix D "Comprehensive Species List of San Diego Bay").

Rhodophyta: The largest group of algae, represented by 25 species, is the red algae. Many species of red algae are quite small and may be present only cryptically attached to a variety of structures or as epiphytes, living atop another plant or algal form.

Morphologic Variability

Algal species may change their morphology or form with environmental conditions. Changes in water quality, including turbidity, dissolved gasses, and chemical constituents, can trigger this morphological response. Such changes, which can result in cryptic forms, produce an apparent seasonal variation in species composition that is usually due to change in light or temperature. Other changes are related to a life cycle characteristic known as "alternation of generations," which confers extensive variability and often causes taxonomic confusion. For example, the greens that occupy the intertidal and upper subtidal zones will often "die out" during the summer. What has actually taken place is that the next "generation" of individuals has simply germinated in a more favorable nearby habitat, and often in a cryptic form on a plant or algal form, or attached to some fixed object. When conditions change, the following generation will reoccupy old habitat and assume the appropriate morphology. Though typical of the chlorophytes, this habit is not restricted to them as some browns and many red algae undergo the same sort of changes.

Ecological Roles of Algae

The contribution made by algae begins with being principal producers in the ecosystem. Substantive structure is also imparted to the habitat by larger algal species and eelgrass. Additionally, many algal species reproduce with swimming gametes and zoospores not only to enhance dispersal, but to provide an important food resource for zooplankton and filter-feeders.

- Algal mats respond to nutrient loading, such as from stormwater outflow.

Seasonal variability in productivity and dominance of algae is high, as is evident in algal mats that become more predominant with warm summer temperatures. These mats also respond to nutrient loading, such as from stormwater. In the salt marsh, seasonal variability has been looked at only in terms of phytoplankton and in the salt marshes near San Diego Bay (Mission Bay and Tijuana Estuary). Epibenthic algal mats underneath the open canopy of salt marsh vegetation have been shown to match or exceed the productivity of vascular plants. Epibenthic algae predominated only in winter, whereas mats with blue-green algae and diatoms dominated in summer. High light and high temperatures favored blue-green algae and phytoplankton, whereas low light and low temperature stimulated the green macroalgae. Lower salinity delayed phytoplankton blooms, and the species composition changed to more blue-green types (Lapota *et al.* 1997, discussed in Section 2.5.1.1 "Phytoplankton").

San Diego Bay has not experienced harmful algal blooms like other bays such as the Chesapeake.

Algae-Habitat Relationships in San Diego Bay

Algal species are found in association with a wide range of habitats. In some cases, these associations are strongly tied to physical substrate. Some algae are found only on sandy substrate, and many that grow subtidally on rocky substrate are also found on hard intertidal surfaces. In other cases, the relationship seems to be opportunistic—any or all are commonly found in a given habitat.

Algae are categorized here in "ecological" groups. No specific studies on algal distribution for the Bay have been conducted, so these conclusions are made based on studies elsewhere in San Diego Bay and the SCB: Ford (1968), Murray and Bray (1993), and Stewart (1991). A species-by-species summary of habitat associations is presented in Appendix E "Species and Their Habitats."

Ecological Groups of Algae and Plants

A. **Turf algae of sandy substrate, variable depths.** *Tiffaniella snyderae, Polysiphonia pacifica,* and *Hypnea valentiae* (all Rhodophyta) and *Chaetomorpha linum* (Chlorophyta). These algae are found mainly over sandy bottoms in deep subtidal, shallow subtidal, and intertidal habitats.

B. **Microalgae of variable depths.** *Aglaothamnion cordatum, Griffithsia pacifica, Ceramium eatonianum, Dasya sinicola* var. *abyssicola* and *Dasya sinicola* var. *californica* (all Rhodophyta), and *Cladophora* sp. (Chlorophyta). These tiny algae, often occurring as epiphytes on plants or other algae, are found in both the deep subtidal and shallow subtidal zones.

C. **Shallow subtidal, "attached" algae.** *Antithamnion* sp. and *Polysiphonia pacifica* (both Rhodophyta). Found attached to fixed objects, other algae, or plants, these algae occur in shallow waters.

D. **Subtidal/intertidal epiphytes.** *Cladophora* sp. (Chlorophyta) and *Ceramium eatonianum* (Rhodophyta). This pair is usually found as epiphytes on other algae or plants, in shallow waters on *Chaetomorpha* algal mats, and on intertidal hard substrate.

E. **Subtidal/intertidal, muddy-rocky group.** *Chaetomorpha linum* and *Ulva expansa* (both Chlorophyta), *Dictyota flabellata* (Phaeophyta), and *Aglaothamnion cordatum* (Rhodophyta). This group is found in shallow rocky and muddy habitats, and on hard substrate in the intertidal zone.

F. **Shallow subtidal/intertidal rocky group.** *Cladophora* sp. (Chlorophyta) and *Colpomenia sinuosa* (Phaeophyta). These algae are found on hard substrate in both the shallow subtidal and intertidal zones.

G. **Desiccation/hypersaline-tolerant group.** *Enteromorpha* sp. (Chlorophyta) found in the intertidal zone in both muddy and salt panne habitats.

2.5.3 Invertebrates

Taxonomists have estimated that at least 97% of all animal species on earth are invertebrates, forms that lack skeletal vertebrae. In fact, there are more species of invertebrate animals than all other kinds of aquatic and terrestrial animals and plants combined. This is also the case in the major intertidal and subtidal habitats of San Diego Bay, which together support more than 650 species of marine, estuarine, and salt marsh invertebrates (see Appendix D "Comprehensive Species List of San Diego Bay"). These include marine representatives of all the major invertebrate phyla, as well as insects and spiders important as components of the salt marsh community. In addition to the large number of invertebrate species and their great taxonomic and functional diversity, many invertebrate populations are very abundant in San Diego Bay. All of these characteristics make them important ecological components of Bay habitats and essential food sources for marine fishes, birds, and other invertebrate animals in those habitats.

2.5.3.1 Invertebrates of Soft Bottom, Unconsolidated Sediment

The subtidal bottom of San Diego Bay consists primarily of unconsolidated sediments. These include various grain size mixtures of sand, silt, and clay, depending on the degree of water movement and other environmental factors. The silt and clay fractions together are also classified in a more general way as the mud fraction. Around the shoreline of south Bay, and also along the western shoreline of central Bay, there are fairly extensive intertidal areas of unconsolidated sediment forming mudflats and sand flats. With some notable exceptions, these relatively natural intertidal flats are absent from the remainder of the Bay, where they have been replaced by concrete bulkheads and a wide variety of other man-made structures.

It is important to note that intertidal and shallow subtidal habitats of unconsolidated sediment (0 to 13 ft [0 to 4 m] below MLLW) that do not support eelgrass are of great importance to invertebrates and to the ecological functioning of the Bay. Together with eelgrass beds, these unvegetated, shallow areas of soft bottom represent the two primary subtidal habitats and their associated fauna that were present in San Diego Bay prior to its development for human use.

Factors Affecting Invertebrates in Soft Bottom Habitats

- In the intertidal and subtidal soft bottom habitats of San Diego Bay, few marine plants have solid and stable attachment sites. To avoid being carried away, infauna burrow into the substrate, as well as use the substrate for food and protection from predators.

Unconsolidated sediment or soft bottom habitats in the intertidal and subtidal areas of San Diego Bay are fairly unstable. They can be disturbed easily by human activity, wind, waves, tidal currents, and feeding by bottom fishes and shorebirds. Because of this, both plants and invertebrate animals living in soft bottom habitats normally do not have solid and stable attachment sites. Very few marine plants have adapted to this condition in San Diego Bay. One notable exception is eelgrass, the rooted flowering plant which forms thick beds and its own distinct subtidal benthic habitat, as discussed in Section 2.5.3.2 "Invertebrates of Eelgrass Beds."

Because they lack solid places for attachment, a large majority of the invertebrates in soft bottom intertidal and subtidal habitats of San Diego Bay are part of the infauna, animals that burrow into the substrate for food, for protection from predators, and to avoid being carried away by water movement. Relatively few species form part of the epifauna, invertebrates such as sponges, gastropod molluscs, and some larger crustaceans and tunicates that spend all or most of their time on the sediment surface.

Invertebrates living in soft bottom habitats have also developed a variety of methods to burrow through the sediment and to anchor themselves. For example, most free-living worms, such as the San Diego Bay species of *Nereis* and *Nephtys*, alternately flare their anterior body segments and then anchor them to aid in moving forward and pulling their bodies through the sediment. Many species of clams, such as the bent-nosed clam (*Macoma nasuta)*, make their muscular foot thin and penetrate the sediment with it. The end of the foot is then expanded into a thick anchor shape to hold position while the rest of the body is pulled down into the sediment. The foot is also expanded as an anchor to hold the clam in position once it is established at the proper depth below the sediment surface. Many crustaceans, such as amphipods and the red ghost shrimp (*Callianassa californiensis)*, use their jointed appendages to dig through the sediment and to hold position.

- Tiny invertebrates live and move around in spaces between sediment grains or attach to the grain. Thus far, no special sampling has been conducted for these interstitial fauna (they pass through standard sampling sieves).

Some soft bottom invertebrates are so small that they live and move around in the spaces between the sediment grains or attach to the grains. These are called the interstitial fauna. They include protozoans, nematodes, hydroids, polychaete and oligochaete worms, flatworms, and copepods, gastrotrichs, kinorhynchs, rotifers, archiannelids, and gnathostomulids. It should be noted that most of these interstitial species do not appear in the species list for San Diego Bay (Appendix D "Comprehensive Species List of San Diego Bay"), or are represented in that list only by notations such as "unidentified oligochaete spp. or nematode spp.;" most pass through the 0.02 in (0.5 mm) sieves normally used to process standard infauna samples. No special sampling has been conducted for the interstitial fauna or for other meiofauna in San Diego Bay thus far. As a result, our knowledge is incomplete as to the species composition of these animals or their distribution and abundance.

Feeding Relationships of Invertebrates in Soft Bottom Habitats

Most infaunal and some epifaunal species of intertidal and subtidal soft bottom communities in San Diego Bay and other estuaries feed on the abundant detritus suspended in the water and deposited in the sediments (Figure 2-29). This detritus consists of both dead organic matter and the bacteria and other decomposer organisms that live on it. Both these dead and living components of detritus are important in the diet of invertebrate detritus feeders. These detritus feeders include deposit feeders, which are animals that ingest detritus and associated bacteria accumulating on and within the sediment; and suspension feeders, which are animals that capture particles suspended in the overlying water, either by filter feeding or by other means. Examples of such deposit feeders in San Diego Bay include the bent-nosed clam, the mud snails *Nassarius* spp, amphipods like the California horn shell (*Cerithidea californica)*, and some decapod crustaceans. Filter feeders include many clam species, while suspension feeders using other feeding mechanisms, such as tentacles and mucus, include many species of tube-forming polychaete worms. Invertebrate carnivores are also important members of the infauna and epifauna in all soft bottom communities of San Diego Bay. They include polychaete worms, such as *Neanthes* spp. and *Glycera* spp., the tectibranch or sea slug *Navanax inermis*, and the swimming crab (*Portunus xantusi)*.

- Deposit feeders predominate in soft bottom areas with large amounts of mud. These species prefer mud because it contains more bacteria, which is their food. In contrast, suspension feeders are more common in soft bottom areas where sandy sediments predominate, such as in some areas of central and north San Diego Bay.

Bacteria associated with the detritus and sediment are believed to be a primary food source of deposit feeders. These deposit feeding invertebrates tend to consume muddy sediments in preference to sandy ones because the surface area to volume ratio is greater in mud, allowing more bacterial colonization of the grain surfaces. As a result, deposit feeding species tend to predominate in soft bottom areas with large amounts of silt and clay, the primary sediment type throughout most of San Diego Bay. Another reason for this relationship is that more detritus accumulates in the interstitial spaces between fine sediment particles than between those of larger grain size. In contrast, suspension feeders are more common in soft bottom areas where sandy sediments predominate, such as in some areas of central and north San Diego Bay.

Detritus is also considered to be the most important food source for the interstitial fauna, as it is for larger infauna and invertebrates. However, many interstitial species are predators or scavengers. Others are grazing herbivores that feed on diatoms living in the upper few millimeters of the sediment.

Soft Bottom Invertebrate Fauna of South San Diego Bay

The invertebrate fauna of south San Diego Bay has been studied far more extensively than other parts of the Bay. However, all of these studies were conducted after the mid-1960s, during the recovery and stabilization periods following serious effects of habitat disturbance and of sewage and industrial pollution. Therefore, it is important to consider the degree to which the present invertebrate assemblages differ from those that existed in San Diego Bay prior to its extensive modifications by human activity.

- The infaunal species assemblages of south San Diego Bay are very similar to those of San Quentin Bay in Baja California, a nearly natural estuary similar in other characteristics to San Diego Bay.

Lockheed (1981) discussed the results of comparisons of the dominant infaunal species reported in the literature for south San Diego Bay with those reported for San Quentin Bay in Baja California, and Newport Bay and Alamitos Bay, California (Reish and Winter 1954; Barnard and Reish 1959; Reish 1968; Barnard 1970). The results of these comparisons revealed that there were no substantial differences in species composition among these four sites. The results of the comparison with San Quentin Bay, a nearly natural estuary similar in other characteristics to San Diego Bay, are particularly significant. They suggest that the infaunal species assemblages of south San Diego Bay probably are relatively natural ones similar to those that existed there prior to disturbances caused by humans.

- Polychaete worms, crustaceans, and molluscs are the dominant invertebrate fauna living on and in the soft bottom sediment of south San Diego Bay. This is true for most soft bottom habitats everywhere.

As in soft bottom sediments of most locales, and as described by Ford (1968), Ford and Chambers (1973), Ford *et al.* (1975), Lockheed (1981), Macdonald *et al.* (1990), and others, the invertebrate fauna living on and in the soft bottom sediment of south San Diego Bay is dominated in terms of numbers of species, abundance, and biomass by polychaete worms, crustaceans, and molluscs (Table 2-6).

Table 2-6. South Bay Invertebrate Sampling 1976-1989.

Dominant South Bay Invertebrate Sampling 1976–1989, by Number of Species and Percent[1].		
Polychaetes	118	40.0%
Crustaceans	85	29.0%
amphipods	32	11.0%
decapods	15	5.0%
ostracods	10	3.0%
others	28	10.0%
Molluscs	53	18.0%
bivalve	25	8.5%
gastropod	28	9.5%
Other invertebrate species	36	13.0%
Total No. Species	292	

[1]. Data tabulated by Macdonald *et al.* (1990).

Recent data on the infauna of south San Diego Bay (Kinnetic Laboratories Inc. 1990) indicate that the numerically dominant species include:

- Polychaetes (*Capitella capitata, Cirriformia* spp., *Exogone* sp., *Fabricia limicola, Leitoscoloplos elongatus, Lumbrineris* spp., *Mediomastus* spp., *Megalomma pigmentum, Neanthes acuminata, Streblospio benedicti, Typosyllis* spp.), and the phoronid *Phoronid* spp.
- Crustaceans (*Acuminodeutopus heteruropus, Caprella mendax, and Caprella* spp., *Euphilomedes carcharadonta, Parasterope barnesi, Rudilemboides stenopropodus,* and *Synchelidium* spp.)

- Molluscs (bivalves *Lyonsia californica, Musculista senhousia* [an extremely invasive exotic species], *Tagelus californianus,* and the gastropods *Barleeia californica* and *Cylichnella inculta).*
- Unidentified species of oligochaete and nematode worms.

As expected, many of the species that occur in intertidal habitats of south Bay also occur subtidally (Ford and Chambers 1973). The subtidal areas are nearly all quite shallow and sediment characteristics at a given location are much the same both intertidally and subtidally. However, the number of intertidal species present generally appears to be much smaller (Ford and Chambers 1973; Ford *et al.* 1975; Macdonald *et al.* 1990). This may be partly because some subtidal species may not tolerate the desiccation that occurs in the intertidal zone.

- Some species of molluscs are used as human food. South San Diego Bay has long been considered good for clam digging.

Some species of common intertidal and subtidal bivalve molluscs inhabiting south San Diego Bay are used as human food, and the area has long been considered good for clam digging. These include the banded, smooth, and wavy cockle clams (*Chione californiensis, C. fluctifraga,* and *C. undatella*), the littleneck clam (*Protothaca staminea*), the bent-nosed clam, and others (Ford and Chambers 1973). However, the size of most individuals of these species appears to be small compared with those in nearby clamming areas, such as the San Diego River mouth. The jackknife clam (*Tagelus californianus* and *T. subteres*), rosy razor clam (*Solen rosaceus*), and other small bivalves are commonly used as bait for fishing. The ghost shrimp is also used as bait. While the other invertebrates present are not of direct value to man, they are extremely important to the ecological functioning of south Bay. The feeding of nematode and polychaete worms, gastropod molluscs, brittlestars, crabs, isopods, and a wide variety of smaller crustaceans serves to transform detritus, bacteria, and small invertebrates into usable food for larger invertebrates and fishes. The latter, in turn, are eaten by other large fishes and aquatic birds, many of which are of sport fishing value or esthetic value to man. Bivalve molluscs and other suspension feeders serve a similar function in transforming plankton and suspended detrital material into food for fishes and birds (Ford 1968; Ford and Chambers 1973).

An unusual colonial ectoproct or bryozoan animal, *Zoobotryon verticillatum*, is present on the bottom sediment throughout much of south San Diego Bay, where it forms large, flexible, tree-like masses during the warmer months of the year. Some clumps are attached to shell material embedded in the sediment or to algae, while much of it simply moves around freely on the bottom. Like the benthic plants discussed above, it serves as food for a variety of invertebrates and as refuge or cover for both motile invertebrates and small fishes. It is a suspension feeder.

Another unusual epifaunal species is a large purple and green basket sponge. These sponges are so large and abundant in some areas of south San Diego Bay that they give the bottom the appearance of an underwater "cabbage patch." This sponge has been identified in previous studies of San Diego Bay as *Tetilla mutabilis*, originally described from inner Newport Bay. However, recent examination by specialists indicates that it may be an undescribed species.

Invertebrate Fauna in Soft Bottom Habitats of Central and North San Diego Bay

There has been only one multiseason study of soft bottom communities in north San Diego Bay, that conducted by Ford *et al.* (1975) in the downtown area adjacent to and offshore from the Broadway and Navy piers. All of the sampling stations employed were in relatively deep subtidal areas. In addition, the 1996 study by Fairey *et al.* (Tables 7 through 11) provided very important information about infaunal invertebrate assemblages at a large number of sites throughout

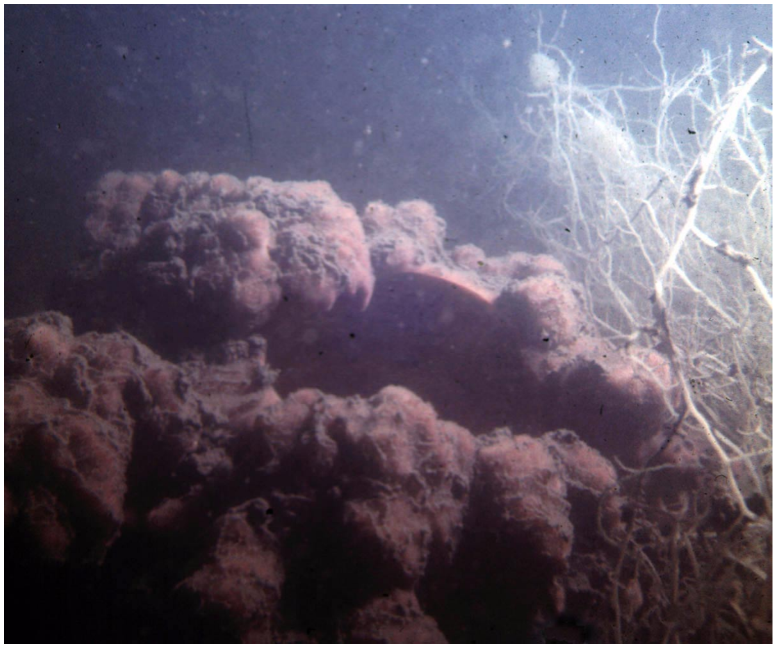


*Photo 2-13. Wandering Sponge (*Tetilla mutabilis*) with the Ectoprot* Zoobotryon verticillatum *and Algae, Including* Gracilaria *spp.*

central and north San Diego Bay. Other environmental impact studies of limited scope have also provided useful information about the invertebrate fauna of soft bottom habitats in other areas of the central and north Bay.

Of the 218 invertebrate species in soft bottom habitats sampled during four seasons in 1972–1978 near and offshore of the Broadway and Navy piers, 81 (37%) were polychaete worms, 47 (22%) were crustaceans, and 24 (11%) were bivalve and gastropod molluscs (Ford *et al.* 1975, partial list cited). While the number of species in each category was smaller at the north Bay location, the percentages were very similar to those reported for south San Diego Bay. This indicates, as expected, that polychaetes, crustaceans, and molluscs are the dominant invertebrates in both areas. Data on abundance and biomass also confirm the dominance of these three invertebrate groups at the north Bay location. This ranking is typical of soft bottom habitats elsewhere.

Because of their limited coverage, the data now available are insufficient to characterize the numerically dominant species of these major taxonomic groups in central and north San Diego Bay. The most complete, recent species list for infauna of these areas of the Bay is that reported in Table 7 of the study by Fairey *et al.* (1996). However, comparison of the data for infaunal invertebrates reported from north and central San Diego Bay by Ford *et al.* (1975) and Fairey *et al.* (1996) with those for the south Bay (Macdonald *et al.* 1990) indicates that there is considerable overlap, with many of the same species occurring in all three areas.

2.5.3.2 Invertebrates of Eelgrass Beds

On the basis of a seasonal study of eelgrass beds in central San Diego Bay, Takahashi (1992) and Takahashi and Ford (1992) reported 117 different species or higher taxa of invertebrates associated with this habitat. Polychaete worms were the dominant group during all seasons and at all sampling sites. Of these, the two dominant infaunal species were *Lumbrineris zonata* and *Exogone lourei*, both considered to be deposit feeders. Most of the abundant polychaete species found in eelgrass beds are deposit feeders.

Takahashi (1992) found that the other dominant invertebrate groups in San Diego Bay eelgrass beds were crustaceans and molluscs. Among crustaceans, the dominant forms were either tube forming or infaunal amphipods. Tanaid crustaceans were more abundant than amphipods only in the January samples. The high densities of amphipods in *Zostera* beds may occur because of the protection afforded by the eelgrass blades. The introduced Asian mussel, *Musculista senhousia*, was the dominant bivalve mollusc at all sites throughout the study. Gastropod mollusc species were also dominant forms.

- Both eelgrass habitats and unvegetated shallows of unconsolidated sediment are equally important to San Diego Bay invertebrates, to many fish predators, and to the ecological functioning of the Bay ecosystem.

Takahashi (1992) found that densities of infaunal species, as well as the number of these species, were considerably higher in the San Diego Bay eelgrass beds sampled than those values reported for adjacent, unvegetated areas of unconsolidated sediment. In addition, the infaunal species composition of these two habitats differed very markedly, with consistently greater numbers of polychaete, amphipod, and mollusc species present in the eelgrass bed habitat and with relatively few species common to both habitats. It is important to note, however, that both eelgrass habitats and unvegetated shallow subtidal habitats of unconsolidated sediment are equally important to San Diego Bay invertebrates, to many fish predators, and to the ecological functioning of the Bay ecosystem.

2.5.3.3 Invertebrates of Man-made Habitats

Since the 1800s San Diego Bay has been developed to support a wide variety of human activities. The resulting man-made features, including concrete bulkheads, rock riprap, pier pilings, marina floats, and a wide range of other dock structures are now and will continue to be intertidal and subtidal habitats for marine algae, invertebrates and fishes. The fact that they are not natural Bay habitats is of little consequence, because these diverse structures will not be removed and will continue to support a wide variety of marine life.

Unfortunately, there have been few detailed, quantitative marine ecological studies of these man-made habitats in San Diego Bay. Most of the work thus far involves very limited studies to develop environmental impact assessments.

The only detailed, multiseason study of this kind was conducted on the concrete and wooden piling structures of the B Street, Broadway, and Navy piers during 1972–1973 (Ford *et al.* 1975). These pilings were sampled at a series of intertidal and subtidal depths to obtain quantitative data on species composition, abundance and distribution of marine algae, invertebrates, and fishes.

Sponges, cnidarians (sea anemones, hydroids and others), bryozoans, polychaete worms, crustaceans, molluscs, and tunicates dominated the rich sessile (attached to the bottom or a surface) and free living invertebrate fauna associated with concrete and wooden pier pilings in this study area in terms of numbers of species, abundance, surface coverage, and biomass (Ford *et al.* 1975). These same animal groups also appear to be the dominant forms on similar structures elsewhere in north San Diego Bay. Of the invertebrate species encountered on pier pilings in the study area during the period September 1972–August 1973, five (2%) were sponges, 24 (8%) were cnidarians, seven (2.5%) were bryozoans, 89 (30%) were polychaetes, 75 (27%) were crustaceans, 65 (23%) were molluscs, and seven (2.5%) were tunicates (Ford *et al.* 1975). With the exception of the purple hinge rock scallop, *Hinnites multirugosus*, none of these species is of commercial or sportfishing importance.

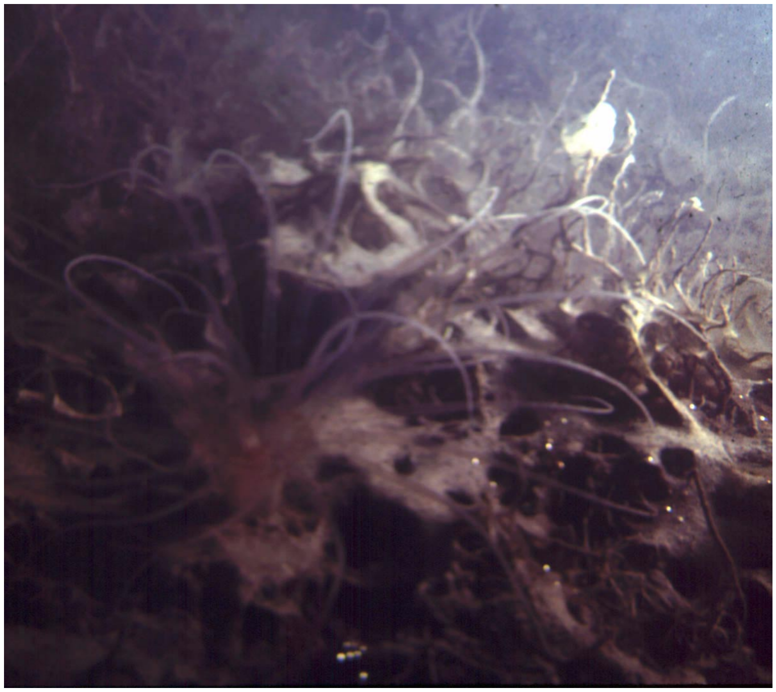


Photo 2-14. Anemones and Tube-forming Polychaete Worms Living on Man-made Surface (a Sunken Boat).

The results of this study also showed that these epifaunal invertebrates and associated algae living on the pilings changed fairly markedly in species composition and abundance from one season to the next. This is typical of species assemblages on artificial structures elsewhere and underscores the need to conduct such studies on a multiseason basis.

2.5.3.4 Assessment of Invertebrates as Indicators of Pollution or Habitat Disturbance

Infaunal invertebrates have many characteristics that make them good subjects and good ecological indicators for studies concerning the effects of pollution, residual toxicity in marine sediments, and habitat disturbance. The invertebrate infauna tend to remain in the same area and are, therefore, consistently exposed to existing conditions in the sediment and in the water passing over them. A majority of these species have planktonic larval stages and enter their benthic habitats through metamorphosis settling into sediments with suitable characteristics. The settlement process involves responses of the larvae or post larvae to a variety of species-specific physical and chemical cues, including those produced by pollution and habitat disturbance. Of particular importance is the fact that many infaunal species have relatively short life spans, with population turnover occurring as often as two to ten times per year. These species seem to show a corresponding rapid response to changing environmental conditions, which makes many of them good short-term indicators of environmental quality.

- While the short life spans and rapid turnover rates of infaunal species make them good indicators of environmental degradation, those same characteristics also can make it very difficult to interpret the biological data obtained from "snapshot" samples, such as those taken only every few months at a limited number of stations.

While the short life spans and rapid turnover rates of infaunal species make them good indicators of the effects caused by environmental degradation, those same characteristics also can make it very difficult to interpret the biological data obtained from "snapshot" samples, such as those taken only every few months at a limited number of stations. These opportunists are also more tolerant of habitat degradation. Short life spans and rapid population turnover also produce wide and often unpredictable fluctuations in species composition, biomass, and abundance of infaunal species. Under these conditions, it is particularly difficult to interpret infrequent biological "snapshots" and relate them to either conditions of environmental degradation or to natural environmental changes. Ecological data from more frequent sampling and those data from sampling over a long series of years usually allow a more meaningful interpretation, as shown for the studies concerning ecological effects of thermal effluent in south San Diego Bay. (See, for example, Lockheed 1981; Kinnetic Laboratories Inc. 1990.)

Studies in San Diego Bay, such as those of Ford and Chambers (1973), Ford *et al.* (1975), Lockheed (1981), and Fairey *et al.* (1996), illustrate the value of using quantitative data for the invertebrate infauna to assess the effects of pollution and sediment toxicity. In the toxicity study by Fairey *et al.* (1996), analyses were made of infaunal community structure and degree of community degradation, using a variety of methods, based on sampling at 75 benthic stations in north and central San Diego Bay. This information was then employed in conjunction with data from different measures of chemical toxicity in the sediments to develop rankings that identified and prioritized sediment toxicity problems at each station site.

- There is a much richer fauna in "back harbor" sites with a few boats, than in similar sites with a large number of boats. Motile invertebrate species were found to be associated with microhabitats rather than number of boats.

Lenihan *et al.* (1990) conducted field studies of invertebrates and algae inhabiting floats, pilings, and other man-made structures in a representative series of boat mooring harbors or embayments at different locations at San Diego Bay. The study found that the inner "back harbor" sections of areas which contained a large number of boats were characterized by depauperate hard-bottom communities with lower biomass, lower percent cover, and fewer species than for similar "back harbor" areas with few boats. The fauna and flora of "back harbor" sites with large numbers of boats consisted of a simpler species assemblage dominated by the solitary tunicate *Ciona intestinalis* (an exotic species), serpulid polychaete worms, and filamentous algae. These species appear to tolerate the environmental stresses associated with large numbers of boats. In similar "back harbor" sites with few boats, a much richer fauna was present, in which the dominant forms were species of mussels, sponges, ectoprocts (bryozoans), and tunicates.

The associated motile invertebrate species, primarily polychaetes and crustaceans, that nestle or live among these sessile invertebrates and algae were found to be strongly associated with microhabitats (e.g. dense algal or serpulid worm aggregations) rather than with conditions related to the number of boats moored at a given location. However, Lenihan *et al.* (1990) found that there were more species of these nestling invertebrates present at inner harbor locations where smaller numbers of boats were moored. In comparing these boat harbors with large and small numbers of boats, sampling was confined to inner or "back harbor" locations. Hard-bottom communities found in the outer or front portions of these boat harbors were generally similar to one another and also most closely resembled those of inner or "back harbor" locations with few boats.

- The concentrations of TBT, then used extensively as a toxic additive to antifouling paint for boats, were found to be higher in the mooring harbor areas where large numbers of boats were present. This may have been at least a partial cause of the differences in hard-bottom communities observed.

Evaluation of differences in hydrographic conditions among boat harbors with large and small numbers of boats could not explain the consistent community patterns Lenihan *et al.* (1990) observed. The concentrations of TBT, then used extensively as a toxic additive to antifouling paint for boats, were found to be higher in the mooring harbor areas where large numbers of boats were present. This may have been at least a partial cause of the differences in hard-bottom communities observed. Similar effects on hard-bottom epifaunal species attributed to TBT (Valkirs and Davidson 1987; Salazar and Salazar 1991) and copper in possible combination with other toxic chemicals (Johnston 1989, 1990; Vander-Weele 1996) have been evaluated in Shelter Island Yacht Harbor and elsewhere in San Diego Bay.

2.5.4 Fishes

Photo US Navy Southwest Division.

Photo 2-15. Killifish.

2.5.4.1 Description

- The warm water temperatures present in bays and estuaries during the spring and summer months, as well as their high productivity, enable them to support large numbers of juvenile fishes.

Bays and estuaries are known to be important nursery and refuge areas for marine fishes (Cronin and Mansueti 1971; Haedrich and Hall 1976). The warm temperatures present in these enclosed bodies of water during the spring and summer months, as well as their high productivity, enable them to support large numbers of juvenile fishes. While there are relatively few truly natural bays and estuaries in southern California, and most are small in comparison with large, river-dominated estuaries common in other parts of the world, they do function as nursery and refuge areas for some species. At least one commercially and recreationally important species, the California halibut, is known to rely on southern California bays and estuaries as nursery areas (Allen 1988; Kramer 1990). Other fisheries species, including the kelp bass (*Paralabrax clathratus*), appear to use these bays as alternative habitat refuges for a portion of their life histories. Juveniles of other fish species can be extremely abundant and usually dominate the fish species assemblages of bays and estuaries in the SCB (Allen 1982). Many of these abundant species (e.g. gobies, anchovies, and silversides) are important forage fishes for fish species of commercial or sport fishing value (Horn 1980) and for sea birds. Another important, but often overlooked, characteristic of the fishes inhabiting southern California bays and estuaries is that they form distinct species assemblages found nowhere else (Horn 1980; Horn and Allen 1981; Allen 1985, 1997; Macdonald *et al.* 1990).

- The first truly Baywide seasonal study of fishes was completed by Allen in 1999.

The fish fauna of San Diego Bay has been studied fairly extensively. Earlier, multi-season studies by Ford (see, for example, Ford 1968, 1994; Ford *et al.* 1971a, 1971b; Macdonald *et al.* 1990) and by San Diego Gas & Electric Company (1980), characterized juvenile and adult fishes inhabiting south San Diego Bay (Ford 1968, 1994; Ford *et al.* 1971a, 1971b; San Diego Gas & Electric Company 1980; Macdonald *et al.* 1990).Work by McGowen (1977, 1981) and San Diego Gas & Electric Company (1980) was concerned with larval fishes (ichthyoplankton) of the south Bay and their entrainment in the cooling water system of the South Bay Power Plant, as described in Section 2.5.1 "Plankton." Until recently, information about fish populations and their species assemblages of the central and north Bay regions was more limited, based on larger-scale studies in the central Bay by Lockheed (1983), Baywide studies by Peeling (1975) and Lockheed (1979), and site-specific work by Ford and Macdonald (1986) and Macdonald *et al.* 1990. Comparisons have also been made by Hoffman (1986) concerning the use of eelgrass beds and adjacent, unvegetated, soft bottom habitats by fish populations in the Bay. The first truly Baywide seasonal study of fishes was completed in April 1999, after five years of sampling (Allen 1996, 1997, 1998, 1999).

All of these studies indicate that the fish fauna of San Diego Bay is typical of other embayments along the coast of southern California and northern Baja California. At least 89 species of bottom living and open water fishes are known to occur in San Diego Bay (Appendix D "Comprehensive Species List of San Diego Bay"). It is instructive to compare the species composition of fishes from San Diego Bay reported by Eigenmann (1892) with that described in recent studies. Eigenmann reported at least 56 species of fishes from the Bay. All of these species were also encountered in one or more studies in San Diego Bay conducted since 1968. The difference in number of species found in 1892 (56) and that reported in more recent studies (89) may be simply a reflection of the limited collecting methods Eigenmann used. While today's species list of fishes may approach that of the historic Bay, the relative and total abundances of many fish species in San Diego Bay have probably changed markedly, considering the large reductions in intertidal and shallow subtidal habitats that have occurred. In addition, there have been at least two introductions since the 1890s: the sailfin molly, yellowfin goby, and probably others.

The first extensive seasonal sampling of fishes in San Diego Bay was conducted quarterly by Macdonald *et al.* (1990) throughout the south Bay during 1988–1989. This sampling effort included a multiple-gear approach (otter trawl, two sizes of beach seines, and multipanel gill nets) in order to sample the different habitat areas occupied by fishes. The study concluded that the species composition, relative abundances, and biomass characteristics of south Bay fishes have remained very similar since 1968. Topsmelt, slough anchovy, arrow goby, barred pipefish (*Syngnathus auliscus)*, and California killifish were the most abundant species found in south San Diego Bay, while the round stingray, California halibut, and spotted sand bass were the dominant forms in terms of biomass. This study also provided a comprehensive review and data compilation of all fish studies conducted in the Bay prior to 1989.

Hoffman (1986) compared the abundance and biomass of fish species inhabiting eelgrass beds and adjacent, unvegetated subtidal areas of unconsolidated sediment in three major areas of San Diego Bay. Beach seine hauls were made in the northern, central, and southern portions of the Bay on a quarterly basis, from 1980 through 1981. Topsmelt, shiner surfperch (*Cymatogaster aggregata)*, the arrow goby, cheekspot goby, shadow goby, and the bay goby (*Lepidogobius lepidus*) accounted for approximately 93% of the individuals taken. Topsmelt, shiner surfperch, spotted sand bass, staghorn sculpin (*Leptocottus armatus)*, round stingray, and California halibut accounted for more than 87% of the fish biomass. Hoffman concluded that nearly twice as many individual fish and fish species were taken in samples at eelgrass stations than at unvegetated stations, when data for all samples were considered together. He also found that the total number of individuals and total biomass of fishes remained relatively constant from season to season in these shallow nearshore areas. Hoffman's results called attention to the importance of the eelgrass habitat in San Diego Bay as a productive habitat for juvenile and adult fish populations. His work also led to the more recent studies by Allen (1996, 1997, 1998, 1999), which continued to compare eelgrass and unvegetated sites as habitats for fishes.

Hoffman is also carrying out a long-term beach seine study of fishes in the north-central Bay. A single station at the base of the San Diego-Coronado bridge, on the Coronado side, was sampled quarterly beginning in January 1988, and work continues at this site (see http://swr.ucsd.edu/hcd/cumcb.htm). Results are still in the preliminary stages of analysis. This long-term study was the only true time series for fishes in San Diego Bay, prior to the work by Allen (1996, 1997, 1998, 1999).

- Specific sampling sites of the ongoing, Baywide study by Allen are shown in Maps C-2 to C-5 in Appendix C.

The Baywide study by Allen, sponsored jointly by the Navy and SDUPD, involved quarterly sampling of fish assemblages at representative locations in four regions of San Diego Bay: north, north-central, south-central, and south. These specific sampling sites and their relationship to the four Bay regions are shown in Maps C-2 to C-5 in Appendix C. At each of these four locations, five subhabitat types were sampled. They were, from deep to shallow water: (1) channel, (2) nearshore, unvegetated, (3) nearshore, vegetated, (4) intertidal, unvegetated, and (5) intertidal vegetated (Allen 1999).

The study involved the use of a wide variety of standard fish sampling methods designed to capture nearly all species of bottom living and open water fishes. These sampling methods were as follows (Allen 1997): A 50 x 6 ft (15.2 x 1.8 m) large seine fitted with a 6 x 6 x 6 ft (1.8 x 1.8 x 1.8 m) bag (0.5 in [1.2 cm] mesh in wings and 0.2 in [0.6 cm] mesh in the bag) was employed to sample juvenile fishes in the nearshore portion of the station at a depth of 0 to 7 ft (0 to 2 m). This net was set parallel to shore, and hauled to shore by 49.2 ft (15 m) lines. The seine was an accurate sampler of nearshore schooling fishes, and produced reliable density estimates. Two replicate hauls were made at each station, each of which sampled a bottom area of approximately 2,368 square feet (ft^2) (220 square meters [m^2]). A square enclosure 3 x 3 x 3 ft (1 x 1 x 1 m), constructed of 1 in (2.5 cm) PVC pipe and canvas, was used to sample small fish species, such as gobies, that inhabit burrows in shallow water. The enclosure was set randomly within each subhabitat, at depths ranging from 0.8 to 2.5 ft (0.25 to 0.75 m), where it was firmly settled into the substrate. One liter of 3:1 acetone-rotenone solution was added to the enclosed water. The substrate was then searched thoroughly for ten minutes, using a long-handled dipnet of.04 in (1 mm) mesh size. This method sampled a bottom area of 11 ft^2 (1 m^2). A 5.2 ft (1.6 m) beam trawl (0.2 in [4 mm] mesh in the wings and 0.07 in [2 mm] knotless mesh in the cod end) was used to sample smaller fishes on the surface of the sediment. Standardized ten minute tows were employed, using a 16 ft (5 m) skiff to tow the trawl. A 217 x 20 ft (66 x 6 m) purse seine (0.5 in [1.2 cm] mesh in the wings and 0.2 in [0.6 cm] mesh in the bag) was employed to sample juvenile and adult fishes in the water column of nearshore areas and in channels. A 26 ft (8 m) semiballoon otter trawl (0.8 in [2 cm] mesh in the wings and 0.3 in [0.8 cm] mesh in the cod end) was towed behind the R/V Yellowfin, to sample demersal juvenile and adult fishes from the deepest channel portions of each sampling area. Large seines, small seines, and square enclosures were used to sample both types of intertidal subhabitat. Both the nearshore subhabitats (unvegetated and vegetated) were sampled using a beam trawl and purse seine. The channels were sampled using an otter trawl and purse seine. Three replicates were taken with each of these gear types. Water temperature (° C), salinity (parts per thousand [ppt]), dissolved oxygen (mg O_2/l), and pH were recorded at each station at the shoreline, at the surface and bottom in the nearshore zone, and at the surface and bottom in channels. All fishes (or subsamples of large catches) were identified, counted, and weighed aboard the sampling vessel or in the laboratory after freezing. Weights were measured to the nearest 0.004 ounces (oz) (0.1 grams [g]) (Allen 1997).

2.5.4.2 Species Composition Baywide

During twenty seasonal sampling periods (July 1994–April 1999), Allen (1999) reported taking 78 species of fishes from throughout San Diego Bay. Of these, the northern anchovy (*Engraulis mordax)* was the most abundant species Baywide, forming 43% of the total catch. It was followed in abundance by the topsmelt (23%), the slough anchovy (19%), the Pacific sardine (*Sardinops sagax caeruleus)* (3%), and the shiner surfperch (2%), with all other species accounting for only 10%. In terms of biomass, the round stingray was the dominant form (25%), followed by the spotted sand bass (14%), the northern anchovy (9%), the bat ray (9%), the topsmelt (9%), and the slough anchovy (7%), with the biomass of all other species accounting for 27%. These abundances and biomasses are broken down by region in Section 2.5.4.4 “Comparison of Total Abundance and Biomass Among Bay Regions” and Section 2.5.4.5 “Comparisons of Species Abundance and Biomass by Region.”

2.5.4.3 Rankings Based on Ecological Index

Allen (pers. comm.) employed the Ecological Index to identify the fish species that dominate San Diego Bay based on their abundance, biomass, and frequency of occurrence. This index is expressed as:

Ecological Index = %N x %W x %F

Where N = Abundance, W = Biomass, and F = Frequency

This measure is a modification of the Index of Relative Importance, which is used extensively in studies considering prey species from the gut contents of fishes (Pinkas *et al.* 1971).

- Plankton studies (Section 2.5.1.3 “Ichthyoplankton”) gave a completely different ranking for ichthyoplankton (fish larvae) than Allen’s Ecological Index does for juvenile and adult fishes.

In applying the Ecological Index, data for all of the Baywide sampling during 1994–1999 were employed. The ten species considered to be most dominant, based on their Ecological Index values, are listed in Table 2-7. The list includes eight of the nine dominant species considered in Section 2.5.4.4 “Comparison of Total Abundance and Biomass Among Bay Regions” on the basis of their high density or biomass values. This indicates that use of separate density, biomass, and Ecological Index values all identify essentially the same species as the dominant fishes in the San Diego Bay, even though the rankings they produce differ somewhat.

Table 2-7. Ranking of Top Ten "Ecological Index" Fish Species in San Diego Bay[1].

Scientific name	Common name	Rank
Atherinops affinis	topsmelt	1
Urolophus halleri	round stingray	2
Engraulis mordax	northern anchovy	3
Anchoa delicatissima	slough anchovy	4
Paralabrax maculatofasciatus	spotted sand bass	5
Paralabrax nebulifer	barred sand bass	6
Paralichthys californicus	California halibut	7
Cymatogaster aggregata	shiner surfperch	8
Sardinops sagax	Pacific sardine	9
Heterostichus rostratus	giant kelpfish	10

[1]. Sampled by Allen (1994–1999), Based on Values Calculated as Follows: Ecological Index = %N x %W x %F where N = Abundance, W = Biomass, and F = Frequency.

2.5.4.4 Comparison of Total Abundance and Biomass Among Bay Regions

- The north Bay area, or at least the region of Station 1, may afford better feeding or water quality conditions for juvenile fishes, and may serve as a nursery for them. There was a downward trend in total abundance of fishes at locations progressively closer to the south Bay.

As shown in Figure 2-12, the largest number of fishes was taken in samples at north Bay Station 1 (198,141), with the next highest catch at north-central Bay Station 2 (188,147). The total catch figures were considerably lower for samples taken at south-central Bay Station 3 (57,892), and somewhat lower still for those taken at south Bay Station 4 (53,164). Clearly, there was a downward trend in total abundance of fishes at locations progressively closer to the south Bay. The primary reasons for this trend in abundance may be the better water circulation and greater interchange with ocean water in the north and north-central areas of the Bay; the presence of a greater variety of fish species in these north Bay areas, including species that also occur on the open coast; and the presence of more open water habitat in the north Bay. The higher catch values at north Bay Station 1, compared to other stations, were also due in part to the large number of juvenile northern anchovy, Pacific sardine, and topsmelt that were taken in samples there (Allen 1999). This suggests that the north Bay area, or at least the region of Station 1, may afford better feeding or water quality conditions for juveniles of these species, or may even serve as a nursery area for them. However, further study will be required to test these ideas (Allen 1997).

- Overall, north Bay is the area of greatest fish productivity. The primary reasons for this trend in abundance may be the better water circulation and greater interchange with ocean water in the north and north-central areas of the Bay.

The data summarized in Figure 2-13 show generally similar trends in total fish biomass for the years 1994–1999. Approximately equal total biomass values were taken in samples at the north Bay Station 1, and north-central Bay Station 2 locations, while lower, but approximately equal biomass, values were taken in samples at the south-central and south Bay stations. The higher biomass values for the north and north-central regions reflect the higher abundance of fish taken in those areas.

2.5.4.5 Comparisons of Species Abundance and Biomass by Region

The abundance of fishes sampled regionally provides a perspective about disparities and similarities across the fish communities of San Diego Bay. Over the period July 1994–April 1999, Allen (1999) took 68 species of fishes in the north Bay region at Station 1. These species and their abundance and biomass values are shown in Table 2-8. The northern anchovy was the most abundant species, forming 62% of the total catch. Next was the topsmelt (22%), followed by the Pacific sardine (7%) and the sough anchovy, the California grunion and the shiner surfperch (each at 2%). The round stingray and the bat ray were the dom-

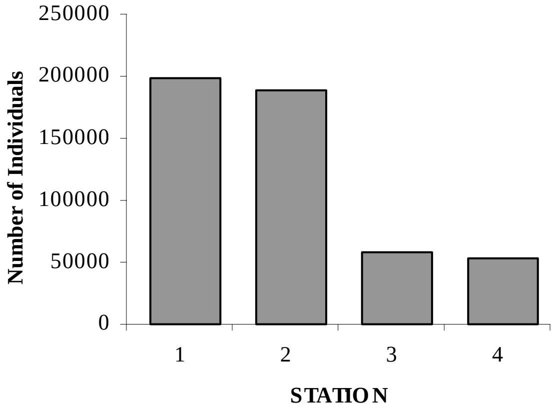


Figure 2-12. Abundance of Fishes in San Diego Bay by Station, 1994–1999.

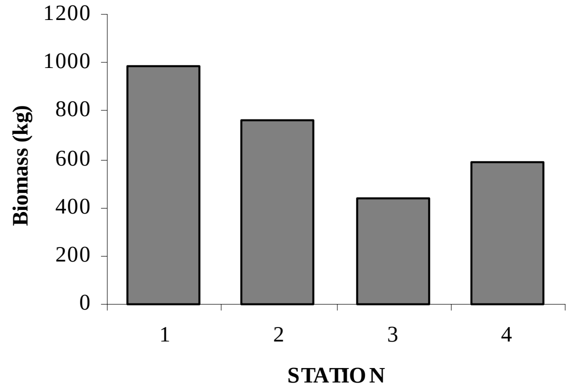


Figure 2-13. Biomass of Fishes in San Diego Bay by Station, 1994–1999.

inant forms in total biomass (each at 18%). These two species were followed by the northern anchovy (14%), the topsmelt (11%), the spotted sand bass (7%), and the Pacific sardine (5%), as shown in Table 2-8.

Fifty-five species were taken in the north-central Bay region at Station 2. Of these, the northern anchovy was also the most abundant species representing nearly 47% of the total catch, followed by the topsmelt (27%), the slough anchovy (14%), the jacksmelt (4%), the shiner surfperch (2%), and the giant kelpfish (*Heterostichus rostratus)* (1%), as shown in Table 2-9. The round stingray formed the largest portion of total biomass (22%), followed closely by the spotted sand bass (20%), then the northern anchovy (15%), the topsmelt (10%), and the slough anchovy (8%), as shown in Table 2-9.

Forty-nine species were taken in the samples at south-central Bay Station 3. The slough anchovy was the most abundant fish species, representing 55% of the total catch. It was followed by the topsmelt (22%), the northern anchovy (6%), the shiner surfperch (6%), and the bay pipefish (*Syngnathus griseolineatus)* (2%) (Table 2-10). The round stingray was the dominant form in terms of total biomass (28%), followed by the spotted sand bass (20%), the slough anchovy (15%), the topsmelt (7%), and the California halibut (5%).

In the south Bay region at Station 4, there were at total of 51 species taken. The slough anchovy was the most abundant fish species, as in the south-central region, representing over 66% of the total catch. The next most abundant was the topsmelt (14%), the arrow goby (3%), the round stingray (3%), and the shiner surfperch (2%), as shown in Table 2-11. The round stingray was the dominant species in total biomass (37%), as it was for the south-central Bay region, followed by the spotted sand bass (13%), the bat ray (10%), and the barred sand bass (8%). Allen (1999) concluded that the species composition and abundances of fishes he sampled in the south Bay region were remarkably similar to those reported by Ford in his 1988–1989 study of the south Bay (Macdonald *et al.* 1990). This suggests that the fish fauna of the south Bay probably has remained relatively stable over the past six to eight years.

Table 2-8. Total Number of Individuals and Biomass (g) of Fish Species Captured in the North Bay (Station 1), July 1994–April 1999.

Species	Common Name	Total #	%	Total Wt.	%
Engraulis mordax	northern anchovy	121888	61.52	138927	14.10
Atherinops affinis	topsmelt	44055	22.23	104236	10.58
Sardinops sagax caeruleus	Pacific sardine	12964	6.54	46650	4.73
Anchoa delicatissima	slough anchovy	4315	2.18	10395	1.05
Leuresthes tenuis	California grunion	4225	2.13	15245	1.55
Cymatogaster aggregata	shiner surfperch	3191	1.61	26621	2.70
Heterostichus rostratus	giant kelpfish	1687	0.85	14273	1.45
Urolophus halleri	round stingray	715	0.36	175747	17.83
Syngnathus leptorhynchus	bay pipefish	701	0.35	512	0.05
Ilypnus gilberti	cheekspot goby	580	0.29	115	0.01
Atherinopsis californiensis	jacksmelt	399	0.20	24109	2.45
Syngnathus auliscus	barred pipefish	390	0.20	313	0.03
Paralichthys californicus	California halibut	316	0.16	38017	3.86
Paralabrax nebulifer	barred sand bass	311	0.16	27180	2.76
Embiotoca jacksoni	black surfperch	272	0.14	13858	1.41
Paralabrax clathratus	kelp bass	268	0.14	2309	0.23
Micrometrus minimus	dwarf surfperch	244	0.12	2971	0.30
Paralabrax maculatofasciatus	spotted sand bass	226	0.11	65634	6.66
Seriphus politus	queenfish	216	0.11	6222	0.63
Hypsoblennius gentilis	bay blenny	128	0.06	911	0.09
Pleuronichthys ritteri	spotted turbot	120	0.06	7829	0.79
Symphurus atricauda	California tonguefish	87	0.04	1976	0.20
Xenistius californiensis	salema	76	0.04	44	0.00
Hypsopsetta guttulata	diamond turbot	69	0.03	13600	1.38
Xysteurys liolepis	fantail sole	62	0.03	4674	0.47
Synodus lucioceps	California lizardfish	56	0.03	1473	0.15
Gibbonsia elegans	spotted kelpfish	56	0.03	165	0.02
Cheilotrema saturnum	black croaker	55	0.03	5533	0.56
Clevelandia ios	arrow goby	51	0.03	8	0.00
Umbrina roncador	yellowfin croaker	42	0.02	5684	0.58
Quietula ycauda	shadow goby	40	0.02	18	0.00
Scorpaena guttata	spotted scorpionfish	37	0.02	6400	0.65
Myliobatis californica	bat ray	27	0.01	175731	17.83
Porichthys myriaster	specklefin midshipman	27	0.01	2040	0.21
Halichoeres semicinctus	rock wrasse	24	0.01	743	0.08
Oxyjulis californica	senorita	24	0.01	667	0.07
Trachurus symmetricus	jack mackerel	18	0.01	4095	0.42
Syngnathus californiensis	kelp pipefish	18	0.01	86	0.01
Hyporhamphus rosae	California halfbeak	18	0.01	51	0.01
Sphyraena argentea	California barracuda	14	0.01	2009	0.20
Genyonemus lineatus	white croaker	13	0.01	610	0.06
Scomber japonicus	Pacific mackerel	11	0.01	4128	0.42
Albula vulpes	bonefish	10	0.01	133	0.01
Bryx arctos	snubnose pipefish	10	0.01	2	0.00
Leptocottus armatus	staghorn sculpin	9	0.00	119	0.01
	Post-larval goby	9	0.00	30	0.00
Mugil cephalus	striped mullet	8	0.00	2	0.00
Cynoscion parvipinnis	shortfin corvina	6	0.00	4679	0.47
Girella nigricans	opaleye	6	0.00	1796	0.18
Pleuronichthys coenosus	CO turbot	6	0.00	867	0.09
Anisotremus davidsoni	sargo	6	0.00	18	0.00
Mustelus henlei	brown smoothhound	5	0.00	4536	0.46
Rhinobatis productus	shovelnose guitarfish	4	0.00	10150	1.03
Atractoscion nobilis	white sea bass	3	0.00	909	0.09
Strongylura exilis	California needlefish	3	0.00	483	0.05
Citharichthys stigmaeus	speckled sand dab	3	0.00	37	0.00
Gymnura marmorata	California butterfly ray	2	0.00	7727	0.78
Zapteryx exasperata	banded guitarfish	2	0.00	1067	0.11
Phanerondon furcatus	white surfperch	2	0.00	605	0.06
Syngnathus exilis	barcheek pipefish	2	0.00	5	0.00
Mustelus californicus	grey smoothhound	1	0.00	336	0.03
Roncador stearnsii	spotfin croaker	1	0.00	102	0.01
Pseudupeneus grandisquamous	red goatfish	1	0.00	100	0.01
Porichthys notatus	plainfin midshipman	1	0.00	9	0.00
Parophrys vetulus	English sole	1	0.00	5	0.00
Anchoa compressa	deepbody anchovy	1	0.00	2	0.00
Paraclinus integripinnis	reef finspot	1	0.00	1	0.00
Medialuna californica	halfmoon	1	0.00	0	0.00
Rimicola muscarum	kelp clingfish	1	0.00	0	0.00
Total		198141		985530	

Table 2-9. Total Number of Individuals and Biomass (g) of Fish Species Taken in the North-Central Bay (Station 2), July 1994–April 1999.

Species	Common Name	Total #	%	Total Wt.	%
Engraulis mordax	northern anchovy	88925	47.26	115387	15.20
Atherinops affinis	topsmelt	51041	27.13	78188	10.30
Anchoa delicatissima	slough anchovy	25526	13.57	61171	8.06
Atherinopsis californiensis	jacksmelt	7290	3.87	4210	0.55
Cymatogaster aggregata	shiner surfperch	3821	2.03	28134	3.71
Heterostichus rostratus	giant kelpfish	1989	1.06	13589	1.79
Sardinops sagax	Pacific sardine	1417	0.75	5547	0.73
Syngnathus leptorhynchus	bay pipefish	1394	0.74	650	0.09
Urolophus halleri	round stingray	1060	0.56	167033	22.00
Paralabrax nebulifer	barred sand bass	954	0.51	35350	4.66
Syngnathus auliscus	barred pipefish	777	0.41	406	0.05
Leuresthes tenuis	California grunion	767	0.41	10801	1.42
Ilypnus gilberti	cheekspot goby	582	0.31	37	0.00
Paralabrax maculatofasciatus	spotted sand bass	570	0.30	152308	20.06
Clevelandia ios	arrow goby	484	0.26	26	0.00
Anchoa Compressa	deepbody anchovy	212	0.11	592	0.08
Paralichthys californicus	California halibut	200	0.11	22443	2.96
Quietula ycauda	shadow goby	193	0.10	30	0.00
Hypsoblennius gentilis	bay blenny	129	0.07	1210	0.16
Xenistius californienses	salema	116	0.06	2508	0.33
Albula vulpes	bonefish	115	0.06	744	0.10
Scomber japonicus	Pacific mackerel	97	0.05	11405	1.50
Pleuronichthys ritteri	spotted turbot	84	0.04	7843	1.03
Hypsopsetta guttulata	diamond turbot	71	0.04	12198	1.61
Sphyraena argentea	California barracuda	43	0.02	821	0.11
Cheilotrema saturnum	black croaker	39	0.02	4520	0.60
Gibbonsia elegans	spotted kelpfish	35	0.02	150	0.02
Fundulus parvipinnis	California killifish	29	0.02	111	0.01
Paralabrax clathratus	kelp bass	24	0.01	496	0.07
Strongylura exilis	California needlefish	23	0.01	1771	0.23
Hyporhamphus rosae	California halfbeak	15	0.01	29	0.00
Seriphus politus	queenfish	12	0.01	169	0.02
Leptocottus armatus	staghorn sculpin	12	0.01	119	0.02
Symphurus atricauda	California tonguefish	11	0.01	379	0.05
Xysteurys liolepis	fantail sole	9	0.00	4175	0.55
Cynoscion parvipinnis	shortfin corvina	8	0.00	4981	0.66
Scorpaena guttata	spotted scorpionfish	8	0.00	1161	0.15
Embiotoca jacksoni	black surfperch	8	0.00	344	0.05
Syngnathus californiensis	kelp pipefish	8	0.00	38	0.01
Hippocampus ingens	Pacific seahorse	7	0.00	267	0.04
Syngnathus exilis	barcheek pipefish	7	0.00	7	0.00
Porichthys myriaster	specklefin midshipman	5	0.00	384	0.05
Pleuronichthys verticalis	hornyhead turbot	4	0.00	597	0.08
Umbrina roncador	yellowfin croaker	4	0.00	499	0.07
Synodus lucioceps	California lizardfish	4	0.00	54	0.01
Micrometrus minimus	dwarf surfperch	3	0.00	38	0.00
Bryx arctos	snubnose pipefish	3	0.00	29	0.00
Paraclinus integripinnis	reef finspot	3	0.00	1	0.00
Menticirrhus undulatus	California corbina	2	0.00	2600	0.34
Acanthogobius flavimanus	yellofin goby	2	0.00	22	0.00
Heterodontus francisi	California hornshark	1	0.00	2420	0.32
Mustelus californicus	grey smoothhound	1	0.00	968	0.13
Atractoscion nobilis	white sea bass	1	0.00	250	0.03
Gibbonsia metzi	striped kelpfish	1	0.00	0	0.00
Mugil cephalus	striped mullet	1	0.00	0	0.00
Total		188147		759210	

Table 2-10. Total Number of Individuals and Biomass (g) of Fish Species in the South-Central Bay (Station 3), July 1994–April 1999.

Species	Common Name	Total #	%	Total Wt.	%
Anchoa delicatissima	slough anchovy	31874	55.06	65690	14.92
Atherinops affinis	topsmelt	12791	22.09	29324	6.66
Engraulis mordax	northern anchovy	3556	6.14	2486	0.56
Cymatogaster aggregata	shiner surfperch	3194	5.52	17525	3.98
Syngnathus leptorhynchus	bay pipefish	1040	1.80	1042	0.24
Heterostichus rostratus	giant kelpfish	881	1.52	8407	1.91
Urolophus halleri	round stingray	720	1.24	123010	27.94
Atherinopsis californiensis	jacksmelt	664	1.15	2231	0.51
Leuresthes tenuis	California grunion	600	1.04	10007	2.27
Syngnathus auliscus	barred pipefish	598	1.03	378	0.09
Sardinops sagax caeruleus	Pacific sardine	398	0.69	7560	1.72
Paralabrax nebulifer	barred sand bass	342	0.59	13494	3.07
Paralabrax maculatofasciatus	spotted sand bass	334	0.58	87005	19.77
Hyporhamphus rosae	California halfbeak	203	0.35	676	0.15
Paralichthys californicus	California halibut	167	0.29	21142	4.80
Quietula ycauda	shadow goby	84	0.15	117	0.03
Clevelandia ios	arrow goby	82	0.14	6	0.00
Ilypnus gilberti	cheekspot goby	70	0.12	7	0.00
Hypsopsetta guttulata	diamond turbot	43	0.07	4681	1.06
Umbrina roncador	yellowfin croaker	37	0.06	5793	1.32
Cheilotrema saturnum	black croaker	31	0.05	4202	0.95
Xenistius californiensis	salema	24	0.04	260	0.06
Anchoa compressa	deepbody anchovy	23	0.04	454	0.10
Scomber japonicus	Pacific mackerel	20	0.03	3647	0.83
Syngnathus californiensis	kelp pipefish	14	0.02	15	0.00
Leptocottus armatus	staghorn sculpin	11	0.02	123	0.03
Porichthys myriaster	specklefin midshipman	10	0.02	1394	0.32
Fundulus parvipinnis	California killifish	10	0.02	25	0.01
Strongylura exilis	California needlefish	9	0.02	363	0.08
Hypsoblennius gentilis	bay blenny	9	0.02	205	0.05
Syngnathus exilis	barcheek pipefish	8	0.01	8	0.00
Acanthogobius flavimanus	yellowfin goby	7	0.01	388	0.09
Pleuronichthys ritteri	spotted turbot	5	0.01	154	0.03
Hippocampus ingens	Pacific seahorse	4	0.01	129	0.03
Albula vulpes	bonefish	4	0.01	42	0.01
Paralabrax clathratus	kelp bass	4	0.01	29	0.01
Gibbonsia elegans	spotted kelpfish	3	0.01	28	0.01
Myliobatis californica	bat ray	2	0.00	17500	3.98
Rhinobatis productus	shovelnose guitarfish	2	0.00	6595	1.50
Cynoscion parvipinnis	shortfin corvina	2	0.00	1476	0.34
Synodus lucioceps	California lizardfish	2	0.00	45	0.01
Micrometrus minimus	dwarf surfperch	2	0.00	28	0.01
Paraclinus integripinnis	reef finspot	2	0.00	3	0.00
Mustelus californicus	grey smoothhound	1	0.00	950	0.22
Mustelus henlei	brown smoothhound	1	0.00	813	0.18
Anisotremus davidsoni	sargo	1	0.00	579	0.13
Scorpaena guttata	spotted scorpionfish	1	0.00	151	0.03
Tridentiger trigonocephalus	chameleon goby	1	0.00	4	0.00
Mugil cephalus	striped mullet	1	0.00	0	0.00
Total		57892		440185	

Table 2-11. Total Number of Individuals and Biomass (g) of Fish Species Taken in the South Bay (Station 4), July 1994–April 1999.

Species	Common Name	Total #	%	Total Wt.	%
Anchoa delicatissima	slough anchovy	35106	66.03	45201	7.66
Atherinops affinis	topsmelt	7693	14.47	39800	6.74
Clevelandia ios	arrow goby	1677	3.15	187	0.03
Urolophus halleri	round stingray	1371	2.58	221280	37.48
Engraulis mordax	northern anchovy	1249	2.35	1498	0.25
Cymatogaster aggregata	shiner surfperch	1051	1.98	3653	0.62
Syngnathus auliscus	barred pipefish	917	1.72	519	0.09
Fundulus parvipinnis	California killifish	598	1.12	1318	0.22
Mugil cephalus	striped mullet	510	0.96	2270	0.38
Atherinopsis californiensis	jacksmelt	395	0.74	13875	2.35
Paralabrax maculatofasciatus	spotted sand bass	347	0.65	77259	13.09
Quietula ycauda	shadow goby	325	0.61	103	0.02
Syngnathus leptorhynchus	bay pipefish	292	0.55	101	0.02
Paralichthys californicus	California halibut	250	0.47	30770	5.21
Paralabrax nebulifer	barred sand bass	240	0.45	46907	7.95
Ilypnus gilberti	cheekspot goby	190	0.36	71	0.01
Hyporhamphus rosae	California halfbeak	174	0.33	303	0.05
Heterostichus rostratus	giant kelpfish	131	0.25	1034	0.18
Anchoa compressa	deepbody anchovy	130	0.24	1479	0.25
Hypsopsetta guttulata	diamond turbot	74	0.14	6228	1.05
Sardinops sagax caeruleus	Pacific sardine	74	0.14	4711	0.80
Cheilotrema saturnum	black croaker	53	0.10	8500	1.44
Albula vulpes	bonefish	46	0.09	880	0.15
	Post-larval anchovy	45	0.08	1	0.00
Porichthys myriaster	specklefin midshipman	37	0.07	926	0.16
Myliobatis californica	bat ray	28	0.05	61336	10.39
Umbrina roncador	yellowfin croaker	27	0.05	4492	0.76
Acanthogobius flavimanus	yellowfin goby	25	0.05	420	0.07
Gillichthys mirabilis	longjaw mudsucker	19	0.04	51	0.01
Cynoscion parvipinnis	shortfin corvina	14	0.03	801	0.14
Mustelus californicus	gray smoothhound	9	0.02	3793	0.64
Pleuronichthys ritteri	spotted turbot	8	0.02	121	0.02
Syngnathus exilis	barcheek pipefish	8	0.02	7	0.00
Strongylura exilis	California needlefish	7	0.01	1137	0.19
Synodus lucioceps	California lizardfish	7	0.01	73	0.01
Roncador stearnsii	spotfin croaker	5	0.01	1163	0.20
Leptocottus armatus	staghorn sculpin	4	0.01	60	0.01
Gibbonsia elegans	spotted kelpfish	4	0.01	9	0.00
Atractoscion nobilis	white sea bass	3	0.01	568	0.10
Dorosoma petenense	threadfin shad	3	0.01	224	0.04
Gymnura marmorata	California butterfly ray	2	0.00	2714	0.46
Hippocampus ingens	Pacific seahorse	2	0.00	91	0.02
Paralabrax clathratus	kelp bass	2	0.00	83	0.01
Porichthys notatus	plainfin midshipman	2	0.00	61	0.01
Xenistius californiensis	salema	2	0.00	27	0.00
Syngnathus californiensis	kelp pipefish	2	0.00	3	0.00
Rhinobatis productus	shovelnose guitarfish	1	0.00	3757	0.64
Xystreurys liolepis	fantail sole	1	0.00	188	0.03
Scorpaena guttata	spotted scorpionfish	1	0.00	182	0.03
Menticirrhus undulatus	California corbina	1	0.00	150	0.03
Hypsoblennius gentilis	bay blenny	1	0.00	3	0.00
Bryx arctos	snubnose pipefish	1	0.00	0	0.00
Total		53164		590386	

2.5.4.6 Seasonal Changes in Abundance and Biomass

There were substantial changes in the number of individuals and total biomass over the course of the twenty seasonal sampling periods (Allen 1999). Abundance was highest in the spring (April 1995, 1996, 1997, 1998, and 1999) and summer (July 1995, 1996, and 1998) months, based on pooling the data for all species and stations (Figure 2-14). Heavy recruitment of juvenile surfperches and topsmelt in April of 1995 and 1996 appeared to be largely responsible for those spring abundance peaks. Large numbers of topsmelt, slough anchovy, shiner surfperch, and California grunion contributed to the high numbers in April 1997, while the April 1998 catches were dominated by slough anchovy. Very large catches of juvenile northern anchovy and Pacific sardine caused the pronounced peaks in July 1995 and 1996. The virtual absence of northern anchovy caused the low numbers in July 1997. The July 1998 catch was dominated by slough anchovy, northern anchovy and topsmelt (Allen 1999).

Lowest abundances were encountered in January 1995, 1996, 1997, and 1999, when water temperatures were lowest. In January 1998, fish abundance tripled from previous January samples, due to a large recruitment of jacksmelt. This abundance pattern was consistent among Stations 1, 2, and 3. However, fishes at the southernmost location, Station 4, exhibited peak abundance in October 1994, 1996, and April 1998 (Allen 1999).

Biomass varied greatly from season to season. This appeared to be related primarily to the abundances of northern anchovy, round stingrays, bat rays, and spotted sand bass (Figure 2-15). Biomass values of the fish samples consistently were highest in the spring (April 1995, 1996,1997, and 1998) and the summer (July 1995 and 1996). Significant catches of bat rays in October 1998 at Station 1 and in January 1999 at Station 4 greatly disrupted the pattern of the first four years, as shown in Figure 2-15.

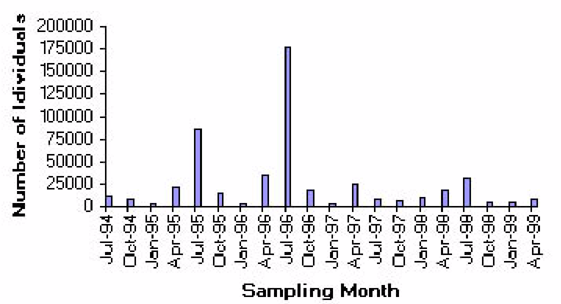


Figure 2-14. Abundance of Fishes in San Diego Bay by Sampling Period.

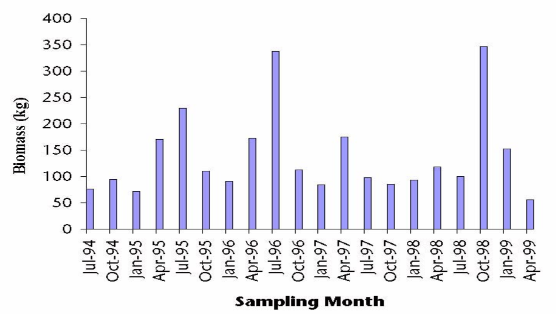


Figure 2-15. Biomass of Fishes in San Diego Bay by Sampling Period.

2.5.4.7 Patterns of Biodiversity and Species Assemblages in Four Regions of the Bay

Allen's results suggest that there is considerable overlap in the composition of numerically dominant or important fish species within different areas of the Bay. Northern anchovy was the most abundant species in both the north and north-central areas of the Bay, while the slough anchovy was the most abundant form in the south-central and south Bay regions. Topsmelt, shiner surfperch, and the round stingray were relatively common in all four regions (Tables 2-8 through 2-11).

However, the study also concluded that fish assemblages sampled in the north, north-central, south-central, and south Bay regions showed subtle differences from one another, in both species composition and the relative abundances of the fish species found there. Allen illustrated these subtle differences qualitatively in a series of figures which we have adapted for this Plan. Figures 2-16 through 2-19 provide a pictorial comparison of the primary species that form the fish assemblages in the north and south Bay regions. As shown in Figure 2-16, the northern anchovy, Pacific sardine, dwarf surfperch (*Micrometrus minimus)*, kelp bass, jacksmelt, California grunion (*Leuresthes tenuis)*, topsmelt, giant kelpfish, bay blenny (*Hypsoblennius gentilis*), round stingray, California halibut, black surfperch (*Embiotoca jacksoni)*, spotted sand bass, barred sand bass, shiner surfperch, bay pipefish, slough anchovy, and cheekspot goby are all important components of this species assemblage. As shown in Figure 2-17, however, the northern anchovy, topsmelt, jacksmelt, giant kelpfish, round stingray, California halibut, spotted and barred sand bass, shiner surfperch, bay pipefish, slough anchovy and cheekspot goby also occur throughout the Bay. Therefore, only six of these eighteen common members of the north Bay fish assemblage are limited primarily to the north and central Bay regions. They are Pacific sardine, California grunion, dwarf surfperch, black surfperch, bay blenny, and kelp bass.

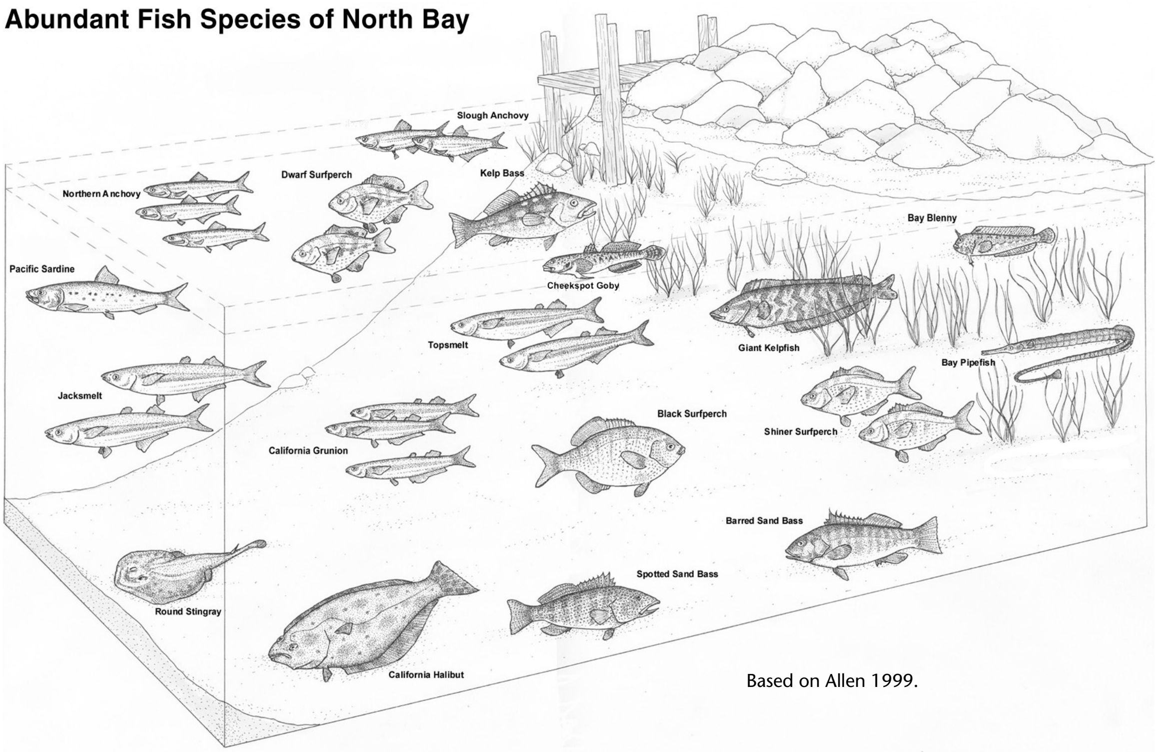


Figure 2-16. Abundant Fish Species of North Bay.

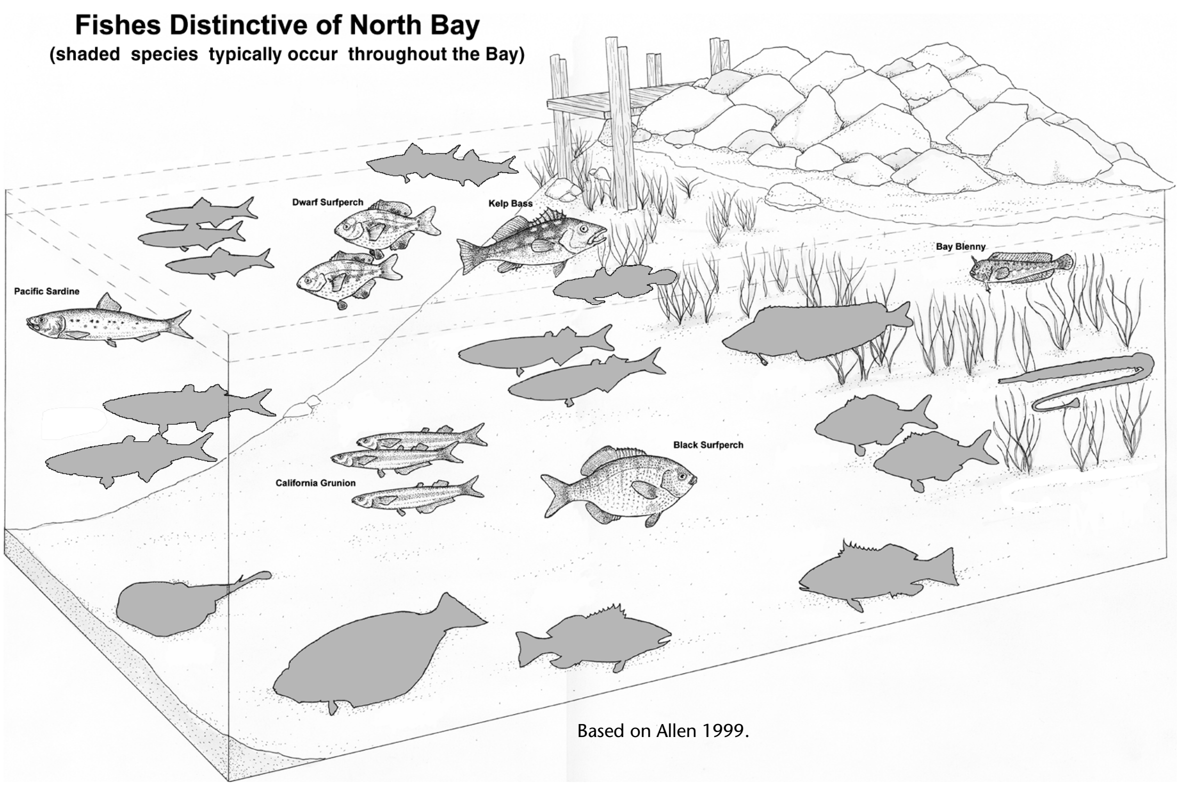


Figure 2-17. Fishes Distinctive of North Bay, and Not Typically Found in South Bay.

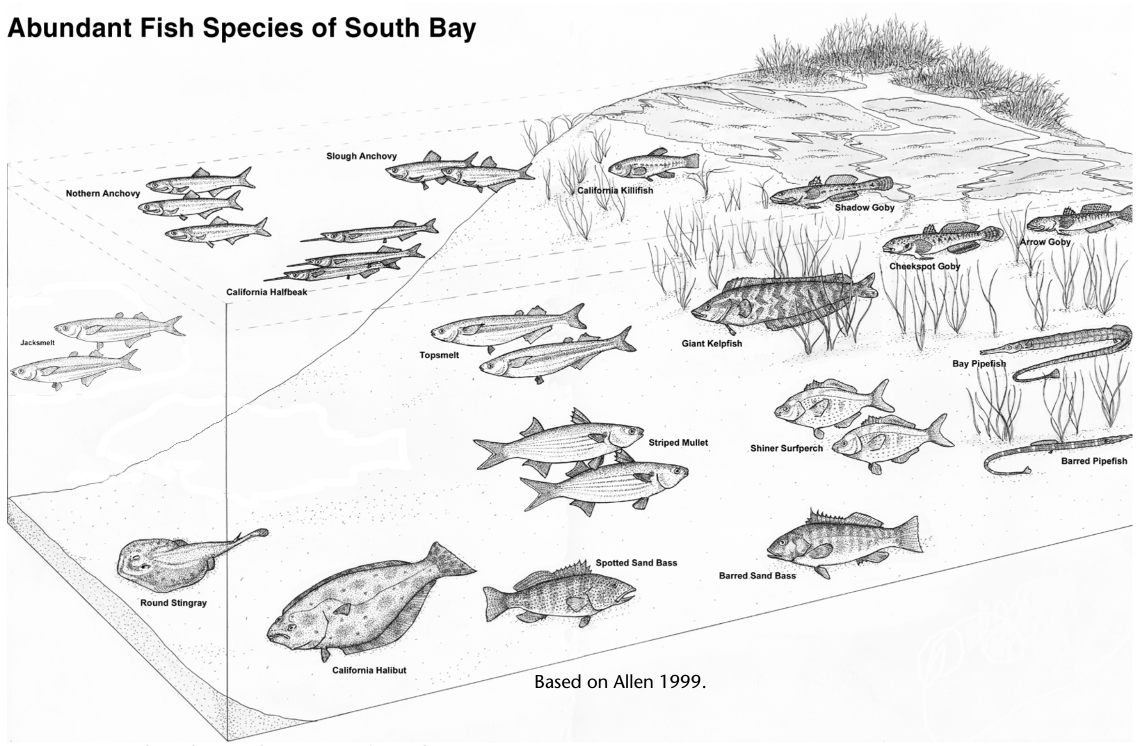


Figure 2-18. Abundant Fish Species of South Bay.

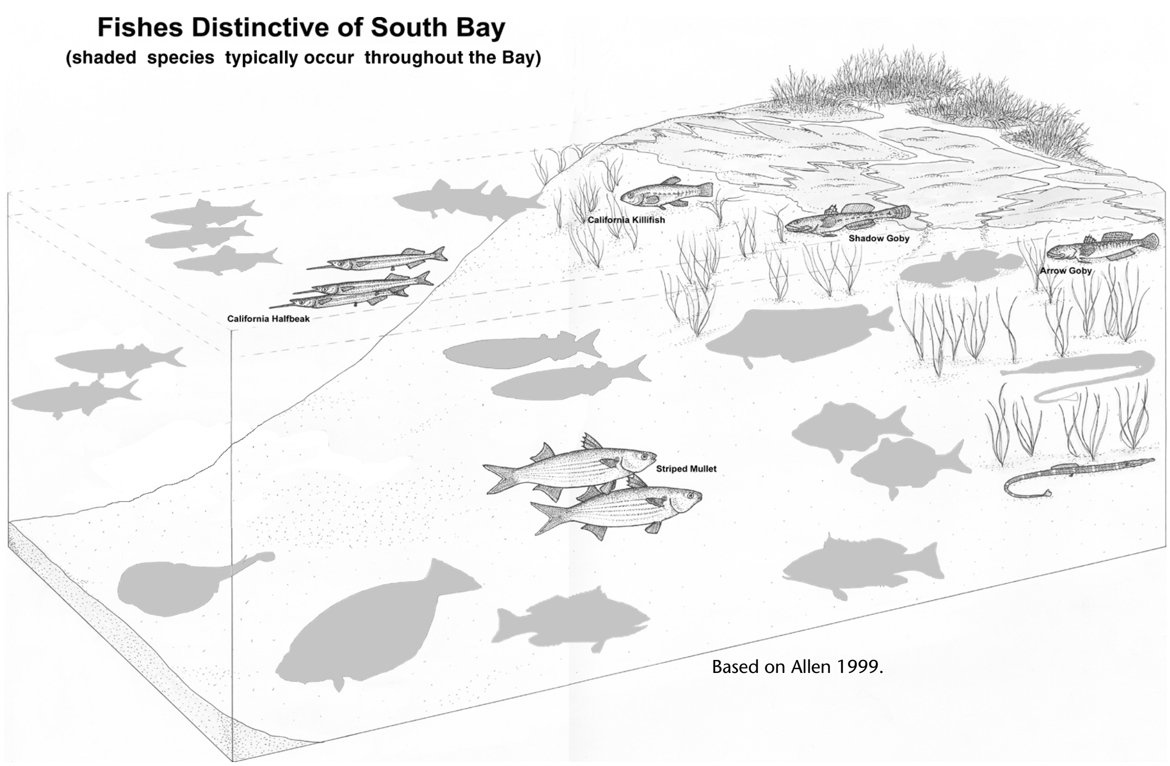


Figure 2-19. Fishes Distinctive of South Bay, and Not Typically Found in North Bay.

The same point is illustrated for the south Bay fish assemblage in Figures 2-18 and 2-19. Only six of the eighteen common species are restricted primarily to central and south portions of the Bay. They are the barred pipefish, California halfbeak, striped mullet, California killifish, shadow goby, and arrow goby.

Considering species richness as one reflection of biological diversity, conditions in the north Bay appear to provide for the greatest diversity in San Diego Bay. The 68 species sampled in the north Bay represented substantially greater diversity than the other three regions that shared a comparable species richness ranging from 49 to 55 species.

Despite differences in the total number of fishes sampled, all regions had a similar pattern of fish abundance in that a small number of all species present regionally made up the bulk of the total catch there. Two species, the northern anchovy and the topsmelt, accounted for about 79% of the total catch at the northern stations. Similarily, the slough anchovy and topsmelt accounted for about 79% of the total catch at the stations in the south half of the Bay. Figure 2-20 illustrates this skewed distribution for the ten most common fishes sampled in north and south Bay.

Biomass of fishes regionally followed a similar pattern as fish abundance with slight variation. Biomass was greatest at the northern Bay stations than at the southern Bay stations, although they were roughly similar between sampling stations in their respective regions. The higher biomass values for the north and north-central regions reflect the higher numbers of fish taken in those areas. As with fish abundance, the majority of the biomass was also consistently concentrated in a smaller subset of all species sampled. However, as Figure 2-20 shows, that concentration of biomass was greater in the south Bay than in north Bay.

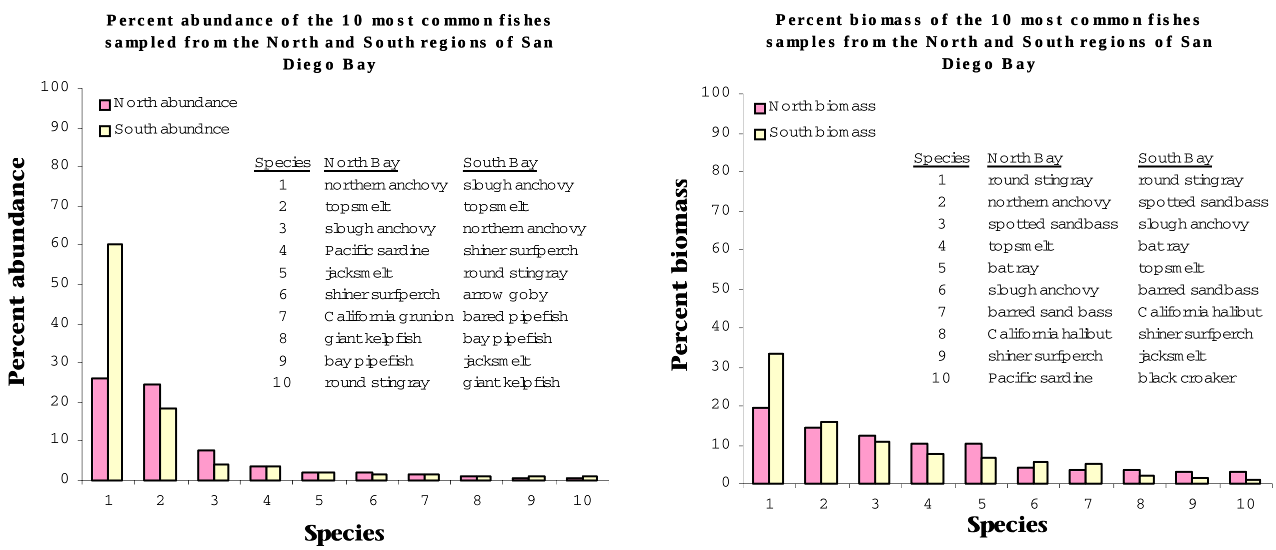


Figure 2-20. Patterns of Abundance (left) and Biomass (right) of the Ten Most Common Fishes sampled from the Northern and Southern Halves of San Diego Bay (based on Allen 1999).

Allen's findings are instructional about the nature of fish communities and biological diversity at the ecosystem, species and population levels. From a species diversity standpoint, the northern Bay regions had not only the greatest abundance and biomass of fishes, but the greatest number of species, and hence could be considered more diverse than the rest of the Bay. In contrast, fish communities in all regions of the Bay shared the common feature that, in general, a small subset of all species accounted for a majority of the fish numbers and biomass present. In that respect, fish communities across the Bay did not differ.

The genetic diversity of the fish communities is also an important component of biological diversity that is not addressed by Allen's data. Certain regions of the Bay may contain higher numbers of species of disproportionate genetic importance, such as endemics and rare and declining species. Conserving these species will be a critical component of any comprehensive strategy aimed at maintaining and restoring the biodiversity of San Diego Bay.

2.5.4.8 Functional Groups of Fishes

Using cluster analyses of his fish data for 1994–1997, Allen (pers. comm.) identified several other distinct species groups besides the Top Ten Ecological Index Group described in Section 2.5.4.3 "Rankings Based on Ecological Index." Clustering was based on fish abundances by Station, month of capture, and sampling gear type. This was done to increase resolution. The clustering method employed Pearson's correlation coefficient among all possible combinations of 36 species with complete linkage (L. Allen, California State University Northridge, pers. comm.).

Species Associated with Eelgrass and Subtidal Unvegetated Habitat

The results of these cluster analyses also identified eleven species of fishes closely associated with eelgrass habitat in San Diego Bay. These are listed in Table 2-12.

Table 2-12. San Diego Bay Fish Species Closely Associated with Subtidal Eelgrass Habitat.

Scientific Name	Common Name	Scientific Name	Common Name
Cymatogaster aggregata	shiner surfperch	*Micrometrus minimum*	dwarf surfperch
Embiotoca jacksoni	black surfperch	*Paralabrax clathratus*	kelp bass
Gibbonsia elegans	spotted kelpfish	*Paraclinus integripinis*	reef finspot
Heterostichus rostratus	giant kelpfish	*Syngnathus auliscus*	barred pipefish
Hypocampus ingens	Pacific seahorse	*Syngnathus leptorhynchus*	bay pipefish
Hypsoblennius gentilis	bay blenny		

A complete list of all fish species taken in eelgrass habitats is given in Table 2-13. A comparable list of all species of fishes taken in subtidal unvegetated habitat of unconsolidated sediment is shown in Table 2-14. Both of these species lists are based on samples taken at all four stations during the period 1994–1997 by Allen (1997). They were not produced by cluster analysis.

Table 2-13. San Diego Bay Fish Species Taken in Subtidal Eelgrass Bed Habitat.[1]

Scientific Name	Common Name	Scientific Name	Common Name
Urolophus halleri	round stingray	*Heterostichus rostratus*	giant kelpfish
Albula vulpes	bonefish	*Acanthogobius flavimanus*	yellowfin goby
Sardinops sagax caeruleux	pacific sardine	*Clevelandia ios*	arrow goby
Engraulis mordax	northern anchovy	*Gillichthys mirabilis*	longjaw mudsucker
Anchoa compressa	deepbody anchovy	*Ilypnus gilberti*	cheekspot goby
Anchoa delicatissima	slough anchovy	*Quietula ycauda*	shadow goby
Hyporhamphus rosae	California halfbeak	*Tridentiger trigonocephalus*	chameleon goby
Strongylura exilis	California needlefish	*Xenistius californiensis*	salema
Fundulus parvipinnis	California killifish	*Umbrina roncador*	yellowfin croaker
Atherinopsis californiensis	jacksmelt	*Medialuna californiensis*	halfmoon
Atherinops affinis	topsmelt	*Cymatogaster aggregata*	shiner surfperch
Bryx arctos	snubnose pipefish	*Embiotoca jacksoni*	black surfperch
Syngnathus californiensis	kelp pipefish	*Micrometrus minimus*	dwarf surfperch
Syngnathus leptorhynchus	bay pipefish	*Mugil cephalus*	striped mullet
Syngnathus auliscus	barred pipefish	*Sphyraena argentea*	California barracuda
Syngnathus exilis	barcheek pipefish	*Hypsoblennius gentilis*	bay blenny
Leptocottus armatus	staghorn sculpin	*Hypsopsetta guttulata*	diamond turbot
Paralabrax nebulifer	barred sand bass	*Paralichthys californicus*	California halibut
Gibbonsia montereyensis	crevice kelpfish		

1. Based on Data for 1994–1997 (Allen 1997).

Table 2-14. San Diego Bay Fish Species Taken in Subtidal Unvegetated, Unconsolidated Sediment Habitat.[1]

Scientific Name	Common Name	Scientific Name	Common Name
Mustelus californicus	gray smoothhound	*Ilypnus gilberti*	cheekspot goby
Mustelus henlei	brown smoothhound	*Quietula ycauda*	shadow goby
Myliobatis californica	bat ray	*Paralabrax clathratus*	kelp bass
Urolophus halleri	round stingray	*Paralabrax maculatofasciatus*	spotted sand bass
Sardinops sagax caeruleus	pacific sardine	*Paralabrax nebulifer*	barred sand bass
Engraulis mordax	northern anchovy	*Trachurus symmetricus*	jack mackerel
Anchoa compressa	deepbody anchovy	*Anisotremus davidsoni*	sargo
Anchoa delicatissima	slough anchovy	*Xenistius californiensis*	salema
Porichthys myriaster	specklefin midshipman	*Seriphus politus*	queenfish
Hyporhamphus rosae	California halfbeak	*Atractoscion nobilis*	white sea bass
Strongylura exilis	California needlefish	*Cheilotrema saturnum*	black croaker
Leuresthes tenuis	California grunion	*Cynoscion parvipinnis*	shortfin corvina
Atherinopsis californiensis	jacksmelt	*Umbrina roncador*	yellowfin croaker
Atherinops affinis	topsmelt	*Cymatogaster aggregata*	shiner surfperch
Bryx arctos	snubnose pipefish	*Embiotoca jacksoni*	black surfperch
Syngnathus californiensis	kelp pipefish	*Micrometrus minimus*	dwarf surfperch
Hippocampus ingens	pacific seahorse	*Phanerodon furcatus*	white surfperch
Syngnathus leptorhynchus	bay pipefish	*Mugil cephalus*	striped mullet
Syngnathus auliscus	barred pipefish	*Sphyraena argentea*	California barracuda
Scorpaena guttata	spotted scorpionfish	*Oxyjulis californica*	senorita
Gibbonsia elegans	spotted kelpfish	*Halichoeres semicinctus*	rock wrasse
Gibbonsia montereyensis	crevice kelpfish	*Hypsoblennius gentilis*	bay blenny
Gibbonsia metzi	striped kelpfish	*Scomber japonicus*	Pacific mackerel
Heterostichus rostratus	giant kelpfish	*Citharichthys stigmaeus*	speckled sand dab
Acanthogobius flavimanus	yellowfin goby	*Hypsopsetta guttulata*	diamond turbot
Clevelandia ios	arrow goby	*Paralichthys californicus*	California halibut
Gillichthys mirabilis	longjaw mudsucker	*Pleuronichthys ritteri*	spotted turbot

1. Based on Data for 1994–1997 (Allen 1997).

As evident in Maps C-2 and C-3, Allen (1999) found that very similar total numbers of fish were taken in intertidal and subtidal vegetated (239,607) and unvegetated (224,983) habitats over the period of July 1994 to April 1999. However, Allen concluded that the only meaningful way to evaluate both numerical and biomass densities among different habitats was to limit comparisons to data taken by the same gear-type. These comparisons are shown in Figures 2-21 and 2-22.

Purse seine samples yielded total fish densities that were similar at vegetated and unvegetated sites (Figure 2-22), with slightly higher values at the unvegetated sites. However, purse seine catches were highly variable, and this small difference was not statistically significant (Allen 1999). For the large seine, fish densities were again slightly higher in unvegetated samples, but the difference was not significant. As shown in Figure 2-22, all other sampling methods yielded significantly higher catches in vegetated areas than in unvegetated areas.

All three seining methods captured comparable biomass densities in unvegetated and vegetated areas (Figure 2-22). While densities in unvegetated areas were slightly higher than in vegetated areas, the differences were not significant for any of the seining methods. The biomass values measured by using the beam trawl and square enclosure were significantly greater in the vegetated than the unvegetated areas (Allen 1999).

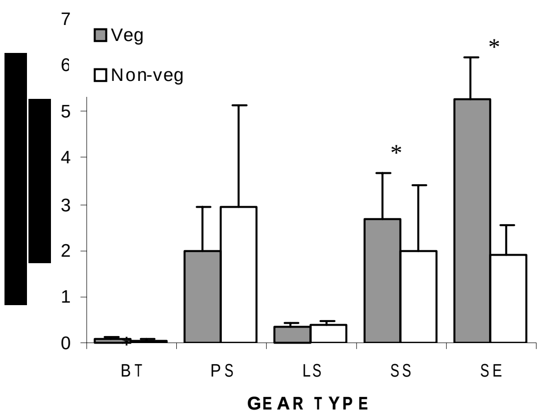


*Figure 2-21. Comparison of Fish Numerical Density in Vegetated and Unvegetated Samples. *Statistically significant differences.*

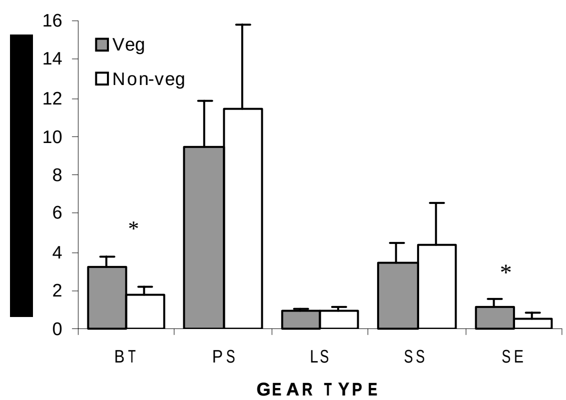


*Figure 2-22. Comparison of Fish Biomass Density in Vegetated and Unvegetated Sites. *Statistically significant differences.*[1]

[1] Gear Type: BT=Beam Trawl, PS=Purse Seine, LS=Large Seine, SS=Small Seine, SE=Square Enclosure.

Allen's finding of significantly higher catches at vegetated sites in five of the ten possible gear comparisons is generally consistent with the results of Hoffman (1986), who concluded that catches were generally twice as large over eelgrass compared to unvegetated sites. Allen (1999) concluded that the data from his small seine, large seine, and purse seine sampling should be interpreted with caution, both because of variability in catches and because the unvegetated sites he sampled actually had varying degrees of eelgrass coverage. He also noted that when making the original selection of station sites, it was difficult to locate truly unvegetated sites. As a result, it was difficult to make clear comparisons. Additionally, seasonal growth and die-off of eelgrass probably added to the variance in fish catches (Allen 1999).

Fishes Associated with Deep Subtidal Habitats

The group of fish species taken in deep subtidal habitats (>20 ft/6 m below MLLW) is listed in Table 2-15. This species list, which was not produced by cluster analysis, is based on all samples taken during the period 1994–1997 (Allen 1997).

Fishes Associated with Artificial, Man-made Habitats

Fishes associated with artificial or man-made habitats have not been studied extensively in San Diego. The species list shown in Table 2-16 was compiled by reviewing data from a large series of ecological studies conducted to develop environmental impact statements for projects throughout the Bay (See, for example, Ford and Macdonald 1986; Michael Brandman and Associates 1989).

The species listed in Table 2-16 also occur in other natural Bay habitats. However, apparently they are adaptable enough to occupy areas that have been disturbed or modified by the presence of rock riprap, concrete bulkheads, piers, marina floats, and a wide variety of other artificial habitats.

Table 2-15. San Diego Bay Fish Species Taken in Deep Subtidal Habitats.[1]

Scientific Name	Common Name	Scientific Name	Common Name
Heterodontus francisi	California horn shark	*Xenistius californiensis*	salema
Mustelus californicus	gray smoothhound	*Seriphus politus*	queenfish
Rhinobatus productus	shovelnose guitarfish	*Atractoscion nobilis*	white sea bass
Myliobatis californica	bat ray	*Cheilotrema saturnum*	black croaker
Urolophus halleri	round stingray	*Genyonemus lineatus*	white croaker
Sardinops sagax caeruleux	pacific sardine	*Roncador stearnsii*	spotfin croaker
Engraulis mordax	northern anchovy	*Umbrina roncador*	yellowfin croaker
Anchoa compressa	deepbody anchovy	*Cymatogaster aggregata*	shiner surfperch
Anchoa delicatissima	slough anchovy	*Embiotoca jacksoni*	black surfperch
Synodus lucioceps	California lizardfish	*Phanerodon furcatus*	white surfperch
Porichthys myriaster	specklefin midshipman	*Mugil cephalus*	striped mullet
Porichthys notatus	plainfin midshipman	*Oxyjulis californica*	senorita
Hyporhamphus rosae	California halfbeak	*Halichoeres semicinctus*	rock wrasse
Strongylura exilis	California needlefish	*Hypsoblennius gentilis*	bay blenny
Atherinopsis californiensis	jacksmelt	*Heterostichus rostratus*	giant kelpfish
Atherinops affinis	topsmelt	*Scomber japonicus*	Pacific mackerel
Syngnathus californiensis	kelp pipefish	*Citharichthys stigmaeus*	speckled sand dab
Hippocampus ingens	Pacific seahorse	*Xysteurys liolepis*	fantail sole
Syngnathus leptorhynchus	bay pipefish	*Symphurus atricauda*	California tonguefish
Syngnathus auliscus	barred pipefish	*Hypsopsetta guttulata*	diamond turbot
Scorpaena guttata	spotted scorpionfish	*Paralichthys californicus*	California halibut
Leptocottus armatus	staghorn sculpin	*Pleuronectes vetulus*	English sole
Paralabrax clathratus	kelp bass	*Pleuronichthys coenosus*	CO turbot
Paralabrax maculatofasciatus	spotted sand bass	*Pleuronichthys ritteri*	spotted turbot
Paralabrax nebulifer	barred sand bass	*Pleuronichthys verticalis*	hornyhead turbot

1. Based on Data for 1994–1997 (Allen 1997).

Table 2-16. San Diego Bay Fish Species Associated with Artificial, Man-made Habitats.

Scientific Name	Common Name	Scientific Name	Common Name
Platyrhinoidis triseriata	thornback	*Medialuna californiensis*	halfmoon
Rhinobatus productus	shovelnose guitarfish	*Cymatogaster aggregata*	shiner surfperch
Urolophus halleri	round stingray	*Damalichthys vacca*	pile surfperch
Sardinops sagax caeruleux	Pacific sardine	*Embiotoca jacksoni*	black surfperch
Engraulis mordax	northern anchovy	*Hyperprosopon argenteum*	walleye surfperch
Anchoa compressa	deepbody anchovy	*Phanerodon furcatus*	white surfperch
Anchoa delicatissima	slough anchovy	*Rhacochilus toxotes*	rubberlip surfperch
Porichthys myriaster	specklefin midshipman	*Hypsoblennius gentilis*	bay blenny
Atherinops affinis	topsmelt	*Hypsoblennius jenkensi*	mussel blenny
Syngnathus leptorhynchus	bay pipefish	*Paraclinus integripinnis*	reef finspot

Table 2-16. San Diego Bay Fish Species Associated with Artificial, Man-made Habitats. (Continued)

Scientific Name	Common Name	Scientific Name	Common Name
Scorpaena guttata	spotted scorpionfish	*Gibbonsia elegans*	spotted kelpfish
Leptocottus armatus	staghorn sculpin	*Gibbonsia montereyensis*	crevice kelpfish
Paralabrax clathratus	kelp bass	*Heterostichus rostratus*	giant kelpfish
Paralabrax maculatofasc	spotted sand bass	*Clevelandia ios*	arrow goby
Paralabrax nebulifer	barred sand bass	*Ilypnus gilberti*	cheekspot goby
Anisotremus davidsoni	sargo	*Lepidogobius lepidus*	bay goby
Seriphus politus	queenfish	*Quietula ycauda*	shadow goby
Cheilotrema saturnum	black croaker	*Scomber japonicus*	Pacific mackerel
Genyonemus lineatus	white croaker	*Hypsopsetta guttulata*	diamond turbot
Umbrina roncador	yellowfin croaker	*Paralichthys californicus*	California halibut
Girella nigricans	opaleye		

Indigenous Bay-estuarine Species Group

As shown in Table 2-17, the results of cluster analyses identified twelve species that form an Indigenous Bay-estuarine Species Group. These are species that occur primarily in the shallow, more truly estuarine habitats of south and central San Diego Bay. With the exception of the striped mullet, they are restricted to bays and estuaries.

Therefore, this functional group contains eleven species that are endemic to estuarine habitats, making them unique and particularly important members of the San Diego Bay Ecosystem.

Table 2-17. Indigenous Bay-estuarine Species.

Scientific Name	Common Name
Anchoa compressa	deepbody anchovy
Anchoa delicatissima	slough anchovy
Fundulus parvipinnis	California killifish
Clevelandia ios	arrow goby
Gillichthys mirabilis	longjaw mudsucker
Syngnathus leptorhynchus	bay pipefish
Syngnathus auliscus	barred pipefish
Ilypnus gilberti	cheekspot goby
Mugil cephalus	striped mullet
Paralabrax maculatofasciatus	spotted sand bass
Hypsoblennius gentilis	bay blenny
Quietula yauda	shadow goby

2.5.4.9 Species Caught by Commercial or Recreational Fishing

- There is no commercial fishing within San Diego Bay; however, seven species inhabiting the Bay support commercial fisheries elsewhere in southern California.

Species of fishes inhabiting San Diego Bay that are taken by commercial or recreational fishing are listed in Table 2-18. Those species that also support a commercial fishery in southern California waters are indicated in Table 2-18 with an asterisk.

It is important to note that no fish species is now caught by commercial fishermen inside San Diego Bay. The last commercial fishery, a small one for striped mullet in south San Diego Bay, ended in 1998. While there is no commercial fishing within the Bay, seven species inhabiting San Diego Bay support commercial fisheries elsewhere in southern California waters. The most important of these fishery populations is the California halibut, and to a lesser extent the white seabass. The northern anchovy is taken commercially primarily for use as live bait. In addition, the Pacific sardine is taken as part of this catch. Fish caught for this purpose are held in bait receivers located in north San Diego Bay, where they are sold to commercial and recreational fishermen.

A much larger group of species are caught within the Bay by recreational fishermen and those who fish primarily to obtain food. Because of the many ethnic groups now fishing in San Diego Bay, the number of different species taken has increased markedly. As shown in Table 2-18, at least 58 species are involved in the recreational catch, although most of these probably are taken only in very small numbers.

Table 2-18. Fish Species of San Diego Bay Taken by Recreational and Commercial Fishermen. [1]

Scientific Name	Common Name	Scientific Name	Common Name
Osteichthyes	Bony Fish	*Pleuronichthys ritteri*	spotted turbot
Atherinops affinis	topsmelt	*Pleuronichthys verticalis*	hornyhead turbot
Atherinopsis californiensis	jacksmelt	*Cheilotrema saturnum*	black croaker
Leuresthes tenuis	California grunion	*Atractoscion nobilis**	white seabass
Hippoglossina stomata	bigmouth sole	*Genyonemus lineatus*	white croaker
Xysteurys liolepis	fantail sole	*Menticurrhus undulatus*	California corbina
Caranx caballus	green jack	*Roncador stearnsii*	spotted croaker
Caranx hippos	crevalle jack	*Seriphus politus*	queenfish
Trachurus symmetricus	jack mackerel	*Umbrina roncador*	yellowfin croaker
Chanos chanos	milkfish	*Sarda chiliensis*	Pacific bonito
Clupea harengus pallasii	Pacific herring	*Scomber japonicus*	Pacific mackerel
*Sardinops sagax caeruleus**	Pacific sardine	*Scomberomorus sierra*	sierra
Scorpaena guttata	sculpin	*Medialuna californiensis*	halfmoon
Scorpaenichthys marmoratus	cabezon	*Morone saxatilis*	striped bass
Amphistichus argenteus	barred surfperch	*Paralabrax clathratus**	kelp bass
Cymatogaster aggregata	shiner surfperch	*Paralabrax maculatofasciatus*	spotted sand bass
Damalichthys vacca	pile surfperch	*Paralabrax nebulifer*	barred sand bass
Embiotoca jacksoni	black surfperch	*Sphyraena argentea*	California barracuda
Hyperprosopon argenteum	walleye surfperch	*Albula vulpes*	bonefish
Micrometrus minimus	dwarf surfperch	*Cynoscion parvipinnis*	shortfin corvina
Phanerodon furcatus	white surfperch	*Chondrichthyes*	Sharks and Rays
Rhacochilus toxotes	rubberlip surfperch	*Carcharhinus remotus*	narrowtooth shark
*Engraulis mordax**	northern anchovy	*Galeorhinus zyopterus*	soupfin shark
Girella nigricans	opaleye	*Mustelus californicus*	gray smoothhound
*Mugil cephalus**	striped mullet	*Mustelus henlei*	brown smoothhound
Hypsopsetta guttulata	diamond turbot	*Mustelus lunulatus*	sicklefin smoothhound
*Paralichthys californicus**	California halibut	*Prionace glauca*	blue shark
Platichthys stellatus	starry flounder	*Triakis semifasciata*	leopard shark
*Parophrys vetulus**	English sole	*Sphyma zygaena*	smooth hammerhead shark
Pleuronichthys coenosus	CO turbot	*Squalus acanthias*	spiny dogfish

1. ** Indicates species of commercial importance in southern California waters.*

2.5.4.10 Warm Water Fishes in San Diego Bay During El Niño

In common with other bays along the California coast, San Diego Bay serves as a warm water "trap" or refuge for tropical or warm-temperate species of fishes that normally occur farther south. This effect is most pronounced during and following strong El Niño conditions. A prime example is the Pacific seahorse (*Hippocampus ingens*), as described by Jones *et al.* (1988). Although rare in southern California waters, this species apparently became reestablished in San Diego Bay during the 1980s El Niño events and has remained, taking advantage of warm water conditions.

Other unusual open water species were recently reported from San Diego Bay during the large El Niño event of 1997–1998 (LaRue 1998). Mike Irey, formerly involved in the fishery for striped mullet in south San Diego Bay, reported to LaRue that he has caught bigeye trevally, Pacific triple tail, and the Mexican lookdown in the gill net gear he employed to take striped mullet.

All three of these tropical species are normally found only in warmer Mexican waters to the south. During the strong El Niño conditions of 1997–1998, they apparently entered San Diego Bay and took up residence in the warmer waters of the south Bay. Water temperature effects produced by the South Bay Power Plant may possibly have contributed to their survival there, but this has not been established.

It is questionable whether these three species should be listed as part of the fish fauna of San Diego Bay because they would not be expected to reproduce and establish populations there. However, their occurrence in the Bay is noteworthy, illustrating the effect of changing oceanographic conditions on the presence of particular fish species in San Diego Bay.

2.5.4.11 Correlation of Fish Abundance With Environmental Factors

Allen (1999) employed univariate correlation analysis on log-transformed data for fish abundance and biomass from each station, in relation to water temperature, salinity, and pH. For these data summarized by month, water temperature was found to show significant positive correlations with the number of individuals of all fish species combined, as well as with the abundance of the slough anchovy, northern anchovy, deepbody anchovy, California halfbeak, black croaker, California killifish, and yellowfin croaker. A negative correlation was found for jacksmelt, spotted turbot, and bay pipefish. This suggests that water temperature has a strong influence on many of the important fish species in the Bay.

- Three prominent environmental factors of distance from the mouth of the Bay, water temperature, and salinity were evaluated against abundances at each station of the 25 most abundant fish species in the Bay. They accounted for nearly 95% of the variance in abundance of these individual species among stations for each monthly sampling period. Temperature and salinity alone accounted for almost 89% of this variance.

Allen (1999) also applied multivariate correlation analysis in comparing three prominent environmental factors of distance from the mouth of the Bay (Station location), water temperature, and salinity with the log-transformed data for abundances at each station of the 35 most abundant fish species in the Bay. These three factors accounted for nearly 95% of the variance in abundance of these individual species among stations for each monthly sampling period. Temperature and salinity alone accounted for almost 76% of this variance. The very high correlation coefficient values obtained emphasize the great influence that water temperature, salinity, and distance from the Bay entrance have on fish assemblages in San Diego Bay.

2.5.4.12 Possible Sensitive Habitats or Nursery Area for Fishes in San Diego Bay

Eelgrass beds are well recognized as nurseries for many species. Densities of fish (Hoffman 1986; Allen 1999) and density and abundance of infaunal species (Takahashi 1992a) are usually considerably higher in the eelgrass habitat as compared with adjacent, unvegetated soft bottom habitats.

- The abundance of young-of-the-year surfperch and topsmelt in north Bay suggests the presence of a nursery. At least one commercially important species, the California halibut, has been shown to rely heavily on southern California bays and estuaries as nurseries.

The locations of other nursery areas in the Bay have not been identified. However, the abundance of young-of-the-year surfperch and topsmelt in north Bay suggests the presence of a nursery. At least one commercially important species, the California halibut, has been shown to rely heavily on southern California bays and estuaries as nurseries (Allen 1988; Kramer and Hunter 1990). Juveniles of noncommercial fishes usually dominate the fish assemblages of bays and estuaries in the SCB (Allen 1982).

Other sensitive areas may be locations of hard substrate, even artificial substrate such as riprap and piers, which support invertebrates necessary as prey for fish.

- South San Diego Bay appears to be an important nursery area for juvenile California halibut, and for the young of spotted and barred sand bass and other species. Young-of-the-year and larger juveniles of the white seabass have been taken in samples from south San Diego Bay during recent years.

South San Diego Bay appears to be an important nursery area for juvenile California halibut, and for the young of spotted and barred sand bass and other species (Macdonald *et al.* 1990; Ford 1994). Young-of-the-year and larger juveniles of the white seabass have been taken in samples from south San Diego Bay during recent years. This is particularly significant because the population of white sea bass in southern California apparently has been reduced significantly by overfishing or other causes.

At SMNWR, juveniles of certain species take advantage of rich foraging areas and protection from predators (Johnson 1999). Despite the marsh's accessibility to fish being limited to high tide, only 16% of the time, the vegetated surfaces provide important forage such that fishes with access to the marsh consumed a greater amount of food and more diverse prey items than those that remained in subtidal habitats (Johnson 1999). California killifish, longjaw mudsucker, topsmelt, arrow goby, and cheekspot goby dominate the fish assemblage at SMNWR (Johnson 1999).

2.5.5 Birds

- San Diego Bay provides the largest expanse of protected Bay waters in southern California to migrants on the Flyway. The Bay also serves as the northern range of some tropical species, including several that breed and nest locally.

Ecological Role of San Diego Bay for Birds

The Bay is a part of the Pacific Flyway used by millions of birds traveling between northern breeding grounds and southern wintering sites. It is one of a dwindling number of stopover sites used by migrants to replenish their energy during their long journey. It supports large populations of over-wintering birds that depend on its resources for food, shelter, resting, and staging before migration. San Diego Bay provides the largest expanse of protected Bay waters in southern California to migrants on the Flyway. The Bay also serves as the northern range of some tropical species, including several that breed and nest locally. A look at historical accounts on use of the Bay by birds provides some insight into its role prior to development, as described in Table 2-19.

Table 2-19. Historic Changes in Bay Bird Populations.

While we have only anecdotal information on historic use of the Bay by birds, examining it in the context of broader, national trend provides some insight into the status of birds today in the Bay.

In the latter half of the 1800s, San Diego's human population grew with statehood and took advantage of a large bird population for market hunting. Waterfowl most often killed were the most common: wigeon, pintail, and teal ducks that dabbled in shallow water. Canvasbacks were also abundant and rafted by the thousands, but being in the more open waters of the Bay were not so easily killed by hunters (Minshall 1980, citing his own recollections of growing up in the area in the early 1900s). Black brant were also plentiful. Their pattern of flying in dense flocks and being less wary made them vulnerable to hunters. C.A. McGrew (1922) recalled when 50,000 to 100,000 black brant could be seen coming into the Bay from the sea around the Spanish Bight in the 1880s and lamented *"reckless, idiotic shooting...has reft the Bay of one of its chief attractions."* Whimbrel, semipalmated plover and willet were plentiful shorebirds that also fell victim to gunners, and their populations were nearly decimated. The red knot was reported as "common" in the Bay (Abbott 1939).

The American economy was prospering in the mid-1800s, with more dollars spent on nonessentials. This allowed the rise of a feather industry used to adorn women's hats and men's fedoras. By 1900, one out of every 1,000 Americans worked in the millinery trade and plumes sold for up to $80/ounce. This fashion depleted bird populations for 30 years, presumably those using San Diego Bay as well as nationally, as millions of birds were killed. Feathers of the great egret and snowy egret were especially favored, and by 1913, the egret population was decimated. The American Ornithologists Union, founded in 1883, campaigned to stop the industry as did the Audubon Society. The hobby of oology, specimen egg collecting, of the early 1900s also hindered the reproductive efforts of birds such as the black rail in San Diego Bay.

The federal government began to protect birds at the turn of the century with the writing of the Lacey Act of 1890, which addressed interstate transport of birds killed in violation of state laws. The Migratory Bird Treaty between the United States and Canada set hunting seasons for game birds and made hunting of shorebirds and other nongame birds illegal. Similar treaties were later signed with Mexico (1936), Japan (1972), and the Soviet Union (1976). The Migratory Bird Conservation Act of 1927 authorized the Department of Agriculture to acquire wetland to preserve for waterfowl habitat. In 1934, the Migratory Bird Hunting Stamp Act (Duck Stamp Act) provided means of raising money to fund land acquisition. About 5,500,000 acres (2,225,780 ha) have been purchased with Duck Stamp funds.

As activity in the Bay increased and Bayfront development altered habitats, the salt ponds (created in 1902) became more important to certain birds. The western shore still had shallow flats and marsh along the Silver Strand almost to Coronado with *"thousands of shorebirds feeding on the flats at low tide and great flocks of duck and brant feeding on eelgrass and sea lettuce so many they darkened the sky"* (Minshall 1980). As the tide receded, the birds would sort out by their foraging ability—the length of their legs, and length and shape of their bills. Dowitchers, red knots, Wilson's phalarope, greater yellowlegs, dunlins, and marbled godwits could be seen together.

In addition, the habitat remaining was becoming degraded. Sewage dumping into the Bay had reached a level for which tidal flushing no longer compensated. Contamination from industrial operations fouled the water and bioaccumulated in marine life. In 1952, the San Diego Regional Water Quality Control Board reported *"the presence of low dissolved oxygen concentrations and the effect on the fauna have unquestionably affected this area's suitability for migratory game birds."* By 1963, when the new sewage plant routed treated effluent out to sea, the CDFG declared that much of the Bay was a virtual "marine desert."

Pollution and habitat loss were believed to be the cause of the black rails's extirpation from San Diego Bay. Belding's savannah sparrow and the light footed clapper rail suffered population declines with the loss and degradation of salt marsh. California least terns and western snowy plovers found sandy beaches crowded with humans and predators concentrated on the remaining nesting sites.

Despite difficulties, the list of birds that occur on the Bay is about the same length, with some extirpations and some newcomers. However, relative abundances have changed, and total abundances appear to have diminished from anecdotal historic accounts. Anecdotally, there has been a shift towards relatively more generalist species or those tolerant of human presence. Many species have recovered from overshooting, and efforts are being made to recover wetlands and correct pollution. When eggs of the brown pelican, osprey, white-faced ibis, and the double-crested cormorant were found to be thin-shelled and the species threatened by failure to reproduce, attention was brought to agricultural runoff and dichloro-diphenyl-trichloroethane (DDT), and these problems were subsequently corrected. Black brant now have an abundant eelgrass habitat. To determine why abundance is changing, a look at a species' whole range is necessary, and international cooperation required.

- When compared to midwinter populations of the SCB, the Bay provided habitat for more than half of the entire midwinter duck population. The majority of the regional surf scoter (72%) and brant (66%) populations were present in central and south Bay. Forty-four percent of the region's bufflehead population used central and south Bay in 1994, as did a similar percentage of scaup (US Fish and Wildlife Service 1995a).

More than 300 bird species have been documented to use the Bay (see Appendix D "Comprehensive Species List of San Diego Bay"). About 136 avian species that directly depend on the Bay are found within the footprint of this Plan. These species, and their status, distribution, and foraging needs in the Bay are described in Appendix E "Species and Their Habitats." The majority of Bay birds, representing 30 families, are migratory and may only stop to rest and feed, while others spend the winter or breed. Several are terrestrial birds of special concern or influence that are found about the Bay but may not directly depend upon it. Resident birds live and breed in the area year-round. Migrants that would not usually be in the area, disoriented in their travel, on the edges of their range, or simply looking for suitable habitat are regarded as vagrants. Although vagrants are not considered ordinarily dependent on the Bay, a considerable number of them pass through and visit each year.

- When compared to the 1994 winter waterbird population estimate of the Pacific Flyway and the State of California (Bartonek 1994), the Bay supported a substantial proportion of midwinter sea bird and waterbird populations. The Bay surf scoter population comprised over 40% of the state's midwinter population and about 25% of the entire Flyway's population. Thirty-one percent of the midwinter brant population was in central and south Bay.
- Fully one-third of birds dependent on San Diego Bay have been identified as sensitive or declining by the federal or state governments or by the Audubon Society.

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Habitat Partitioning

Habitat and foraging dependencies specific to San Diego Bay are, in general, only known in a broad sense and extrapolated from other locations. The use of various habitats by Bay-dependent birds is summarized in Appendix E "Species and Their Habitats." Figure 2-23 is a simplified view of foraging habitat partitioning by birds. However, whether birds actually use an available site is much more complicated. Factors such as habitat fragmentation, parcel size and connectivity, juxtaposition of other habitats, predator-prey relations, competition, disturbance, and species behavior patterns all affect a site's value and carrying capacity for birds. Although some habitats may not be used very often, they could be of importance for use by a species of a much larger area and array of habitats. An example is the availability of roosting structures with relatively low human disturbance near foraging areas. Ogden (1995) and US Fish and Wildlife Service (1995b) documented the use of various artificial structures around the Bay for roosts, and use of dikes at the Salt Works has also been noted (US Fish and Wildlife Service 1994a). Ogden (1994, 1995) showed a significant preference of many waterbirds and sea birds for shallow, nearshore areas compared to deeper water.

Important bird movement areas, such as crossover points between the Bay and ocean at Emory Cove and Delta Beach, have been identified (E. Copper, pers. comm.). USFWS (J. Manning, US Fish and Wildlife Service, pers. comm.) observed that brant geese established a movement corridor between beds of eelgrass in south Bay. For shorebirds, there is substantial movement between the Tijuana Estuary and the Bay, and between the agricultural fields of the Tijuana River Valley and the Bay.

Abundance, Distribution, and Biodiversity

Maps 2-8 and 2-9 depict relative abundance and biodiversity of birds based on three surveys conducted in 1993–1994. The first, sponsored by the Navy and conducted by Ogden Environmental and Energy Services (Ogden 1994, 1995), covered waterbirds of north and central Bay over the course of two years, 1993 and 1994. The second, conducted by the US Fish and Wildlife Service (1995a) surveyed waterbirds of south and central Bay. The third, also conducted by US Fish and Wildlife Service (1994a), covered birds of the Salt Works. For areas of overlap between surveys (both geographic overlap and types of birds surveyed), the mapping grids were merged and an average of the two surveys depicted. Table 2-20 compares the methods and

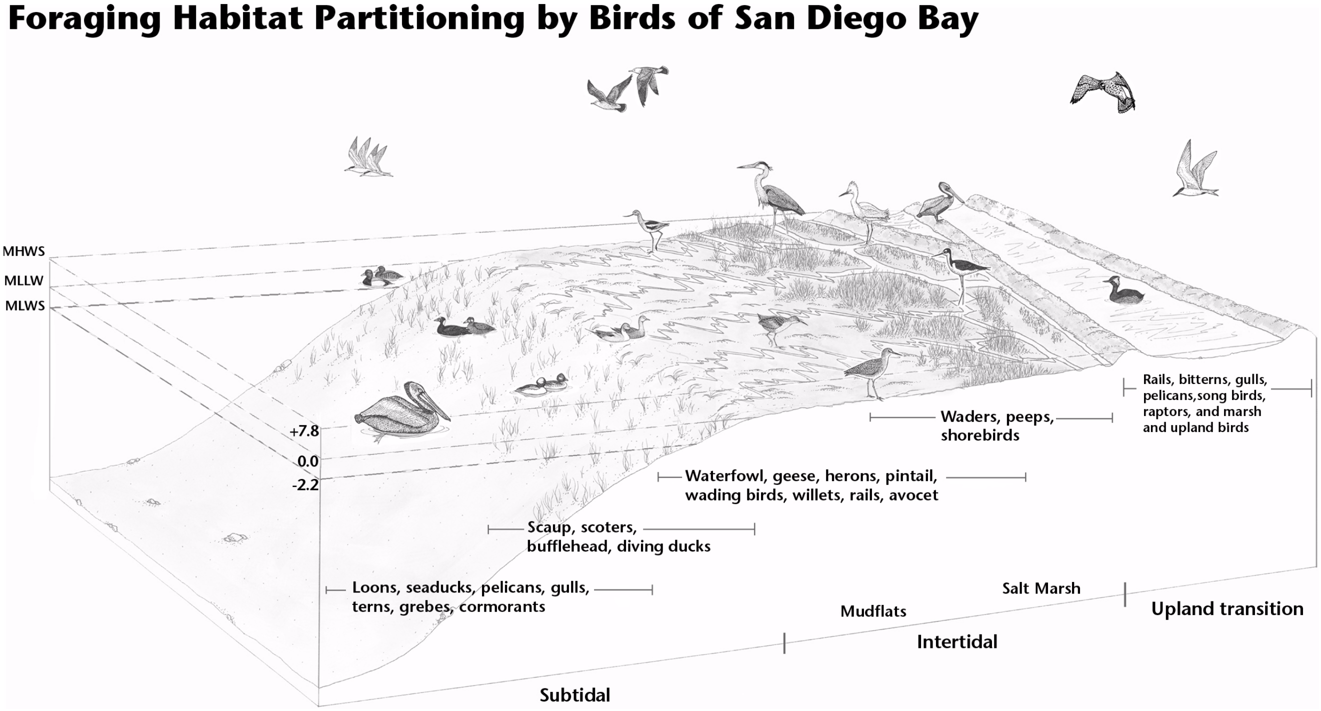


Figure 2-23. Foraging Habitat Partitioning by Birds of San Diego Bay. Dabbling Ducks Forage in Brackish Water, Unrelated to Tidal Elevation.

Table 2-20. Comparison of Three Concurrent Surveys of Bay Avifauna Conducted in 1993, and One 1994 Survey of Central Bay.

Survey	Location and Area Surveyed	Survey Period	Total Observations	Methods Summary
Ogden 1994	North and central Bay (3,937 acres [1,593 ha] in north Bay).	Jan. 1, 1993–Dec. 31, 1993	208,564	Performed 48 surveys for north Bay approximately once/week. Central Bay surveyed approximately once/month. Made observations during boat transects traveling 5 to 15 mph with stops. The Bay was stratified by grids into 1,000 ft (305 m) lengths across from shore to shore, then divided into depth categories (shallow, intermediate, deep), then further divided into marina, pier, and other shoreline categories. Did not identify most gulls and shorebirds to species.
US Fish and Wildlife Service 1995a	Central and south Bay, excluding Coronado Yacht Club, 7th St. Channel, Coronado Cays, and diked ponds of Salt Works.	April 15, 1993–April 14, 1994	149,553 (52,853 waterbirds in central Bay)	Performed 46 surveys approximately once/week totaling 350 field hours. Made observations from boat traveling 5 to 20 mph with 5 minute stops. Survey routes were 1,000 ft (305 m) widths. Staggered time of start at each location throughout the season. Observations recorded within a 500 ft (152 m) radius of the boat (18 acre [7 ha] circle). Did not record shorebirds, herons, egrets. Missed most ducks. Combined most gulls, terns, scaup, and western and Clark's grebe.
US Fish and Wildlife Service 1994a	Salt Works, Emory Cove, Marine Biological Study Area	Feb. 17, 1993–Feb. 2, 1994	522,553	Performed 52 surveys once/week. Biologists on foot covered four survey routes. Recorded tidal conditions at time of observation.
Ogden 1995	Central Bay (4,298 acres [1,739 ha]) of water and shoreline habitat.	Jan. 1, 1994–Dec. 31, 1994	181,488 total birds (126,008 waterbirds)	Performed 47 surveys approximately once/week totaling 290 field hours. Same methods as for Ogden 1994.

level of effort by the surveys. The surveys of north, central, and south Bay did not account for use by shorebirds. Dabbling ducks were under-represented in south Bay. Also, some terns and gulls were not identified to species.The biggest discrepancy between the Ogden and USFWS surveys in areas where they overlapped in central Bay was the difference in scoter and scaup counts (scoters 78,309 vs 32,929; scaup 13,976 vs 1,035 for Ogden and USFWS, respectively). These occurred in different years (US Fish and Wildlife Service 1993; Ogden 1994), which most significantly seemed to affect the scoter counts. Otherwise these differences may be at least partly due to survey coverage and method. Ogden surveyed both shore and open water areas, whereas USFWS surveyed primarily in open water and did not survey Glorietta Bay and Seventh Street Channel, known scaup concentration areas. Scaup were shown to prefer shoreline areas in Ogden's 1993 surveys. USFWS had less survey effort in central Bay, spending 350 total hours on central and south Bay together, while Ogden spent 290 hours in central Bay alone. Ogden did not limit the survey time for collecting data (typical survey time: six hours), whereas USFWS limited field effort to approximately four hours per survey. USFWS' counts at each point location (18 acre [7 ha] circle) were restricted to five minutes to minimize errors from bird movement. Ogden counted all individuals without any time restriction. Certain well-recognized bird concentration areas appear under-represented in Maps 2-8 and 2-9, such as off of Gunpowder Point and, on the west shore, off of Silver Strand State Beach (J. Coatsworth, San Diego Audubon Society, pers. comm.).

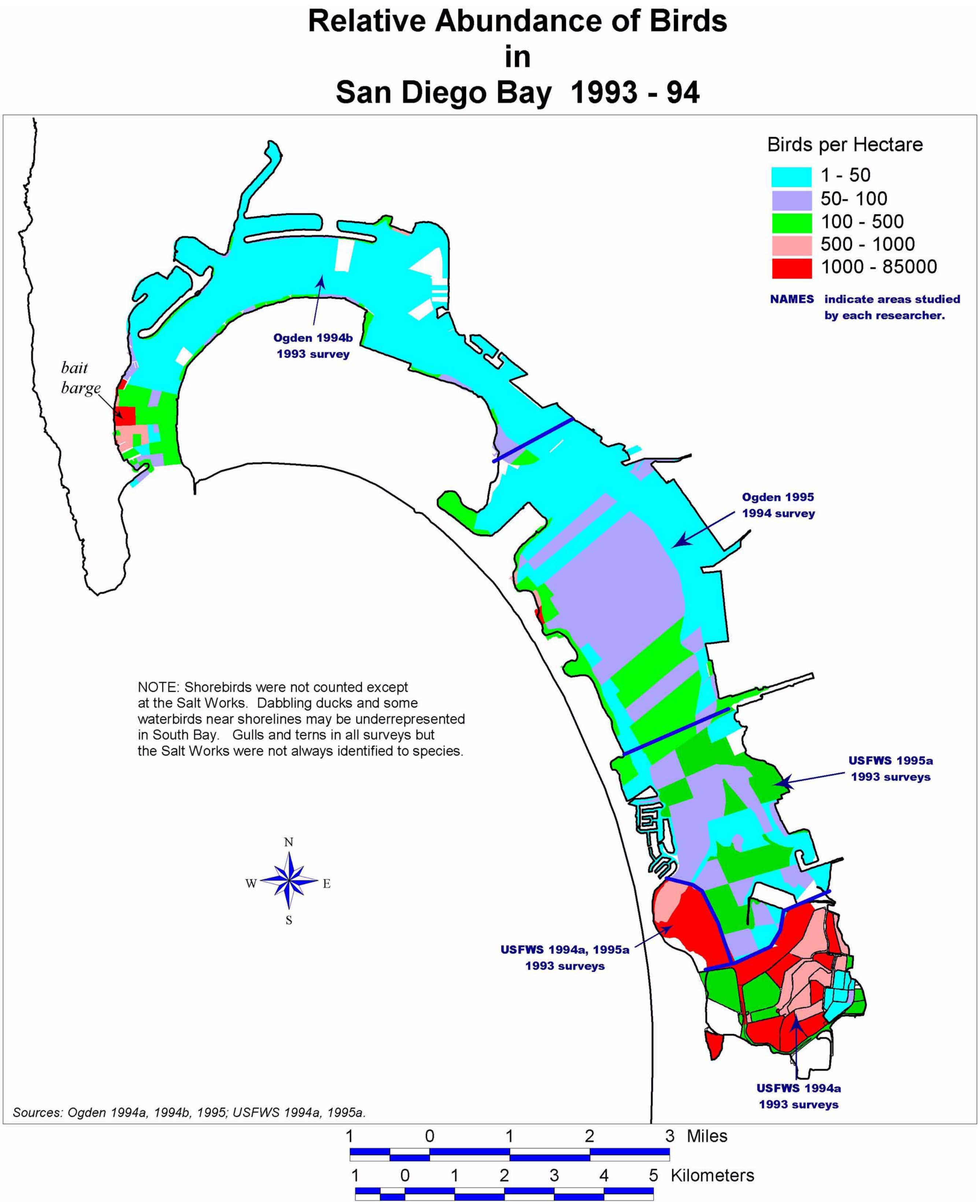
These separate surveys of avifauna of San Diego Bay in 1993–1994 resulted in an estimate of over seven million bird-use days per year, or an average of over 19,000 birds per day (with substantial peaks and lows), based on the average number of sightings during survey days (US Fish and Wildlife Service 1994b; Ogden 1995; US Fish and Wildlife Service 1995a).

In the SCB as a whole, bird numbers and biomass are highest in the winter, when high-latitude nesters stop in the area. A very different assemblage of waterbirds occurs on the Bay in spring and summer than in the winter when northern migrants dominate.

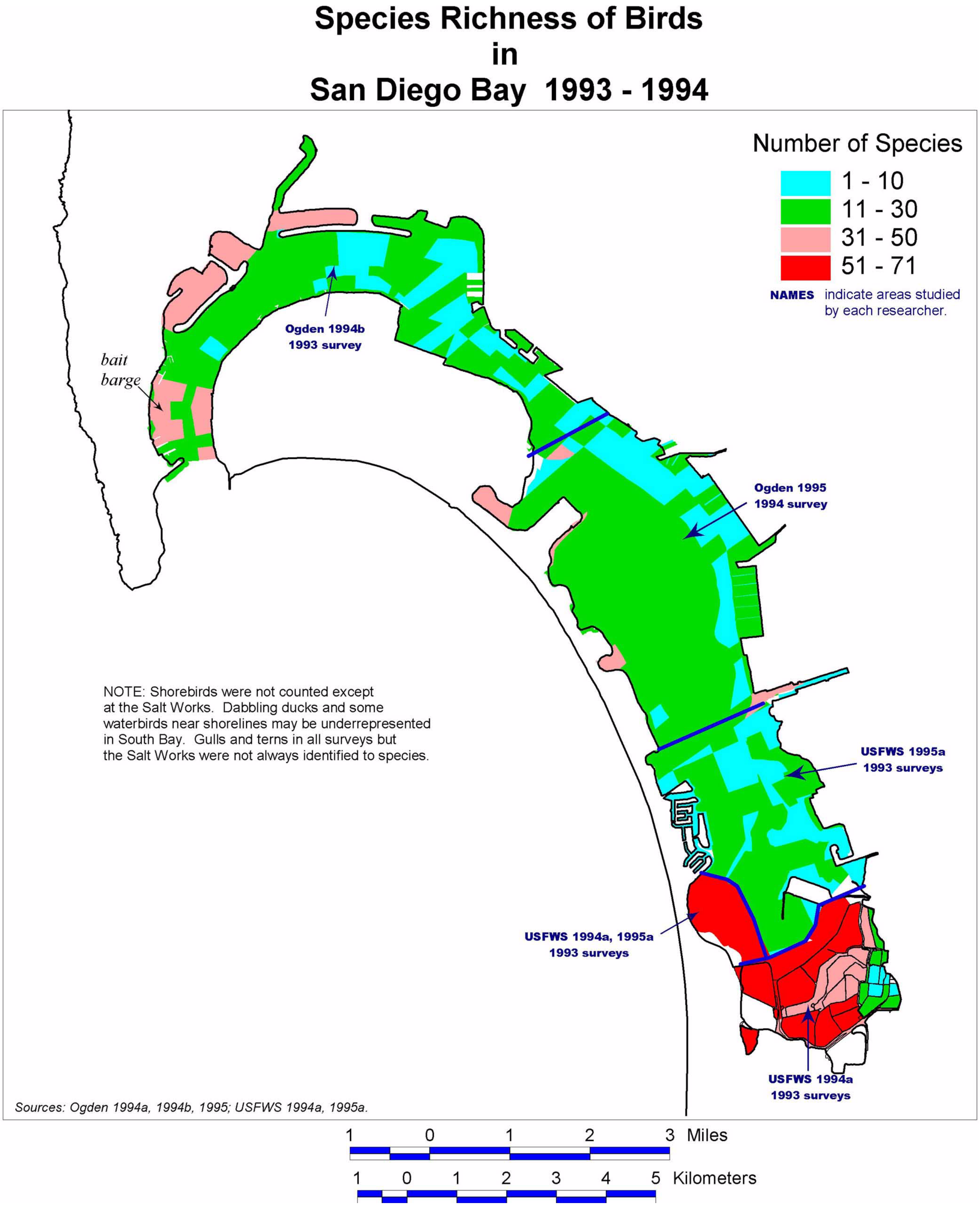
The three surveys all reported an abundance peak about December (November through February for central Bay by Ogden 1995), but in the Salt Works there was another peak in August due to the arrival of many red-necked phalaropes. Abundance peaks at the Salt Works in December were attributable to a great number of western sandpipers. All surveyors found a survey abundance low point around June.

In contrast to the December abundance peak, censuses conducted at the Tijuana Estuary (Kus and Ashfield 1989) and throughout the Pacific Flyway (Warnock *et al.* 1989; Page *et al.* 1990) have documented that the number of migratory waterbirds peaks in the fall and is an order of magnitude greater than the number present in the spring, by which time most birds have departed for breeding grounds.

Abundance summary tables from the three surveys are presented below under headings for each species group (Tables 2-21 through 2-24). The groupings of birds that follow are that of Baird (1993). Passerines and raptors are not discussed in detail because of their minimal dependence on the marine environment. Sensitive passerines and raptors are addressed in Section 2.6 "Sensitive Species," along with other sensitive species.



Map 2-8. Relative Abundance of Birds Based on Three Surveys Conducted in 1993–1994.



Map 2-9. Biodiversity of Birds Based on Three Surveys Conducted in 1993–1994.

Waterfowl (Ducks, Geese, Coots, Grebes)

Table 2-21. Cumulative Observations of the Most Abundant Waterfowl.[1]

Species	Number of Observations
Surf scoter	94,240
Eared grebe[2]	40,433
Scaup (lesser and greater)	36,688
Bufflehead	20,803
Brant	9,095
Western grebe	8,934
American wigeon	3,636
Ruddy duck	3,528
Mallard	3,000
Red-breasted merganser	1,738
Northern pintail	1,395
Northern shoveler	939

1. Based on surveys conducted in 1993 and 1994 covering all areas of the Bay (Ogden 1994 for North Bay, Ogden 1995 for Central Bay, US Fish and Wildlife Service 1995a for South Bay, US Fish and Wildlife Service 1994a for the Salt Works).

2. Observations made completely at the Salt Works by US Fish and Wildlife Service (1994a).

Most waterfowl nest in Canada and Alaska, visiting San Diego Bay during migratory stopovers. Waterfowl as a group have a range of diet preferences and foraging behaviors, with different species specializing in aquatic vegetation, aquatic invertebrates, grain, or molluscs and crustaceans. The red-breasted merganser (*Mergus serrator*), with saw teeth on the edges of its bill, which enable it to catch fish, is one of the few ducks specializing in eating fish.

Ogden (1994) found biodiversity in north Bay to peak in January. US Fish and Wildlife Service (1995a) found biodiversity of birds to peak in December to March in central and south Bay, and reach a low point in June and July. Ogden (1995) found a slightly later peak in biodiversity in February and March, with a similar low point in June in central Bay.

- The most abundant birds on the waters of San Diego Bay are surf scoters. They make greater use of deep water than any other waterfowl.

Surf scoters were found to be the most abundant birds on the Bay. They were the predominant species in both central and south Bay. They appear from the surveys to be more widely distributed and make greater use of deep water than other waterfowl. They seem to prefer nearshore areas along the shoreline of Naval Air Station North Island (NASNI) of north Bay and around Submarine Base (SUBASE). Surf scoter have been declining in San Diego Bay (Macdonald *et al.* 1990).

Diving ducks feed by diving from the surface and swimming underwater. Those dependent on the Bay include the greater scaup (*Aythya marila*) and, most abundantly, the lesser scaup (*Aythya affinis*), which primarily feeds on clams and snails, but also eats aquatic insects, crustaceans, and plants. Scaup also were relatively more abundant in central and south Bay. Scaup are more heavily dependent on south Bay than scoters and more restricted to the west side of central Bay. Scaup are absent from April to mid-November. They have also been declining in the Bay (Macdonald *et al.* 1990). The bufflehead feeds especially on the brine shrimp and brine fly larvae of Salt Works ponds.

- Black brant depend upon eelgrass beds for food, and sometimes sea lettuce.

During the 1993–1994 surveys (Ogden 1994; US Fish and Wildlife Service 1994a; Ogden 1995; US Fish and Wildlife Service 1995a), black brant were found to be relatively restricted to south Bay (USFWS' 6,929 cumulative observations and 2,166 at the Salt Works, compared to Ogden's 280 in central Bay and none in north Bay). Known areas for brant include off Delta beaches, Emory Cove, and the Otay River mouth, shores of Chula Vista Bayfront from the D-Street Fill south to F Street, and shallow waters between Chula Vista Marina and Emory Cove (E. Copper, pers. comm.). Brant depend on eelgrass for food and USFWS' observations of their distribution overlapped that of eelgrass beds. However, this species has been observed feeding on sea lettuce in the Bay (Moffitt 1938; Ogden 1994). Members of the family Anatidae typically have larger clutches than shorebirds and perhaps greater chance of recovery from impacts. A member of the same family, Canada geese (*Branta canadensis)* was more abundant historically than at present based on anecdotal accounts, but this species has also been recognized as declining on a regional basis.

The western grebe (*Aechmophorus occidentalis*) and Clark's grebe (*Aechmophorus clarkii*) winter in flocks and were relatively more abundant in north Bay. The eared grebe (*Podiceps nigricollis californicus)*, which feeds more on insects than other grebes, was more abundant at the Salt Works.

Dabbling ducks are concentrated at the mouths of the Sweetwater and Otay Rivers, J Street, the salt ponds, Shelter Island Yacht Basin, east and west basins of Harbor Island, Glorietta Bay the shoreline of NAB, and seasonal wetlands at NRRF. Their numbers are under-represented in the table above because surveyors in south Bay did not approach shoreline areas where these birds are known to concentrate (US Fish and Wildlife Service 1995a). They forage on aquatic plants at the water's surface or up-end with head and neck submerged and tail up, while finding food in the underwater mud. Several dabbling ducks have adaptations to their bills enabling them to strain planktonic food out of the water. Dabbling ducks on the Bay include the cinnamon teal (*Anas cyanoptera*) with a small local breeding population, the northern shoveler (*Anas clypeata*), the American wigeon (*Anas americana*), the gadwall (*Anas strepera*), the northern pintail (*Anas acuta*), the green-winged teal (*Anas crecca*), and the mallard (*Anas platyrhynchos*).

Shorebirds

Slender, long-legged shorebirds are seen primarily at the south end of the Bay. Peak abundance is in August during the fall migration (US Fish and Wildlife Service 1994b). Shorebirds can be hard to identify in the field, so often go uncensused. Most are migratory and they are highly mobile, adding to the surveying difficulty. Some areas around the Bay are predictable for seeing shorebirds at low tide, but high-tide refugia are as hard to predict as feeding areas. Their use of an area sometimes depends upon predator activities and human disturbance.

- Shorebirds are difficult to survey because they are migratory and highly mobile.

Shorebird abundances have been impacted by the loss of intertidal flats for foraging, as well as upland transitional areas for nesting. Shoreline stabilization and bulkheads can preclude intertidal habitats, from which shorebirds get most of their nutrition. Bird use at the Chula Vista Bayfront, examined over 1.5 years (Jones and Stokes Associates, Inc. 1988), was found to be highest where mudflat was the dominant habitat. Boland (1981) studied shorebird ecology of the Tijuana Estuary in 1980–1981. "The long-billed birds feed at their preferred tides with or without daylight and rest during unfavorable tides, while the short-billed birds feed all day, switching between tidal and nontidal habitats, and rest at night." The agricultural fields, riparian woodlands, and salt marshes of the Tijuana River Valley and Tijuana National Estuarine Sanctuary all lie a short distance to the south of

San Diego Bay, and casual observations indicate regular movement of shorebirds back and forth between these nesting and foraging areas (US Fish and Wildlife Service, in conversation, 1996, cited in US Fish and Wildlife Service 1998).

Table 2-22. Cumulative Observations of the Most Abundant Shorebirds.[1]

Species	Number of Observations
Western sandpiper	112,115
Red-necked phalarope	70,960
Peeps (western and least sandpipers undifferentiated)	45,884
Marbled godwit	32,099
Willet	28,073
Black-bellied plover	17,295
Dowitchers (long-billed and short-billed)	16,642
Black-necked stilt	14,864
Dunlin	9,671
Red knot	5,964
American avocet	5,935
Semipalmated plover	3,454
Killdeer	1,172
Sanderling	826

1. Based on 1993 Surveys by US Fish and Wildlife Service (1994a).

- The period of greatest competition among shorebirds for prey is midwinter.

Shorebirds normally redistribute themselves when feeding areas become scarce. However, when marshes and mudflats are as scarce and isolated as they are in southern California, and because only so much food is available, this normal redistribution may be impossible (Baird 1993). The removal of just a part of a feeding area may mean that the affected population will not be able to move to an already occupied habitat and, therefore, may move away from the area entirely. The period of greatest competition among shorebirds is midwinter (Quammen 1981, 1982, cited in Baird 1993). The reasons for this are that the actual prey biomass is lower (Baird *et al.* 1985), and the prey also make themselves less available by burrowing too deep or becoming less active. Greater minus tides in winter may partially offset this (Baird 1993). Choice of feeding location is influenced by soil resistance to mechanical probing, as well as prey density.

The largest family of shorebirds are the sandpipers. Western sandpiper is most abundant in the south Bay along with least sandpiper (*Calidris pusilla*). Curlews dependent on the Bay are the whimbrel (*Numenius phaeopus*) and long-billed curlew (*Numenius americanus*). The latter often moves with the marbled godwit (*Limosa fedora*), a large sandpiper that forages by wading deeply with its head underwater for molluscs and crustaceans. Godwits were among the larger shorebirds that were taken by market hunters in the early 1900s and are now declining with loss of habitat at their nesting grounds. Phalaropes are different than other sandpipers as they forage while swimming, spinning in circles to stir up crustaceans. Turnstones, so called for their foraging behavior, include ruddy turnstone (*Arenaria interpus*) and black turnstone (*Arenaria melancephala).* They may be seen on rocky sites favoring barnacles and limpets. Found more often on sandy beach than mudflats are sanderlings (*Calidris alba*), which chase the waves in search of sand crabs and other invertebrates.

Plovers find their food by sight and glean the ground with their short straight bills. Of the plovers, black-bellied (*Pluvialis squatarola*) is the most common. The semipalmated plover (*Charadrius semipalmatus*) was seriously depleted by overshooting in the 1900s; it is now recovered. The western snowy plover is a federally threatened species. The snowy plover prefers the open sandy beaches that are in high demand for human use in southern California.Killdeer (*Charadrius vociferus*) are common and widespread. Black-necked stilts use their needle-like bill to feed on brine shrimp and brine flies. American avocets (*Recurvirostra americana)* also feed on brine shrimp and flies by moving their upturned bill from side to side, stirring up the tiny invertebrates and quickly picking them out.

Shorebirds in decline on a regional basis include the American avocet, western snowy plover, and common snipe (*Capella gallinayo delicata*) (Baird 1993).

Sea Birds (Terns, Loons, Cormorants, Pelicans, Gulls)

Table 2-23. Cumulative Observations of the Most Abundant Sea Birds.[1]

Species	Number of Observations
Brown pelican	19,102
Elegant tern	16,823
Heerman's gull	16,090
Double-crested cormorant	15,772
Brandt's cormorant	12,789
Forster's tern	10,076
Western gull[2]	8,483
Black skimmer	5,702
Gulls (undifferentiated)	4,697
Caspian tern	3,795
California gull	3,608
California least tern	1,670
Terns (undifferentiated)	1,633
Bonaparte's gull	1,494
Common loon	351
Red-throated loon	186
Gull-billed tern	135

1. Based on surveys conducted in 1993 and 1994 covering all areas of the Bay (Ogden 1994 for North Bay, Ogden 1995 for Central Bay, US Fish and Wildlife Service 1995a for South Bay, US Fish and Wildlife Service 1994a for the Salt Works).

2. Observations made completely at the Salt Works by US Fish and Wildlife Service (1994a), resulting in what is expected to be a substantial under-representation in numbers.

- Diving species of sea birds prefer areas where certain processes maintain standing stocks of phytoplankton and an abundance of anchovies.

Sea birds spend at least a portion of their lives on or near offshore waters. Many of them are diving birds that pursue fish and other prey underwater. They most commonly eat fishes, squid, and crustaceans (Baird 1993). Diving species of sea birds predominate in areas where certain processes maintain standing stocks of phytoplankton, making the water turbid (Briggs and Chu1987). The northern anchovy is one of the most common prey items for sea birds of the Bight. Abundance of northern anchovy larvae is tied to these areas of concentrated phytoplankton off the coast, and the large numbers of dinoflagellates that are a component of the phytoplankton and serve as food for anchovy larvae (Baird 1993). Sea birds using the Bay are often foraging for schooling fishes such as anchovies.

The three 1993–1994 surveys show gulls, pelicans, cormorants, and loons all more abundant in north Bay compared to central and south Bay. Terns appear more abundant in north and central Bay compared to south Bay, probably due to increased foraging opportunities in these areas. Many sea birds use artificial hard structures for roosting, and Salt Works dikes for roosting and nesting.

- The brown pelican can be observed resting and foraging on subtidal lands.

The brown pelican uses subtidal waters for resting and foraging, as well as a staging area for fall migration. Juvenile pelicans use the Bay as a dispersal ground to find new territory.

Terns common in the Bay are elegant tern, Caspian tern, Forster's tern (*Sterna forsteri*), gull-billed tern, royal tern, and California least tern. With the exception of the gull-billed tern, they feed on small schooling fish such as anchovies and top smelt. Breeding colonies of Caspian, Forster's, elegant, a few royal terns, a few gull-billed terns, and black skimmer are found at the Salt Works. Elegant, Forster's, and royal terns especially, benefit when nesting close to the more aggressively protective Caspian terns (US Fish and Wildlife Service 1994a). Predation by gulls, the peregrine falcon (*Falco peregrinus anatum)*, and terrestrial nonnative predators such as dogs and cats often reduce their reproductive success as well as that of the black skimmer.

The double-crested cormorant may be found throughout the Bay on docks, jetties, pilings, and boats where the opportunity to roost is available. While Brandt's cormorant (*Phalacrocorax penicillatus*) is seen over Bay waters, it is typically on the ocean side, where it can take advantage of deep water for power dives up to 150 ft (46 m) below the surface for fish.

- The western gull is the only resident breeding gull on the Bay. They eat almost anything, enabling them to adapt to habitat impacts.

The 1993–1994 Bay bird surveys as a group probably greatly underestimate the importance of gulls, since they generally were only well documented at the Salt Works. Gulls dependent on the Bay include western (*Larus occidentalis*), ring-billed (*Larus delawarensis*), Heerman's (*Larus heermanni*), California (*Larus californicus*), Bonaparte's (*Larus philadelphia*), glaucous winged (*Larus glaucescens*), herring (*Larus argentatus*), and mew (*Larus canus*). The western gull is the only resident breeder. Seen abundantly throughout the Bay, this bird will eat almost anything, including fish, crustaceans, molluscs, echinoderms, small birds and eggs, carrion, garbage, and offal. Western gulls are known to nest around other nesting colonies, preying on eggs and chicks. The gulls' ability to consume a wide variety of foods gives them a greater flexibility; if one food source is impacted they may adjust their diet or move to another area. They help keep beach areas clean of edible garbage and cycle waste back into the nutrient cycle.

Loons find their food by diving under water. The common loon (*Gavia immer*) feeds mostly on fish in the winter, usually in shallow waters by itself. At night the common loon may gather in loose flocks.

- Some sea birds of the Bight are declining in numbers.

Sea birds identified as declining in numbers in the Bight include Caspian, Forster's, elegant, and royal terns (Baird 1993).

Marsh Birds (Herons, Rails, Egrets)

Marsh birds were not targeted in the three 1993 surveys of San Diego Bay, but herons and egrets are fairly visible and broadly distributed compared to other marsh birds, so any observations were recorded and are presented in Table 2-24.

Table 2-24. Cumulative Observations of Herons and Egrets.[1]

Species	Number of Observations
Great blue heron	2,716
Snowy egret[2]	2,015
Great egret	810
Black-crowned night heron	54

1. Based on surveys conducted in 1993 and 1994 covering all areas of the Bay (Ogden 1994 for North Bay, Ogden 1995 for Central Bay, US Fish and Wildlife Service 1995a for South Bay, US Fish and Wildlife Service 1994a for the Salt Works).

2. Observations made completely at the Salt Works.

- Egrets and herons feed on fish, crayfish, amphibians, and snakes, as well as terrestrial rodents, lizards, and insects. Rails consume decapods, molluscs, aquatic insects, beetles, snails, spiders, and crustaceans.

Marsh birds are relatively scarce in southern California compared to other parts of the world because of the paucity of suitable habitat (Baird 1993). Feeding habits are not well known, and are based on general accounts from California. Egrets and herons feed on a variable mix of fish, crayfish, amphibians, snakes, terrestrial rodents, lizards, and insects. The black-crowned night heron (*Nycticorax nycticorax hoactli*) feeds mostly at night, feeding its young shrimp and fish, but adults have a broader diet of terrestrial rodents, amphibians, aquatic insects, and crustaceans. Rails consume decapods (shrimp, crayfish, crabs), small molluscs, aquatic insects, beetles, snails, spiders, and crustaceans.

Marsh birds often fly a short distance inland to roost and nest in groves of trees, but return to the marsh every day to feed. Heron rookeries are known to exist at NASNI, SUBASE, and NAVSTA.

Marsh birds that are reportedly declining in numbers in the Bight include the great blue heron (*Ardea herodias*), light footed clapper rail, Virginia rail (*Rallus limicola limicola)*, and black rail (*Laterallus jamaicensis coturniculus)* (Baird 1993). The tiny black rail is now extirpated from the Bay, which was the lower end of its range.

Reproductive Ecology

San Diego Bay and the Bight are relatively unimportant as breeding areas for most migratory waterbirds. Also, few shorebirds breed in southern California, but exceptions are American avocet, black-necked stilt, snowy plover, least and spotted sandpiper (*Tringa macularia)*, willet (*Catoptrophorus semipalmatus inornatus)*, and black oystercatcher (*Haematopus bachmani*). The proportion of nesting species overall is also quite small in southern California compared to northern and central California (Briggs and Chu1987).

- Sea birds that breed completely within southern California are the California least tern, brown pelican, black storm-petrel, and Xantus' murrelet.

Most sea birds migrate north or south to breed. Exceptions that breed completely within southern California are the California least tern, black storm-petrel (*Oceanodroma melania)*, and Xantus' murrelet. San Diego Bay breeding grounds for sea birds and shorebirds include NASNI, Silver Strand, NAB, Salt Works, and SMNWR. Western Salt Works is a significant breeding ground for colonial nesting sea birds (US Fish and Wildlife Service 1993).

A summary of what has been documented about nesting or breeding birds is shown in Table 2-25.

Table 2-25. Nesting/Breeding Areas of Bay Birds (and Number of Nests or Pairs Where Reported).[1]

Species	Breeding Area Record
Double-crested cormorant	Salt Works 1987, 1993 (53 nests), 1997 (49 nests), 1998 (34 nests), 1999 (80 nests)
Brandt's cormorant	San Diego Bay side of Point Loma (artificial structure)
Great blue heron	NASNI 1997 (31 nests), 1999 (22 nests), NAVSTA, SUBASE
Black-crowned night heron	NASNI 1997 (164 nests), 1999 (166 nests), NAVSTA, SUBASE
Little blue heron	San Diego Bay
Great egret	NASNI
Snowy egret	NASNI 1997 (52 nests), 1999 (37 nests)
Osprey	San Diego Bay in 1912, NASNI 1998
Peregrine Falcon	Coronado Bay Bridge, National City, Point Loma
Northern pintail	Salt Works
Western gull	North San Diego Bay (artificial structures) (large numbers), south San Diego Bay (smaller numbers)
Black skimmer	Salt Works 1976, 1988 (200 pairs), 1993 (473 nests), 1994 (310 pairs), 1997 (460 pairs), 1998 (472 nests), 1999 (395 nests)
Brown pelican	Point Loma National Monument
Gull-billed tern	Salt Works first confirmed in 1987 (3 pairs), 1988 (5 pairs), 1989 (6 pairs), 1990 (10 pairs), 1991 (27 pairs, 30 nests), 1992 (30 pairs), 1993 (10 pairs, 11 nests), 1994 (9 pairs), 1995 (10 pairs), 1997 (8 pairs), 1998 (14 nests), 1999 (29 nests)
Caspian tern	Salt Works 1941 (78 pairs), 1953 (100 nests), 1965 (382 nests), 1966 (351 nests), early 1980s (400 to 450 pairs), 1993 (382 nests), 1994 (320 pairs), 1997 (300 pairs), 1998 (331 nests), 1999 (281 nests); Zuniga jetty (1998 attempted)
Royal tern	Salt Works 1959 (1 nest), 1991 (2 pairs), 1993 (13 nests), 1994 (0 nests), 1997 (2 nests), 1998 (0 nests), 1999 (35 nests)
Elegant tern	Salt Works 1959 (31 nests) 1981 (861 nests), 1990 (0 nests), 1991 (250 pairs), 1993 (511 nests), 1994 (80 pairs), 1997 (2 nests), 1998 (104 nests), 1999 (3100 nests); Zuniga jetty (1998 attempted)
Forster's tern	Salt Works 1993 (510 nests), 1997 (520 nests), 1998 (225 nests), 1999 (174 nests); CVWR 1998 (46 nests), 1999 (121 nests)
California least tern	Pairs reported 1997: Lindbergh Field (102), NASNI (27), North Delta Beach (310), South Delta Beach (15), SMNWR (38), Salt Works (36); Salt Works 1992 (16 nests), 1994 (65 nests), 1995 (24 nests), 1996 (29 nests), 1997 (49 nests), 1998 (42 nests), 1999 (25 nests)
Black-necked stilts	Salt Works 1999 (57 nests)
American avocet	Salt Works 1999 (26 nests)
Cinnamon teal	San Diego Bay
Killdeer	Many locations
Western snowy plover	Beaches and uplands adjacent to Bay, Salt Works 1977 (20 nests), 1981 (16), 1993 (9 nests, 7 pairs), 1994 (1 nest), 1995 (0 nests), 1996 (1 nest), 1997 (4 nests), 1998 (3 nests), 1999 (0 nests); CVWR 1998 (1 nest); throughout Bay 1997 (64 nests)
Burrowing owl	Disturbed uplands on NASNI, NRRF, NAB, Imperial Beach Outlying Landing Field
Belding's savannah sparrow	San Diego Bay 1977 (199 pairs), 1988 (230 pairs); 1996 (17 pairs at Salt Works, 31 pairs at Emory Cove, total pairs unknown)
Loggerhead shrike	Terrestrial uplands around San Diego Bay

1. Data compiled primarily by US Fish and Wildlife Service (1993), San Diego Natural History Museum (1998), and Patton 1999.

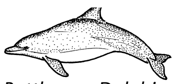
Effects of Human Activities

Many Bay-dependent birds are in decline. Some suspected declines in San Diego Bay include the goldeneye, lesser scaup, surf scoter, red knot (*Calidris canutus roselaari*), Bonaparte's gull, dabbling ducks, and nesting by elegant terns (E. Copper, pers. comm.). Scaup throughout California are 36% below the long-term average statewide (California Waterfowl Association 1998). Scoter nesting populations have declined in Alaska in recent decades perhaps due to contaminants (Henny *et al.* 1990). The most common reason attributed to declines is habitat loss. While the Bay's habitat losses are similar to those of other bays, this complicates an assessment of local declines versus those due to regional or more distant causes.

Most dabblers (northern shoveler, American wigeon, gadwall, northern pintail, green-winged teal, cinnamon teal, and mallard) are at or above North American Waterfowl Management Plan population goals. They can use freshwater wetlands as alternate locations, so they are somewhat more flexible than other species. Numerically increasing birds include the more generalist species and those tolerant of human disturbance such as the western gull, common raven (*Corvus corax clarionensis)*, American crow (*Corvus brachyrhynchos hesperis*), and cattle egret (*Bubulcus ibis ibis)*.

Shrinking habitat locally, regionally, and along the entire Pacific Flyway is probably the most important issue to survival of many birds dependent on the Bay. It results in overcrowding, stress, competition, poor nutrition, and increased mortality.

2.5.6 Marine Mammals



Coastal Bottlenose Dolphin

Marine mammals include those mammals that spend the majority of their lives at sea and are almost totally dependent on marine organisms for food. Common examples include seals, sea lions, dolphins, and whales. These mammals fall into the orders Carnivora (suborder Pinnipedia) and Cetacea. Food is variable, from plankton for filter-feeders, to benthic invertebrates of soft bottom areas for the gray whale, to fishes and squid for carnivores such as dolphins.

In San Diego Bay, two pinniped species occur: California sea lion and the Pacific harbor seal (*Phoca vitulina)*. Pinnipeds are carnivores with both front and rear appendages in the form of flippers best suited for swimming, but also allowing limited locomotion on land. Annual pup counts for this group contain anomalously low years that seem to be correlated with El Niño events. The hypothesis is that the displacement of food fish species during calving/lactation periods causes a high pup mortality and/or lowered pupping levels.

Cetaceans are those marine mammals that possess a "blowhole," flippers as anterior swimming appendages, and horizontal flukes as posterior swimming appendages. They live their entire lives in the water column, with occasional strandings (cetaceans washed up on the beach). San Diego Bay is presently not a common habitat for these whales and dolphins, except for the coastal bottlenose dolphin.

2.5.6.1 Mammals of Interest

Although 39 marine mammal species may be encountered in the Bight, only a handful are species of interest to San Diego Bay (Bonnell and Dailey 1993). Since no surveys of marine mammals have been performed in the Bay, their relative occurrence was estimated for this Plan from interviews with marine mammal experts in the area (S. Ridgeway, Space and Naval Warfare Command, pers. comm.; R. Defran, San Diego State University, pers. comm.; J. Barlow and J. Cordaro, National Marine Fisheries Service, pers. comm.; M. Fluharty, California Department of Fish and Game, pers. comm.). Occurrence or probability of occurrence can be categorized into three levels:

Species known to be regularly encountered within the Bay

- California sea lion
- coastal bottlenose dolphin

Species that are occasional-to-frequent visitors to the north channels of the Bay

- Pacific harbor seal
- gray whale

Species that are found in the Southern California Bight, with potential for isolated occurrence in San Diego Bay

- northern elephant seal
- long-beaked common dolphin
- Pacific white-sided dolphin
- short-finned pilot whale
- minke whale
- finback whale

2.5.6.2 Historical Changes in the Bay

Gray whales were historically common in the Bay, but are no longer (Scammon 1874). Whaling for gray whales began offshore of California in the 1840s, and probably within the Bay around the same time (Leet *et al.* 1992). San Diego Bay peaked as a whaling center from 1850–1870, but declined by the 1890s. With waterfront development, shipping traffic, and increasing pollution levels, the Bay was no longer a hospitable environment for gray whale calving in the early 20th century. Today, however, gray whales occasionally visit the Bay, especially during their northward migration in the spring (S. Ridgeway, pers. comm.).

- "San Diego Bay Grampus," now called Risso's dolphin, was a common marine mammal in the Bay during the 1870s.

Risso's dolphin (*Grampus griseus*) was another historical inhabitant of the Bay (Scammon 1874). In fact, this species was originally called the "San Diego Bay Grampus" by Scammon in the 1870s, who observed them "passing into and out of the estuaries connecting with the main lagoon" and ascending the estuaries to feed on fish (Scammon 1874). Estuaries at the mouths of tributaries are no longer a dominant feature of the Bay due to urbanization, with only Sweetwater and Otay Rivers retaining some estuarine behavior in their altered states. Today there are no identified dolphins of this species in the Bay. They are now most commonly found in deep water habitat with warm temperate to tropical water conditions (Leet *et al.* 1992). Only the coastal bottlenose dolphin appears to be a regular cetacean inhabitant.

The Bay probably never supported a breeding colony of harbor seals or sea lions due to beach access by land predators. The populations of these animals have likely fluctuated in San Diego Bay over the past two centuries in response to cycles of human pressures. Many pinnipeds were killed in California during the 1860s and 1870s for their oil or body parts, and many females were captured for displays or animals acts (Leet *et al.* 1992). Until California law in 1938 gave them complete protection from hunting, pinnipeds were hunted commercially. Sport and commercial fishermen were allowed to kill sea lions and harbor seals for interfering with their operations, until the 1972 Marine Mammal Protection Act (MMPA).

2.5.6.3 Ecological Roles in the Bay

Ecologically, the marine mammals occurring in or near San Diego Bay are high-order carnivores. With few exceptions, all derive their sustenance from several prey species, often with seasonal or spatial dynamics facilitating variations in prey abundance, partitioning of resources, and/or special nutritional requirements (pregnancy or lactation). This combination of food-related characteristics causes a great deal of complexity in both the specific contribution of each prey resource and the effect of this predation on each prey species population.

Examples of specific prey found in the Bay are listed under individual marine mammal species accounts that follow.

2.5.6.4 Species Accounts

Descriptions follow about each species' occurrence, status, and their ecological contribution to the Bay. The rare species listed above are not described due to their low abundance in the Bay. Where possible, specific examples are given regarding the species in San Diego Bay.

California sea lion—*Zalophus californianus californianus*

Occurrence. California sea lions inhabit the entire western coast of North America from central Mexico through the Canadian coastline. These animals are most abundant in the Bight area during the May to July breeding period. The majority of the west coast population is in the Bight since most sea lions breed at the Channel Islands. This species is commonly seen in San Diego Bay.

- Sea lions are most easily seen in the Bay at their resting spots on rocks, buoys, and sometimes piers. They likely feed on octopus, shark, and fish within the Bay.

Sea lions seek a variety of structures, such as rocks, piers, and buoys, for "hauling out" or resting periods in the Bay. These behaviors can be destructive to structures due to the weight of the animal and due to fouling (M. Fluharty, pers. comm.). If sea lions find an easy food source at tourist spots or fishing piers, their presence can become a nuisance at certain areas in the Bay, as they have at marinas in Monterey and San Francisco Bay (Leet *et al.* 1992). Marina operators and commercial and sport fishermen tend to consider them a major nuisance, leading to some human-caused mortality.

Status. The Bight includes the southernmost breeding area for the "US stock" (as opposed to the separate "western Baja California stock") and is estimated to be near 180,000 animals. During 1994, a minimum of 84,195 sea lions were counted at rookeries and haul out sites, while more than 90,000 sea lions were recently estimated for the Bight (Barlow *et al.* 1994; National Marine Fisheries Service 1997a). Until the El Niño events of 1983, 1992, and 1997–1998, the populations were on the increase. The El Niño years cause a cyclical decrease in the food supply and a resulting decline in reproductive success and survival of sea lions. Fishery-related mortality of roughly 2,000 per year is declining and is substantially below the NMFS "Potential Biological Removal" (PBR), or allowable take level of 6,680. There is little concern at present about sustaining this species' population, particularly since the closure of set gillnet fisheries in the region (National Marine Fisheries Service 1997b). No estimate has been made of the California sea lion population in San Diego Bay.

Ecological contribution to San Diego Bay. California sea lions' food consists of squid, octopus, and a variety of fishes. While no studies have occurred of their diet in the Bay, studies of food sources have been done in other California coastal areas (Antonelis *et al.* 1987; Lowry *et al.* 1987; Melin *et al.* 1993; Hanni and Long 1995; Henry *et al.* 1995). Fish species found in the Bay that sea lions most likely feed on include spiny dogfish, jack mackerel, Pacific herring, Pacific sardine, and northern anchovy. They also eat octopus and leopard shark.

Coastal bottlenose dolphin—*Tursiops truncatus*

Occurrence. These animals occur worldwide and their distribution and even taxonomy is still being resolved (Leatherwood and Reeves 1990). California contains coastal and offshore populations that the NMFS is currently managing as separate stocks (National Marine Fisheries Service 1997b).

The coastal stock population is found within 0.6 mi (1 km) of shore and generally distributed from Point Conception through Ensenada, Mexico. These dolphins have been studied by R. H. Defran at SDSU since 1982, but mostly from the Scripps pier northward (Defran *et al.* 1986; Hanson and Defran 1993). El Niño events seem to severely displace certain members of the population northward making it extremely difficult to account for them.

Status. While no studies have occurred of this species in San Diego Bay, they are observed almost every day, at least at the northern portion. US management of the coastal stock is conservatively based on the average number of 140 animals. In comparison, the offshore stock's abundance estimate is 2,555 animals. No trend in abundance is apparent based on the available data, but Defran believes the population is stable. While the stock has a PBR of only 1.3 animals per year, the removal of set gillnet fisheries in California in 1994 has reduced human-caused mortality (National Marine Fisheries Service 1997b). However, pollutant levels (especially DDT residues) measured in southern California coastal bottlenose dolphins were among the highest of any cetacean examined in the 1980s, with a new pollutant evaluation presently underway (Schafer *et al.* 1984; J. Heyning, Los Angeles County Museum of Natural History, pers. comm.). While not well understood, the effects of such pollutants may suppress reproduction or make the species more susceptible to other mortality factors. The contribution of San Diego Bay to supporting this stock's abundance is unknown. The small population is vulnerable to disease, oil spills, or other dramatic events, but the dolphin's main protection is the extensive distribution of their numbers.

Ecological contribution to San Diego Bay. Specific prey items of bottlenose dolphins along the California coast were studied by Defran *et al.* (1986). San Diego Bay bottlenose dolphins forage on species such as jack mackerel, Cortez grunt, striped mullet, black croaker, white seabass, white croaker, spotted croaker, yellowfin croaker, California corvina, queenfish, Pacific mackerel, Pacific bonito, and sierra.

Pacific harbor seal—*Phoca vitulina richardsi*

Occurrence. These animals range from Alaska to Baja California, but only 14% are found south of Alaska (Bonnell and Dailey 1993). As the name implies, harbor seals prefer inshore waters, being especially fond of protected inlets and embayments. They are observed in San Diego Bay on an occasional basis (S. Ridgeway, pers. comm.). In the Bight, they are most abundant during the peak haul out period (May to July) on the Channel Islands but are also encountered year-round (Stewart 1984; Bonnell and Dailey 1993). When the Spanish Bight still existed, it was a haul out area for harbor seals when sand islets were exposed at low tides (J. Coatsworth, pers. comm.).

Besides the Channel Islands and the Coronados Islands in Mexico, haul out sites include scattered intertidal sand bars, rocky shores, and beaches. A colony of harbor seals has created a nuisance at Children's Pool in La Jolla, where the animal's feces have contaminated a popular beach (M. Fluharty, pers. comm.).

- Pacific harbor seals have a stable status in the region and likely visit the Bay to feed on octopus and various fishes.

Status. During the 19th century, this species was subjected to commercial hunting pressure and the population level of the extant stock was probably reduced to a few hundred individuals (Barlow *et al.* 1995). A 1995 estimate of the "California" stock of harbor seals was approximately 30,000, and the trend seems to be toward a slow increase except during El Niño years. The PBR for this stock is 1,678, with fishery mortality on the decline since gillnet fishery closures in 1994 (National Marine Fisheries Service 1997b).

Ecological contribution to San Diego Bay. Harbor seals prefer sheltered coastal waters and feed on schooling benthic and epibenthic fish species in shallow water (Bonnell and Dailey 1993). While not studied in the Bay, specific prey species have been studied in other California waters (Stewart and Yokem 1985; Oxman 1993; Torok and Harvey 1993; Stewart and Yokem 1994; Henry *et al.* 1995). Of particular note to San Diego Bay are these potential prey species: specklefin midshipman, plainfin midshipman, jack mackerel, shiner surfperch, yellowfin goby, and English sole. Harbor seals also really like to eat octopus, of which two species are found in the Bay (R. Ford, pers. comm.). Although their ecological niche in the Bay has not been studied, pinnipeds are not likely to play a significant role (B. Stewart, Hubbs-Sea World Research Institute, pers. comm.) because of their low numbers. No habitat issues are known to be of particular relevance for this California stock (National Marine Fisheries Service 1997b).

■ Gray whales occasionally visit the north Bay.

Gray whale—*Eschrichtius robustus*

Occurrence. Before the 1870s, gray whales inhabited San Diego Bay during their winter calving season (Scammon 1874). Calving now occurs in shallow bays and lagoons of northern Baja California from early January to mid–February (Rice and Wolman 1971). They pass by the Bay during their north bound (spring) and south bound (fall) migrations between Mexico and Alaska, though the majority follow an offshore instead of a nearshore route in the Bight region (Rice *et al.* 1984). However, they are occasionally seen in the north Bay, particularly during their northward migration (S. Ridgeway, pers. comm.).

Status. Today, the eastern North Pacific stock of gray whales is estimated to number about 23,000 animals, with its PBR determined to be 434 animals per year. Current population trend shows an annual increase of about 2 to 3%. Since 1994, the species is no longer listed as endangered or threatened under the federal Endangered Species Act (ESA) (Small and DeMaster 1995).

Ecological contribution to San Diego Bay. Gray whales use their baleen to sift out crustaceans, molluscs, and other invertebrates, which they suck from bottom sediments. Bay species of potential benefit to gray whales for food would include medium to large size bivalve molluscs and decapod crustaceans, depending on the spacing between the baleen elements (R. Ford, pers. comm.). However, they are unlikely to be feeding in the Bay.

2.5.7 Exotic Marine and Coastal Species

The invasion of exotic species is one of the most serious threats to the integrity of San Diego's coastal ecosystems (Zedler 1992a; Crooks 1997). Such animals and plants are also variously referred to as nonnative, alien, introduced, or nonindigenous species. Within the Plan's "footprint" are a surprising number of nonindigenous species of marine, coastal, and nonmarine origins. In San Diego County, the rate of newly found alien marine species is rapidly expanding, as shown in Figure 2-24 (Crooks 1997). Lambert and Lambert (1998) also noted the recent rapid increase of nonindigenous tunicates in southern California harbors and marinas.

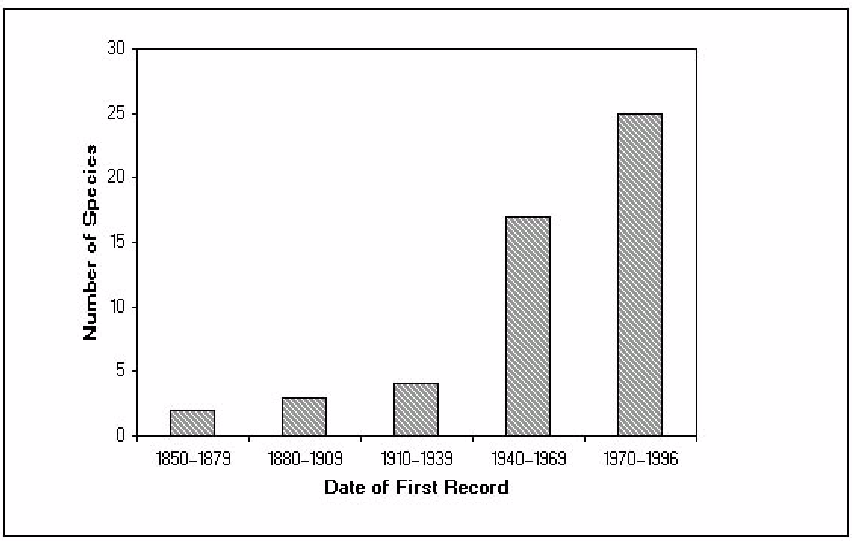


Figure 2-24. First Records of Marine Non-native Species in San Diego Bay.

2.5.7.1 History and Background

The first introduction of nonnative marine species into San Diego Bay could have come from the ships used by the early Spanish explorers, as they were commonly riddled with shipworms, gribbles, and other fouling organisms. A fouling organism is an invertebrate, such as a barnacle or a shipworm, that bores into or encrusts on submerged surfaces such as boats or pilings. However, we will never know which species, if any, arrived during the explorer period. Some exotics have been around for so long that they were assumed to be natives until recent genetic analyses proved otherwise (Crooks 1996; J. Crooks, Scripps Institute of Oceanography, pers. comm.; A. Cohen, Scripps Institute of Oceanography, pers. comm.). In addition, advancements in genetics are rapidly changing the taxonomy of marine species and making it more challenging to develop an up-to-date, accurate inventory of species with which to determine what is alien or not.

No comprehensive surveys have evaluated the scope or impact of nonindigenous species in San Diego Bay. Only one study has apparently been performed to evaluate the status of one group of exotic marine organisms in southern California (Lambert and Lambert 1998). Two studies on the San Francisco Bay and Delta estuary have described the known impacts of introduced species (California Department of Fish and Game 1994; Cohen and Carlton 1995). This estuary has been invaded by at least 234 nonnatives, with over 100 different species of aquatic invertebrates alone. A new species moves in every twelve weeks and some say it is the most invaded ecosystem in the world (DeSena 1997). Its ecosystem is seriously suffering from impacts of the more successful invasive species, such as the Chinese mitten crab and Asian clam (Miller *et al.* 1998; Veldhuizen and Hieb 1998). More than a few of San Francisco Bay's nonnative marine species, but not these two, are also located in San Diego Bay, with others having a high potential to arrive here soon, as noted later in this section. The introduced green crab (*Carcinus maenus)*, for example, has spread into central California from San Francisco Bay (Grosholz and Ruiz 1995).

2.5.7.2 Species of Interest

Few articles have been published on nonindigenous species in San Diego Bay, and those report primarily on just a few species. Local marine biologists were consulted in the compilation of the following lists (J. Crooks and L. Levin, Scripps Institute of Oceanography; S. Williams, San Diego State University; R. Ford, San Diego State University emeritus; G. Williams, Pacific Estuarine Research Laboratory-San Diego State University; A. Cohen, San Francisco Estuary Institute). Table 2-26 lists marine algae and coastal plants, while Table 2-27 includes animals. For many species, little information is known, so not all of the categories can be completed in the tables at this time. A current estimate of the number of exotic marine species in the Bay includes one species of marine algae, one marine protozoan, 47 marine invertebrates, and five marine fish. There are also 28 species of alien coastal plants. In total, at least 82 nonindigenous species are found in the Bay's planning zone.

- As noted from the tables, not all are invasive or causing problems.

The nonnative marine species are found in benthic, fouling, and water column habitats. Coastal plant exotics are found in sand dunes, mudflats, salt marshes, riparian zones, filled wetland sites, upland transition zones, and restoration sites (Zedler 1992a). As noted from the tables, not all are invasive or causing problems, at least not at this time.

Nonmarine exotic species found on the edge of San Diego Bay include rats, house mice, European starlings, house sparrows, opossum, and cats. These upland species are not discussed in this section. Those that prey on birds and sensitive species are discussed under those topics.

Table 2-26. Exotic Marine Algae and Coastal Plants at San Diego Bay.[1]

Species	Habitat Problems or Effects	Comments
Marine Algae		
Sargassum muticum	Conspicuous in shallow water where large plants grow near docks and piers, spreads rapidly and interferes with boating.	Probably introduced on Japanese oysters in Puget Sound in 1930s. Intensive eradication program in England has not succeeded (Dawson and Foster 1982); location in Bay unknown.
Coastal Plants		
Sea fig (*Carpobrotus* [*Mesembryanthemum*] *chilensis*)	Invades disturbed sites; major pest in sandy sites.	From South Africa. @ SMNWR.
Hottentot fig (*Carpobrotus edulis*)	Invades disturbed sites; major pest in sandy sites.	From South Africa. @ SMNWR.
Iceplant (*Mesembryanthemum crystallinum*)	Invades coastal strand, dunes, salt marsh.	Eradication difficult; needs continual maintenance.
Slender-leaved or Little iceplant (*Mesembryanthemum nodiflorum*)	Invades disturbed sites and wetlands.	Probably arrived in Calif. before Europeans; abundant in the Channel Islands.
Sweet fennel (*Foeniculum vulgare*)	Forms solid stands making it difficult for any other plant to establish itself.	Native to Europe.
Bassia (*Bassia hyssopifolia*)	Invades disturbed sites and alkaline habitats.	From Eurasia.
Star thistle (*Centaurea melitensis*)	Invades disturbed sites; likely precludes native forbs.	From Mediterranean.
Tricolor chrysanthemum (*Chrysanthemum carinatum*)	Invades filled areas; very difficult to control.	Being controlled at Tijuana Estuary. @ SMNWR.
Garland chrysanthemum (*Chrysanthemum coronarium*)	Invades filled areas; very difficult to control.	@ SMNWR.
Brass buttons (*Cotula coronopifolia*)	Invades depressions within salt flats of the upper intertidal zone and in open mudflats that receive freshwater runoff.	Needs brackish water to germinate.
Sweet allysum (*Lobularia maritima*)	Invades as a groundcover over disturbed sites, preventing native plants from establishing.	In local nursery trade as a groundcover. Potential to become problem at SMNWR.
Lindley's salt bush (*Atriplex lindleyi*)	Impacting native species at CVWR mitigation site.	From Australia.
Australian salt bush (*Atriplex semibaccata*)	Invades high marsh/upland transition in southern California.	From Australia.
Russian thistle (*Salsola kali*)	Invades disturbed sites.	From Eurasia.
Common sow thistle (*Sonchus oleraceus*)	Invades high marsh areas of low salinity, single to small groups about 3 ft (1 m) high.	@ SMNWR.
Prickly sow thistle (*Sonchus asper*)	Invades high marsh areas of low salinity, single to small groups about 3 ft (1 m) high.	@ SMNWR.
Curly dock (*Rumex crispus*)	Invades periphery of salt marshes, sharing higher marsh sites with native saltgrass.	Invades following prolonged inundation by local runoff causing lower salinities. @ SMNWR.
Common knotweed (*Polygonum aviculare*)	Opportunistic weed.	Easy to remove; not a good competitor with native plants.
Tree tobacco (*Nicotiana glauca*)	Can become invasive.	@ SMNWR.
Tamarisk (*Tamarix*)	Competes with native riparian plants for space and water.	Riparian areas and brackish water; bad pest at Tijuana Reserve.
Peruvian pepper tree (*Schinus molle*)	Invades marsh, riparian areas.	@ SMNWR. A pest at Tijuana Reserve.
Red brome (*Bromus madritensis ssp. rubens*)	Invasive on disturbed sites and highly competitive with native species; large seed bank makes it very difficult to control or eradicate.	@ SMNWR.
Black mustard (*Brassica nigra*)	Invasive on disturbed sites and very competitive with native plants; very difficult to eradicate once it has become "naturalized" as it has at SMNWR.	@ SMNWR.
Sterile barley (*Hordeum murinum*)	Theoretically "sterile" and noninvasive, but batches have included nonsterile seed that spread.	Used by California Department of Transportation (CalTRANS) for erosion control along roads.
Castor bean (*Ricinus communis*)		@ SMNWR.
Sickle grass (*Parapholis incurva*)	Very common exotic in higher marshes; aggressively outcompetes native marsh species in low salinity areas.	Common at SMNWR.
Rabbit foot grass (*Polypogon monspeliensis*)	Invades disturbed sites.	From England, where it is now rare.
Pampas grass (*Cortaderia jubata*)	Found at CVWR; very dominant invasive of uplands.	Native to Andes, introduced as ornamental.
Southern cattail (*Typha domingensis*)	Can spread into saline marshes and compete with native cattails when salinity is reduced due to higher or prolonged freshwater inflows. Some consider a native, but it is not indigenous to San Diego Bay.	Invades following reduction in salinity but not a salt marsh species; invaded San Diego River marsh after 1980 flood. Location in Bay not known.

1. Primary sources are Zedler (1992a); Brian Collins and Brenda McMillan at USFWS; California Exotic Pest Plant Council (CEPPC) 1996; Dr. Gary Sullivan, PERL, SDSU; and Species List of San Diego Bay (Appendix D "Comprehensive Species List of San Diego Bay").

Table 2-27. List of Exotic Marine Animals Found in San Diego Bay, Their Probable Source, Problems, or Effects Caused, and Other Comments.[1]

Common name/Species	Probable Source	Problems or Effects Caused	Comments
Protozoans			
Lobochona prorates	unknown	unknown	
Cnideria			
Anemone (*Bunodeopsis sp.)*	unknown/most probably an exotic	Impacting eelgrass beds in Mission Bay, but not apparently in San Diego Bay for unknown reasons.	SDSU research (Sewell 1996; S. Williams, San Diego State University, pers. comm.).
Anemone (*Diadumene lineatu)*	Asia	unknown	
Polychaetes			
capitellid *(Capitella "capitata")* (taxonomy changing by splitting into sibling species)	unknown	unknown	High density indicates pollution (Fairey *et al.*1996); need new survey based on new taxonomy.
eunicid (*Marphysa sanguinea)*	unknown	unknown	
nereid *(Neanthes acuminata)*	unknown	unknown	See Fairey *et al.* 1996 for Bay sites.
spionid *(Polydora ligni)*	Mariculture operations; infested outplantings.	Shell borers of marine molluscs; soft bottom species.	Most prevalent in mariculture, but found on past species lists in Bay.
spionid *(Seudopolydora paucibranchiata)*	Asia/Japan	Competition for habitat space.	See Fairey *et al.* 1996 for Bay sites; studied at Mission Bay (Levin 1981).
Sponges			
Haliclona sp.	unknown	unknown	
Hydroids			
Obelia sp.	unknown	Clusters on pilings.	Some species tolerate poor water quality.
Naked hydroid *(Tubularia crocea)*	NW Atlantic Ocean	Fouls piles or floating docks at extreme low tide zone.	
Crustaceans: Cirripeds			
Acorn barnacle (*Balanus amphitrite)*	US eastern seaboard?	Attaches to objects in the intertidal zone.	One of few estuarine barnacles. Being studied by SDSU students under S. Williams. Dominant in the Salton Sea.
Crustaceans: Ostracods			
Aspidochoncha limnoriae	unknown	unknown	
Redekea californica	unknown	unknown	
Crustaceans: Amphipods			
Corophium acherusicum	unknown	unknown	For Bay sites, see Fairey *et al.* 1996
Corophium heteroceratum	Asia	unknown	For Bay sites, see Fairey *et al.* 1996
Corophium uenoi	Asia/Japan	unknown	
Grandidierella japonica	Asia	unknown	Tolerant of high sediment toxicity; for Bay sites, see Fairey *et al.* 1996
Jassa marmorata (falcata)	NW Atlantic Ocean	unknown	
Podocerus brasiliensis	unknown	unknown	
Stenothoe valida	unknown	unknown	
Crustaceans: Isopods			
Iais californica	Probably came from Australia with host.	unknown	Commensal on *Sphaeroma quoyanum.*
Gribble *(Limnoria tripunctata)*	Wood ships, drift wood, ballast water.	Bores wooden piles from mid intertidal to 39 ft (12 m) depth.	
Gribble *(Limnoria quadripunctata)*	Wood ships, driftwood, ballast water.	Bores wooden piles from mid intertidal to 39 ft (12 m) depth.	
Sphaeroma quoyanum (formerly misidentified as *S. pentodon)*	Native to Australia; came to SF Bay in 1800s on hulls of ships; first noted in SD Bay in 1927.	Habitat alteration: Burrows in salt marsh banks, clay, and friable rock; increases erosion; loss of salt marsh habitat; wood is secondary habitat.	Found in high densities in banks of Paradise Creek in 1990s near SMNWR (Crooks 1997). Of concern for wetland restoration and moving of "contaminated" plugs to other sites (B. Collins, pers. comm.).
Sphaeroma walkeri	Indian Ocean	unknown	
Crustaceans: Decapods			
Oriental shrimp (*Palaemon macrodactylus)*	Asia	unknown	Monitored at SMNWR.
Crustaceans: Tanaidacea			
Tanais sp.	unknown	unknown	
Molluscs			
Southern shipworm (*Lyrodus pedicellatus)* (formerly *Teredo diegensis)*	Ships from the south or Hawaii.	Damages ships and pilings in SD Bay.	Prefers warm water.

Table 2-27. List of Exotic Marine Animals Found in San Diego Bay, Their Probable Source, Problems, or Effects Caused, and Other Comments.[1] (Continued)

Common name/Species	Probable Source	Problems or Effects Caused	Comments
Japanese mussel (*Musculista senhousia)*	Accidentally introduced from Japan; first noted in Mission Bay in 1960s.	Habitat alteration: Forms extensive mats on mudflats, altering sediment properties; may displace native bivalves; but mat also may promote macrofaunal diversity. Impedes eelgrass propagation in fragmented beds. Inhabits seagrass and salt marsh restoration sites.	Dominant in West Basin, downtown piers, and Glorietta Bay (Fairey *et al.* 1996). Opportunist that moves into constructed marshes like Sweetwater. Eelgrass impact research at SDSU by Williams (in press).
Japanese littleneck (*Tapes semidecussata)*	Asia/Japan. Introduced for mariculture and clamming.	unknown	Found in coarse, sandy mud
Atlantic ribbed mussel (*Geukensia) (Modiolus) (Ischadium) demissum **	Accidental introduction with eastern oysters; in 1953, only found in SF Bay.	Dense stands on mudflats, attached to marsh plants and rocks; competes with natives. Benefit: food for shorebirds, esp. clapper rails.	*Current status in Bay unclear. Early reports were probably *Musculista senhousia*. If not here yet, then likely invader. Present in Newport Bay salt marsh.
Common mussel (*Mytilus galloprovincialis)*	Mediterranean Sea	Appears to have displaced native mussel in Bay.	Formerly thought to be *M. edulis*.
Shipworm (*Teredo navalis)*	First seen in SF Bay about 1910–1913.	Causes serious damage to pilings; spreads rapidly.	Tolerates low salinity.
Theora fragilis (lubrica)	Asia/Japan	unknown	For Bay sites, see Fairey *et al.* 1996.
Tunicates/Ascidians			
Ascidia zara (similar to A. ceratodes)	Japanese freighters; first reported from SD Bay in 1996.	Established as part of fouling community in marinas.	Common at marinas in Bay in 1996 and 1997 (Lambert and Lambert 1998).
Ascidia sp.	First reported in SD Bay in 1983 at Harbor Island.	Established as part of fouling community in marinas.	Great differences in abundance from year to year in Bay 1994–1997 (Lambert and Lambert 1998).
Botrylloides diegensis	Very early arrival or a native; noted in 1917 survey in SD Bay.	Coats rocks, piers, and other hard substrates with layer of orange gelatinous slime.	Thought to be an exotic by some (Cohen 1997) and a native by others (Lambert and Lambert 1998). A major marina pest in New England.
Botryllus schlosseri	Europe via ship fouling; first noted in SD Bay in 1960s.	Colonies can cover up to 10 cm patches of substrate. Present throughout the year.	Very common on floats in Bay in early 1960s. Rare in SD Bay 1994–1997 (Lambert and Lambert 1998).
Ciona intestinalis	Northern Europe/north Atlantic via ship fouling; first reported in SD Bay in 1917.	Established at marinas. Massive recolonizations occur in spring following massive dieoffs from winter rains.	Requires relatively clean water; common throughout world ports. Rare in Bay in 1994–1996, very abundant in 1997 (Lambert and Lambert 1998).
Ciona savignyi	Presumed from Japan via container ships at Long Beach Harbor; first reported from SD Bay in 1994.	Established as part of fouling community in marinas. Abundant seasonally in San Diego Bay marinas.	Rare in Bay in 1994, very abundant in spring 1997 (Lambert and Lambert 1998).
Microcosmus squamiger	Australia via ships' hulls; first reported in SD Bay in 1994.	Present in all harbors, though most numerous in San Diego and Mission Bays. May be replacing *Styela canopus* in SD Bay, another exotic.	Very abundant in 1994–1995 in SD Bay, with complete cover of large portions of substrate (100 m^2) in 1996–1997 (Lambert and Lambert 1998).
Polyandrocarpa zorritensis	Possibly Peru; first reported in SD Bay in 1994.	Fouling organism in marinas, and aggressive invader.	Common in all parts of San Diego Bay in 1994–1997 (Lambert and Lambert 1998). Tolerant of temp. and salinity fluctuations.
Styela canopus (formerly *S. partita)*	Presumed from East Coast via Navy ships; first reported in SD Bay in 1972 on south Bay floats near NAVSTA.	Established on floats and at marinas.	Abundant on floats in 1970s and remains common today, though restricted to San Diego Bay (Lambert and Lambert 1998).
Styela clava	Korea via ships' hulls or ballast water, or aquaculture imports; first reported in 1933 in So. Calif.	Fouls ship hulls; can occur in very dense assemblages.	Native to Orient; common in So. Calif. harbors. Tolerates low temp. and salinity. Common in Bay in 1994–1995, rare in 1996–1997 (Lambert and Lambert 1998).
Styela plicata	First reported in 1915 in SD Bay; assumed to be nonindigenous.	Dominant and abundant in all harbors in So. Calif.; grows extremely rapidly and can attain maximum size in six months.	Very abundant in SD Bay in 1961, and in 1994–1997 (Lambert and Lambert 1998). Widespread in other oceans.
Symplegma brakenhielmi (formerly *S. oceania)*	First noted on drift kelp in San Pedro Bay in 1991. First noted in SD Bay in 1994.	Attaches to wires, ropes, and mussel shells at various locations on both sides of SD Bay. Grows on *Styela canopus* and other tunicates.	May be ephemeral species, as rare in 1994–1995 and absent from Bay in 1996–1997 (Lambert and Lambert 1998). Found worldwide in warm water harbors.

Table 2-27. List of Exotic Marine Animals Found in San Diego Bay, Their Probable Source, Problems, or Effects Caused, and Other Comments.[1] (Continued)

Common name/Species	Probable Source	Problems or Effects Caused	Comments
Marine Fish			
Yellowfin goby (*Acanthogobius flavimanus*)	Japan; possibly from ballast of ships travelling between ports, and also migration of larvae and adults; first collected in 1963 in California.	May compete for food and habitat with native species; alteration of native food webs; direct predation on native species.	One of largest species in salt marsh habitat and 8th most abundant in monitoring @ SMNWR by Pacific Estuarine Research Laboratory 1989–1996 (G. Williams *et al.* 1998). Allen's surveys found 25 fish from 1994–1996 in nearshore and intertidal sites in Bay. Tolerant of lowered salinities; self-reproducing in Bay.
Chameleon goby (*Tridentiger trigonocephalus*)	Introduced in Calif. in 1950s; recent arrival in SD Bay.	Insignificant data to assess impacts on native species at SF Bay.	California Department of Fish and Game 1994; None found in Allen's SD Bay surveys.
Sailfin molly (*Poecilia latipinna*)	Probably from upstream sources: aquarium, or bait release. First noted in SD Bay in 1989.	May harm native species based on aggressive interactions observed in aquaria; may compete for habitat due to high density in shallow habitats and use of marsh surface (esp. killifish).	Tolerant of salinity changes and degraded waters. Monitored by Pacific Estuarine Research Laboratory 1989–1996 in SMNWR, where it was 12th most abundant species (G. Williams *et al.* 1998).
Striped sea bass (*Morone saxatilis*)	Stocking for sport fishery.	Depends upon dominance; predator of other fish.	Isolated sightings and not a sustaining population in Bay as it needs large river for spawning.
Threadfin shad (*Dorosoma petenense*)	Stocking for sport fishery.	Competition for food.	Uncommon. Cannot reproduce in salt water.

1. Primary sources: CDFG 1994; Scatolini and Zedler 1996; Zedler 1996; Crooks 1997; Allen 1998; Williams *et al.* 1998; J. Crooks, pers. comm.; A. Cohen, pers. comm.; L. Levin, pers. comm.

2.5.7.3 Sources of Marine and Coastal Exotics

Exotic marine species have arrived in San Diego Bay from all over the world through direct and indirect means, and for intentional and unintentional purposes:

- Ballast water in international ships that is discharged while docking. Ballast water can convey larval forms of benthic species, but not the natural predator associated with adult form; plankton and their resting stages are also transported.)
- Attachment to hulls of ships and pleasure boats.
- Attachment to an intended introduced species, such as oysters for commercial harvesting.
- Intended introduction for commercial or sport fishery or mariculture.
- Release of unwanted organisms by aquarists or bait fishermen.
- Natural spread from original point of introduction.

Coastal plant introductions and invasions can come from a variety of sources and causes (Zedler 1992a): (1) dispersal (e.g. wind, birds, shoes, ships, landscaping), (2) disturbance of soil, (3) temporary environmental changes that permit invasion, such as a reduction in salinity, (4) prolonged environmental changes, such as from impoundments, or (5) combinations of the above. It should be noted that climate or current shifts, such as El Niño events, can cause a temporary shift in species composition. These new range extensions of species native to an adjacent regime (e.g. subtropical) are not considered “exotic” for the purposes of this Plan. An example is the June 1998 influx of large numbers of pelagic blue crabs (*Callinectes arcuatus* or *C. bellicosus*) in San Diego Bay, an extension of the northern reach of their range probably due to warmer water and currents associated with the recent El Niño event (McKee-Lewis 1998).

2.5.7.4 Ecological and Economic Impacts

Nonindigenous species can have several different types of impacts on native species (Lafferty and Kuris 1996; L. Levin, pers. comm.):

- No detectable effect, or nonreproducing populations.
- Replacement of a functionally similar native species through competition.
- Inhibition of normal growth or increased mortality of the host and associated species.
- Serious species competition caused by extremely high population densities from lack of natural enemies.
- Development as novel predators or novel prey.
- Creation or alteration of original substrate and habitat.
- Hybridization with native species.
- Direct or indirect toxicity (e.g. toxic diatoms).

- See Sections 2.5.5 "Birds" and 2.6 "Sensitive Species" for discussion of impacts of exotic animal predators.

Some species are both competitors and predators, like the yellowfin goby. When native animals are dependent upon specific native plants, an invading alien plant that is outcompeting the native one will create multispecies repercussions (Zedler 1992a). Exotic nonmarine predators, such as feral cat and red fox, have caused heavy losses of light footed clapper rails and other birds breeding in southern California coastal wetlands, as discussed in Birds and Sensitive Species sections (Zembal 1993).

- Ecosystem-level changes in the Bay's intertidal habitat are being caused by the exotic Japanese mussel, *Musculista senhousia.*

As noted in Tables 2-26 and 2-27, many problems are being, or can be, caused by nonnative species in San Diego Bay. The most studied exotic locally is probably the Japanese mussel *Musculista senhousia,* which is found in both Mission Bay and San Diego Bay (Takahashi 1992b; Crooks 1996; Scatolini and Zedler 1996; Crooks 1997.) Its rapid spread, recent population explosion, and extreme densities (up to 27,000 mussels/m^2 in the intertidal zone and up to 178,000/m^2 in the shallow subtidal) have attracted scientists' attention. Research has shown that its effects can be both negative and positive (Crooks 1998b). While its dense mats can crowd out native clams and dominate marsh restoration sites, the mats also provide a new habitat that supports greater species diversity and densities of native macrofauna than other areas. However, the mussel's dense beds can inhibit growth and vegetative propagation of eelgrass (Reusch and Williams in Crooks 1997; Williams, in press). If the eelgrass beds are dense and unfragmented, however, the mussel starves. Overall, the concern about habitat-altering exotics is that they can significantly change the structure and functioning of invaded ecosystems (Crooks 1997).

- An introduced isopod is now severely impacting Paradise Creek's salt marsh, 70 years after first reported in the Bay.

Another exotic species in the Bay producing "ecosystem-level effects through habitat alteration" is the isopod *Sphaeroma quoyanum* (Crooks 1997). Though known to be in the Bay since 1927, it was not detected as a problem until the early 1990s. High densities (>10,000/m^2) were observed in the banks of the salt marsh in Paradise Creek, causing the overlying vegetated marsh flat to slump into the creek and the creek to widen. This recent ecological release after a long lag period since the species' introduction also illustrates one of the problems in dealing with nonindigenous species—their potential for impact may be underestimated.

- Pilings in the Bay are covered with and often damaged by exotic marine invertebrates. Economic damage and public health concerns are both caused by marine pests.

In addition to ecological damage, exotic pests can cause significant economic damage to boats, commercial fisheries, and marine structures or create public health problems. Fouling organisms are the most notorious, such as the zebra mussel (*Dreissena polymorpha*) of Great Lakes and Atlantic coast fame. In the Bay, exotic tunicates, shipworms, gribbles, and hydroids are commonly found on or in pilings. A newer type of fouling impact is the blockage of outlets, such as storm drains and other pipes. Human health can also possibly be affected. For example, the Chinese mitten crab (now in San Francisco Bay, but not in San Diego Bay) carries a human parasite, the oriental lung fluke, which causes tuberculosis-type symptoms that are treatable but serious (DeSena 1997). The local anemone *Bunodeopsis sp.* is considered to be a public nuisance by the City of San Diego because it stings humans who touch it; it is also destroying eelgrass beds in Mission Bay though not in San Diego Bay, for unknown reasons (Sewell 1996; S. Williams, pers. comm.). Often marine pests are exotic species that have become overpopulated because they lack their own native conditions, such as a local predator, or can more readily exploit the current habitat condition than can a native species.

- Eradication of most exotic plants is very difficult or impossible, especially if the plant propagates readily.

Exotic plants that have become "naturalized," or extensively spread throughout the native plant community, can become difficult, if not impossible, to eradicate (Zedler 1992a). In contrast, eradication efforts for the New Zealand mangrove (*Avicenna marina),* which was introduced in Mission Bay over 30 years ago, have been quite successful (L. Levin, pers. comm.). Fortunately, the propagules of this species have limited dispersal capabilities. In comparison, little experience exists in trying to eradicate or control nonnative marine animals but the outlook is not optimistic once numbers begin to escalate (Crooks 1997). On a positive note, tunicates (ascidians) are able to remove and sequester heavy metals and other pollutants from harbor waters. The excessive populations of nonindigenous tunicates at marinas could be used as biological monitors or as a means of heavy metal removal (with removal of the organism) from the ecosystem (Monniot *et al.* in Lambert and Lambert 1998).

2.5.7.5 Potential Invasions of Exotics to San Diego Bay

The expansion of the global economy will bring along increased international shipping throughout the Pacific Coast and probably the Port of San Diego. Such shipping continues to have the potential to expand the rate of ballast-water introductions of exotic species, as will be discussed further in Chapter 4 "Ecosystem Management Strategies." For example, resting spores of a toxic *Alexandrium* species of dinoflagellate were introduced to the harbor of Hobart, Tasmania through ships' ballast water and the risk presently exists for a similar introduction from ships visiting San Diego Bay (Hallegraeff and Bloch 1991). Pollution, which the Bay suffers from for certain constituents, can also favor invasions by opportunistic species, such as the amphipod *Grandidierella japonica* (Fairey *et al.* 1996).

- Possible management strategies to prevent invasions are discussed and proposed in Chapter 4 "Ecosystem Management Strategies."

One scenario that could occur in the Bay is for open intertidal habitat to be transformed into dense meadows of tall grass by the exotic cordgrass *Spartina alterniflora* or its hybrid with the native species *S. foliosa* (Daehler and Strong 1997). This alteration would impair the many invertebrate and bird species dependent on the Bay's unvegetated mudflat, located primarily in the south Bay. *Spartina densiflora,* a native of Chile, currently outcompetes native pickleweed in San Francisco Bay, and could transform marshes of San Diego Bay if allowed to be introduced.

Certain exotic pest species may be some of the most likely ones to appear in San Diego Bay in the near future (Zedler 1992a; Lafferty and Kuris 1996; Sewell 1996; J. Crooks, pers. comm.). These imminent aliens include:

Plants

- Cajeput tree, *Melaleuca quinquinervia*—now in San Diego County landscaping and Tijuana Estuary.
- Oriental cattail, *Typhus orientalis*—now spreading rapidly in Australian salt marshes.
- Cordgrass, *Spartina densiflora, S.anglica, and S. alterniflora*—now on the U.S. west coast, potentially outcompeting native species or overtaking mudflats.
- Japanese eelgrass, *Zostera japonica*—now in Pacific Northwest.

Animals

- Green crab, *Carcinus maenus*—now in San Francisco Bay.
- Chinese mitten crab, *Eriocheir sinensis*—now in San Francisco Bay Delta.
- Asian clam, *Potamocorbula amurensis*—now in San Francisco Bay.
- Copepod, *Pseudodiaptomus marinus*—now in Mission Bay.
- Calanoid copepod, *Tortanus dextrolibotus*—now in San Francisco Bay Delta.
- Mysid shrimp, *Acanthomysis* sp.—now in San Francisco Bay.

The ecological ramifications of the introduction of any of these species could range from minor to very significant, depending on local conditions and natural competition. Based on experience in San Francisco Bay, the species of greatest ecological impact are probably the exotic cordgrass, Chinese mitten crab, green crab, and Asian clam. Food webs and habitats were strongly altered and populations of indigenous species of the same niche were depressed (California Department of Fish and Game 1994; Veldhuizen and Hieb 1998).

2.6 Sensitive Species

There are many listed and sensitive species that occur in and around San Diego Bay. There are seven federally listed species occurring within the San Diego Bay area. Of these, two are in salt marsh habitats (light footed clapper rail, salt marsh bird's beak), two occur on sandy beaches (California least tern, western snowy plover), and one occurs in coastal dune habitats (sand dune tiger beetle). Another, the California brown pelican, primarily uses open water and roosts on artificial structures. The green sea turtle is a year-round resident in warm water of south Bay.

In addition to the federally listed species described above, there are a number of other sensitive species occurring within the San Diego Bay area. Eleven of these species can be found in salt marsh habitats, four occur on sandy beaches, six on intertidal flats, six on dunes, and four on coastal strand or beach habitats. Six also utilize uplands and grasslands to some extent. Four species occur on the Salt Works levees (black skimmer, elegant tern, gull-billed tern, western snowy plover), and one (double-crested cormorant) primarily utilizes artificial structures.

Brief accounts for each of these sensitive species are given below in Table 2-28. Appendix F "Narratives on Sensitive Species Not Listed Under Federal or State Endangered Species Acts" contains narratives on all other sensitive species not listed under the state or federal ESAs, but that must be considered to meet the Port's environmental documentation requirements (which include more state-protected species than the Navy is responsible to protect).

Table 2-28. Sensitive Species, Their Habitats and Risk Factors in San Diego Bay.

Species* and Status	Habitat	Suspected Principal Threats/Risk Factors in San Diego Bay
BIRDS		
Belding's savannah sparrow *(Ammodramus sandwichensis beldingi)* (CE, SC)	Higher salt marsh for nesting, other salt marsh, salt flats, tidal creeks, channel edges, and other intertidal areas for foraging.	Loss of vegetative cover, pickleweed.
Black skimmer *(Rynchops niger niger)* (CSC)	Salt works dikes, intertidal salt flats.	Resident colony appears stable or increasing; nesting sites protected by current land use.
Burrowing owl *(Athene cunicularia hypugaea)*, coastal population (CSC, SC)	NRRF, NASNI disturbed uplands, Imperial Beach Outlying Landing Field, Chula Vista Nature Center.	Loss of upland transition habitat, predation, control programs for ground squirrels.
California brown pelican *(Pelecanus occidentalis californicus)* (FE, CE)	Open water, roost on hard substrate.	Deep water foraging habitat, roosting-site protection.
California horned lark *(Eremophila alpestris)* (CSC)	Higher salt marsh for foraging.	Loss of upland transition habitat.
California least tern *(Sterna antilarium browni)* (FE, CE)	Salt panne, beaches, dunes.	Predation; nest site disturbance, loss of shallow-water foraging habitat.
Double-crested cormorant *(Phalacrocorax auritus)* (CSC)	Intertidal hard substrate.	Loss of protected roosting sites. Its only known nest site in the county is on a salt marsh dredge.
Elegant tern *(Sterna elegans)* (CSC, SC)	Mudflats, salt flats, open beaches.	Nest site disturbance on salt works dikes.
Gull-billed tern (nesting colony) *(Sterna nilotica vanrossemi)* (CSC, SC)	Salt works.	Predation; lack of high tide refuge.
Light footed clapper rail (*Rallus longirostris levipes*) (FE, CE)	Lower salt marsh.	Loss of undisturbed nest sites; loss and fragmentation of tall cordgrass salt marsh; inadequate tidal flushing; sedimentation from storms and floods; predators.
Large-billed Savannah sparrow (wintering) *(Ammodramus sandwichensis rostratus)* (CSC, SC)	Salt marsh.	Habitat loss and degradation.
Loggerhead shrike *(Lanius ludovicianus)* (CSC, SC)	Higher salt marsh for foraging, adjacent uplands.	Habitat loss and degradation.
Long-billed curlew *(Numenius americanus)* (CSC)	Middle salt marsh, intertidal flats.	Habitat loss and degradation.
Short-eared owl (*Asio flammeus flammeus*) (CSC)	Salt marsh and adjacent uplands.	Vegetative cover for nest.
Western snowy plover *(Charadrius alexandrinus nivosus)* (FT, CSC)	Intertidal mudflats, beaches, dunes, salt flats and dikes; NRRF.	Nest site disturbance on open beaches.
INVERTEBRATES		
Globose dune beetle *(Coelus globosus)* (former Proposed FT, SC)	Coastal foredunes.	Habitat loss and degradation, invasive weeds.
Tiger beetles		
Sandy beach tiger beetle *(Cicindela hirticollis gravida)* (CSC, SC)	Sandy areas subject to tidal flows.	Tiger beetles in general are severely threatened by development, insecticide use, recreational use of coastal areas.
Sand dune tiger beetle *(C. latesignata latesignata)* (FT, CSC)	Coastal dunes and mudflats.	
Mudflat tiger beetle *(C. trifasciata sigmoidea)* (CSC)	Mudflats and other areas of dark, moist soils.	
Gabb's tiger beetle *(C. gabbi)* (CSC)	Mud and salt flats of coastal marshes.	
REPTILES		
San Diego coast horned lizard *(Phrynosoma coronatum blainvillei)* (CSC, SC)	Higher salt marsh, dunes, coastal scrub, other upland communities.	Habitat fragmentation, nonnative ant species (degrade native food source), or use, predation by domestic animals, collectors.
Silvery legless lizard *(Anniella pulchra pulchra)* (CSC, SC)	Coastal dunes and coastal scrub, as well as other upland habitats.	Invasive weeds, vegetation destruction, soil compaction.
Green sea turtle (*Chelonia mydas*) (FT)	Shallow subtidal.	Loss of artificially warm water, harassment by boats.
PLANTS		

Table 2-28. Sensitive Species, Their Habitats and Risk Factors in San Diego Bay. (Continued)

Species* and Status	Habitat	Suspected Principal Threats/Risk Factors in San Diego Bay
Salt marsh birds's beak *(Cordylanthus maritimus* ssp. *maritimus)* (FE, CE)	Higher salt marsh.	Habitat loss or degradation of salt marsh and adjacent uplands.
Nuttal's lotus *(Lotus nuttalianus)* (CNPS List 1B)	Coastal strand and coastal scrub, NRRF.	Development, habitat disturbance, invasive weeds.
Coast woolly heads *(Nemacaulis denudata* var. *denudata)* (CNPS List 2)	Coastal dunes.	Habitat destruction.
Palmer's frankenia *(Frankenia palmeri)* (CNPS List 2)	Coastal dunes and salt marshes.	Development, habitat disturbance, invasive weeds.

*Other species with some sensitive status but not considered a management concern in San Diego Bay: black-crowned night heron, California gull, common loon, Cooper's hawk, merlin, osprey, northern harrier, sharp-shinned hawk (all CSC); black oystercatcher, red knot, reddish egret, mountain plover (all Audubon Watch List); California black rail (RSD, CT) (currently extirpated).
Coastal dune milk vetch (CNPS List 1/CE) (presumed extirpated in San Diego Co.)
San Diego barrel cactus (CNPS List 2) (an upland species but known to occur at NRRF)

State codes: **CE** = California Endangered **CT** = California Threatened **CSC** = California Species of Concern
Federal codes: **FE** = Federal Endangered **FT** = Federal Threatened **SC**=Federal Species of Concern
Local codes: **RSD** = Rare in San Diego County

2.6.1 Federally Listed Species

2.6.1.1 Green Sea Turtle—*Chelonia mydas*

The only marine reptile found in Bay waters is the east Pacific green sea turtle (Macdonald *et al.* 1990). This species is the same as the Atlantic green sea turtle, but the east Pacific stock has a distinctive color morphology (S. Eckert, Hubbs-Sea World Research Institute, pers. comm.). Recent genetic studies confirm this same species status though some biologists continue to refer to this stock as the black sea turtle, *Chelnia mydas agassizii* or *C. agassizii* (P. Dutton, National Marine Fisheries Service, pers. comm.).

- San Diego Bay represents the northernmost dwelling habitat of the east Pacific green sea turtle, which is the only marine reptile found in the Bay.

This species is found in warm waters throughout the world, where the turtles tend to follow the 64° F (18° C) isotherm temperatures in the ocean (S. Eckert, pers. comm.). This eastern Pacific stock uses nesting beaches primarily located along the Pacific Coast of the Mexican State of Michoacan and also rookeries in Baja California and its offshore islands. They commonly range into the Sea of Cortez and southeast to Central and South America (Macdonald *et al.* 1990). Turtles in the eastern North Pacific have been sighted from Baja California to southern Alaska when temperatures are supportive (National Marine Fisheries Service and US Fish and Wildlife Service 1991). San Diego Bay, however, represents the turtles' northernmost dwelling habitat. As populations along the California coast are rare, their occurrence in San Diego Bay is considered "noteworthy" and "extremely interesting" (Macdonald *et al.* 1990; S. Eckert, pers. comm.). Genetic analysis of local turtles reveals that a few appear more closely related to the Hawaiian/central Pacific stock (P. Dutton, pers. comm.).

While the east Pacific green sea turtle (*Chelonia mydas)* is federally listed as threatened under the ESA, the eastern Pacific stock with a breeding population off the Pacific coast of Mexico is listed as endangered (National Marine Fisheries Service and US Fish and Wildlife Service 1991). The species is imperiled throughout its world range. Total population estimates are not available; however, nesting females on US beaches (all in Florida) are estimated to range from 200 to

1,100. As of 1991, a recovery team for the NMFS concluded that the species status had not appreciably improved since listing in 1970. In Mexico, the breeding population appears to be declining. As a result, an east Pacific green sea turtle recovery plan was recently prepared just for this stock (S. Eckert, pers. comm.). The number of turtles using the Bay is dynamic but is estimated to range from 30 to 60 animals, based on tagged animals recovered in and around the SDG&E cooling channel (P. Dutton, pers. comm.).

History and Background

Many scientists previously believed that the green sea turtle was not historically a resident of San Diego Bay, but now they have concluded that it would naturally have sought out the Bay, at least during the summer months (Macdonald *et al.* 1990; S. Eckert, and P. Dutton, pers. comm.). In 1857, numbers of these turtles were first brought up from Mexico and temporarily kept in pens within the Bay before being shipped north for sale in San Francisco (Stinson 1984). This practice apparently continued for many decades, as a photograph dated 1910 can be seen at the San Diego Maritime Museum showing stacks of sea turtles piled up on a Bay wharf "awaiting shipment." Even a cannery featuring canned turtle soup existed in San Diego at one time (P. Dutton, pers. comm.). Some of these animals escaped and became inhabitants of the Bay.

San Diego Bay conditions were unintentionally altered to provide attractive year-round habitat for this warm water seeking reptile. In the 1920s, SDG&E built a power plant on Broadway in downtown San Diego and added its Silvergate plant on the eastern shore in 1941 (Smith and Graham 1976). In 1951, these power plants created a thermal discharge that was up to 15° F (9° C) warmer than the intake temperature as the result of their water-cooling system, though they are not in operation today (Terzich 1965). In 1960, SDG&E began operating a larger, new power plant in the south Bay, which expanded into additional units over the next several years. The first report of sea turtles in the plant's warm water discharge channel was made in 1968 as part of a study of the ecological effects of the discharge (Ford 1968). Water temperatures at the surface ranged from 95° F (35° C) at the outfall to 82° F (28° C) at the end of the 6,000 ft (1,829 m) channel, compared to 79° F (26° C) in the central Bay (Ford *et al.* 1970). Operational effects of the power plant's thermal effluent were recently reevaluated (McDonald *et al.* 1994).

A specific study of the green sea turtle in the Bay was conducted in the early 1980s as a master's thesis at SDSU (Stinson 1984). Since 1989, the turtles in San Diego Bay have been monitored for various organizations to determine their status, size and sex ratios, physical condition, origins, movements and migration, and feeding habits (Dutton and McDonald 1990; McDonald and Dutton 1992,1993; P. Dutton, pers. comm.).

- Because they need undisturbed beaches for nesting, Pacific green sea turtles do not breed or nest in the Bay, but apparently somewhere along the coast of Mexico.

Both adults and juveniles have been sighted, with individuals seen throughout the summer and winter at the SDG&E channel, the South Bay, and around Coronado Bridge near a thick stand of eelgrass (Ford and Chambers 1973; Stinson 1984; Macdonald *et al.* 1990; McDonald and Dutton 1992). Even in temperatures as cold as 58° F (14.4° C), turtles are actively swimming in the Bay. They do not breed or nest in San Diego Bay, because they need undisturbed beaches for nesting (Macdonald *et al.* 1990). Females nest somewhere along the coast of Mexico. Tagged individuals are known to return to the Bay in subsequent years for unknown reasons (Stinson 1984). Residency time in the Bay is unknown; the local population may be a closed genetic unit that does not return to breeding grounds or there may be significant immigration and emigration (S. Eckert, pers.

comm.). Based on the number of juveniles recently observed, there is some recruitment into the population (McDonald and Dutton 1992). Warm water El Niño events could stimulate an increase in migrations. Flipper tags on at least eighteen turtles can now help track their movements.

Ecological Role in the Bay

- The warm water effluent of the SDG&E power plant has allowed the green sea turtle to remain in the Bay during cooler winter months, and the warmer environment appears to have stimulated growth rates in the turtles to twice that of non-Bay turtles.

Sea turtles are primarily herbivore grazers of marine algae and grasses. During the day, the Bay turtles reside in the deeper portion of the south Bay power plant warm water discharge channel, while at night, they feed on eelgrass beds in the south Bay, such as by Coronado Cays (Stinson 1984). Stomach content analysis revealed that they also eat red alga (*Polsiphonia* sp.), eelgrass, and sea lettuce *(Ulva* sp.*)* within the south Bay (McDonald and Dutton 1992). It is unknown whether they feed within the warm water discharge channel. Young turtles are carnivorous from hatchling until juvenile size, and then gradually become herbivorous; they are also described as opportunistic feeders, eating jellyfish, ctenophores, bivalves, or gastropods if readily available (S. Eckert, pers. comm.). The warmer environment of the channel appears to have stimulated growth rates in the turtles that are twice that of non-Bay turtles, possibly by increasing their digestive efficiency (McDonald and Dutton 1992). San Diego Bay is unique in the eastern Pacific as having the only thermal gradient where turtles can select their optimum space (S. Eckert, pers. comm.). The warm water effluent of the power plant has allowed the green sea turtle to remain in the Bay during the normally cooler winter months. When temperatures rise in the channel, turtles disperse in the Bay; in fact, none were observed when channel temperatures exceeded 85 to 90° F (29 to 32° C), which is approaching their lethal limit (McDonald and Dutton 1992, 1993). Their crucial habitat zones in other parts of the Bay in the warmer months are not known.

The turtle has no natural predators in the Bay. Mortalities tend to be caused by collisions with boats or ships (McDonald and Dutton 1992). Unlike the Hawaiian stock where tumors on green turtles are now epidemic in polluted waters, the San Diego Bay population has shown only a few individuals to have fibropapilloma tumors, which usually begin in the eye area (McDonald and Dutton 1990; P. Dutton, pers. comm.).

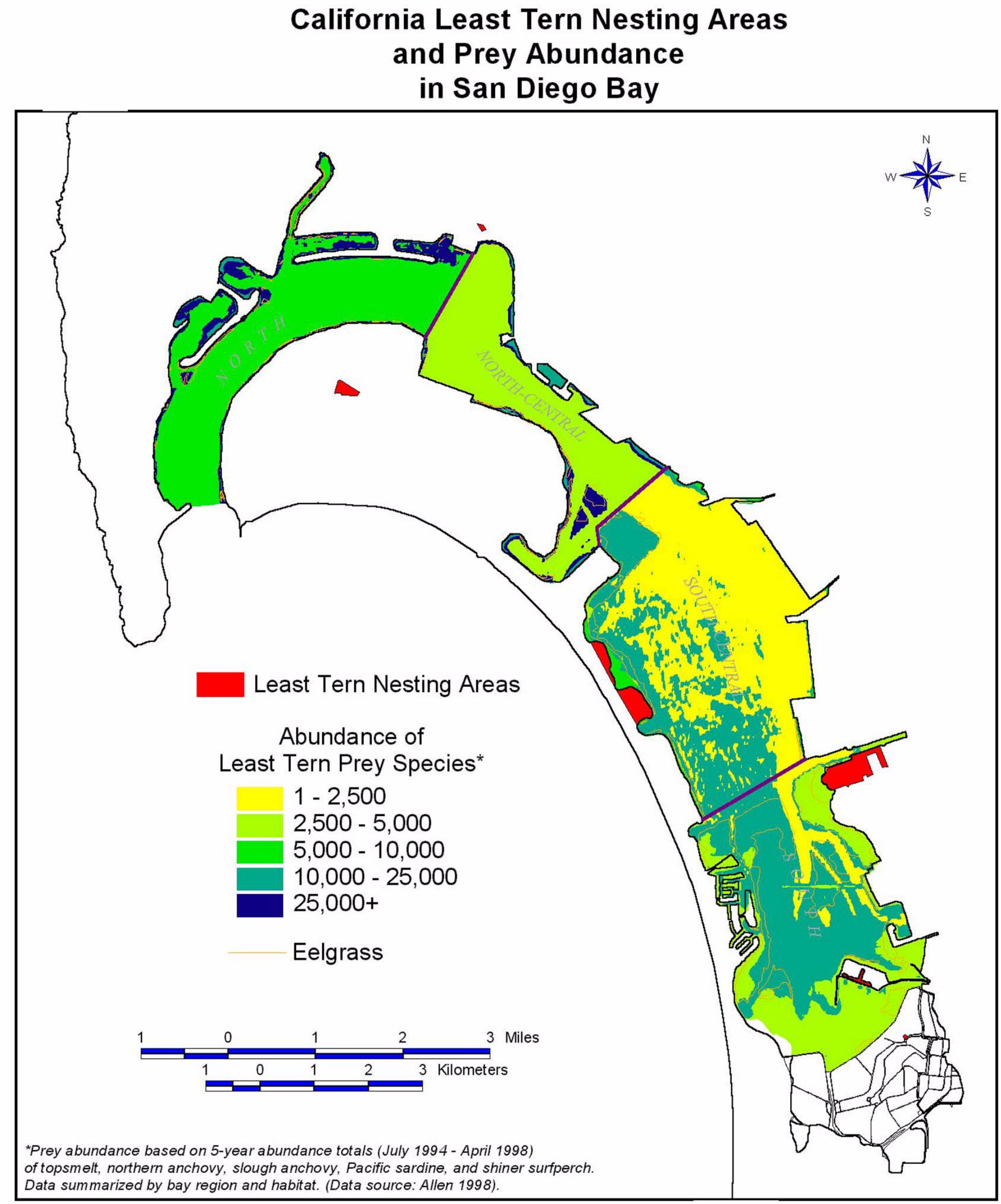
2.6.1.2 California least tern—*Sterna antilarium browni*

The California least tern is a federal and state endangered species that has been listed since 1970. California least terns are inshore foragers and surface-feeding fish eaters. They are opportunistic in their search for prey, eating fish that are small enough to catch including anchovies and smelt (*Atherinops* sp.) (Baird 1997). There is some indication that piers, docks, sea walls, and other artificial structures along the shoreline may attract California least terns, as these structures act as artificial reefs for juvenile schooling fish, which terns feed upon (Baird 1997). California least terns also frequently forage in the open waters of the ocean and Bay. Areas used for foraging will often vary from year to year, depending upon stage of breeding and prey species availability (Baird 1997). The presence of eelgrass is important as habitat for several prey species of the California least terns, such as northern anchovy, topsmelt, and jacksmelt (Baird 1997). However, California least terns do not demonstrate any preference for feeding in eelgrass areas.

- Prey species of the California least tern require eelgrass, although the terns have no preference for feeding in eelgrass locations.

- Adult California least terns and their young eat small marine fish found in surface waters of the Bay during their nesting season. Generally, they return to successful breeding sites each year.

California least terns nest in colonies at several areas on the beaches adjacent to San Diego Bay (Map 2-10).. Open sandy or gravelly shores with light-colored substrates, little vegetation, and nearby fishing waters are used for nesting (Minsky 1987). California least tern nests are simple depressions in the substrate either lined or unlined with shell debris. Average clutch size is about two eggs per nest, and the chicks hatch

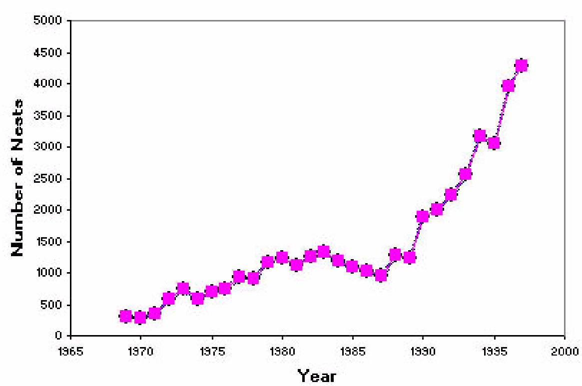


Map 2-10. Least Tern Foraging and Nesting Areas in San Diego Bay.

in about 21 to 28 days. Another twenty days are required for fledging. During the nesting season adult terns and their young feed almost solely on small marine fish (smelt and anchovies) in the surface waters (top 6 ft [2 m]) of the Bay, river mouths, and near-shore ocean waters adjacent to the Silver Strand. California least terns generally will return each year to breeding sites that have been used successfully in the past (Atwood and Massey 1988). California least terns over-winter in Central America and breed mainly in Baja California and southern California, but a few colonies exist in the San Francisco Bay area (Caffrey 1993). They are present in San Diego Bay from about mid-April to early September

- California least tern numbers have increased since being listed as endangered. However, threats still exist.

Since their listing as endangered in 1970, their numbers have increased (Figure 2-25) but there can still be large fluctuations in numbers from year to year (Fancher 1992). Conditions such as El Niño can cause major impact to populations due to effects on anchovy abundance, flooding, or other disruption of nesting sites (Fancher 1992). Additional threats to the California least tern include the loss of roosting platforms in the mooring areas of Shelter Island and City of San Diego, urbanization of nesting habitat, recreational use of nesting areas, and invasive weeds in nesting areas (Baird 1997; Copper and Patton 1997). The presence of larger terns can also be detrimental. For instance, California least terns at Bolsa Chica were displaced by larger terns, and Caspian terns have been documented as preying on California least tern eggs and chicks (E. Copper, pers. comm.).



Data from USFWS.

Figure 2-25. Population Trend in the California Least Tern.

Some of the nesting sites in the San Diego Bay area and elsewhere in the county have experienced increases in the number of fledglings produced in recent years (Table 2-29, Figure 2-26 and Figure 2-27). Intensive management of the California least tern has proven effective in increasing their population and in securing terrestrial habitats around the Bay where other species also benefit, including snowy plovers and horned larks. The US Navy currently funds intensive monitoring and management of its nest sites around the Bay. The SDUPD also currently funds monitoring of California least terns at its properties and is working in concert with the Zoological Society of San Diego andUSFWS in examining how to improve site management efforts (Patton 1997).

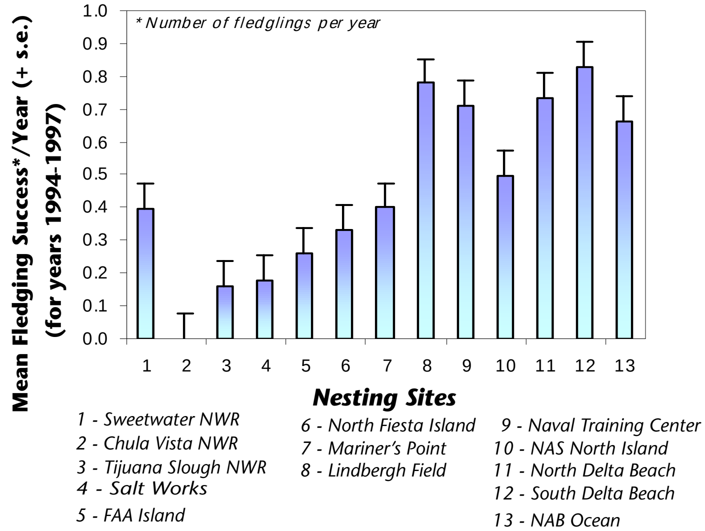


*Figure 2-26. Mean Annual Fledging Success for Least Tern Nesting Sites in San Diego Bay and Vicinity.**

* Fledging success defined as number of fledges per nest, averaged over the years 1994–1997. Some sites may have a high fledging success rate, but very few nests (such as Naval Training Center), whereas South Delta Beach had both high nest numbers and high fledging success.

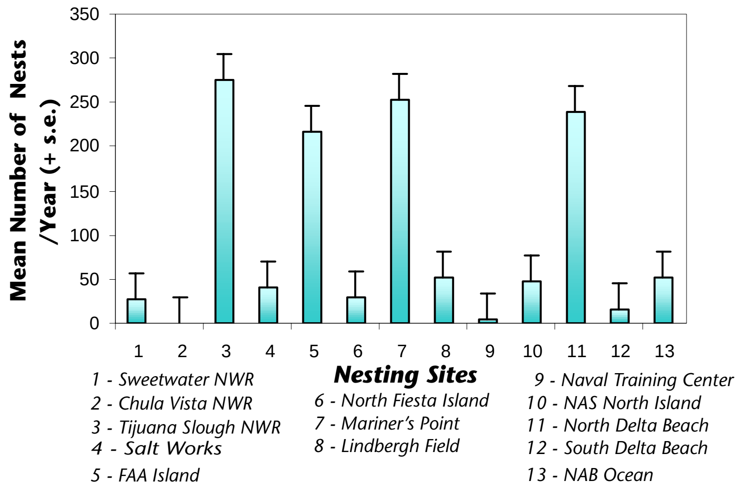


Figure 2-27. Mean Number of California Least Tern Nests in San Diego Bay and Vicinity, 1994–1997.

Table 2-29. Colony Sizes, Reproduction, and Fledging Success at Least Tern Nesting Sites in San Diego Bay, Mission Bay, and Tijuana Slough.[1]

San Diego Area	1994				1995				1996				1997			
Nesting Site	Pairs	Nests	Fledges	Success	Pairs	Nests	Fledges	Success	Pairs	Nests	Fledges	Success	Pairs	Nests	Fledges	Success
FAA Island	330	352	140	40%	200	236	60	25%	188	255	3	1%	20	26	10	38%
North Fiesta Island	10	12	6	50%	12	12	4	33%	11	17	4	24%	76	76	20	26%
Mariner's Point	62	107	25	23%	210	270	125	46%	250	294	125	43%	268	342	165	48%
Naval Training Center	13	13	12	92%	5	6	3	50%	0	0	0	0%	0	0	0	0%
Lindbergh Field	10	10	3	30%	26	27	25	93%	63	71	100	141%	102	102	49	48%
NASNI	43	51	32	63%	54	60	24	40%	49	53	22	42%	27	27	15	56%
North Delta Beach	150	210	100	48%	150	177	125	71%	190	224	200	89%	310	349	300	86%
South Delta Beach	15	18	8	44%	1	1	2	200%	15	21	10	48%	15	25	10	40%
NAB, ocean	1	1	1	100%	22	31	17	55%	74	82	50	61%	85	91	45	49%
SMNWR	8	9	3	33%	26	27	15	56%	25	28	15	54%	38	41	7	17%
Chula Vista WR	1	1	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
Salt Works	52	65	6	9%	23	24	10	42%	22	29	2	7%	36	49	7	14%
Tijuana Slough NWR	151	180	58	32%	275	318	70	22%	137	303	26	9%	211	298	5	2%
TOTALS	846	1029	394	38%	1034	1189	483	41%	1025	1377	557	40%	1198	1077	633	59%

1. Fledging success is defined as the number of fledges per nest, 1994–1997.

2.6.1.3 Light footed clapper rail—*Rallus longirostris levipes*

The light footed clapper rail is a federal and state endangered species that is currently found from Santa Barbara County to San Quentin, Baja California. It lives, nests, and forages entirely within the salt marsh, preferred habitat being large estuaries dominated by cordgrass and pickleweed (Jorgensen 1975). It is not a strong flyer and does not migrate. Clapper rails require cordgrass of the lower marsh habitat for nesting, and an abundance of intertidal marine invertebrates for its food supply (Massey *et al.* 1984; Zedler 1993b). It will feed on insects, small fish (including larval fish), and some plant material. Clapper rails tether their nests with cordgrass so that they do not wash away or become inundated during high tide (Massey 1979). Cordgrass also is used to form a canopy over the nest to hide it (Massey *et al.* 1984; Zedler 1993b). They lay generally six eggs from March through May, and the chicks hatch from April to June (Unitt 1984). Adjacent middle and upper marsh and upland transition habitat is important as a safe area during very high tides, large storms, or as a temporary refuge if lower marsh habitats become degraded (Zembal 1989).

- In recent decades, there has been a dramatic decline in the population of light footed clapper rails due to destruction of salt marsh habitat. Predation by raptors and mammals are the main causes of nest failure. Storm events and watershed runoff also contribute.

Light footed clapper rails have declined dramatically in recent decades due to destruction of salt marsh habitat (Garrett and Dunn 1981; Macdonald *et al.* 1990). The entire southern California population crashed from 277 pairs in 1984 to 142 pairs in 1985, partly due to tidal closure of the Tijuana Estuary (Zedler 1992b). Statewide, only 325 light footed clapper rails, nesting in fourteen wetlands, were known to exist in 1996 (USFWS data). Over half the population of clapper rails occurs at Upper Newport Bay. Tijuana Estuary supports the second largest population in existence, approximately 90 birds in 1998, and these could be a source population for dispersing the clapper rail into areas of the Bay restored to appropriate habitat (B. Collins, pers. comm.). In the San Diego Bay area, clapper rails have been found in various locales, including the SMNWR, an area on the Sweetwater River near Plaza Bonita, at the South Bay Ecological Study Area, and the last 300 ft (91 m) of the Otay River (Wilbur *et al.* 1979; Macdonald *et al.* 1990; Notable Discoveries 1998; USFWS data; J. Coatsworth, pers. comm.). Tidal inundation, which can carry off or drown eggs, and predation by raptors and mammals are the main causes of nest failure (Macdonald *et al.* 1990). Large storm events may destroy nests and make the habitat unsuitable for clapper rail use (Zedler 1993b). Lower marsh habitats can also be damaged from watershed runoff and made unsuitable for nesting (Zembal 1989).

- Since the light footed clapper rail is sedentary, the discontinuity of remaining salt marsh habitat restricts genetic exchange when breeding. Efforts are needed to reduce sedimentation and the channel filling of marshes.

There are other factors to consider regarding the clapper rail. One is that many remaining marshes are highly fragmented. This discontinuity of habitat restricts genetic exchange of the light footed clapper rail when breeding, since the bird is so sedentary. Inadequate tidal flushing can also result in the loss of both salt marsh cordgrass habitat, and the invertebrates upon which rails feed. Adequate tidal flow also prevents stagnation of the salt marsh and maintains salinity levels of the soil and water. For successful nesting to occur, high marsh areas must be protected from predators and disturbance. Efforts are needed to reduce sedimentation and channel filling of marshes caused by storms and flooding. Any species management plan must address the need to maintain salt marshes of adequate size and species diversity. Educating the public to the bird's sensitivity to human and domestic animal disturbance is also important (Macdonald *et al.* 1990).

2.6.1.4 California brown pelican—*Pelecanus occidentalis*

The migratory California brown pelican is a federal and state endangered species. In San Diego Bay, the pelicans, especially post-breeding juveniles, stage fall migration, roost, and prepare to scatter to find new territory (US Fish and Wildlife Service 1997a). Up to 85% of California's brown pelican breeding population of about 7,000 pairs (Small 1994) nests on the Coronado Islands (Schoenherr 1992). Others breed and nest in Mexico. Brown pelicans roost primarily on tire dikes and other artificial structures, seldom roosting on natural structures (US Fish and Wildlife Service 1995a). As many as 20,000 brown pelicans migrate from Mexico northward, following food associated with migrating ocean currents from about mid-May to November (Small 1994). Populations are at their lowest level around February.

The species underwent a considerable decline in the 1960s—mostly due to use of organochlorine pesticides such as DDT (Garrett and Dunn 1981). Pesticide residues in its prey are now drastically reduced, and the species has rebounded (R. Patton, pers. comm.; Small 1994). However, die-offs at the Salton Sea have probably delayed its likely delisting under the ESA. The major El Niño conditions of 1981–1983 also contributed significantly to their more recent decline. Population numbers are highly sensitive to fluctuations in anchovy abundance (Baird 1993).

2.6.1.5 Western snowy plover—*Charadrius alexandrinus nivosus*

The western snowy plover is a federally threatened bird species that nests in colonies on sandy beaches along the west coast of the United States and into southern Baja California (US Fish and Wildlife Service 1997b). They occur on the beaches in the San Diego Bay area, and on the salt work levees in the south Bay (Jehl and Craig 1970). Vegetation and driftwood are generally sparse or absent from plover nesting sites. Plovers may nest several times during the breeding season, which extends from March into mid-to-late September (Warriner *et al.* 1986; Terp 1996; Copper 1997a,b). There are usually three eggs per clutch, and the chicks hatch in approximately 27 days, leaving the nest within hours to search for food (Unitt 1984). The male plovers tend to care for the chicks, while the females will often nest again with a new mate (Terp 1996). Adults and chicks feed on terrestrial and aquatic invertebrates such as amphipods, sand hoppers, and flies (Cramp and Simmons 1983). Kelp wrack provides an abundant food source of the invertebrates that frequent these kelp piles. Mudflats are also used for foraging (A. Powell, US Geological Survey, pers. comm.).

- The western snowy plover population is present year-round; however, an estimated 70% migrates in winter.

The majority (78%) of the coastal breeding colonies in California occurs on eight sites from San Francisco Bay to Oxnard and the Channel Islands (US Fish and Wildlife Service 1997b). There were an estimated 282 snowy plovers in San Diego County in 1997 (Powell *et al.* 1997). Of the 174 nests in the county, approximately 35% were at Camp Pendleton, 21% at Batiquitos lagoon, and 37% were in the San Diego Bay area at several sites (in decreasing order of importance—NAB Coronado [Beach], SMNWR, Silver Strand State Beach, NAB Coronado [Bay], and NRRF) (Powell *et al.* 1997; Copper 1997a,b). An estimated 70% of the snowy plover population migrates in the winter, but the remainder are present all year (A. Powell, pers. comm). The San Diego Bay area also serves as the over-wintering grounds for plovers from Monterey Bay and Oregon (A. Powell, pers. comm.). San Diego Bay now holds much of the remaining nesting grounds for snowy plovers in Southern California (A. Powell, pers. comm.), where annual counts of snowy plovers are conducted at California least tern nesting areas around San Diego Bay (E. Copper, pers. comm.). As its natural nesting areas have come under development or heavy human usage, the salt pond area has become increasingly important for this species locally (Jehl and Craig 1970).

- Human activities during nesting season should be limited. Nesting areas with predator control programs in place have shown marked improvements in reproductive success over unprotected sites (US Fish and Wildlife Service 1997b).

Its preference for nesting on sandy beaches has led to its decline along the west coast, where much of its habitat has been developed or is subject to moderate-to-heavy human use (Copper 1997b; A. Powell, pers. comm.), especially since plover nests and chicks can be difficult to detect (Terp 1996). Foraging areas have also been compromised by development and human recreational use. Intrusion of salt marsh vegetation, or of nonnative vegetation, on plover nesting grounds may pose problems for plover chicks, possibly preventing them from moving freely to forage or escape incoming tides (Copper 1997a,b). Predation by birds and mammals (especially ravens, crows, and red fox) is the primary cause of reproductive failure for plovers (Copper 1997a,b; US Fish and Wildlife Service 1997b). A significant problem in San Diego County is predation of eggs by ravens and crows (B. Collins, pers. comm.). Nesting areas with predator control programs in place have shown marked improvements in reproductive success over unprotected sites (US Fish and Wildlife Service 1997b). Trash accumulation on the beaches can also act as an attractant to certain predators such as ravens and crows (US Fish and Wildlife Service 1998).

2.6.1.6 Sand dune tiger beetle—*Cicindela latesignata latesignata*

The sand dune tiger beetle (*Cicindela latesignata latesignata)* inhabits coastal dune habitats and mudflats. It is a federal threatened species that historically occurred at SMNWR, NASNI, and Imperial Beach. The only population located in the San Diego Bay area in 1979 was at the SMNWR, where it was present in low numbers. A larger population was found at Border Field at Tijuana Estuary. To date, these are the only known populations of this beetle.

2.6.1.7 Salt marsh bird's beak—*Cordylanthus maritimus maritimus*

Salt marsh bird's beak is a federally endangered species that is found in the saline and alkaline habitat of the high salt marsh (Hickman 1993; California Native Plant Society 1994). It is an annual, hemiparasitic plant that can tap into the roots of other plants to derive nutrition and water, possibly resulting in increased biomass and longer growing seasons than might be possible without this trait (Zedler 1996). The species ranges from San Luis Obispo County into Baja California (Reiser 1996). It inhabits a narrow elevation range in coastal salt marshes coinciding with the upper limit of high spring tide. It blooms from May to October (California Native Plant Society 1994).

Its abundance can vary significantly from year to year. Entire colonies have disappeared and reappeared two years later at Tijuana Estuary (Pacific Estuarine Research Laboratory 1996). Reduction and expansion of the salt marsh bird's beak population in SMNWR appear to be related to fluctuations in annual rainfall. Increases in plant cover can also reduce seed germination (Pacific Estuarine Research Laboratory 1996). The particular requirements of this species include suitable hosts (it may prefer *Distichlis spicata* and *Monanthochloe littoralis*), open canopies, soil moisture, appropriate salinities, low herbivory, and pollination success (Dunn 1987; Macdonald *et al.* 1990; Zedler 1992b; Zedler 1996). At SMNWR, some patches of bird's beak have been affected by seed predation by the salt marsh snout moth (*Lipographis fenestrella*), the degree of effect apparently being tied to flowering time of the patches (Zedler 1996). The abundance and species composition of pollinators, though, appear to have the greatest influence on reproductive success of bird's beak at SMNWR. Pollinators of bird's beak appear to be bees of the genera *Bombus*, *Halictus*, *Lasioglossum*, *Anthidium*, and *Melissodes* (Lincoln 1985; Zedler 1996). When pollinators of patches of bird's beak included Halictine bees, seed set was lower than when one or more of the genera was present, and overall pollinator visits were correlated with proximity to pollinator nests, bird's beak patch area, and clustering of patches rather than the density of individual patches (Zedler 1993a; Zedler 1996). Tidal inundation during the growing season is also necessary for the plant's survival. However, high mortality can occur as a result of unusually high tides and groundwater flooding (Vanderwier and Newman 1983; Zedler *et al.* 1992).

Fifty years ago, the species was found in eighteen southern California coastal marshes and was characterized as a "frequent" inhabitant of those in San Diego County (Purer 1942). Aside from the reintroduced population at SMNWR, only three populations are known in San Diego County: one at the Tijuana Estuary one at NRRF in Imperial Beach, and the other at the E. Street Marsh in Chula Vista (Reiser 1996; Zedler 1996; David Pivorunas, botanist, Commander Naval Region Southwest, pers. comm. 2000). Additional populations still persist in scattered locales throughout its original range. Management of this plant has involved vegetation monitoring since 1979. Salt marsh bird's beak had not been observed at SMNWR since 1987, but was reestablished there in 1991 to fulfill a California Department of Transportation mitigation requirement. Monitoring of these plants has indicated that although seed set was almost as high as the natural population for some colonies, for others it was very poor. Concern over the ability of the SMNWR population to become self-sustaining encouraged the Department of Transportation to fund a study on factors affecting reproductive potential of bird's beak. This research project has resulted in valuable information on the ecology of the plant and implications for its management. The reestablishment of bird's beak at SMNWR has been successful according to the mitigation criteria (three year period with at least 100 plants), with an estimated 14,000 plants in 1994 (Zedler 1996). The success of the population in terms of long-term stability is still not certain as there seems to be variation in population size from year to year and on longer time scales, due to unknown factors.

2.6.2 State Listed Species and Species of Concern

Belding's savannah sparrow—*Ammodramus sandwichensis beldingi*

Belding's savannah sparrow is a state endangered bird, and formerly a federal Category 2 species, that inhabits the salt marshes bordering coastal estuaries. It is a year-round resident of the salt marsh, mainly using the midmarsh pickleweed habitat. Belding's savannah sparrow nests in patches of pickleweed, boxthorn or other plant, of which its nests are built. It feeds on insects from most areas of the salt marsh, as well as in mudflat and dune habitats (Zedler 1992b). It will also feed on *Salicornia* when insects are scarce. Eggs are laid from mid-March to July, and the young are fledged in late April to August (Unitt 1984). The savannah sparrow can actually drink sea water, as it possesses a highly efficient urinary system for concentrating sea salts.

The Belding's savannah sparrow is an excellent indicator species for overall marsh quality because it spends its entire life in salt marsh habitat. Additionally, it is more easily seen than the secretive light footed clapper rail. Availability of undisturbed marsh land is the main limiting factor (Macdonald *et al.* 1990). There were an estimated 199 breeding pairs around San Diego Bay in 1977 (Massey 1977), and 230 in 1988 (Zembal and Massey 1988). Current populations include seventeen nesting pairs in the salt marsh strips along the dikes at the salt ponds, and 31 nesting pairs in the 27 acre (11 ha) area on the southeast corner of the study area between Emory Cove and the salt ponds (US Fish and Wildlife Service 1996). It has been estimated that 1 acre (0.4 ha) of upper salt marsh habitat can support fourteen breeding pairs (Massey 1979).

The Belding's savannah sparrow is vulnerable to predation since its nests are placed on or near the ground. Common predators include crows, skunks, rats, weasels, and domestic cats. The primary reason for the declines of this species, though, is habitat loss (Zedler 1992b; Small 1994).


Photo © US Fish and Wildlife Service 1999.

Photo 2-16. Belding's Savannah Sparrow on Pickleweed.

2.7 The Ecosystem as a Functional Whole

2.7.1 Ecosystem Attributes

In the previous sections of this chapter, San Diego Bay was looked at by components. We now view it as an integrated ecosystem with interacting parts. Ecosystems have the following types of organization:

- structural (what the parts are), such as their size, acres of each habitat, numbers of species and their relative abundance, etc.
- functional (what the parts do), such as the way they process solar energy into food chains, nutrient cycling, tidal energy and sediment transport, competition, and recoverability from disturbance.

Pressures are exerted on an ecosystem's integrity primarily by way of physical restructuring (such as loss or modification of habitat), impacts on the food web and other community functions (such as by introduction of exotics), and modification of natural disturbance regimes (such as weather extremes or climate cycles). This section describes how we know the most about physical restructuring of the Bay, but relatively little about effects on functional organization, or on disturbance regimes.

Figure 2-28 is an example of how complex a diagnosis of effects can be on a single species group, without consideration of ecosystem-level or cumulative effects.

2.7.2 Physical Structure

The physical structure of the Bay and its habitats is already described (see, for example, Section 2.2 "Physical Conditions" and Section 2.4 "Bay Habitats" and Map 3-1 on changes in the historic footprint of the Bay). One aspect of restructuring that has occurred is habitat loss. Others are change in pollutant load, sediment condition, hydrology, and morphology (such as fetch, exposure, cross-sectional depth profile, mean-depth to maximum-depth ratio, inlets and outlets, channels and islands), and adjacent upland to wetlands ratio (Adamus *et al.* 1987).

While we can describe the current physical parameters of the Bay and generally how they have changed based on sporadic surveys, we do not understand the strength of the dependency biota have on these various physical factors. Therefore, we can only suggest what the significance of changes over time. The Bay now is much smaller and deeper, traversed by channels, and contains more hard substrate. While in the past invertebrates requiring hard substrate had difficulty finding a home here, they now have abundant substrate around the Bay's perimeter stabilization structures, piers, docks, and the hulls of boats and ships. Large stream systems no longer contribute sediment or organic material, or much water to the system for flushing out pollutants. Water quality has improved since a historic and biota-devastating low in the 1940s through the 1960s.

- Severe losses of shallow-water, intertidal, and upland transition habitats have, beyond a doubt, reduced the Bay's carrying capacity, especially for migratory and some resident birds and mammals, and probably as a nursery and feeding ground for fish and shellfish.

However, severe losses of shallow-water, intertidal, and upland transition habitats have, beyond a doubt, reduced the Bay's carrying capacity, especially for migratory and some resident birds and mammals, and probably as a nursery and feeding ground for fish and shellfish. Carrying capacity is also, however, a matter of nutrient availability and the rate at which nutrients are made available for primary production. How these have been affected by historic changes and, more importantly, how these can be best managed, has never been examined.

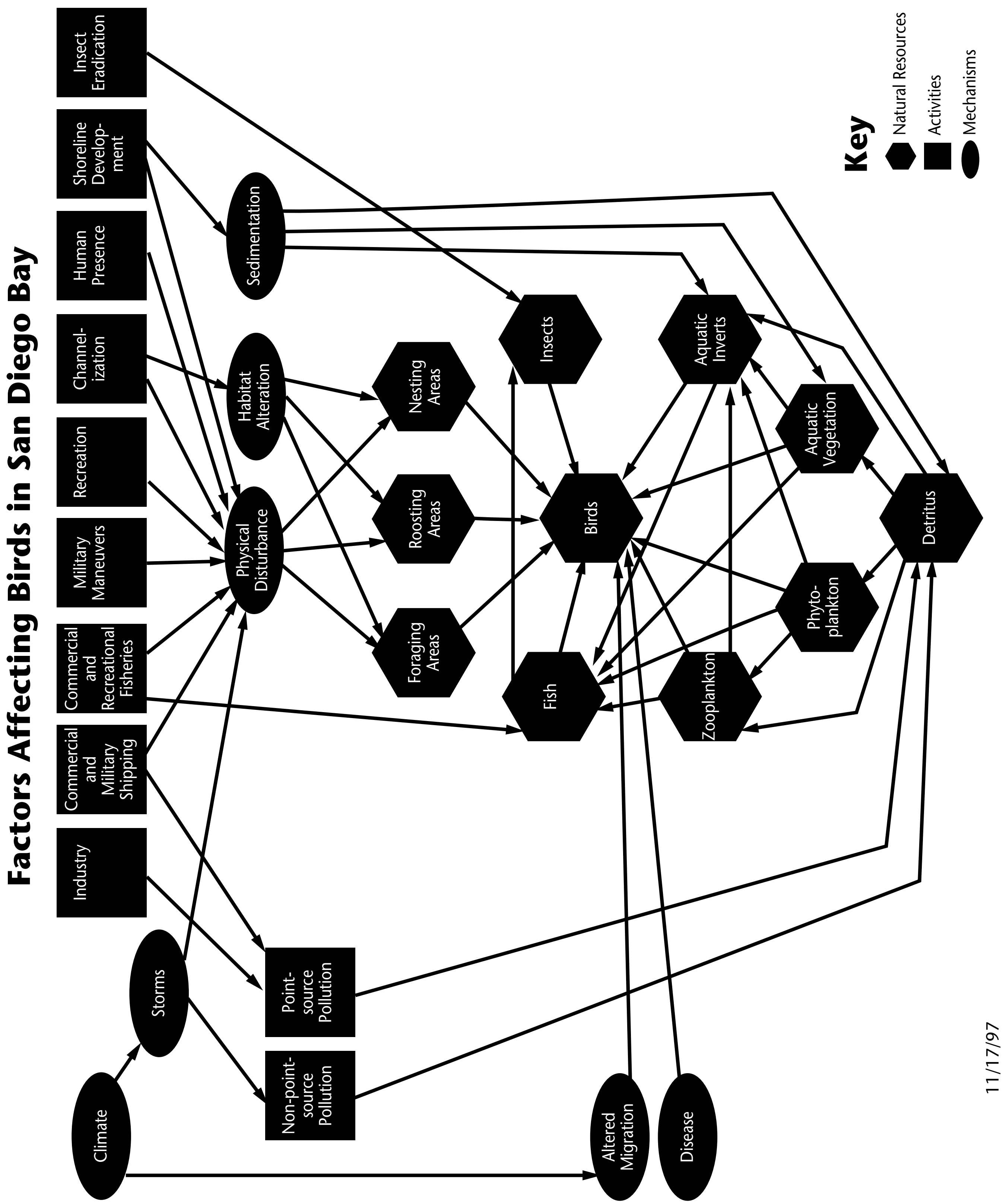


Figure 2-28. Factors Affecting Abundance and Diversity of Birds in San Diego Bay.

2.7.3 Community Organization

The way living things organize themselves can be an indicator of whether a system is healthy or degraded. A measure of this organization might be the percent of species in a system that is sensitive to toxics or other stressors, percent exotic introductions, relative species dominance, relative abundance, biodiversity within a taxonomic group, total biomass of a taxonomic group in an area, size class, and diversity of functional feeding strategies. External pressure on community organization may be exercised by overharvesting, introduction of exotics, and many other means.

A fundamental way biological communities organize themselves is by food webs. A food web must have primary producers to capture energy from the sun (algae, vascular plants, phytoplankton), a means of energy transfer by feeding, and nutrient cycling between the biotic and abiotic environment by excretion, bacteria, fungi, and detritus to provide nutrients back to primary producers. Figure 2-29 shows an example of a simplified San Diego Bay food web.

- The different habitats of the Bay are linked by these nutrient cycles and food webs. As tides and currents move water among the habitats, dissolved and particulate organic matter and nutrients also flow among the sites.

The different habitats of the Bay are linked by these nutrient cycles and food webs. As tides and currents move water among the habitats, dissolved and particulate organic matter and nutrients also flow among the sites. Fish and shellfish move among the communities as water covers their habitats. Birds will often feed in one habitat and nest in another, which expands the range of energy flow among habitats.

2.7.3.1 Nutrient Cycling

The amount of energy generated by photosynthesis is limited by the supply of nutrients, usually nitrogen, to the zone where light can penetrate. This is because while only carbon dioxide, water, and sunlight are needed to make simple sugars by photosynthesis, nutrients are needed to convert these sugars into organic compounds such as proteins and nucleic acids. A limited nutrient supply, in turn, limits the food available to consumers. An understanding of nutrient dynamics will give the resource manager more predictive and cause-effect capability about the abundance and distribution of organisms.

Studies conducted over a one-year period (Lapota *et al.* 1993) showed that stormwater flows that supply nutrients to the Bay may drive productivity. Other than these observations, nutrient availability has only been looked at in the salt marsh. It is likely that the nitrogen budget of the Bay's marshes is dependent on bacteria and fungi that recycle nitrogen from decaying organic matter and other microbes that fix nitrogen from the air. Compared with marshes of the Atlantic coast, the nutrient levels and nitrogen-fixation rates are very low. The reason for the lower nitrogen-fixation rates was explored experimentally and shown to be related to concentrations of soil organic matter (Zalejko 1989) and also related to coarse soil texture (Zedler 1991).

- Detritus derived from eelgrass probably represents the largest single source of energy-rich organic material available to the Bay.

Most energy flowing through the Bay passes through detritus-based food chains to consumer animals. Decaying algae is probably the most significant source of dissolved organic carbon consumed by microorganisms and invertebrate larvae. Currently, eelgrass leaves decompose and add a large amount of detritus to the ecosystem. Because much of the energy flowing through the Bay food webs is derived from detritus, eelgrass is important to productivity of the ecosystem as a whole. Detritus derived from eelgrass probably represents the largest single source of energy-rich organic material available to the Bay. A large amount of energy is lost or exported from the Bay after it is consumed by migratory birds and fishes.

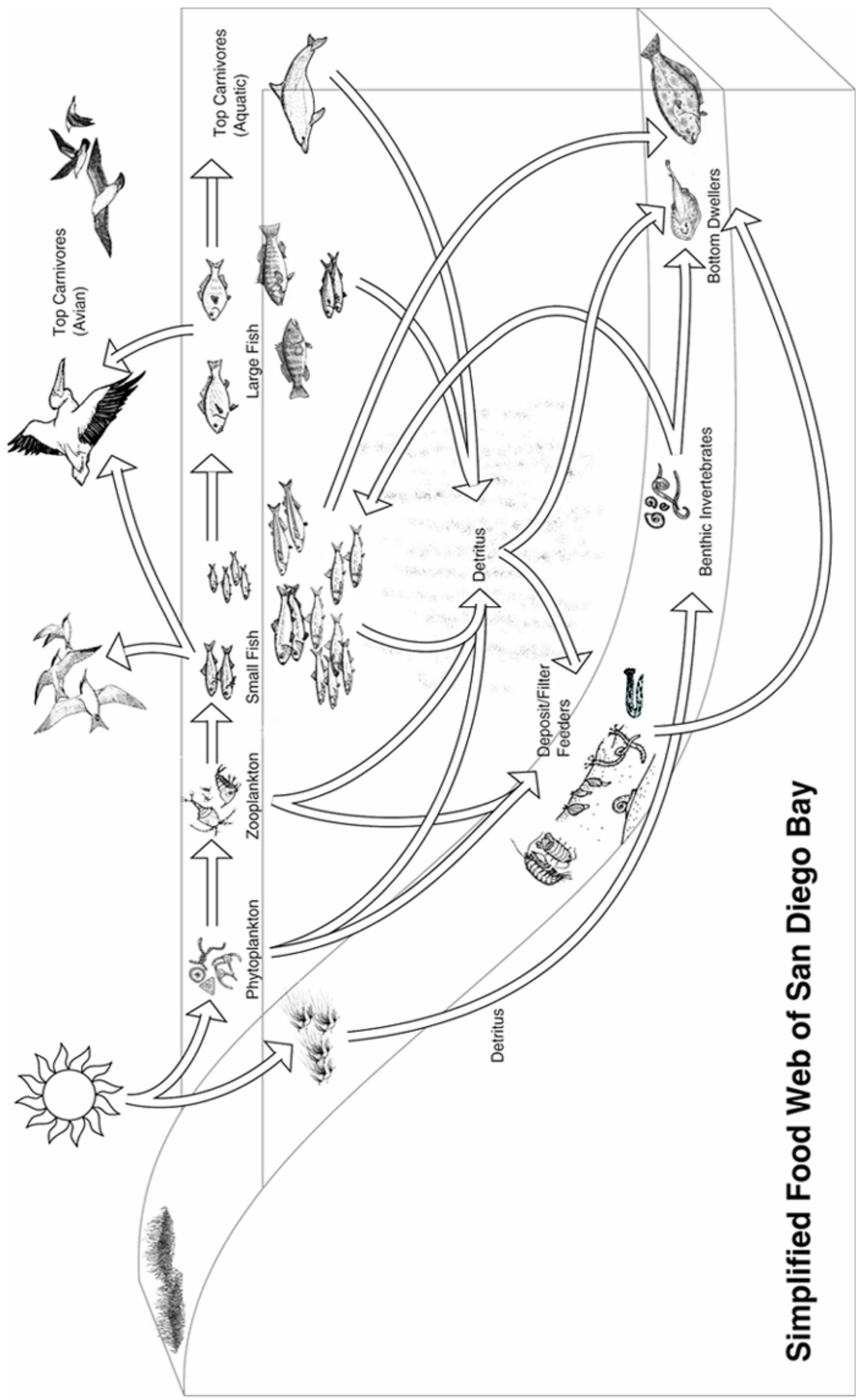


Figure 2-29. Simplified San Diego Bay Food Web.

It is also likely that organic matter from decaying marsh plants and leaves entering from riparian drainages supported a much more productive detrital food chain than exists today.

2.7.3.2 Primary Production

As with other ecosystem-level processes in San Diego Bay, primary productivity has been studied very little. The major primary producers are marsh grasses, eelgrass, macroalgae, algae and diatoms that live on mud, and phytoplankton adrift in the water (such as blue-green algae, green algae, and diatoms). Large concentrations of plankton produced in bays are sought out as a preferred food supply to sustain young anchovies, smelt, herring, and other juvenile and adult fishes.

- Large concentrations of plankton produced in bays are sought out as a preferred food supply to sustain young anchovies, smelt, herring, and other juvenile and adult fishes.

Studies on primary productivity have been conducted in the salt marsh (Zedler 1991). If comparable to other coastal embayments, productivity would be expected to be highest in the salt marsh, next in eelgrass, and lowest in mud or sand. However, the relative importance of different primary producers can vary: cordgrass productivity has been found to be lower than in other marshes of the Atlantic and Gulf coasts, possibly due to hypersalinity during droughts of southern California summers. Instead, open canopies of cordgrass admit light to the marsh bottom where abundant mats of filamentous, blue-green, and green algae and diatoms abound on nutrients carried in by the tides. The algae provide a matrix where dozens of species of diatoms can take hold. In both nearby Tijuana Estuary and Mission Bay, studies found the epibenthic, green algae to predominate only in winter, with blue-green algae and phytoplankton dominating in summer under conditions of high light and high temperatures (Rudnicki 1986; Fong 1991). By transforming sunlight and nutrients into biomass, algae provide food for invertebrate grazers such as worms and snails. Invertebrates provide biomass and an essential source of oil and protein for fishes and birds.

The spatial distribution of phytoplankton has not been looked at in the Bay. In other bays and estuaries, the slowest current, longest residence times for phytoplankton occur in dead-end sloughs and on flooded islands, where phytoplankton are far more abundant than in deep, dredged channels. In quiet waters that are shallower, warmer, richer in nutrients and have lower tidal circulation, plankton blooms will be much more pronounced.

- Phytoplankton and water quality studies along the Bay's longitudinal cross-section over a year-long period (Lapota *et al.* 1993) provide some insight into seasonal dynamics of phytoplankton. Blooms peaked in January.

Phytoplankton and water quality studies along the Bay's longitudinal cross-section over a year-long period (Lapota *et al.* 1993) provide some insight into seasonal dynamics of phytoplankton. Blooms peaked in January. This contrasts with peak blooms of the Tijuana Estuary. There, seasonal peaks in chlorophyll and cell counts occurred in spring when weather was warm and tidal action minimal, and prevailing winds caused algal mats to accumulate. At other times, tides continually dilute and export algae and maintain clearer water.

2.7.3.3 Energy Transfer Through Food Webs

Powered by the sun, primary producers are at the base of the food web, transforming solar energy and combining simple nutrients from the soil and water into the organic compounds that form consumable biomass. Some plant tissue is consumed directly, such as the black brant feeding on eelgrass, dabbling ducks on sea lettuce, or the globose dune beetle consuming ragweed leaves. However, most vegetation dies uneaten. The dead vegetation is attacked by decomposing bacteria and eventually breaks down into small, nutrient-rich, bacteria-coated detrital particles. This is then combed from the water column by filter-feeders or is gleaned off the surface by deposit-feeders.

Zooplankton feed on phytoplankton. In shallow water such as San Diego Bay, the filter feeding benthic invertebrates may compete directly with zooplankton for food. This situation is not present in offshore waters due to separation of layers exposed to light from the substrate below where invertebrates live (Nybakken 1997). Young predatory fish, shrimp, and benthic invertebrates feed on zooplankton. Invertebrates are then fed upon by carnivorous molluscs, bat rays, leopard sharks, bottom feeding fish like flounder and halibut, and shorebirds.

- Microbial portions of marine food chains have only been recently discovered.

The food chain depicted in Figure 2-30 depicts trophic levels from producers to a top predator. The illustration is very simplified and glosses over complexities such as predator-prey relationships that change throughout an animal's life history, and microbial portions of the food chain that have only recently been discovered in the field of marine biology (Castro and Huber 1997). This microbial portion refers to the flow of energy from phytoplankton, dissolved organic matter, bacteria, protozoan grazers, and zooplankton.

- The role of shorebirds in energy and nutrient transfer in intertidal habitats of southern California is substantial. They remove 17-40% of all invertebrate animal production on their wintering grounds. Sea birds are also important members of the upper trophic levels and are responsible for removing anywhere from 14 to 29% of various fish stocks.

We have an understanding of Bay food webs based on general knowledge of predator-prey relationships, but little specific data on the Bay's relative contribution to supporting resident and migrant species, nor on how it may change due to natural cycles or anthropogenic change. Baird (1993) examined the literature on the trophic importance of birds in the southern California bight. The energy transfer from invertebrate to bird predator varies widely from place to place, and no absolutely clear relationship seems to exist between productivity of prey and prey consumption by birds (Baird 1993). Shorebirds are one of the major paths of energy flow from intertidal benthic invertebrates (Goss-Custard 1977; Baird *et al.* 1985). They reportedly have removed up to 90% of the standing crop of prey, such as large *Hydrobia* or *Nereis*, during a single winter (Evans *et al.* 1979). A more conservative estimate is probably 35 to 60% (Goss-Custard 1977; Baird *et al.* 1985). Taking into consideration studies from Europe where this has been examined in more depth than in southern California, it is safe to say that shorebirds consume from 17 to 40% of all invertebrate annual production on their wintering grounds (Baird *et al.* 1985). Sea birds are also important members of the upper trophic levels and are responsible for removing anywhere from 14 to 29% of various fish stocks (Schaefer 1970; Robertson 1972; Furness and Cooper 1982; Furness and Ainley 1984, all cited in Baird 1993).

2.7.3.4 Biodiversity

Biodiversity has ecological importance and direct human benefits. The term is difficult to work with in a management context because it can be measured at a number of scales including genetic, species, population and ecosystem scales. Different scales are appropriate for different management decisions. The term also has many definitions from the perspectives of many knowledgeable individuals, and should only be used with reference to an explicit management objective.

While we do not attempt to discuss the biodiversity of the Bay in a qualitative or quantitative sense for this Plan, we have provided information from which such a discussion may be based. We have compiled a comprehensive species list for the Bay (Appendix D "Comprehensive Species List of San Diego Bay"), and an inventory of exotic introductions (see Section 2.5.7 "Exotic Marine and Coastal Species"). While we know of a few species extirpations, we know of many more exotic introductions. We do not know relative abundances or total abundances currently or in the past, except for a few highly visible species. We do know that the upland transition, intertidal and shallow habitats have expe-

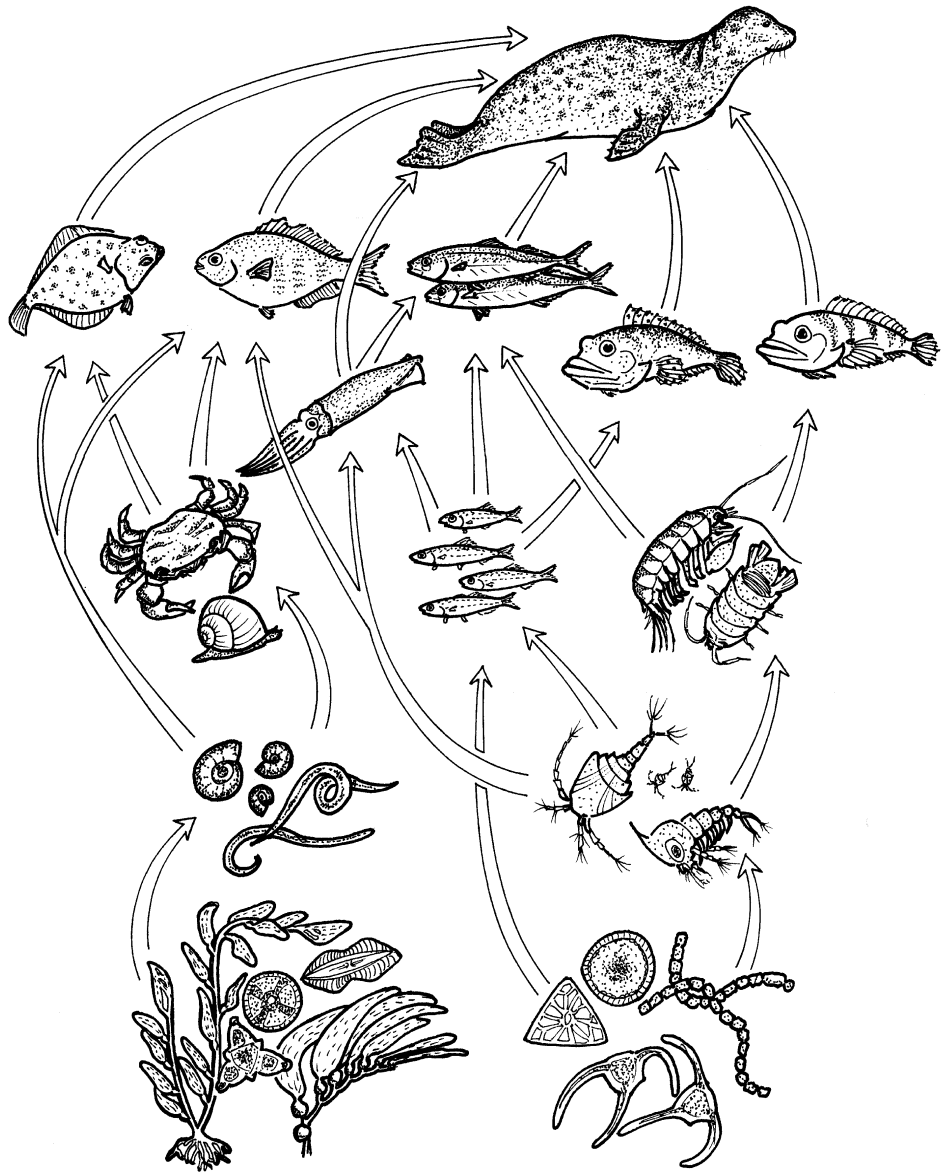


Figure 2-30. This Simplified Food Web Represents Trophic Levels From Producers to a Top Predator, Such as a Harbor Seal.

rienced dramatic losses overall and in proportion to deep water habitat, and that the carrying capacity of these now-scarce habitats has to have been reduced in comparison to historic values.

2.7.4 Disturbance Regimes and Time Scales of Change

The purpose of this section is to recognize that natural disturbance cycles exist in the Bay, but have not been characterized except to say that, like all ecosystems with a Mediterranean climate regime, the Bay exhibits high inherent variability. Comparisons of almost any ecological trend over time or space is not very profitable without accounting for natural variability, and our capacity to characterize ecosystem functioning at any single time or location is thus limited.

Natural cycles relating to San Diego Bay include diurnal, tidal, seasonal, El Niño-La Niña, and longer-term global climate shifts. Physical conditions in the Bay change with all of these cycles, as well as biotic conditions. While the strength and dependency of these relationships is not understood, there is widespread consensus that marine populations respond to climatic events and that major changes have taken place in the past twenty years in the marine ecosystems of the Pacific (Francis and Hare, cited in McGowan *et al.* 1998).

- By using sea surface temperature and sea-level pressure, scientists are learning that the relation between large-scale, low-frequency climatic variability and that of community dynamics and population biology is close.

There have been large sea-surface temperature changes off the West Coast of North America during the past 80 years both over years and over decades. Interannual anomalies appear and disappear rather suddenly and synchronously along the entire coastline, and the frequency of warm events has increased since 1977 (McGowan *et al.* 1998). By using sea surface temperature and sea-level pressure, scientists are learning that the relation between large-scale, low-frequency climatic variability and that of community dynamics and population biology is close, and, over time, of ecosystem structure and function (McGowan *et al.* 1998).

- Marginal Bay habitats are at risk from storms and tides, which can decrease prey availability up the food chain.

Temperature variations not only affect an organism's metabolic rate directly but also influence other equally important variables such as sea level, and therefore, the exposure of intertidal organisms, local currents and the movement of planktonic larvae. Erosional regimes are also influenced, including substrate structure, photosynthetic light intensity (cloudiness), water-column stratification and nutrient cycling, which in turn, affects production (McGowan *et al.* 1998). In the Bay, eelgrass beds may be affected because of changing water clarity, depth, and temperature. High tide refugia for avian species may be depleted, and there may be a loss of intertidal areas, such as happened in cordgrass habitat occupied by clapper rails in the Tijuana Estuary, decimating the clapper rail population. These marginal Bay habitats without protective buffers are most at risk, especially those that require special salinity conditions, intermittent inundation, or light penetration. Storms and tides with the highest amplitude of the year can cause the loss of habitat due to storm surges, or the overgrowth of vegetation at higher tidal elevations. When this happens, prey availability decreases sharply and shorebirds may no longer feed in the area (Baird 1993). Changes in water temperature affect mud temperatures, which has been correlated with the concentration of certain prey species (Goss-Custard 1979), and thus the availability of prey to shorebirds.

Finally, sea birds such as cormorants, loons, grebes, scoters, and alcids pursue their prey underwater, often to great depths. It has been demonstrated that in years when fish or invertebrates stocks may be stratified at greater depths, the pursuit divers tend to catch more of the preferred prey because they can sample the entire water column. It is also known that their reproductive output during these years remains at levels similar to those in good food years (Vermeer 1980; Baird 1991 cited in Baird 1993).

2.8 State of Ecosystem Health: Information Needs Assessment

- We need to develop specific, unambiguous criteria that relate ecosystem processes to some measures of Bay health. This can only be done by developing information about the Bay as a whole over the long term, rather than only about its individual parts, or on scales and time frames typical of routine projects.

One of the purposes of promoting an ecosystem vision for this Plan is to help establish criteria for managing human use of the Bay as a whole. Since we cannot return to the historical Bay as a desired "normal" reference condition, we need to develop specific, unambiguous criteria that relate ecosystem processes to some measures of Bay health, taking into consideration the current ecological context of the Bay and human standpoint of Bay users. This can only be done by developing information about the Bay as a whole over the long term, rather than only about its individual parts, or on scales and time frames typical of routine projects. Cumulative effects assessment, in particular, centers on understanding the complexity of interconnections among environmental variables and parameters over regional or extended time and space scales.

Ecosystem health may be described as a combination of vigor (energy flow, which means productivity and nutrient cycling), organization (complexity with respect to species number and variety and intricacy of interactions such as competition, mutualism, symbiosis, as well as interdependence between biotic and abiotic elements of the ecosystem) and resilience (capacity to recover from stress) (Rapport *et al.* 1998). It can also mean the sustained maintenance of ecosystem services to humans—such as detoxification of pollutants, water purification, military support, fisheries, boating, birdwatching, and the like. Human use can result in a reduction in quantity and quality of these services.

There are currently widely varying perspectives on the state of San Diego Bay's health. Looking at the habitat losses that have occurred this century, some say that the Bay is still healthy, that crucial components are still there, or that the changes are within the oscillations of natural cycles. Others claim that the system is polluted and seriously impaired in function. These differences in perspective are partly political posturing, but partly a result of a lack of knowledge about the conditions and trends of the Bay ecosystem.

- A fundamental problem is that current data sets have little predictive power. Much of the data for San Diego Bay have been collected in response to regulatory requirements, rather than ecosystem status and trends questions.

A fundamental problem is that current data sets have little predictive power. Much of the data for San Diego Bay have been collected in response to regulatory requirements, rather than ecosystem status and trends questions. Natural resource work has been done episodically for academic or regulatory reasons; for example, development of restoration methods to address compliance requirements, various masters theses, or US Navy work in relation to Navy activities. As a consequence, our understanding about the quality of habitats and about population trends is episodic and patchy. We can say the most about how to protect habitat acreages that remain. We can say little about cause and effect, ecosystem processes, or anything much more than acreage changes and a list of species.

The following discussion on information needs to describe the "State of the Bay Ecosystem" is organized in two primary parts: (1) what we need to know, and (2) what we currently understand. Individual studies describing our current state of knowledge are cited earlier in this chapter and are not repeated here.

2.8.1 What We Need to Know to Describe the State of the Bay Ecosystem

Table 2-30 is a synthesis of ecosystem-level management issues. Other management issues are addressed in later chapters. This table looks at two fundamental ways that human activities can affect San Diego Bay: by altering the physical structure of habitats and populations, or by altering the interconnections among habitats and populations (i.e. nutrient exchange, food webs, competition) that also support the ecosystem vigor, organization, and resilience described above. The table then asks whether these things are changing in San Diego Bay, which is the other key information element needed to support management decisions.

Table 2-30. Information Needs to Evaluate Whether Bay Ecosystem Health is Adequately Protected.

Key Ecosystem-level Management Issues	Key Questions to Address Management Issues	Example Information Needs
1. What is the condition of the Bay ecosystem, and what is the relative importance of factors that contribute to it?	Are habitats, singly and together, providing their full benefit with respect to supporting fish and wildlife populations, food chain pathways, elemental/nutrient cycling, and natural diversity? How do human activities such as military support, commercial shipping, recreation, and fisheries affect the continued viability of specific aspects of ecosystem functionality? What specific factors of ecosystem functionality are presently threatened? What is the relative importance of substrate, tidal flushing, nutrient flows from stormwater, predation, competition, or other parameters in contributing to or moderating these threats? What is the relative importance of climate cycles or naturally episodic events in structuring the ecosystem and driving change?	■ Habitat quantity. ■ Habitat use. ■ Models relating habitat use to the level and spatial pattern of basic indices of environmental structure: temperature, salinity, dissolved oxygen, nutrients, water transparency, sediment quality. ■ Abundance, spatial pattern of populations. ■ Species or functional diversity. ■ Models of adequate buffers, corridors, or connections to other habitats. ■ Habitat maturity (stability of plant composition, density and size). ■ Recolonization, reproductive and growth rates.
2. What is the trend of the ecosystem due to human activities?	Are basic markers of environmental structure changing, such as temperature, salinity, dissolved oxygen concentration, nutrients, and water transparency? Are the abundance, composition, or spatial distribution of populations changing? What are the correlations between changes in environmental structure and populations? Is productivity and nutrient cycling changing? Is community structure changing (diversity, patterns of dominance, relative importance of functional groups)? To what extent are specific, observed changes in the elements described above due to human versus natural causes, or local versus regional causes?	■ Long-term data sets that encompass local and regional variability and trends in abundances, water quality, etc. ■ Long-term data sets that encompass natural variability and trend. ■ Future use/trend models.

■ While loss of the quantity and quality of most habitats in the Bay has been substantial, the food web is another direct way environmental change influences ecosystems whether the change is natural or anthropogenic.

For San Diego Bay, losses of shallow subtidal, intertidal, and upland transition habitat quantity and quality have been severe. However, altered food chains and related aspects of environmental structure are another direct way that environmental change influences the ecosystem. This is crucial to management decisions because the relative importance of these influences to specific management questions is poorly known. Many of the changes seen in fish, bird, and mammal populations in the offshore waters of California appear to be caused by trophic interactions. The ecosystem changes in ways that affect the growth rate and abundance of the phytoplankton; usually a change in nutrient input causes this change in productivity. This, in turn, affects the abundance of the herbivorous zooplankton that feed upon the phytoplankton. The zooplankton are the food source for fish, birds, and mammals, either as adults or during their juvenile stages. There are strong correlations over time in the long-term trends in the abundance of the plankton and indices of physical structure of the environment (temperature, salinity, ocean currents). These changes in plankton abundance are clearly associated with climate change, and they have important effects upon fish, bird, and mammal populations (T. Hayward, Scripps Institute of Oceanography, pers. comm.).

- It is important to identify long-term trends in the Bay in order to support management decisions, so that variability that is natural can be sorted out from variability that is related to human activity.

Table 2-30 shows that one of the most important means of supporting management decisions on the state of the Bay health is by the study of long-term trends, and what drives those trends. Long-term trends are even more important to identify in a system such as San Diego Bay, which has high natural inherent variability compared to other systems. It is possible that extreme or episodic events such as storms, El Niño, and La Niña may regulate many fundamental processes in the Bay, but this cannot be determined with episodic or site-specific monitoring.

- Bay managers have direct control only over trends that are local and attributable to human activity. However, even if disturbance in the Bay is not the primary reason for a species' decline, it still must be managed as a declining resource if human influence is believed to be a contributing factor.

Once trends are established, the key to targeting monitoring efforts is determining whether changes in populations are due to natural variability or human influences, and, if the trends are anthropogenic, whether they are caused by local influences, which may be corrected by San Diego Bay management, or large-scale influences, which may be beyond the scope or only partly addressed by local management. Bay managers have direct control only over trends that are local and attributable to human activity. However, even if factors in the Bay are not the primary reason for a species' decline, it still must be managed as a declining resource if human influence is believed to be a contributing factor.

2.8.2 What We Currently Understand About Bay Ecosystem Health

Physical Conditions, Sediments, and Water Quality

Current State of Knowledge

We have documented changes in the Bay's historical dimensions and estimated the approximate extent of flow diversions and related sedimentation rates related to damming and channelization of streams. We have a general understanding of circulation, turbidity, temperature, and salinity gradients over seasons and along the length and depth of the Bay. We have learned that temperature and salinity are strongly correlated with the abundance patterns of Bay fishes.

We have a general map of grain sizes and organic matter, using data compiled from late 1960s to 1990s. We understand the general distribution of water and sediment pollution in the Bay, and the relative occurrence of water column pollutants as detected by the Mussel Watch Program. The ecological effects of thermal effluent from the south Bay power plant on the channel and south Bay's benthic invertebrate community have been studied.

- In the 1950s and 1960s, there was a "dead zone" along the east shore of the Bay. This zone was the result of built-up sewage sludge.

We have witnessed dramatic changes in historical water quality that impaired services to Bay communities so significantly that action was taken, and the resultant changes provide insight into the resilience of the Bay. We know that water quality conditions have improved since the 1950s and 1960s, when coliform counts were up to 70 mpn/ml, that there was a "dead zone" along the Bay's eastern shore due to sludge build-up to 3 ft (1 m) deep, and that eelgrass was reported to have disappeared from the Bay.

Much of the major structural changes in the Bay occurred during the same period that poor water quality was increasingly impairing Bay function. The relative importance of each impact is not known, except that life returned to the Bay after sewage treatment was rerouted to an ocean outfall.

A few long-term water quality assessments have been ongoing:

1. NOAA's National Status and Trends Program, *National Benthic Surveillance Program* (1984–present): physical, chemical, and biological (diseases and bioaccumulation in fish) parameters; offshore in central and north Bay.
2. NOAA's National Status and Trends Program, *Mussel Watch Project* (1986–present): bioaccumulation in mussels, plus other parameters; offshore in south Bay and intertidal and offshore in north Bay.
3. SWRCB and CDFG, *State Mussel Watch Program* (1977–present): bioaccumulation in mussels (transplanted), plus other parameters; offshore throughout entire Bay and Bay approaches.
4. SCCWRP, *General Monitoring Activities*: sediment, stormwater, tissue, ecological assessment; SCB (1974–present), San Diego Bay, Chollas Creek (1986–88; as needed). Implementation of the Coordinated Monitoring Program of the Bay Panel.

Limitations of Knowledge for Understanding Bay Physical Conditions

We cannot answer fundamental questions about the "State of the Bay" as described in Table 2-30 with respect to physical and chemical parameters. For instance, to what extent do these factors contribute to the abundance, distribution, and diversity of Bay biota? What is their relative importance in supporting habitat quality, providing food chain support, and other functions? Are these fundamental environmental factors changing over time?

Despite programs that monitor bioaccumulation, we cannot say whether it is safe to swim in the Bay or to eat fish and shellfish from the Bay. We do not know how much the Bay's watershed is presently contributing to water quality impairment.

The effects of copper on plankton and benthic communities are not quantified from sources such as diffusion from antifouling paint applied to boat hulls in marinas, in-water hull cleaning, and urban runoff. Nor are the effects documented of PAHs on plankton and benthic communities. There is no understanding of atmospheric fallout of pyrogenic PAHs and pathways to receiving waters. The occurrence and bioavailability of many chemicals remain unstudied. There is a lack of understanding of the relationship between amphipod survival in sediment, sediment pore concentrations, and diversity in benthic communities.

Habitat Structure

Current State of Knowledge

We have a fundamental understanding about the location and acreage of Bay habitats, and the significant loss of shallow and intertidal habitat acreage due to human intervention. We have lost carrying capacity based upon this acreage reduction. We may have lost additional carrying capacity beyond that associated strictly with acreage loss of a habitat type, based on linkages between habitats, and the break-up and isolation of parcels. Loss of natural intertidal shoreline continues.

We have developed a significant amount of expertise in protecting and restoring eelgrass and salt marsh habitat, based on the requirement to comply with mitigation or restoration criteria.

Limitations of Knowledge for Understanding Bay Habitat Structure

We do not know what attributes of structure in each habitat contribute most to carrying capacity and ecosystem function, or if these are changing.

Habitat and Population Functions

Current State of Knowledge

We have a general understanding of habitat partitioning and use by the various species groups and individual sensitive species, and how one habitat may be used by organisms from other habitats for specific life cycle needs, such as feeding, resting, shelter, nursery, etc.

Limitations of Knowledge for Understanding Bay Habitat Function and Trend

Functions or linkages among habitats and populations are too poorly understood to assess their significance, strength of dependency, or priority. For example, are patterns of dominance and diversity changing? What is the role benthic communities play in providing nutrients to primary producers in the water column? Is the amount and quality of the food eaten by birds limiting their numbers, the number and nature of competitors that compete for the same food and habitat resources, or the number and nature of the predators that feed upon them? Alternatively, is overall ecosystem "quality" (e.g. temperature, salinity, pollutant load, water transparency, etc.) regulating bird productivity? We do not understand the relative importance of these factors in contributing to the Bay's functional health. Finally, we do not know how the controlling factors are changing over time.

Plankton

Current State of Knowledge

Studies of plant and animal plankton inhabiting south Bay characterized different plankton groups. Phytoplankton assemblages from central and north Bay sites have also been described at certain points in time. These studies indicate that San Diego Bay supports plankton assemblages similar to those of other large bays in the temperate zone, and that at least south Bay is similar to other bays and estuaries of southern California, in that individuals are volumetrically quite abundant, but there are relatively few species.

- Mean chlorophyll levels for the Bay as a whole do not show major changes seasonally, but a relatively large increase in mean chlorophyll levels has been measured in January, primarily in south Bay. This increase was the result of stormwater runoff into the Bay at that time, which carried high nutrient loads.

The seasonal patterns and interrelationships of physical, chemical, and phytoplankton characteristics of the Bay were studied in 1993. Seawater clarity was reportedly highest in the fall and lowest in winter and early spring. Mean chlorophyll levels for the Bay as a whole did not show major changes seasonally, but a relatively large increase in mean chlorophyll levels was measured in January, primarily in south Bay. This increase clearly was the result of substantial stormwater runoff into the Bay at that time, which carried high nutrient chemical loads. Increased photosynthesis by phytoplankton in the Bay in January also resulted in greater oxygen production, leaving higher concentrations of dissolved oxygen in the seawater.

It is believed that the numbers of species and the densities of many species of zooplankton are greater in north rather than south San Diego Bay. Zooplankton from the north Bay consists of a higher proportion of species that remain in planktonic form throughout their life cycle and a somewhat lower proportion of meroplankton or "temporary" plankton species. The meroplankton represent the most diverse and abundant zooplankton component of the south Bay.

Limitations of Knowledge for Understanding the Status and Trend of Plankton

- In offshore waters, there are strong correlations between plankton abundance, physical factors such as sea temperature, and disturbance patterns such as climate change.

An understanding of long-term trends in species composition, large-scale distribution, abundance, and seasonal dynamics of Bay plankton would help evaluate possible relationships between these characteristics and the physical or environmental structure and dynamics of the Bay. In the offshore waters, there are strong correlations between plankton abundance and physical parameters. These changes in plankton abundance are clearly associated with climate change, and they have important effects upon fish, bird, and mammal populations. If this is also true of San Diego Bay, then there is a fundamental need to separate these dynamics from those caused by local, human-induced impacts. Then the question can be asked: can the major factors responsible for changes and long-term trends in plankton characteristics be controlled by management practices, or are they either natural or anthropogenic conditions beyond the control of Bay managers?

Algae

Current State of Knowledge

We have a general understanding of how algae distributes itself among habitats, and which are more opportunistic than others and thus related to disturbance patterns. However, there have been no specific studies of algae in San Diego Bay except in the salt marsh. There are only observations made during studies with other objectives.

In salt marshes near those of San Diego Bay, (Mission Bay and Tijuana Estuary), epibenthic algal mats underneath the open canopy of the vegetation have been shown to match or exceed the productivity of vascular plants. Epibenthic algae predominated only in winter, whereas mats with blue-green algae and diatoms dominated in summer. High light and high temperatures favored blue-green algae and phytoplankton, whereas low light and low temperature stimulated the green macroalgae. Lower salinity delayed phytoplankton blooms, and the species composition changed to more blue-green types.

- Large areas of unvegetated shallows contain extensive masses or mats of living algal material interspersed with areas of exposed sediment that may extend into the intertidal. These mats provide physical structure, cover, or refuge from predators and food for invertebrates and fishes.

In the unvegetated shallows, abundant algae (and invertebrates that grow on eelgrass leaf blades) provide primary and secondary productivity for consumption by larval and juvenile fish. Large areas are often covered by extensive masses or mats of living algal material interspersed with areas of exposed sediment that may extend into the intertidal. The dense, heavily branched red alga *Gracilaria verrucosa* forms the bulk of this mat, which also includes the red algae *Hypnea valentiae* and *Griffithsia pacifica*. These mats are an important subhabitat, providing physical structure, cover, or refuge from predators and food for invertebrates and fishes.

Limitations of Knowledge for Understanding the Status and Trend of Algae

- As a pollution or disturbance indicator, algae can play a key role.

As primary producers and food for zooplankton, invertebrates, fish, and some birds, algae play an important ecosystem role. They can impart habitat structure in some situations. Algae can also play a key role as a pollution or disturbance indicator. Yet, we have little information on how the abundance, distribution, and composition of algae relates to physical environmental factors in the Bay. Fundamentally, their ecosystem role in the Bay is obscured by a lack of information on how these attributes change over time as compared to changes outside the Bay.

Invertebrates

Current State of Knowledge

Despite fairly extensive studies of south San Diego Bay since the early 1970s, ecological information about benthic invertebrates in the Bay as a whole has not been characterized. This is true for infaunal and epifaunal invertebrates inhabiting unconsolidated sediment and for epifaunal species associated with man-made structures. The information gap is greatest for the central and north Bay regions. However, we do know that the infaunal species assemblages of south Bay are similar to neighboring bays that are in a more natural condition. We also know that polychaete worms, crustaceans, and molluscs are the dominant invertebrate fauna living on and in the soft bottom sediment of south San Diego Bay. This is true for most soft bottom habitats everywhere. Finally, we know that there is a much richer fauna in "back harbor" sites with a few boats, than in similar sites with a large number of boats. Motile invertebrate species were found to be associated with microhabitats rather than number of boats.

Limitations of Knowledge for Understanding the Status and Trend of Invertebrates

- The strength of the relationship between benthic invertebrates and primary producers is not yet understood.

The abundance and spatial pattern of invertebrates is largely undescribed, and so it is unknown to what extent these may regulate populations at higher trophic levels in the various habitats of the Bay. Benthic invertebrates can have a limiting role in supplying nutrients to primary producers, but the strength of this relationship in the Bay is far from being understood. Also unknown is to what extent the seasonal and long-term changes in invertebrate assemblages are correlated with changes in such environmental factors as temperature, sediment grain size composition, and the presence of chemical toxicity in the sediments or surrounding water. Can the important factors responsible for changes and long-term trends in the characteristics of these invertebrate assemblages be controlled by management, or are they either natural or anthropogenic conditions beyond the control of Bay managers?

Fishes

Current State of Knowledge

Recent and past work on Bay fishes has now provided a comprehensive characterization of fishes in nearshore habitats of the Bay, as well as good time series data and important information about species assemblages in most fish habitats throughout the Bay. The work documents a strong correlation, accounting for nearly 95% of the variance, between temperature and salinity and individual fish species abundances at sampling stations over a sampling month.

Limitations of Knowledge for Understanding the Status and Trend of Fishes

With the availability of time series data and attempts to relate abundance of fishes to physical parameters, there has been a basis for discussion of how fish populations can change over the short term. New studies should be conducted to better characterize the fish species assemblages associated with different artificial or man-made habitats in San Diego Bay. Very little is known about these assemblages and the environmental factors affecting their populations.

An evaluation of long-term trends in the composition, large-scale distribution, and abundance of fishes from an ecosystem perspective is still needed, emphasizing the relationships between these biological characteristics and unstudied physical or environmental structure and dynamics of the Bay.

For example, are the seasonal and long-term changes in fish assemblages and fish species abundances correlated with changes in such environmental factors as temperature, sediment, or the presence of chemical toxicity in the sediment? Can the important factors responsible for changes and long-term trends in the characteristics of these fish assemblages and populations be affected by management, or are they either natural or anthropogenic conditions beyond the control of Bay managers?

Birds

Current State of Knowledge

The joint agency-sponsored bird surveys conducted in 1993 and 1994 as well as earlier surveys of south Bay provide the most comprehensive description of abundance and diversity of Bay birds to date. Despite data limitations in some regions, these surveys and other project or site-specific ones have produced an overall picture of habitat use and spatial distribution of Bay birds. However, it is essentially only one point in time.

- Bird species declines are related to habitat loss and other causes.

Declines of bird species are recognized primarily due to regional data-gathering along the Pacific Flyway or anecdotal observations. However, we do not know if San Diego Bay is contributing to these declines. While it is believed that declines are related to habitat losses both in the Bay and elsewhere along the Flyway, there is a strong possibility that particular declines are due to some other cause. A well-known example is bioaccumulation of the pesticide DDT in the California brown pelican. Other pesticide-related declines may still be occurring that migrate to countries where such pesticides remain unregulated.

Limitations of Knowledge for Understanding the Status and Trend of Birds

While the contribution of San Diego Bay to supporting birds is known in a general sense, how physical or chemical factors contribute to habitat quality supporting these populations has only been examined for species that are listed under the ESA. How the proximity of one habitat to another affects predator-prey relations, and how important this is to other ecological processes, is also not known. Therefore, how to maximize the carrying capacity of Bay habitats for birds is far from understood. Whether bird use of the Bay is most limited by physical structure or ecological relationships such as food availability, predation, or competition is not known. As birds are at the higher end of the food chain, understanding of the dependencies and reasons for change in bird populations is complex. Experienced managers have a sense of what is lacking, especially knowing the severe habitat losses in areas birds depend upon, but their decisions need support from monitoring and research.

Marine Mammals

Current State of Knowledge

- Effects of pollution on certain marine mammal species in the Bight has been studied.

Stock assessments and monitoring by NMFS of marine mammals along the California coast provides abundance and trend data on marine mammals on a regional basis. Prey species have been studied for the sea lion and harbor seal in the Channel Islands, for the gray whale in the eastern Pacific, and for the bottlenose dolphin in other oceans. The effects of pollution on certain marine mammal species in the Bight have been studied.

Limitations of Knowledge for Understanding Status and Trend of Marine Mammals

We have little information on specific distributional patterns and times marine mammals use the Bay. We do not know whether availability of prey, hauling out substrate, or local pollution problems affect habitat use, or larger-scale factors beyond the Bay's borders.

Our current level of knowledge reveals deficiencies regarding both how the Bay contributes to marine mammal populations, and on the significance of the role played by marine mammals in Bay food webs.

Exotic Species

Current State of Knowledge

- With reference to exotic species, we have knowledge of invasions and population explosions.

Initial identification of exotic marine and coastal species in the Bay has been based on short-term surveys for other purposes. Tunicates (ascidians) are the best-surveyed group in the Bay—nonindigenous tunicates are now the dominant fouling organisms in sheltered marinas and harbors. There has been ecological damage documented from the Japanese mussel, *Musculista senhousia,* on Bay habitat and eelgrass and from the isopod *Sphaeroma quoyanum* on Paradise Creek's salt marsh. The distribution of coastal plant exotics has been studied in areas like SMNWR, and during surveys of Navy properties in support of their INRMPs. We know that projects that alter hydrologic regimes or create disturbed sites may increase the probability of exotic coastal plant establishment in the salt marsh. We know restored wetlands appear particularly vulnerable to invasions. Human-induced changes in ecosystems, such as disturbance or removal of grazers (even if exotic), can create a sudden population explosion of an exotic species.

Limitations of Knowledge for Understanding Status and Trend of Exotic Species

- Establishing the trend in abundance and location of exotic species is important to detect population explosions before they become extensive.

There has been no survey targeted specifically to document the distribution and abundance of exotic marine and coastal species in the Bay. With inadequate taxonomy impeding the consistent separation of native from nonindigenous marine invertebrates, establishing the trend in abundance and location of exotic species is important to be able to detect population explosions of invasive species before they become too extensive. We do not know which species can cause or are causing ecological damage to the Bay's ecosystem, and infrequent sampling prevents the detection of a new exotic with known high potential for invasiveness and ecological damage as it arrives in the Bay. Effects of the Bay's water and sediment quality on the ability of exotics to compete with native species have not been studied. Finally, we are lacking a thorough evaluation of native species, particularly plankton and bacteria, in the Bay ecosystem to evaluate the effect of exotic species.

Sensitive Species

Current State of Knowledge

We know the most about species that are protected under the ESA, and for which mitigation is required for human activity. The California least tern has benefited from study of its breeding, nesting and foraging needs, as well as predator management. Documentation of nesting and fledging success over a period of years allows discussion of trends both within and outside the Bay, and appropriate adjustment of management decisions. Documentation of western snowy plover abundance and nesting success has also benefited from California least tern work, since they often nest in the same area.

While there has not been successful reestablishment of clapper rails in restored salt marsh, much has been learned toward this end during restoration attempts. Numbers of Belding's savannah sparrow and California brown pelican are monitored on a large-scale basis outside the Bay, and sporadically within the Bay. The green sea turtle is monitored for abundance, growth rate, seasonality, and food use, among other things.

Limitations of Knowledge for Understanding Status and Trend of Sensitive Species

While we know the most about listed species of the Bay, and successful management efforts are evidence of this understanding, there are specific information gaps that should be addressed for each species. We make no attempt to summarize those here but, as an example, we still do not understand what factors control the green sea turtle's movement to, from, and within the Bay. For nonlisted sensitive species without specific legal protection, what is known may simply be basic life history, habitat associations, and former distributions. Some of these have not been relocated in a number of years and may no longer survive in Bay habitats.