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Southern California

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The Southern California Bight (SCB) has undergone tremendous changes over the last 100 years resulting from natural and anthropogenic alteration of the coastal zone. A large influx of population during the 1900s has propelled the coastal community along the SCB from $<200{,}000$ in 1900 to the largest metropolitan centre in the US ($\gg$17 million) in 1998. This rapid urbanization has placed extreme pressures on marine resources, including loss of habitat, discharge of pollutants, and overfishing.

As population has grown in the four counties bordering the shoreline of the SCB, so have discharges of pollutants to the ocean. The major source of pollutants in the early 1970s was publicly owned treatment works (POTWs). Regulation of these has led to improved treatment, source control, and pretreatment programs. As a result, cumulative pollutant loads for POTWs have been reduced several fold, even orders of magnitude for some. Similar to trends observed in many areas of the nation, non-point sources have become larger contributors of potential pollutants as POTWs have reduced their inputs. In the SCB, urban runoff contributes more trace metals (chromium, copper, lead, and zinc) and nutrients (nitrate and phosphorus) than all other sources combined.

As the inputs of pollutants have declined and dominant sources have shifted, the fate and distribution of pollutants in the SCB has changed over the last 30 years. Studies have observed decreasing concentrations in water, sediments, and biota. For example, decreasing concentrations in near-surface sediments are recorded in sediment core profiles. Also, fish tissue concentrations have decreased compared to similar measurements made in the 1970s and 1980s. However, legacy inputs continue to place both the marine ecosystem and public health at risk. Among the most important constituents of concern in the SCB is total DDT (o,p' and p,p' isomers of DDT, DDE, and DDD). Total DDT is widely dispersed; it is measured in 89% of the SCB sediments and has contaminated nearly 100% of Pacific and longfin sanddab populations. In regions where sediment concentrations of total DDT are highest (e.g., Palos Verdes Shelf), commercial fishing is prohibited and recreational anglers are warned about consuming tainted bottom-feeding fish.

Along with reductions in pollutant inputs over the last 30 years, scientists have observed the recovery of some marine ecosystems. Five phylogenetic groups are evaluated in this article, including kelp (algae), benthic invertebrates, fish, seabirds, and marine mammals. Among the most-studied groups are benthic infauna and fish communities. In 1994 approximately 91% of the SCB mainland shelf contained benthic communities classified as 'reference'. Although fish diseases (e.g., fin rot and epidermal tumours) were common in the 1970s, their occurrence is currently at background levels. In almost all cases, interactions have occurred between natural and anthropogenic factors. For example, kelp beds near large POTW discharges that were a fraction of their historical extent in 1970 have shown exceptional recruitment and are currently flourishing. However, during the same time period, natural events such as the 1987–1988 El Niño negatively impacted the kelp and reduced bed extent to levels not observed since 1970.

Ecosystem management of the SCB is improving as we enter the new millennium. The improvement began when resource managers recognized that traditional monitoring programs were not providing the information they needed to make responsible stewardship decisions. Regulatory and permitted discharge agencies have since created an open dialogue to identify the most important monitoring objectives. In addition, they have cooperatively designed and implemented a coordinated, integrated regional monitoring program. Regional monitoring has evaluated the full range of natural variability and cumulative impacts from multiple discharges, enabling assessment of the overall condition of the SCB.

Physical and Biological Setting

Geography and oceanography

The SCB is an oceanographically defined region off southern California in the US (Fig. 1). This area is formed where the coast makes a sharp bend to the east, causing the southward-flowing California Current to flow far offshore before intersecting the mainland again in northern Baja California. The SCB extends from Point Conception, California (lat. 34°30′N; long. 120°30′W), in the northwest to Cabo Colnett, Baja

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Fig. 1 Map of Southern California, including general circulation patterns in the SCB (after Hickey, 1993).

California (lat. 31°00′N; long. 116°20′W), in the southeast, and is bounded to the west by the California Current (SCCWRP, 1973; Dailey *et al.*, 1993). It includes an area of approximately 78 000 km^2 with a shoreline distance of over 300 km (Dailey *et al.*, 1993).

Surface waters of the SCB flow in a large, counterclockwise eddy, where the warmer surface waters from the northerly flowing Davidson Countercurrent mix with the colder, southerly flowing California Current. Water temperatures range from 12°C to 16°C north of Point Conception and $\gg$18°C in Baja California, whereas temperatures range from 14°C to 20°C in southern California (Eber, 1977).

The oceanic environment off southern California varies decadally (Smith, 1995) and aperiodically, such as during El Niño (anomalously warm) and La Niña (anomalously cold) events (Murphree and Reynolds, 1995; Lynn *et al.*, 1995). El Niño events occur when the location of atmospheric high and low pressure areas in the southern hemisphere shift (hence, El Niño–Southern Oscillation or ENSO). During an El Niño event, the California Current flow weakens, water temperatures increase, and the thermocline deepens as warm, saline, oligotrophic water moves north into the SCB (Lynn *et al.*, 1995; Murphree and Reynolds, 1995). The reverse occurs during La Niña events. During normal periods, the California Current is strong, as is upwelling, and waters are cooler and more productive. Strong El Niño events affected the SCB in 1929–1930, 1957–1959, 1982–1983 (Smith, 1995), and 1997–1998. Strong La Niña events occurred in 1933, 1975–1976, and (with less cold water) 1988–1989 (Smith, 1995). Water temperatures were cooler than normal from 1942–1976 (except for the 1957–1959 El Niño event) and warmer than normal prior to 1942 and since 1976 (particularly since the 1982–1983 El Niño event (Smith, 1995).

The waters of the SCB overlie the continental borderland of southern California (Emery, 1960; Dailey *et al.*, 1993). The outer edge of the borderland is the Patton Escarpment, which lies some 250–300 km offshore, and is defined by a sharp change in slope at 1000 m. The continental borderland consists of a number of offshore islands, submerged banks, submarine canyons, and deep basins. The result is an unusually narrow mainland shelf, which averages 3 km in width (ranging from 1 to 20 km) and ends in waters of 200 m depth. Elsewhere in the US, the mainland shelf may be 10–200 times wider. The narrowness of the mainland shelf in the SCB makes it particularly susceptible to human activities.

The dominant bottom environment in the SCB consists of sandy and muddy sediments (Emery, 1960; Dailey *et al.*, 1993). Sediments with high percentages of sand generally dominate the shelf, whereas sediments with high percentages of silt generally dominate the slope and basins. Along the mainland shelf, rocky bottoms are most commonly found inshore near rocky headlands, along edges of submarine canyons, and at the shelf break. Only rarely do outcrops occur in deep water (i.e., Santa Monica Bay and San Pedro Bay). Rocky bottom is more common along the shelf of the offshore islands and banks where the supply of sand and silt is minimal.

Biogeographic Provinces and Habitats

The SCB is a rich ecosystem; over 5000 species of invertebrates, 480 species of fish, and 195 species of marine birds are found in this region (Dailey *et al.*, 1993). The diversity found in the SCB is owed, in part, to its transitional zonation between two biogeographic provinces. The San Diegan Province to the south introduces sub-tropical species while the Oregonian Province to the north introduces temperate species into the SCB (Briggs, 1974). Each of these provinces has distinctive biota. For example, more than 70% of all algal species found in California occur in the SCB; half of these species have their northern or southern range endpoints located within the SCB (Murray and Bray, 1993).

A number of habitats are found in the SCB, based upon geo-physical structure or other properties of the environment. These include water-column, hard-bottom (and kelp beds), and soft-bottom (sand and mud) habitats. The intertidal zone is a unique habitat due to tidal influences. Estuaries are also unique as they respond to variability in salinities. Estuaries and lagoons in the SCB are typically small (<2 km^2) and have little natural runoff, except during winter storms. Salinity decreases dramatically to near zero during winter storms, whereas estuaries become hypersaline during hot, dry periods.

Hard-bottom habitat provides substrate for attachment of algae and sessile organisms, and crevices for refuge for mobile organisms. Hard-bottom habitats frequently have abundant algal cover in shallow water. Subtidal hard-bottom habitat occurs primarily near headlands and near the shelf break and outcroppings on the shelf. It is more abundant on the islands than on the mainland shelf.

Kelp beds (consisting largely of giant kelp, *Macrocystis pyrifera*) are usually attached to hard-bottom substrate and provide vertical structure of the habitat to the sea surface. This increases the complexity of the habitat, with tangled holdfasts at the bottom, columns of kelp stipes in midwater, and a dense canopy of kelp blades at the surface. For many invertebrates, this substrate also provides a source of food. Kelp beds are typically found at depths shallower than 30 m, being limited by light penetration (Quast, 1968). Kelp beds are patchily distributed along the coast, with large beds in the Santa Barbara area, on the Palos Verdes Shelf, near Point Loma, and on the Channel Islands (CSWQCB, 1964). Unlike hard-bottom habitats, the distribution and extent of kelp beds changes more readily, as kelps are dislodged by storm swells or die off in periods of low nutrients (Stull, 1995).

Soft-bottom habitat is the most extensive benthic habitat, particularly on the mainland shelf, slopes, and basins. Soft-bottom habitat consists of sandy and muddy sediments with much less relief than hard-bottom habitat. Patches of sediment differing in grain size (e.g., gravel, sand, silt, clay) provide distinct habitats to different species of infaunal organisms; however, polychaetous annelids dominate in most unimpacted regions. Grain size covaries naturally with depth on the mainland shelf of the SCB. As a result, four soft-bottom communities are often defined by depth (Bergen *et al.*, 1999; Jones, 1969): a shallow water assemblage (<30 m), a mid-depth assemblage (30–120 m), and two deep assemblages (120 to >200 m) segregated by grain size (stratified at approximately 40% fines).

Human Contributions and Anthropogenic Inputs

Southern California has over 17 million people and is one of the most densely populated areas in the nation. Nearly 25% of the nation's coastal population lives in the four coastal counties that border the SCB (Culliton *et al.*, 1990). In fact, the population of the SCB has doubled in the last 30 years and is expected to increase another 2 million by 2010 (Fig. 2). Rapid urbanization represents risk to the coastal ecology by encroachment of habitat and by contributing anthropogenic contaminants to the coastal environment.

The loss of coastal habitat has reduced some ecosystems to critically small areas. In Santa Monica Bay alone, an estimated 95% of wetland area has been lost to dredge-and-fill operations for marinas and ports, diging for agriculture, or development for coastal urbanization (MBC, 1988). In the SCB, coastal wetland ecosystems provide essential habitat for fish nursery areas, as well as for two marine birds on the endangered species list (California least tern and Belding's savannah sparrow). Moreover, wetlands in the SCB are an important rest

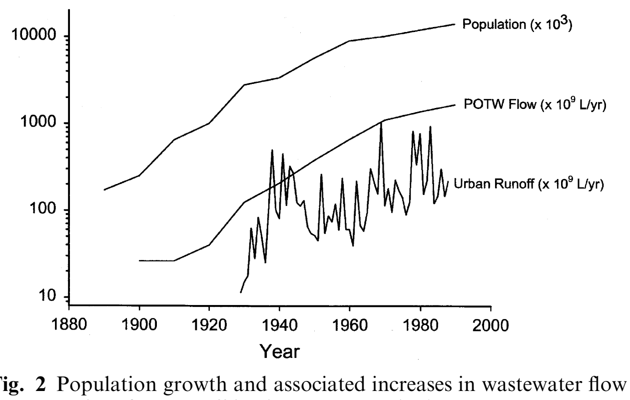

Fig. 2 Population growth and associated increases in wastewater flow and surface runoff in the SCB over the last 100 years. Wastewater flows are from the four largest facilities that represent approximately 95% of all wastewater flows in the region. Surface runoff flows are from the Los Angeles River that represents approximately 33% of the gauged runoff in the region.

stop on the Pacific Flyway, a major bird migratory route between northerly and southerly latitudes. A second habitat lost to urbanization is beaches. Coastal erosion has been attributed to reduced sediment delivery resulting from development within coastal watersheds. Sediment yields of 7.7 million tons were one-third lower than 10 years earlier (Rodolpho, 1970). However, coastal erosion programmes in the SCB have not conclusively identified reduced sediment yields as the primary cause for the loss of this habitat.

Multiple sources discharge pollutants into the SCB (Fig. 3). Sources that contribute pollutants include POTWs, surface runoff from urban and agricultural watersheds, disposal of contaminated dredged materials, industrial facilities, power generating stations, oil and gas production, vessel activities from recreational marinas and commercial ports, aerial deposition, and hazardous material spills, among others. The types of constituents that have been identified as potential pollutants in the SCB include heavy metals; chlorinated hydrocarbons (e.g., pesticides, fungicides, herbicides); petroleum hydrocarbons (e.g., polycyclic aromatic hydrocarbons (PAHs)); nutrients (nitrogenous and phosphate compounds); bacteria; and oxygen-depleting substances (e.g., biosolids).

Although urbanization and population growth have been increasing over the last 30 years, the mass emission of potential pollutants has been decreasing (Raco-Rands, 1999). Overall, there has been a 70% reduction in contaminant inputs to SCB coastal waters from all sources. Between 1971 and 1996, general constituents (e.g., suspended solids and biological oxygen demand) have decreased by 50%; combined heavy metals have decreased by 90%; and chlorinated hydrocarbons have decreased by more than 99%. These reductions have been so significant that some constituents are no longer detected in any source (e.g., polychlorinated biphenyls (PCBs)).

Reductions observed over the last 25 years have largely been the result of reductions from POTWs (Fig. 4). In 1971, the four largest POTWs, which serve the City and County of Los Angeles, County of Orange, and City of San Diego, cumulatively discharged 1035 mgd of wastewater effluent and contributed the vast majority of these potential pollutants to the SCB (SCCWRP, 1973). While POTW flows have been steadily increasing over time, dramatic reductions in mass emissions for all constituents have occurred. In some instances, the reductions were the result of wholesale bans (e.g., DDT and PCB); but for most constituents, the reductions have been the result of increased source control, pretreatment, reclamation, and treatment plant upgrades. In 1971, for example, 105 mgd (10%) of the combined wastewater flow discharged by POTWs underwent secondary treatment. In 1996, 506 mgd (49%) received secondary treatment. Capital improvements to POTWs throughout the SCB are estimated to have cumulatively cost over $5 billion.

While emissions of pollutants from POTWs have decreased over time due to improved controls and treatment, other sources have remained steady or increased. For example, surface runoff from urban and agricultural watersheds has increased due to larger flows and lack of significant concentration reduction strategies. Surface runoff, which is much more variable than POTW flows, has increased over time (see Fig. 2). Larger flows have occurred as a consequence of the impervious materials used in urban areas (i.e., concrete) and inland discharges

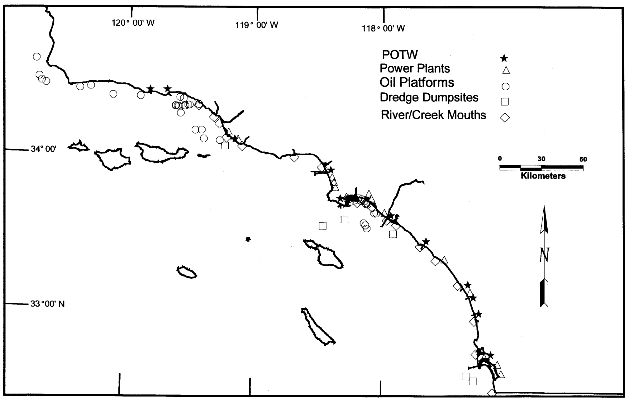

Fig. 3 Map of potential pollutant sources to the SCB.

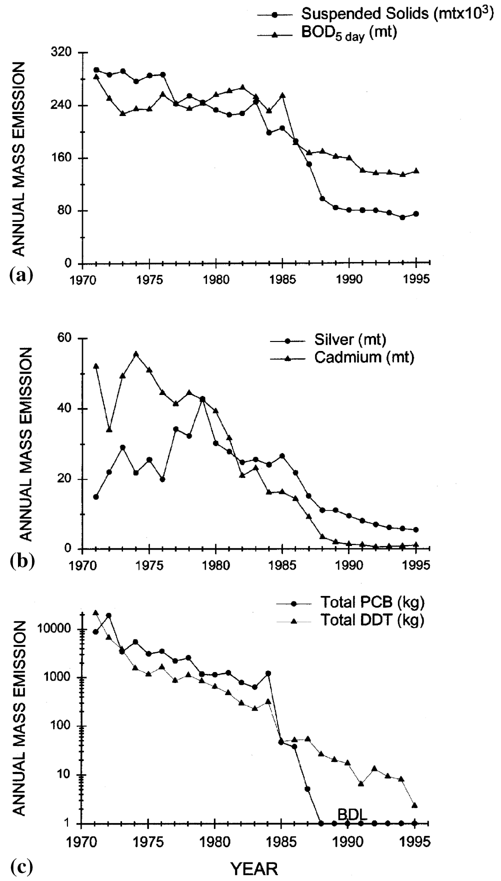

Fig. 4 Cumulative mass emissions of selected constituents from publicly owned treatment works in the SCB between 1971 and 1995.

from municipal and industrial facilities. More than 95% of the flow in the Los Angeles River during dry weather is the result of effluent discharges upstream.

Surface runoff is currently one of the largest sources of pollutants to the SCB (Table 1). In 1995 runoff discharged more nutrients (nitrate and phosphate) and heavy metals (chromium, copper, lead, and zinc) than all other sources combined. Since stormwater sewers and sanitary sewers are not combined in the metropolitan areas of the SCB, surface runoff receives no treatment prior to discharge into coastal oceans, bays, and wetlands. Moreover, POTW discharges are located at great depths (60–100 m) and miles from shore, while storm drains discharge across the beach where potential human contact is great.

Regulation and control of stormwater discharges has lagged behind POTWs partly due to the infrequent rainfall the SCB receives each year. An average of 12–14 storm events occur per year, which typically last from 6–12 h. However, these short but intense rain events generate substantial increases in runoff. For example, flow in large concrete-lined flood control channels measuring more than 90 m in width can increase from <5 to $>20\,000$ cfs in less than 3 h. Such flood events contribute more than 95% of the total runoff volume and pollutant load annually.

Measurements of runoff are tremendously variable and have only recently been addressed in a regulatory context. However, other potential sources remain unmonitored, such as aerial deposition of pollutants either directly to coastal water bodies or indirectly (whereby pollutants are deposited on terrestrial surfaces and then washed into the sea following rain events). Southern California has among the worst air quality in the nation (US EPA, 1997), yet no formal monitoring programme exists to examine this potential source of pollutants to aquatic environments; all air monitoring is used to support the US EPA Clean Air Act Amendments that address human health impacts from respiration of contaminants.

Distribution and Fate of Anthropogenic Inputs

It is evident that the importance of contamination sources affecting the ecology of the SCB has been shifting over the last two decades. This shift has gradually affected the distribution patterns of contaminants in the coastal environment off southern California, which are considered in the examination of contaminant fate and distribution.

Contaminants entering into the SCB undergo a number of physical, chemical, and biological processes in the water column, and settle into the sea floor and/or are accumulated by biota. A large amount of contaminants may be decomposed chemically or biologically or remain buried in sediments. However, some contaminants are likely to re-enter the water column and become available for redistribution or bioaccumulation.

TABLE 1

Total mass emissions of selected constituents from various sources to the coastal oceans of the SCB.

Constituent	Total load	% of total load							
		Urban runoff	Large POTWs	Small POTWs	Industrial facilities	Power plants	Oil platform	Ocean dumping	Hazardous material spills
Year of load estimate		1994–1995	1997	1995	1995	1995	1990	1995	1990
Flow ($l \times 10^9$)	13 668	21.36	11.19	1.44	0.17	65.81	0.04	–	≪0.01
Suspended solids (mt)	674 200	88.76	10.90	0.29	0.05	0.01	≪0.01	–	–
BOD (mt)	140 541	–	98.19	1.68	0.13	≪0.01	≪0.01	–	–
Oil and grease (mt)	19 922	–	96.37	2.32	0.45	0.14	0.72	–	–
Nitrate-N (mt)	9224	95.41	2.87	1.65	–	0.07	–	–	–
Nitrite-N (mt)	151	–	84.11	15.89	–	–	–	–	–
Ammonia-N (mt)	45 898	1.96	90.06	7.84	0.12	0.01	–	–	–
Organic N (mt)	5880	–	99.00	1.00	–	–	–	–	–
Phosphate (mt)	4702	61.68	38.32	–	–	–	–	–	–
Total phosphorus (mt)	1841	–	100.0	–	–	–	–	–	–
Cyanide (kg)	8026	–	80.99	18.71	≪0.01	≪0.01	0.30	–	–
Arsenic (kg)	5723	–	87.37	6.67	4.11	1.00	0.86		–
Cadmium (kg)	2085	–	47.01	21.68	0.21	30.94	0.16	≪0.01	–
Chromium (kg)	38 396	76.05	18.23	3.65	0.25	1.05	0.78	≪0.01	–
Copper (kg)	149 464	58.61	35.46	4.53	0.03	1.31	0.06	≪0.01	–
Lead (kg)	51 349	76.53	4.67	4.64	0.03	2.29	11.83	≪0.01	–
Mercury (kg)	262	–	8.39	4.19	0.03	85.38	2.02	–	–
Nickel (kg)	91 572	63.67	32.53	2.96	0.15	0.01	0.69	≪0.01	–
Selenum (kg)	9212	–	84.67	8.48	6.85	≪0.01	≪0.01	–	–
Silver (kg)	6031	≪0.01	89.54	10.38	0.01	≪0.01	0.07	–	–
Zinc (kg)	443 437	71.35	19.39	3.57	0.24	4.17	1.27	≪0.01	–
Phenols (kg)	166 643	–	97.57	0.02	0.84	≪0.01	1.57	–	–
Chlorinated	2900	–	96.55	3.45	≪0.01	≪0.01	–	–	–
Nonchlorinated	94 966	–	99.83	0.17	≪0.01	≪0.01	–	–	–
Total DDT (kg)	3	–	91.18	8.82	≪0.01	≪0.01	–	–	–
Total PCB (kg)	≪0.1	–	–	–	–	–	–	–	–

Such a cycling of contaminants plays an important role in modifying the spatial and temporal trends of contaminant distribution. Our discussion about fates of environmental contaminants will involve three compartments including water column, sediment, and biota. In each compartment we will examine: (1) the spatial and temporal distributions of contaminants; (2) contaminant correlations among compartments; and (3) mechanisms that influence transport among compartments.

Water column

The waters of the SCB can be classified, based upon the transport dynamics, into three categories: near-surface waters (0–200 m), intermediate waters (200 m to basin sill depth), and deep basin waters (Eganhouse and Venkatesan, 1993). The near-surface waters are density stratified, resulting in much stronger vertical concentration gradients than horizontal gradients. On the other hand, the spatial distribution in the intermediate waters is dominated by advection with insignificant vertical concentration gradient. In the deep basin waters, both density stratification and horizontal advection are weak. Instead, eddy diffusion between the deep and upper waters is the major mechanism for water exchange.

Research in the area of near-surface waters has been focused on the influence of anthropogenic activities. Sea-surface microlayer contamination and bottom fluxes have been the main concerns. Since surface water microfilms have a greater affinity with particles than subsurface water, the sea-surface microlayer is enriched with organic and inorganic materials and is reflective of influences from anthropogenic activities. A survey conducted by Cross *et al.* (1987) in six locations in the SCB found that concentrations of DDTs, PCBs, PAHs, and a group of trace metals (silver, chromium, copper, iron, manganese, nickel, lead, and zinc) were two or three orders of magnitude higher in harbour locations (Los Angeles and Long Beach Harbours) than in nearshore locations (San Pedro Channel, Huntington Beach, Palos Verdes Shelf, and Redondo Harbour). In addition, low molecular weight PAHs were found relatively enriched in the harbour samples while high molecular weight PAHs were relatively dominant in the nearshore samples. This suggested that petroleum-related residues were the main source of contamination inside the harbour. Another study conducted in the coastal area off San Diego also obtained higher concentrations of PAHs and aliphatic hydrocarbons in microlayer samples collected from inside San Diego Bay than those collected in nearshore stations (Zeng and Vista, 1997).

Bottom fluxes of particles and organic and inorganic materials were clearly correlated with sewage inputs in the SCB (Hendricks and Eganhouse, 1992). Sewage-derived contaminants appeared to be transported to basin waters (Crisp *et al.*, 1979), probably via upper water advection. This transfer may have caused a widespread distribution of historically discharged contaminants, such as DDTs, throughout the entire SCB. Indeed, a number of sediments collected from Santa Monica and San Pedro Basins had percent of DDEs (%DDEs) in total DDTs values similar to those contained in nearshore sediments, leading to the conclusion that DDTs in basin sediments were originally derived from nearshore sediments (Zeng and Venkatesan, 1999).

Recent investigations of contaminant distribution in the water column of the SCB have made considerable progress with the application of an *in situ* sampling technique (Green *et al.*, 1986; Tran and Zeng, 1997). Unlike sediment traps typically used in the past to capture sinking particles in the water column, the *in situ* sampling approach collects particles and dissolved materials separately. The capability of this approach to process a large quantity of water permits the detection of ultra-low levels of contaminants. A recent sampling on the Palos Verdes Shelf (heavily contaminated), off Newport Beach (moderately contaminated), and off Dana Point (lightly contaminated) (Fig. 1) using this technique acquired valuable information about the magnitudes of water column DDT, PCB, and PAH contamination (Tran and Zeng, 1997). Concentrations of DDTs at all the sampling stations ($\sim$1 m from the sea floor) were higher than the discharge limit established by the State of California (California State Water Resources Control Board, 1997). Another sampling on the Palos Verdes Shelf showed that the spatial distribution of DDTs (mostly p,p'-DDE) in the water column was similar to that of p,p'-DDE in the sediments. In addition, the vertical concentration of water column DDTs decreased with increasing distance from the sea floor. This evidence, when taken cumulatively, suggests that contaminated sediments remain a main source of DDT contamination to the water column of the Palos Verdes Shelf (Zeng *et al.*, 1999).

Sediment

Sediments of the SCB have been studied extensively since the early 1970s (McDermott *et al.*, 1974; Young *et al.*, 1975, 1976). As a depositing reservoir, sediments often provide critical links to the temporal trends of contaminant inputs as well as the current status of contamination in the marine environment. Earlier investigations mostly converged on 'hot spots' (i.e., areas severely impacted by known sources). Sediments of the Palos Verdes Shelf and of Santa Monica Bay near sewage outfalls have long been recognized as such 'hot spots'. San Diego Bay is another location that has been deemed a 'hot spot' and is on the State of California's list of impaired water bodies. Sediments contain high concentrations of PCBs and PAHs (Mearns *et al.*, 1991), presumably due to discharges from US Navy operations and commercial shipping activities. Newport Bay, another State-listed impaired water body, contains sediments that have high levels of DDTs, non-DDT chlorinated pesticides, PCBs, PAHs, and some trace metals (Phillips *et al.*, 1998).

Scientists in the SCB have been attempting to use molecular markers to identify the source(s) of contaminants that comprise a 'hot spot' and other locations with significant sediment concentrations (Eganhouse *et al*., 1988; Venkatesan and Kaplan, 1990; Sanudo-Wilhelmy and Flegal, 1992; Venkatesan, 1995; Zeng *et al*., 1997). Linear alkylbenzenes (LABs) and coprostanol are two commonly used tracers of sewage inputs. Iron is also used as a reference element for determining trace metal enrichment due to anthropogenic activities (Schiff and Weisberg, 1999). Phillips *et al*. (1997), using a combination of molecular markers and principal component analysis, identified three relatively distinct areas of the San Pedro Shelf impacted by wastewater discharge (near the outfall of the Orange County Sanitation District), riverine inputs (close to the mouths of the Santa Ana River and Newport Bay), and natural seepage and historical pesticide and hydrocarbon inputs (at a deep slope and canyon region). Sewage-derived contaminants are likely to be transported to basin sediments via current advection (mainly northwesterly in the nearshore region of the SCB), as corroborated by the presence of faecal sterols and trialkylamines (Venkatesan and Kaplan, 1990; Venkatesan, 1995) and LABs (Chalaux *et al*., 1992) in sediments of the Santa Monica and San Pedro Basins. It should be recognized that distinguishing contaminants from sources other than sewage inputs remains a difficult task, and much work is needed to develop appropriate tools for such purposes as non-sewage sources have become increasingly important in the SCB.

The vast majority of sediment chemistry evaluations have been performed in a very small portion of the SCB. Only rarely have Bight-wide surveys been conducted to examine the overall condition of the region (Word and Mearns, 1979; Thompson *et al*., 1987, 1993; SCBPP Steering Committee, 1998). The last survey, conducted in 1994, collected and analyzed about 250 sediment samples from Point Conception to the US–Mexico International Border in water depths from 30 to 200 m. This survey identified that 89% of the SCB sediments were anthropogenically contaminated (Table 2) (Schiff, 1999). When sediment quality guidelines were used to evaluate potential biological effects (Long *et al*., 1995), 12% of the SCB sediments contained at least one contaminant at a level where biological effects were likely, and about 66% of the SCB sediments contained contaminants at levels where biological effects may occasionally occur.

Total DDT is the most widespread contaminant of concern in the SCB (Fig. 5, Table 2) (Schiff and Gossett, 1998). In addition to historical inputs of DDT-enriched wastes via sewage outfalls, acid wastes containing DDTs were dumped at two locations until the late 1960s in the Santa Monica and San Pedro Basins (Chartrand *et al*., 1985). The composition of originally discharged DDT residues has been well preserved under the anoxic conditions in the deep basin sediments (Venkatesan *et al*., 1996), which is sharply different from those found in the nearshore sediments (Zeng and Venkatesan, 1999). In two sediment cores taken in areas adjacent to the Santa Monica Basin and San Pedro Basin dump sites, the %DDEs varied with the time of deposition. In sediment sections related to periods during which dumping was active, %DDEs values were similar to those found in the dumped acid wastes. On the other hand, surface layer sediments had %DDEs values similar to those found in the nearshore sediments (i.e., Palos Verdes Shelf and Santa Monica Bay). These observations further verify that sediment DDTs are widely distributed due to continuing redispersal of older deposits to distant areas such as the Santa Monica and San Pedro Basins (Zeng and Venkatesan, 1999).

Sediments near sewage outfalls reflect the trend of mass emissions over the last 50 years, found by exam-

TABLE 2

Percent of mainland shelf area with sediment contamination that was detectable, anthropogenically enriched, or above the sediment quality guidelines effects range-low, and effects range median.[a]

	Detectable	Enriched	Effects range low	Effects range median
Arsenic	100.0	6.8	1.5	0.0
Cadmium	99.1	31.2	2.1	0.0
Chromium	100.0	21.4	7.3	0.0
Copper	100.0	16.4	6.8	0.0
Lead	100.0	16.5	0.5	0.0
Mercury	95.7	–	6.3	0.0
Nickel	99.9	3.2	3.2	1.8
Silver	98.5	20.2	7.3	1.0
Zinc	100.0	16.5	2.7	0.0
LMW PAH	0.0	0.0	0.0	0.0
HMW PAH	0.0	0.0	0.0	0.0
Total DDT	81.8	81.8	63.7	10.4
Total PCB	45.6	45.6	15.3	0.7
Any trace metal	100.0	50.1	13.7	2.8
Any organic	82.1	82.1	63.7	10.4
Any contaminant	100.0	89.0	66.8	12.3

[a] Sediment chemistry data from Schiff and Gossett (1998). Anthropogenic enrichment based upon Schiff and Weisberg (1999). Sediment quality guidelines from Long *et al*. (1995).

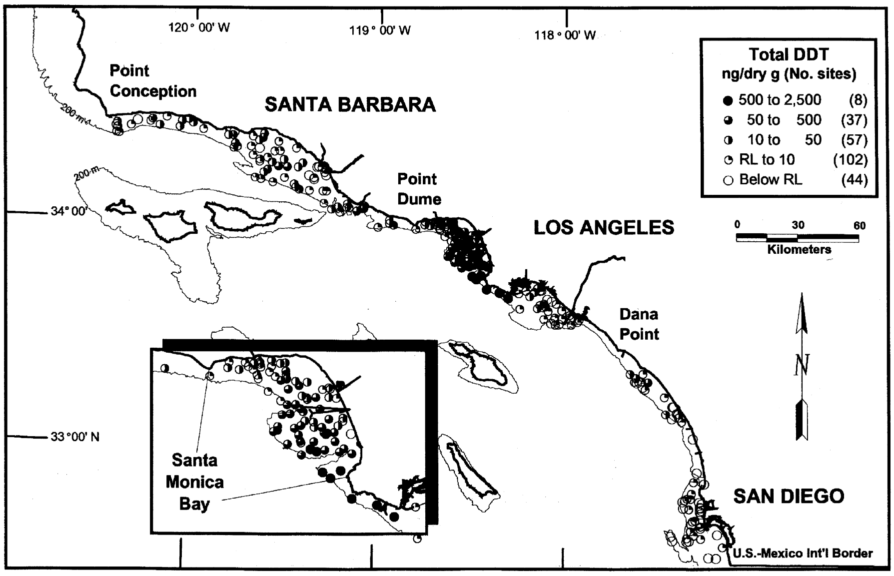

Fig. 5 Distribution of total DDT concentrations in sediment of the SCB in 1994 (from Schiff, 1999).

ining sediment core samples (Fig. 6) (Eganhouse *et al.*, 1988; SCCWRP, 1995; Stull *et al.*, 1996; Anderson *et al.*, 1999). Concentrations of trace metals, PAHs, total organic carbon, and total extractable hydrocarbons experienced a steady increase prior to 1970 when mass emissions from POTWs were also increasing. After 1970, sediment concentrations decreased as mass emissions of organic constituents and trace metals declined due to constantly improved treatment methods and better source control. Concentrations of chlorinated hydrocarbons such as DDTs and PCBs peaked at core depths corresponding to 1970 when the mass emissions of these compounds peaked in POTW effluents in the SCB.

Biota

Biota capable of accumulating contaminants provide another conduit for redistribution of contaminants.

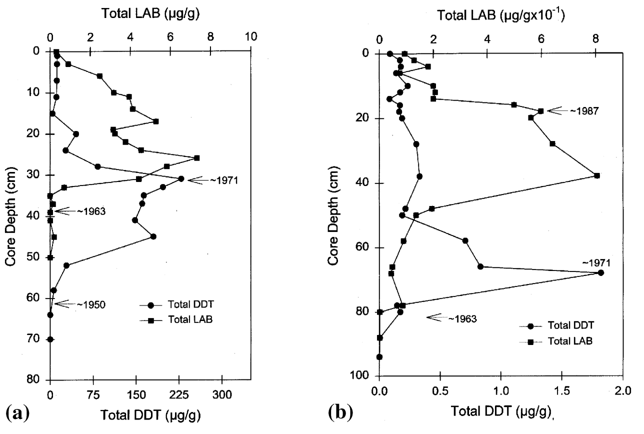

Fig. 6 Profiles of total DDT and LAB concentrations in sediment cores collected near sewage treatment plant outfalls from (a) the Palos Verdes Shelf and (b) Santa Monica Bay (SCCWRP, 1995).

Patterns of bioaccumulation in the SCB indicate that tissue residues of trace metals, organotins, DDTs, PCBs, PAHs, chlordane, and dieldrin are related to the sources of these constituents (Mearns *et al.*, 1991). For example, increasing concentrations of chlorinated hydrocarbons have been observed in plankton, invertebrates (mussels and sand crabs), and a variety of fish species as sample locations approach the Palos Verdes Shelf. A Bight-wide survey in 1994 examined bioaccumulation of chlorinated hydrocarbons in three flatfishes (Pacific sanddab, Longfin sanddab, and Dover sole) and found that nearly 100% of each sanddab species and the majority of the sole were contaminated with total DDT (Schiff and Allen, 2000). Bioaccumulation of DDTs and PCBs has been measured in higher order predators such as fish-eating birds (e.g., brown pelican, bald eagle, and double-crested cormorant) and mammals (e.g., sea lion, dolphin, and sea otter). The spatial relationships to sources for these higher order predators are less clear-cut, however, due to their extended foraging range as well as depuration methods such as reproduction and nursing.

Bioaccumulation patterns in the SCB can be characterized as follows. Firstly, the magnitude of bioaccumulation is generally consistent with the magnitude of sediment contamination. Bioaccumulation of chlorinated hydrocarbons shows the clearest correlations with sediment contamination among all classes of contaminants. Trace metals appear to be the only exception; increased trace metal tissue concentrations have been observed in fish caught from relatively clean areas such as Dana Point (Mearns *et al.*, 1991). Secondly, concentrations of all contaminants in marine species have experienced a dramatic decline during the last three decades. In the 1994 Bight-wide survey, DDTs and PCBs were detected in 100% of the Pacific sanddab and Longfin sanddab individuals, but all 12 of the non-DDT pesticides were consistently not detected. Moreover, DDT and PCB concentrations in Pacific sanddab and Longfin sanddab collected from similar locations had decreased as much as two orders of magnitude from the 1985 to 1994 samples (Schiff and Allen, 2000). Thirdly, PAHs were rarely detected at low levels (Mearns *et al.*, 1991). This is largely attributed to the ability of marine organisms to metabolize PAHs.

Effects of Anthropogenic Activities on Marine Biota

In this paper, effects of human activities in the SCB are evaluated at five phylogenetic levels, including kelp (algae), benthic invertebrates, fish, birds, and marine mammals. Effects on algal species in the SCB have focused largely on giant kelp because of its important role in SCB ecology as well as its value to humans as a recreational and commercial resource. Benthic invertebrates, predominantly soft-bottom infauna, have been studied in great detail owing to their 'sentinel' status. Infauna live within the sediments where potential exposure to deposited contaminants is greatest, where they are relatively sensitive to pollutant effects, and where they are immobile so they cannot escape a large-scale human impact.

Effects on fish communities in the SCB have been studied from two perspectives: fisheries-related and pollutant-related. Fisheries-related assessments focus on impacts to populations of specific species, mostly due to the commercial or recreational value to humans. Pollutant-related assessments focus more on impacts to marine ecosystems. This ecosystem evaluation has two components including effects on individual fish, such as impaired reproduction, or on fish assemblages, such as imbalanced communities.

Kelp

Kelp beds (*Macrocystis pyrifera*) are important habitats in the SCB because they provide habitat and food for rocky subtidal environments. Moreover, drift kelp provides food and habitat for a variety of pelagic and benthic organisms. Although the extent of the kelp canopy in the SCB is estimated to be 88 km^2, less than 0.1% of the SCB area, kelp beds provide nearly 6% of the total energy input into the SCB (Hood, 1993). Kelp growth rates have been measured up to 2 m per day. Therefore, impacts to kelp beds can exert large effects in the SCB.

Kelp beds are sensitive to both natural and anthropogenic impacts. Natural impacts occur largely as the result of fluctuations in water temperature, nutrient availability, and wave energy. The most severe natural disturbances occur during El Niño periods when warm, nutrient-poor waters negatively affect kelp growth and recruitment. In addition, unusually strong storms occur during El Niño periods that can tear kelp holdfasts from their rocky substratum. Anthropogenic impacts can also damage kelp beds. Such impacts have been attributed to increased turbidity that reduces light penetration (Dean *et al.*, 1987) or to potentially toxic pollutants. In other cases, anthropogenic impacts such as inputs of nutrients from POTWs have been shown to stimulate kelp growth (Tegner *et al.*, 1995). Kelp is currently used in many effluent monitoring programmes for toxicity testing to protect ecosystem health (US EPA, 1995).

The kelp beds near POTWs have been slowly returning to their historical areal extent since the 1950s, when extensive kelp beds, such as those near Palos Verdes, were dramatically reduced (Fig. 7). The decline of kelp beds has been attributed to a combination of natural and anthropogenic effects. In the late 1950s, the waters near Palos Verdes were experiencing an increase of pollutant inputs from a nearby sewage outfall while, at the same time, a strong El Niño had occurred in the SCB. In addition, herbivorous sea urchins were abundant as a result of the overfishing of their main competitors (abalone) and predators (lobsters and California sheepshead) (Murray and Bray, 1993). As pollutant inputs decreased, the kelp bed canopy returned and eventually flourished.

Benthos

Studies of benthic organisms have been used for over 30 years to assess environmental conditions in the SCB (Jones, 1969; Word and Mearns, 1979). Most of the benthic monitoring in southern California has examined the mainland shelf (to 100 m depth) with an emphasis on describing the localized effects of discharges from individual sources, including POTW outfalls (Stull *et al.*, 1986; Zmarzly *et al.*, 1994; Diener *et al.*, 1995; Dorsey *et al.*, 1995), industrial discharges (Southern California Edison Company, 1997), dredged material disposal (US EPA 1987), and urban stormwater runoff (Bay *et al.*, 1998).

The most consistent and severe impacts to the benthos have been associated with POTW discharges. Most of the sewage produced by the coastal population of southern California is treated and disposed of through

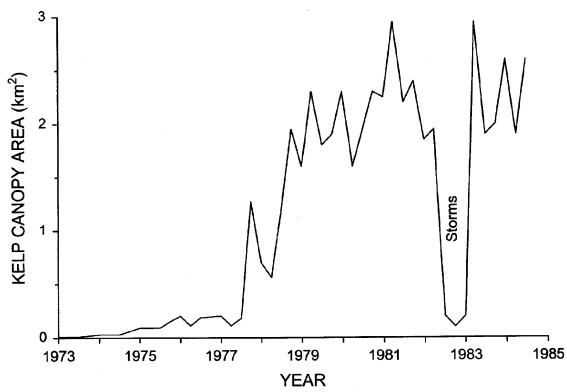

Fig. 7 Changes in kelp canopy over time offshore of Palos Verdes, California (from MBC, 1988).

four large ocean outfall systems, each discharging between 250 and 500 billion l/day. Monitoring studies in the 1970s near these outfalls showed altered benthic communities characterized by low species diversity and reduced abundance in areas nearest the outfalls. These communities were dominated by deposit-feeding annelids and had markedly reduced abundances of key crustacean and echinoderm species, such as the ophiuroid *Amphiodia urtica*. Impacts co-occurred with elevated sediment concentrations of a number of discharge constituents, including organic carbon, chlorinated hydrocarbons, and trace metals.

Substantial improvements to the condition of the benthos near POTW outfalls have occurred in the last two decades, the result of improvements in effluent treatment and industrial source controls. Changes in the benthos off the Palos Verdes Peninsula illustrate this situation (Stull, 1995; Bergen *et al.*, 1999). In the 1970s, degraded conditions (defaunation or the loss of major taxonomic groups) extended more than 15 km away from a large POTW outfall system operated by the County of Los Angeles. By 1990 conditions had improved to the extent that the most severe effects were absent, strong impacts were restricted to an area within 5 km of the outfall, and communities typical of undisturbed areas were present within the monitoring zone.

Areas of altered benthos due to environmental stress presently occupy a very small area of the mainland shelf of the SCB. A regional survey was conducted in 1994 that examined benthic communities at 251 sites between Point Conception and the US–Mexico International Border (Bergen *et al.*, 1999). Benthic communities were classified as typical of reference areas over approximately 91% of the shelf (Fig. 8), with an additional 8% of the area showing slight differences in community composition. Reduced benthic diversity was observed over approximately 2% of the shelf, with many of these areas located near river discharges (Fig. 8).

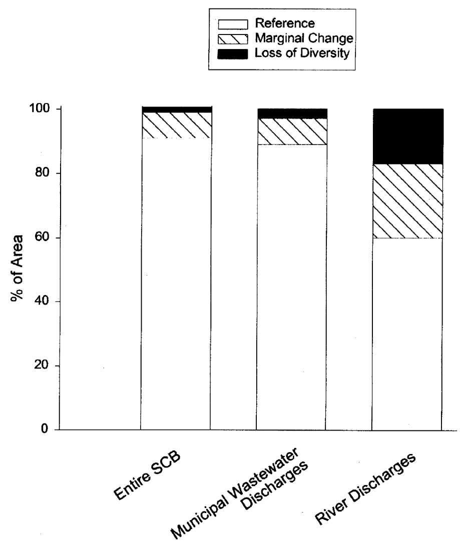

Fig. 8 Percent of area on the mainland shelf of the SCB with impacted benthic infaunal communities during 1994.

Aside from the areas near POTW outfalls, the relationship between benthic community alterations on the mainland shelf and anthropogenic activities is unclear. Over 89% of the SCB has evidence of chemical contamination (Schiff, 1999), yet most communities appear to be unaffected. Altered benthos near river discharges may reflect the combined effects of natural disturbances from flooding and transient contaminant inputs from agricultural and urban runoff (Bergen *et al.*, 1999).

Sediment toxicity studies have also been used to assess sediment quality in the SCB. These studies, first conducted in the 1980s, show temporal improvements in sediment quality near POTW outfalls that reflect to reduced chemical mass emissions and improved benthic communities (Swartz *et al.*, 1986; SCCWRP, 1992). Regional studies during 1992–1994 have examined offshore areas as well as bays and estuaries. Sediment quality was best on the mainland shelf (Bay, 1996), where no significant toxicity to benthic invertebrates was detected (Fig. 9). Toxicity was prevalent in enclosed bays and estuaries, however, with 14–66% of such habitats toxic to amphipod crustaceans (Long *et al.*, 1996). The incidence of sediment toxicity was correlated with a number of contaminants, most notably copper, zinc, PAHs, PCBs, and Chlordane (Fairey *et al.*, 1998). The spatial extent of sediment toxicity in southern California bays and estuaries is relatively high, compared to a national average of 11% (Long *et al.*, 1996).

Commercial fisheries

Commercial fishing is or has been conducted by nets (purse seines, lampara nets, otter trawls, gill-nets, seines), hook-and-line (longlines, rod-and-reel), and traps. Throughout much of the century, the pelagic wetfish fishery dominated the fisheries of the SCB (Frey, 1971). This fishery primarily targets four species including Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), chub (= Pacific) mackerel (*Scomber japonicus*), and jack mackerel (*Trachurus symmetricus*); all are primarily caught by purse seine. The Pacific

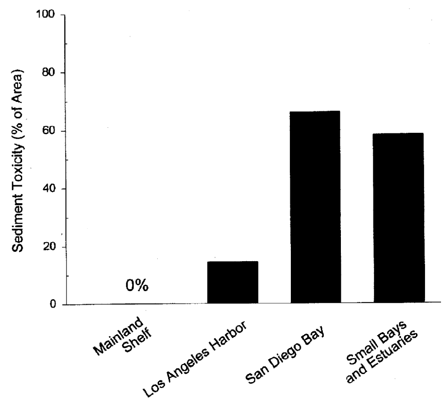

Fig. 9 Percent of area in different habitats of the SCB that exhibited sediment toxicity to amphipod crustaceans during 1994.

sardine fishery dominated from the early 1920s to the early 1950s, but crashed completely from the 1950s to the 1970s (Wolf and Smith, 1992). Chub mackerel followed a similar pattern to Pacific sardine (Konno and Wolf, 1992). Northern anchovy and jack mackerel were the primary focus of the fishery from the 1950s to 1982s. Chub mackerel and California market squid (*Loligo opalescens*) were dominant in the 1980s and California market squid has been the dominant fishery in the 1990s (CDFG, 1998).

The Pacific sardine fishery was reopened in 1986 and, since that time, landings have increased. Although intensive fishing (and perhaps increasing pollution) may have contributed to the crash in sardine populations, a historical record of relative abundance of scales of pelagic fishes from sediment cores in the Santa Barbara Basin suggests that sardines have undergone natural population explosions and crashes (20–80 years in duration) during the past 2000 years (Soutar and Isaacs, 1969; Baumgartner *et al*., 1992).

Commercial trawl fishing is currently limited to the Santa Barbara Channel (off Santa Barbara and off the Channel Islands), and is excluded within 1.9 km (1 nautical mile) of the shoreline (Barsky, 1990). Gillnet fishing was very important during the 1970s and 1980s, but was banned within 4.8 km (3 miles) of the coastline in 1990. Set gillnets were banned due to potential impacts on populations of target species (California halibut, *Paralichthys californicus,* and white seabass, *Atractoscion nobilis*); drift gillnets were banned to protect incidental by-catch of non-target species including marine mammals and seabirds (Weber, 1997). Trap fisheries have come and gone; currently a trap fishery provides live fish for restaurants (CDFG, 1998). Red sea urchin (*Strongylocentrotus franciscanus*) was one of the most valued fisheries in the late 1980s, but landings have decreased since 1988 (CDFG, 1998). Abalone (*Haliotis* spp) populations were heavily fished in the 1970s and 1980s, and populations have decreased so dramatically that all fishing in the SCB has been banned since May of 1997 (CDFG, 1998).

Recreational fisheries

Fishing is an important recreational activity in the SCB. Recreational landings averaged 14 million fish annually between 1981 and 1984 (Helvey *et al*., 1987). Recreational catches vary in species composition between fishing modes and over time. Barred sand bass (*Paralabrax nebulifer*), rockfishes (*Sebastes* spp), and kelp bass (*P. clathratus*) have generally been among the most important species on commercial passenger fishing vessels (CDFG, 1998). Rockfishes (*Sebastes* spp) are important during the fall to winter season, whereas basses (*Paralabrax* spp) and warm-water migrants (Pacific barracuda, *Sphyraena argentea*; yellowtail, *Seriola lalandis*) are important during the summer season. Chub mackerel is one of the most important species taken by anglers on piers or boats (Allen *et al*., 1996). Rockfish abundance has decreased during the past two decades, probably due to decreased recruitment during the recent period of ocean warming and to overfishing (Love *et al*., 1998).

Pollution effects on fish

High levels of total DDT and total PCB have been implicated in reproductive impairment in white croaker (*Genyonemus lineatus*) sampled from San Pedro Bay (Cross and Hose, 1988; Hose *et al*., 1989; Hose and Cross, 1994). The bioaccumulation of these chlorinated hydrocarbons was correlated with decreased proportions of spawning females, decreased fecundity, and decreased fertilization success. Increased levels of these compounds have also been correlated to subcellular damage in white croaker and kelp bass. An increased frequency of micronuclei, a by-product of DNA damage, was observed in blood cells of these two fish species with increased concentrations of total DDT and total PCB. Other subcellular markers of contaminant exposure have been observed in additional fish species including Dover sole, hornyhead turbot (*Pleuroneichthys verticalis*), and English sole (*Pleuronectes vetulus*).

Fish diseases, including fin erosion and epidermal tumours, manifest impacts from human activities. Fin erosion levels were very high in the early 1970s on the Palos Verdes Shelf near the POTW outfall, affecting 33 of 151 species examined, when mass emissions from POTWs were highest (Mearns and Sherwood, 1977). Dover sole was the species with the highest prevalence (30%) of fin erosion in the 1970s, almost all of which occurred on the Palos Verdes Shelf. By the middle 1980s, fin erosion had disappeared in Dover sole from that area (Stull, 1995) and was virtually absent in Dover sole throughout the SCB in 1994 (Allen *et al*., 1998). The cause of this disease was not determined, but was assumed to be related to sediment contamination, based upon its greatest prevalence in benthic fishes found near the POTW outfall, and its disappearance as wastewater treatment improved.

Epidermal tumours were found consistently in Dover sole sampled from the SCB in the early 1970s (Mearns and Sherwood, 1977). Prevalence was greatest in juveniles (60–120 mm) and was similar among areas in the central mainland coast of the SCB. However, the disease had been found outside of the SCB as far back as 1946 (Mearns and Sherwood, 1977). Incidences of this disease have decreased since the 1970s and are presently at background levels (Allen *et al*., 1998). These x-cell pseudotumours are probably the result of amoeboid parasitism (Cross, 1988). Oral papillomas in white croaker and microscopic liver abnormalities in several species have been found near the Los Angeles marine habitats, but the prevalence of these abnormalities is low (Mearns and Sherwood, 1977; Malins *et al*., 1986).

Fish community impacts

Fish assemblages in the SCB vary by habitat and depth with distinct bay, rocky bottom, and soft-bottom assemblages (Allen, 1985). Demersal (soft-bottom) fish assemblages are the focus of studies of pollution impact because outfalls are on soft-bottom habitat and the species are relatively sedentary and respond to environmental stress. Demersal fish assemblages of the shelf vary in species composition by depth, with assemblages roughly corresponding to inner shelf (10–30 m), middle shelf (30–100 m), and outer shelf (100–200 m) zones, and with some distinct assemblages forming where these zones overlap (Allen, 1982; Allen and Moore, 1997; Allen *et al*., 1998, 1999). Fish assemblages also change with depth along the slope below 200 m and in the basins (Allen and Mearns, 1977; Cross, 1987).

Demersal fish communities have shown shifts in abundance, biomass, diversity, and species composition in response to wastewater discharges in the SCB. Some species typical of reference assemblages were absent from, and other species were attracted to, outfalls (Allen, 1977; Cross *et al*., 1985; Stull and Tang, 1996). Missing reference assemblage species included hornyhead turbot and California tonguefish (*Symphurus atricauda*), while species attracted to the outfall included white croaker, shiner perch (*Cymatogaster aggregata*), and curlfin sole (*Pleuronichthys decurrens*). Changes in species composition were attributable to food habits of fishes; as the benthic infaunal community changed from crustaceans to polychaetes, the fish species that preferred crustaceans also diminished. As wastewater treatment improved and benthic communities recovered, outfall fish assemblages became increasingly similar to reference communities at the same depths (Stull and Tang, 1996; Allen *et al*., 1998).

Natural factors also play a role in changes to fish communities. For example, demersal fish communities changed somewhat in species composition between the 1970s and the 1990s, following a warming trend in SCB waters (Allen, 1982; Allen and Moore, 1997). Most changes occurred on the inner shelf (10–30 m) and middle shelf (30–100 m) regions, and were largely the result of increased abundances of warm-water species and decreased abundances of cool-water species.

Birds

Bird populations in the SCB have been impacted by three factors: contamination, loss of habitat, and changes in food availability. Three common species (the brown pelican, California least tern, and Belding's savannah sparrow) are currently listed as endangered species and receive federal protection under the US EPA Endangered Species Act of 1973.

Dramatic declines in the populations of seabirds (brown pelican and double crested cormorant) and birds of prey (bald eagle and peregrine falcon) were observed during the late 1950s to 1970s (Anderson and Hickey, 1970). Discharges and biomagnification of DDTs (and possibly PCBs) during this time caused severe eggshell thinning and nest abandonment in these species and led to reproductive failure in breeding colonies. Diminished reproduction in seagulls due to the estrogenic effects of DDT was also observed (Fry *et al*., 1987). Reduction of DDT inputs resulted in a reduction in egg thinning and the recovery of seabird populations to historic levels (Gress, 1994). Temporal variations in seabird populations still occur in the SCB, but these changes appear to be associated with reductions in food supply caused by natural factors such as El Niño events (Table 3).

Bioaccumulation of DDTs and PCBs remains prevalent in many bird species and is still producing adverse biological effects in sensitive species. Reintroduction programmes have reestablished breeding populations of bald eagles and peregrine falcons on the Channel Islands, but reproductive success is still reduced by eggshell thinning (Wiemeyer *et al*., 1993). The reproductive output of brown pelicans is still below levels considered necessary to maintain a stable population and eggshell thinning is still observed (Gress, 1994).

Development of coastal bays and estuaries has severely restricted the habitat area available for breeding and foraging for several species, leading to population declines in species such as the California least tern and Belding's savannah sparrow. Between 75% and 90% of coastal wetland habitat in southern California has been dredged, filled, or otherwise modified. Restrictions on

TABLE 3

Nesting, reproduction and productivity estimates for brown pelicans from the Channel Islands in the SCB.[a]

Year	Nest attempts	Young produced[b]	Productivity[c]
1969	750	4	0.01
1970	552	1	0.00
1971	540	7	0.01
1972	261	57	0.22
1973	247	34	0.14
1974	416	305	0.73
1975	292	256	0.88
1976	417	279	0.67
1977	76	39	0.51
1978	210	37	0.18
1979	1258	980	0.78
1980	2244	1515	0.68
1981	2946	1805	0.61
1982	1862	1175	0.63
1983	1877	1159	0.62
1984	628	530	0.84
1985	6194	7902	1.28
1986	7349	4601	0.63
1987	7167	4898	0.68
1988	2878	2500	0.87
1989	5959	3500	0.59
1990	2425	654	0.30
1991	6383	1792	0.28
1992	1752	394	0.22
1993	4157	2811	0.68

[a] Shaded rows indicate intervals when El Niño conditions were present, which were often associated with decreased reproductive success. Data from Gress (1994).

[b] Total number of young fledged from all nests.

[c] Number of young produced per nest attempt.

coastal development and remediation efforts in recent years have helped to stabilize the populations of these endangered species.

Marine mammals

At least six pinnipeds species occur in the SCB (Bonnell and Dailey, 1993) and some of the largest rookeries on the west coast of the US are found along the Channel Islands (primarily San Miguel Island). The most common species in the SCB is the California sea lion (*Zalophus californianus*). In the early part of this century, the northern elephant seal (*Miroranga angustirostris*) was nearly extinct as a species. As a result of protection from harvesting, this species has become one of the more abundant pinnipeds off California (Bonnell and Dailey, 1993).

Marine mammals that are resident in the SCB (e.g., sea lions and coastal dolphins) bioaccumulate high concentrations of DDTs and PCBs in their tissues. Tissue concentrations peaked in the 1970s and were associated with an increased incidence of premature births in sea lions (DeLong *et al.*, 1973). Present-day tissue concentrations remain high in southern California marine mammals, but causal links with adverse biological effects have not been established. The population of the California sea lion is increasing at an annual rate of 5–10%. Hundreds of young seals and sea lions strand themselves along the coast each year; principal factors in these strandings are lack of food due to unfavourable oceanographic conditions and parasitic infestations (Bonnell and Dailey, 1993).

Cetaceans are also diverse in the SCB. Among toothed whales, dolphins are the most prominent, with several common species. The most observed baleen whale in the area is the grey whale (*Eschrichtius robustus*), which makes seasonal migrations (winter and spring) between the Bering Sea and the lagoons off southern Baja California (Bonnell and Dailey, 1993). Although populations were depleted in the early part of the century due to whaling, they have rebounded sufficiently so that this species is no longer listed as endangered.

Human Health Concerns

There are two human health concerns in the SCB. First is the risk of contracting illness through body-contact recreation (i.e., swimming, surfing, SCUBA-diving, etc.) along the shoreline. Second is the risk of long-term illness, including cancer, from consuming contaminated fish.

Shoreline impacts

Beaches are among the most valuable recreational resources in the SCB. The US Lifesaving Association estimated that 146 million beach-goers visited SCB beaches in 1997, more than visited beaches in the states of Florida, Hawaii, and New Jersey combined (Schiff *et al.*, 1999). This justifies the tremendous quantity of recreational shoreline monitoring conducted in the SCB; an estimated \$3 million is spent annually assessing the water quality along high-use beaches. This monitoring consists of sampling and measuring indicator bacteria such as total coliform, faecal coliform, and enterococcus.

In the summer of 1998, an integrated assessment of water quality along the SCB shoreline was conducted (Noble *et al.*, 1999). Approximately 95% of the shoreline mile-days met water quality standards; only 5% of the shoreline during any summer day at any random location would have exceeded water quality thresholds for bacteria contamination. However, this level of water quality exceedence was not consistent among various shoreline types. The highest use sandy beaches (> 50 000 swimmers per year) exceeded water quality thresholds less than 2% of their shoreline mile-days, while those adjacent to storm drain outfalls that discharged surface runoff exceeded thresholds as much as 60% of their shoreline mile-days. The density of bacteria that are measured in surface runoff can be quite high. Measurements of faecal coliforms during wet weather discharges routinely reach 10^5–10^6 cfu/100 ml and densities of indicator bacteria are highly correlated to rainfall. Moreover, spatial correlations have been observed as densities along the shoreline decrease with distance from surface runoff outfalls.

Bacteria such as coliforms and enterococcus are only indicators of the potential pathogens that can induce illness. Measurements of human enteric virus have shown that potential pathogens are frequently found in surface runoff, even in dry weather when natural flows do not exist. An epidemiological study conducted in Santa Monica Bay in 1994 indicated that swimmers are more likely to become ill after swimming near storm drain discharges (Haile *et al.*, 1999). The incidence of illness increased from 88 to 305 out of 10 000 swimmers within 50 m of a storm drain. The types of illnesses most frequently observed included respiratory disease, fever, coughing with phlegm, chills, highly credible gastroenteritis, and ear discharge.

Seafood consumption

Health risks from consumption of seafood organisms in the SCB come primarily from two carcinogens, DDTs and PCBs. Current sources of both are sediments in the Los Angeles area. Some recreationally caught seafood organisms (e.g., white croaker) have sufficiently high levels that health advisories restricting consumption are posted in pertinent fishing areas (SCCWRP, 1994; Pollock *et al.*, 1991). Advisories are currently posted when advisory tissue concentrations of DDTs and PCBs exceed 100 ppb wet weight. Advisories have been posted for white croaker, California corbina (*Menticirrhus undulatus*), queenfish (*Seriphus politus*), surfperches (Embiotocidae spp), and California scorpionfish (*Scorpaena guttata*), with white croaker being the most restricted. Advisories have been posted in fishing areas along the Los Angeles County and Orange County coasts; most advisories were in the Palos Verdes and Los Angeles Harbour–Long Beach Harbour areas, where consumption of white croaker was not recommended. White croaker were nevertheless consumed in these areas, mostly (57%) by Hispanic anglers (Allen *et al.*, 1996). Although commercial fishing for white croaker is banned in that area, commercially caught white croaker with high levels of DDT sometimes appear in local Asian markets (Gold *et al.*, 1998).

Monitoring and Management of the SCB

Extensive marine monitoring is conducted in the SCB, yet few of the results are used to assist environmental managers tasked with stewarding natural resources. More than 40 local, state or federal public agencies, private industry, and academic institutions spent an estimated $17 million in 1990 on marine monitoring (NRC, 1990). The majority of these funds were used to assess impacts from single sources in the immediate vicinity of a discharge in compliance with National Pollutant Discharge Elimination System (NPDES) permits.

Reasons why marine monitoring in the SCB cannot be used to assist environmental managers in managing the coastal ecosystem (NRC, 1990) include: first, management objectives are rarely clearly defined and managers are often unsure of what to do with the monitoring data once they have been collected. For example, many monitoring programmes were designed in the early 1970s when little was known about the ocean environment and programmes were based largely upon characterization of near-field and far-field conditions. After 30 years of monitoring, our understanding has improved and management questions required to maintain or improve beneficial uses of the coastal zone have changed; yet the monitoring programmes have remained inflexible. Second, monitoring is inefficient due to poor sampling designs, a lack of monitoring objectives, and the failure of most programmes to incorporate natural variability in space or time. For example, each of the NPDES monitoring programmes has been designed by different individuals in separate jurisdictional agencies. The result is a series of disparate programmes that cannot be integrated to make large-scale assessments of the overall condition of the SCB. Despite all of the effort that is expended, only 5% of the SCB mainland shelf is actually monitored.

Resource managers are attempting to address these limitations as we move into the new millennium by refining important management questions and redesigning monitoring programmes. Both regulators and dischargers have agreed upon a set of four questions that address management objectives:

- Is it safe to swim in the ocean?
- Is it safe to eat the local seafood?
- Is the health of the ecosystem safeguarded?
- Are fisheries and other living resources adequately protected?

Regional monitoring is one example of how SCB resource managers are answering some of these questions and addressing the issues that have plagued current programmes (Cross and Weisberg, 1996). Regional monitoring in the SCB, unlike other areas of the nation, consists of local agencies participating in an integrated and coordinated effort; a minor proportion of effort comes from agencies outside of the SCB (e.g., the US Environmental Protection Agency). Instead, local regulators and permittees work cooperatively to define monitoring objectives. Regulators provide a cost-neutral exchange of effort to participating agencies by relieving permittees of a subset of routine monitoring activities. Regional monitoring designs move away from traditional 'end-of-pipe' stations and sample the entire SCB. This strategy enables assessments of the full range of natural variability, evaluation of the effect of cumulative impacts from multiple discharges, and determination of the overall condition of the SCB. The involvement of multiple agencies in regional monitoring provides benefits that extend beyond the single project, by setting minimum quality assurance goals for all programmes that ensure comparability, establishing data management systems to share information, and establishing communication among regulatory jurisdictions and discharge agencies.

Box 1. Contamination in Southern California

Patterns of contamination and effects in the SCB are dominated by the legacy of the historical production and use of the pesticide 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl) ethane (DDT). Total DDT, which includes both the *ortho*- and *para*-substituted isomers of DDT and its metabolites DDE and DDD, are man-made chemicals that produce neurotoxic, estrogenic, and carcinogenic effects in animals. Originally used throughout the US from the 1930s to 1971, DDT was hailed as a superior pesticide and helped to drastically reduce the incidence of malaria and other diseases passed by insects such as mosquitoes. Due to its resistance to chemical, physical, and biological degradation, however, DDT has been widely distributed in the global ecosystem (including Antarctica). Moreover, its lipophilic nature means that it is fat-soluble and has dramatically affected several non-target organisms including birds and marine mammals.

The DDT contamination is particularly significant in the coastal regions of southern California because the world's largest DDT manufacturer, the Montrose Chemical Corporation, discharged large quantities of DDT-enriched wastes via the Los Angeles County Sanitation Districts' Joint Water Pollution Control Plant (JWPCP) outfall on the mainland shelf off Palos Verdes. An estimated 20 metric tons of total DDT were being discharged through the JWPCP outfall in 1971. Montrose was also discharging DDT wastes by ocean dumping at two locations in the Santa Monica and San Pedro Basins prior to 1970. In 1971, the use of DDT was banned in the US by federal regulation and disposal of DDT residues into the sewer system followed not long afterwards. Currently, inputs of total DDT are extremely low; an estimated 1.4 kg of DDT was discharged from all POTWs in the SCB during 1997.

Historic DDT inputs and their redistribution represent a potential source of contamination that is still impacting sensitive species. It remains unclear how much still exists in the SCB, but an estimated 156 metric tons of total DDT still existed in the sediments on the Palos Verdes Shelf in 1992. The Palos Verdes Shelf is now the site of a Superfund investigation and is the epicentre of the nation's largest environmental damage assessment lawsuit. Although DDT was banned in the US, it is still being used in other countries including Mexico.

Allen, L. G. (1985) A habitat analysis of the nearshore marine fishes from southern California. *Bulletin of the Southern Californian Academy of Science* **84** (3), 133–155.

Allen, M. J. (1977) Pollution-related alterations of southern California demersal fish communities. *American Fisheries Society, Cal-Neva Wildlife Transactions* **1977**, 103–107.

Allen, M. J. (1982) Functional structure of soft-bottom fish communities of the southern California shelf. Ph.D. dissertation. University of California, San Diego, La Jolla, CA, 577 pp.

Allen, M. J., Diener, D., Mubarak, J., Weisberg, S. B. and Moore, S. L. (1999) Demersal fish assemblages of the mainland shelf of southern California in 1994. In *Southern California Coastal Water Research Annual Report 1997–1998*, eds. S. B. Weisberg and D. Hallock, pp. 101–112. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M. J. and Mearns, A. J. (1977) Bottomfish populations below 200 meters. In *Annual Report for the year ended 30 June 1977*, pp. 117–120. Southern California Coastal Water Research Project, El Segundo, California.

Allen, M. J. and Moore, S. L. (1997) Recurrent groups of demersal fishes on the mainland shelf of southern California in 1994.. In *Southern California Coastal Water Research Project*, Annual Report 1996, eds. S. B. Weisberg, C. Francisco and D. Hallock, pp. 122–128. Southern California Coastal Water Research Project, Westminster, CA, 324 pp.

Allen, M. J., Moore, S. L., Schiff, K. C., Weisberg, S. B., Diener, D., Stull, J. K., Groce, A., Mubarak, J., Tang, C. L. and Gartman, R. (1998) *Southern California Bight Pilot Project: V. Demersal Fishes and Megabenthic Invertebrates*. Southern California Coastal Water Research Project, Westminster, CA, 324 pp.

Allen, M. J., Velez, P. V., Diehl, D. W., McFadden, S. E. and Kelsh, M. (1996) Demographic variability in seafood consumption rates among recreational anglers of Santa Monica Bay, California in 1991–1992. *Fishery Bulletin* **94**, 597–610.

Anderson, D. W. and Hickey, J. J. (1970) Oological data on egg and breeding characteristics of brown pelicans. *Wilson Bulletin* **82**, 14–28.

Anderson, J. W., Zeng, E. Y. and Jones, J. M. (1999) Correlation between response of human cell line and distribution of sediment polycyclic aromatic hydrocarbons and polychlorinated biphenyls on Palos Verdes Shelf, California, USA. *Environmental Toxicology and Chemistry* **18**, 1506–1610.

Barsky, K. C. (1990) History of the commercial California halibut fishery. In *The California Halibut, Paralichthys californicus, Resource and Fisheries*, ed. C.W. Haugen, pp. 217–227. California Department of Fish and Game, Fish Bulletin 174.

Baumgartner, T. R., Soutar, A. and Ferreira-Bartrina, V. (1992) Reconstruction of the history of Pacific Sardine and Northern Anchovy Populations Over the Past Two Millennia from Sediments of the Santa Barbara Basin. California Cooperative Oceanic Fisheries Investigations Report 33, pp. 24–40.

Bay, S. M. (1996) Sediment toxicity on the mainland shelf of the southern California Bight in 1994. In *Southern California Coastal Water Research Project Annual Report 1994–1995*, eds. M. J. Allen, C. Francisco and D. Hallock, pp. 128–136. Westminster, CA.

Bay, S., Schiff, K., Greenstein, D. and Tiefenthaler, L. (1998) Stormwater runoff effects on Santa Monica Bay, toxicity, sediment quality, and benthic community impacts. In *California and the World Ocean '97*, Vol. 2, pp. 900–921, eds. O. T. Magoon, H. Converse, B. Baird and M. Miller-Henson. American Society of Civil Engineers, Reston, VA.

Bergen, M., Cadien, D., Dalkey, A., Montagne, D., Smith, R. W., Stull, J. K., Velarde, R. G. and Weisberg, S. B. (1999) Assessment of benthic infauna on the mainland shelf of Southern California. In *Southern California Coastal Water Research Project Annual Report 1997–1998*, eds. S. B. Weisberg and D. Hallock, pp. 143–154. Westminster, CA.

Bonnell, M. L. and Dailey, M. D. (1993) Marine mammals. *Ecology of the Southern California Bight: A Synthesis and Interpretation*, eds. M. D. Dailey, D. J. Reish and J. W. Anderson, pp. 605–681. University of California Press, Berkeley, CA.

Briggs, J. C. (1974) *Marine Zoogeography*. McGraw-Hill, New York, 475 pp.

California State Water Resources Control Board (1997) *California Ocean Plan*. 25 pp.

California Department of Fish and Game (CDFG) (1998) Review of some California fisheries for 1997. California Cooperative Oceanic Fisheries Investigations Report 39, pp. 9–24.

Chalaux, N, Bayona, J. M., Venkatesan, M. I. and Albaigés, J. (1992) Distribution of surfactant markers in sediments from Santa Monica basin, Southern California. *Marine Pollution Bulletin* **24**, 403–407.

Chartrand, A. B., Moy, S., Safford, A. N., Yoshimura, T. and Schinazim L. A. (1985) Ocean dumping under Los Angeles Regional Water Quality Control Board Permit: A review of past practices, potential adverse impacts, and recommendations for future action. Report from California Regional Water Quality Control Board, 47 pp.

Crisp, P. T., Brenner, S., Ventkatesan, M. I., Ruth, E. and Kaplan, I. R. (1979) Organic chemical characterization of sediment-trap particulates from San Nicolas, Santa Barbara, Santa Monica and San Pedro basins, California. *Geochimica Cosmochimica Acta* **43**, 1791–1801.

Cross, J. N. and Weisberg, S. B. (1996) The southern California Bight pilto project: an overview. In *Southern California Coastal Water Research Project Annual Report 1994–1995*, eds. M. J. Allen, C. Francisco and D. Hallock, pp. 104–108. Westminster, CA.

Cross, J. N. (1988) Fin erosion and epidermal tumors in demersal fish from southern California. In *Ocean Processes in Marine Pollution, Vol. 5, Urban Wastes in Coastal Marine Environments*, eds. D. A. Wolfe and T. P. O'Connor, pp. 57–64. Krieger Publishing, Malabar, FL.

Cross, J. N. and Hose, J. E. (1988) Evidence of impaired reproduction in white croaker (*Genyonemus lineatus*) from contaminated areas off southern California. *Marine Environmental Research* **24**, 185–188.

Cross, J. N. (1987) Demersal fishes of the upper continental slope off southern California. *California Cooperative Oceanic Fisheries Investigations Reports* **28**, 155–167.

Cross, J. N., Hardy, J. T., Hose, J. E., Hershelman, G. P., Antrim, L. D., Gossett, R. W. and Crecelius, E. A. (1987) Contaminant concentrations and toxicity of sea-surface microlayer near Los Angeles, California. *Marine Environment Research* **23**, 307–323.

Cross, J. N., Roney, J. and Kleppel, G. S. (1985) Fish food habits along a pollution gradient. *California Department of Fish and Game* **71** (1), 28–39.

California State Water Quality Control Board (CSWQCB) (1964) *An Investigation of the Effects of Discharged Waste on Kelp*. California State Water Quality Control Board, Sacramento, California. Publ. No. 26, 124 pp.

Culliton, T., Warren, M., Goodspeed, T., Remer, D., Blackwell, C. and McDonough III, J. (1990) Fifty Years of Population Changes Along the Nation's Coasts. Coastal Trends Series, Report No. 2, National Oceanic and Atmospheric Administration, Strategic Assessment Branch. Rockville, MD.

Dailey, M. D., Anderson, J. W., Reish, D. J. and Gorsline, D. S. (1993) The California Bight: Background and setting. In *Ecology of the Southern California Bight: A Synthesis and Interpretation*, eds. M. D. Dailey, D. J. Reish, and J. W. Anderson, pp. 1–18. University of California Press, Berkeley, CA.

Dean, T. A., Schroeter, S. and Dixon, J. (1987) The effect of the San Onofre Nuclear Generating Station on the Giant Kelp, *Macrocystis pyrifera*. Report to the Marine Review Committee, Santa Barbara, CA.

DeLong, R. L., Gilmartin, W. G. and Simpson, J. G. (1973) Premature births in California Sea Lions: association with organochlorine pollutant residue levels. *Science* **181**, 1168–1170.

Diener, D. R., Fuller, S. C., Lissner, A., Haydock, C. I., Maurer, D., Robertson, G. and Gerlinger, T. (1995) Spatial and temporal patterns of the infaunal community near a major ocean outfall in southern California. *Marine Pollution Bulletin* **30**, 861–878.

Dorsey, J. H., Phillips, C. A., Dalkey, A., Roney, J. D. and Deets, G. B. (1995) Changes in assemblages of infaunal organisms around wastewater outfalls in Santa Monica Bay, California. *Bulletin of the Southern California Academy of Science* **94**, 46–64.

Eber, L. E. (1977) Contoured Depth-Time Charts (0–200 m, 1950–1966) of Temperature, Salinity, Oxygen and Sigma-t at 23 CalCOFI Stations in the California Current. California Cooperative Oceanic Fisheries Investigations, Atlas 25, 231 pp.

Eganhouse, R. P., Olaguer, D. P., Gould, B. R. and Phinney, C. S. (1988) Use of molecular markers for the detection of municipal sewage sludge at sea. *Marine Environmental Research* **25**, 1–22.

Eganhouse, R. P. and Venkatesan, M. I. (1993) Chemical oceanography and geochemistry. *Ecology of the Southern California Bight: A Synthesis and Interpretation*, eds. M. D. Dailey, D. J. Reish, and J. W. Anderson, pp. 71–174. University of California Press, Los Angeles, CA.

Emery, K. O. (1960) *The Sea off Southern California, a Modern Habitat of Petroleum*. Wiley, New York, 366 pp.

Fairey, R., Roberts, C., Jacobi, M., Lamerdin, S., Clark, R., Downing, J., Long, J., Hunt, J., Anderson, B., Newman, J., Tjeerdema, R., Stephenson, M. and Wilson, C. (1998) Assessment of sediment toxicity and chemical concentrations in the San Diego Bay region, California, USA. *Environmental Toxicology and Chemistry* **17**, 1570–1581.

Frey, H. T. (1971) *California's Living Marine Resources and Their Utilization*. California Department of Fish and Game, Sacramento, CA, 148 pp.

Fry, D. M., Toone, C. K., Speich, S. M., and Peard, R. J. (1987) Sex ratio skew and breeding patterns of gulls: demographic and toxicological considerations. *Studies in Avian Biology* **10**, 13–22.

Gold, M. D., Alamillo, J., Fleischli, S., Forrest, J., Gorke, R., Heibshi, L. and Gossett, R. (1998) Let the Buyer Beware: A Determination of DDT and PCB Concentrations in Commercially Sold White Croaker. Heal the Bay, Santa Monica, CA, 18 pp.

Green, D. R., Stull, J. K. and Heesen, T. C. (1986) Determination of chlorinated hydrocarbons in coastal waters using a moored *in situ* sampler and transplanted live mussels. *Marine Pollution Bulletin* **17**, 324–329.

Gress, F. (1994) Reproductive Performance, Eggshell Thinning, and Organochlorines in Brown Pelicans and Double-Crested Cormorants Breeding in the Southern California Bight. Report 18 in Southern California Bight Natural Resource Damage Assessment Expert Reports. US Department of Justice, Environment and Natural Resources Division, Washington DC.

Haile, R. W., Witte, J. S., Gold, M., Cressey, R., McGee, C., Millikan, R. C., Glasser, A., Harawa, N., Ervin, C., Harmon, P., Harper, J., Dermand, J., Alamillo, J., Barrett, K., Nides, M. and Wang, G. -Y. (1999) The health effects of swimming in ocean water contaminated by storm drain runoff. *Epidemiology* **10** (4), 355–363.

Helvey, M. S., Crooke, J. and Milone, P. A. (1987) Marine recreational fishing and associated state–Federal research in California, Hawaii and the Pacific Island Territories. *Marine Fisheries Review* **49** (2), 8–14.

Hendricks, T. J. and Eganhouse, R. P. (1992) Modification and verification of sediment deposition model. Technical Report 265, Southern California Coastal Water Research Project, Westminster, CA.

Hickey, B. M. (1993) Physical oceanography. In *Ecology of the Southern California Bight: A Synthesis and Interpretation*, eds. M. D. Dailey, D. J. Reish and J. W. Anderson, pp. 19–70. University of California Press, Berkeley, CA.

Hood, D. W. (1993) Ecosystem relationships. In *Ecology of the Southern California Bight: A Synthesis and Interpretation*, eds. M. D. Dailey, D. J. Reish and J. W. Anderson, pp. 782–835. University of California Press, Berkeley, CA.

Hose, J. E. and J. N. Cross. (1994) *Evaluation of Evidence for Reproductive Impairment in White Croaker Induced by dDT and/or pCBs. Prepared for National Oceanic and Atmospheric Administration*. Prepared by Occidental Colleg, VANTUNA Research Group, Los Angeles, CA, 54 pp.

Hose, J. E., Cross, J. N., Smith, S. G. and Diehl, D. (1989) Reproductive impairment in a fish inhabiting a contaminated coastal environment off southern California. *Environmental Pollution* **57**, 139–148.

Jones, G. F. (1969) The benthic macrofauna of the mainland shelf of southern California. *Allan Hancock Monographs in Marine Biology* **4**, 1–219.

Konno, E. S. and Wolf, P. (1992) Pacific mackerel. In *California's Living Marine Resources and Their Utilization*, eds. W. S. Leet, C. M. Dewees and C. W. Haugen, pp. 91–93. University of California, Davis, Department of Wildlife and Fisheries Biology, Sea Grant Extension Program, Davis, California. Sea Grant Extension Publication, UCSGEP-92-12.

Long, E. R., MacDonald, D. D., Smith, S. L. and Calder, F. D. (1995) Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuary sediments. *Environmental Management* **19**, 81–97.

Long, E. R., Robertson, R., Wolfe, D. A., Hameedi, J. and Sloane, G. M. (1996) Estimates of the spatial extent of sediment toxicity in major US estuaries. *Environmental Science Technology* **30**, 3585–3592.

Love, M. S., Caselle, J. E. and Herbinson, K. (1998) Declines in nearshore rockfish recruitment and populations in the Southern California Bight as measured by impingement rates in coastal electrical power generating stations. *Fishery Bulletin* **96**, 492–501.

Lynn, R. J., Schwing, F. B. and Hayward, T. L. (1995) The effect of the 1991–1993 ENSO on the California Current System. *Cooperative Oceanic Fisheries Investigations Report* **36**, 57–71.

Malins, D. C., McCain, B. B., Brown, D. W., Myers, M. S. and Chan, S. L. (1986) *Marine pollution study: Los Angeles vicinity*. Final report to CSWRQB, Sacramento, California. Prepared by National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA, 64 pp.

MBC Applied Environmental Sciences (1988) *The State of Santa Monica Bay. Part One: Assessment of Conditions and Pollution Impacts*. Prepared for Southern California Association of Governments, Los Angeles, CA. Prepared by MBC Applied Environmental Sciences, Costa Mesa, CA, 420 pp.

McDermott, D. J., Heesen, T. C. and Young, D. R. (1974) *DDT in Bottom Sediments Around Five Southern California Outfall Systems*. TM 217, Southern California Coastal Water Research Project, El Segundo, CA, 54 pp.

Mearns, A. J., Matta, M., Shigenaka, G., MacDonald, D., Buchman, M., Harris, H., Golas, H. and Laurenstein, G. (1991) Contaminant Trends in the Southern California Bight: Inventory and Assessment. NOAA Technical Memorandum NOS ORCA 62, 413 pp.

Mearns, A. J. and Sherwood, M. J. (1977) Distribution of neoplasms and other diseases in marine fishes relative to the discharge of wastewater. *Annals of the New York Academy of Science* **298**, 210–224.

Murphree, T. and Reynolds, C. (1995) El Niño and La Niña effects on the Northeast Pacific: The 1991–1993 and 1988–1989 events. *California Cooperative Oceanic Fisheries Investigations Report* **36**, 45–56.

Murray, S. and Bray, R. (1993) Benthic macrophytes. In *Ecology of the Southern California Bight: A Synthesis and Interpretation*, eds. M. D. Dailey, D. J. Reish and J. W. Anderson, pp. 304–368. University of California Press, Berkeley, CA.

Noble, R. T., Dorsey, J. H., Leecaster, M., Orozco-Borbon, V., Reid, D., Schiff, K. and Weisberg, S. B. (1999) A regional survey of the microbiological water quality along the shoreline of the southern California Bight. *Environmental Monitoring and Assessment*, in press.

NRC (1990) *Monitoring Southern California's Coastal Waters*. National Research Council. National Academy Press, Washington, DC, 154 pp.

Phillips, B., Anderson, B., Hunt, J., Newman, J., Tjeerdema, R., Wilson, C. J., Long, E. R., Stephenson, M., Puckett, M., Fairey, R., Oakden, J., Dawson, S. and Smythe, H. (1998) Sediment Chemistry Toxicity and Benthic Community Conditions in Selected Water Bodies of the Santa Ana Region. Report to the State Water Resources Control Board, Sacramento, CA, from University of California, Santa Cruz, CA.

Phillips, C. P., Venkatesan, M. I. and Bowen, R. (1997) Interpretations of contaminant sources to San Pedro Shelf using molecular markers and principal component analysis. In *Molecular Markers in Environmental Geochemistry*, ed. E. P. Eganhouse, pp. 242–260. American Chemical Society, Washington, DC.

Pollock, G. A., Uhaa, I. J., Fan, A. M., Wisniewski, J. A. and Witherell, I. (1991) *A Study of Chemical Contamination of Marine Fish From Southern California II: Comprehensive Study*. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Sacramento, CA, 161 pp.

Quast, J. C. (1968) Some physical aspects of the inshore environment, particularly as it affects kelp-bed fishes. In *Utilization of Kelp-bed Resources in Southern California*, eds. W. J. North and C. L. Hubbs, pp. 25–34. California Department of Fish and Game, Fish Bulletin 139.

Raco-Rands, V. (1999) Characteristics of effluents from large municipal wastewater treatment facilities. In *Southern California Coastal Water Research Project Annual Report 1997–1998*, eds. S. B. Weisberg and D. Hallock, Westminster, CA.

Rodolpho, K. S. (1970) Annual suspended sediment supplied to the continental borderland by the southern California watershed. *Journal of Sedimentary Petrology* **40**, 666–671.

Sanudo-Wilhelmy, A. S. and Flegal, A. R. (1992) Anthropogenic silver in the Southern California Bight: A new tracer of sewage in coastal waters. *Environmental Science and Technology* **26**, 2147–2152.

SCBPP Steering Committee (1998) Southern California Bight 1994 Pilot Project: I Executive summary. Southern California Coastal Water Research Project, Westminster, CA.

SCCWRP (Southern California Coastal Water Research Project) (1973) The Ecology of the Southern California Bight: Implications for Water Quality Management. Southern California Coastal Water Research Project, El Segundo, California. Technical Report 104, 531 pp.

SCCWRP (Southern California Coastal Water Research Project) (1992) Temporal and Spatial Changes in Sediment Toxicity in Santa Monica Bay. In *Southern California Coastal Water Research Project Annual Report 1990–1991 and 1991–1992*, eds. J. N. Cross and C. Francisco, pp. 81–87. Long Beach, CA.

SCCWRP (Southern California Coastal Water Research Project) (1994) Contamination of Recreational Seafood Organisms off Southern California. In *Southern California Coastal Water Research Annual Report 1992–1993*, eds. J. N. Cross, C. Francisco and D. Hallock, pp. 100–110. Southern California Coastal Water Research Project Auth., Westminster, CA.

SCCWRP (Southern California Coastal Water Research Project) (1995) Post-depositional Distribution of Organic Contaminants Near the Hyperion 7-mile Outfall. In *Southern California Coastal Water Research Annual Report 1993–1994*, eds. J. N. Cross, C. Francisco and D. Hallock, pp. 43–54. Southern California Coastal Water Research Project, Westminster, CA.

Schiff, K. C. (1999) Sediment chemistry on the mainland shelf of the southern California Bight. In Southern California Coastal Water Research Project Annual Report 1997–1998, eds. S. B. Weisberg and D. Hallock, pp. 76–88. Westminster, CA.

Schiff, K. C., Weisberg, S. B. and Dorsey, J. H. (1999) Microbiological monitoring of marine waters in southern California. In *Southern California Coastal Water Research Project Annual Report 1997–98*, eds. S. B. Weisberg and D. Hallock, pp. 179–186. Westminster, CA.

Schiff, K. C. and Allen, M. J. (2000) Bioaccumulation of chlorinated hydrocarbons in livers of flatfishes from the Southern California Bight. *Environmental Toxicology and Chemistry* **19**, 1559–1565.

Schiff, K. C. and Gossett, R. W. (1998) *Southern California Bight 1994 Pilot Project: III. Sediment chemistry*. Southern California Coastal Water Research Project, Westminster, CA.

Schiff, K. C. and Weisberg, S. B. (1999) Iron as a reference element for determining trace metal enrichment in Southern California coastal shelf sediments. *Marine Environmental Research* **48**, 161–176.

Smith, P. E. (1995) A warm decade in the Southern California Bight. *California Cooperative Oceanic Fisheries Investigations Report* **36**, 120–126.

Soutar, A. and Isaacs, J. D. (1969) History of fish populations inferred from fish scales in anaerobic sediments off California. *California Cooperative Oceanic Fisheries Investigations Report* **13**, 63–70.

Southern California Edison Company (1997) Annual Marine Environmental Analysis and Interpretation: Report on 1996 data, San Onofre Nuclear Generating Station. Prepared by Southern California Edison, ECOSystems Management, and Ogden Environmental and Energy Services.

Stull, J. K. (1995) Two decades of marine biological monitoring, Palos Verdes, California, 1972 to 1992. *Bulletin of the Southern California Academy of Sciences* **94** (1), 21–45.

Stull, J., Haydock, C. I., Smith, R. W. and Montagne, D. E. (1986) Long-term changes in the benthic community on the coastal shelf of Palos Verdes, Southern California. *Marine Biology* **91**, 539–551.

Stull, J. K., Swift, D. J. P. and Niedoroda, A. W. (1996) Contaminant dispersal on the Palos Verdes continental margin: I. Sediments and biota near a major California wastewater discharge. *Science Total Environment* **179**, 73–90.

Stull, J. K. and Tang, C. L. (1996) Demersal fish trawls off Palos Verdes, Southern California, 1973–1993. *California Cooperative Oceanic Fisheries Investigations Report* **37**, 211–240.

Swartz, R. C., Cole, F. A. Schultz, D. W. and DeBen, W. A. (1986) Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. *Marine Ecology Progress Series* **31**, 1–13.

Tegner, M. J., Dayton, P. K., Edwards, P. B., Riser, K. L., Chadwick, D. B., Dean, T. A. and Deysher, L. (1995) Effects of a large sewager spill on a kelp forest community: catastrophe or disturbance? *Marine Environmental Research* **40**, 181–224.

Thompson, B., Laughlin, J. D. and Tsukada, D. (1987) 1985 Reference Site Survey. SCCWRP Technical Report #221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B., Tsukada, D. and O'Donahue, D. (1993) 1990 Reference Site Survey. SCCWRP Technical Report #269, Southern California Coastal Water Research Project, Long Beach, CA.

Tran, K. and Zeng, E. (1997) Laboratory and field testing on an INFILTREX 100 pump. In *Southern California Coastal Water Research Project Annual Report 1996*, eds. S. B. Weisberg, C. Francisco and D. Hallock, pp. 137–146. Westminster, CA.

US EPA (1987) Environmental Impact Statement for San Diego (LA-5) Ocean Dredged Material Disposal Site Designation. US Environmental Protection Agency, Region IX, San Francisco, CA.

US EPA (1995) Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to West Coast Marine and Estuarine Organisms. US Environmental Protection Agency, Office of Research and Development, Washington, DC, EPA/600/R-95/136.

US EPA (1997) National Air Pollutant Emission Trends, 1900–1996. US Environmental Protection Agency, Office of Air Quality, Research Triangle Park, NC EPA-454/R-97-011.

Venkatesan, M. I. (1995) Coprostanol as a Chemical Probe to Assess Sewage and Toxic Pollutant Inputs in Southern California Basins. Sea Grant Biennial Report, Project No. R/CZ-126PD, pp. 159–169.

Venkatesan, M. I., Greene, G. E., Ruth, E. and Chartrand, A. B. (1996) DDTs and dumpsite in the Santa Monica Basin, California. *Science of the Total Environment* **179**, 61–71.

Venkatesan, M. I. and Kaplan, I. R. (1990) Sedimentary coprostanol as an index of sewage addition in Santa Monica Basin, southern California. *Environmental Science and Technology* **24**, 208–214.

Weber, M. L. (1997) *The Marine Fisheries of Southern California: A briefing Book*. Cabrillo Marine Aquarium, San Pedro, CA, 144 pp.

Wiemeyer, S. N., Bunck, C. M. and Stafford, C. J. (1993) Environmental contaminants in bald eagle eggs 1980–1984 and further interpretations of relationships to productivity and shell thickness. *Archives of Environmental Contamination and Toxicology* **24**, 213–227.

Wolf, P. and Smith, P. E. (1992) Pacific sardine. In *California's Living Marine Resources and Their Utilization*, eds. W. S. Leet, C. M. Dewees and C. W. Haugen, pp. 83–86. University of California, Davis, Department of Wildlife and Fisheries Biology, Sea Grant Extension Program, Davis, California. Sea Grant Extension Publication, UCSGEP-92-12.

Word J. Q. and Mearns, A. J. (1979) 60-m Control Survey off Southern California. Technical Memorandum 229. Southern California Coastal Water Research Project, Long Beach, CA.

Young, D. R., McDermott, D. J. and Heesen, T. C. (1976) DDT in sediments and organisms around southern California outfalls. *Journal of the Water Pollution Control Federation* **48**, 1919–1928.

Young, D. R., McDermott, D. J., Heesen, T. C. and Hotchkiss, D. A. (1975) DDT residues in bottom sediments, crabs, and flatfish off southern California submarine outfalls. *Californian Water Pollution Control Association Bulletin* **12**, 62–66.

Zeng, E. Y., Khan, A. R. and Tran, K. (1997) Organic pollutants in the coastal environment off San Diego, California. 3. Using linear alkylbenzenes to trace sewage-derived organic materials. *Environmental Toxicology and Chemistry* **16**, 196–201.

Zeng, E. Y. and Venkatesan, M. I. (1999) Dispersion of sediment DDTs in the coastal ocean off southern California. *Science of the Total Environment* **229**, 195–208.

Zeng, E. Y. and Vista, C. (1997) Organic pollutants in the coastal environment off San Diego, California. 1. Source identification and assessment by compositional indices of polycyclic aromatic hydrocarbons. *Environmental Toxicology and Chemistry* **16**, 179–188.

Zeng, E. Y., Yu, C. C. and Tran, K. (1999) In situ measurements of chlorinated hydrocarbons in the water column off the Palos Verdes Peninsula, California. *Environmental Science and Technology* **33**, 392–398.

Zmarzly, D. L., Stebbins, R. D. Pasko, D., Duggan, R. M. and Barwick, K. L. (1994) Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: relation to anthropogenic and natural events. *Marine Biology* **118**, 293–307.