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THE ECOLOGY OF THE SOUTHERN CALIFORNIA BIGHT: IMPLICATIONS FOR WATER QUALITY MANAGEMENT

Three-Year Report of the Southern California Coastal Water Research Project

SCCWRP

SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT
A local government agency for marine ecological research

1500 East Imperial Highway, El Segundo, California 90245

A preliminary release--SCCWRP TR 104-I--of the first five chapters of this report was made in October 1972. This document contains those five chapters (with minor revisions).

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SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT
A local government agency for marine ecological research

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21 March 1973

Mr. Bert Bond
President, Commission
Southern California Coastal Water
Research Project Authority

Dear Mr. Bond:

Your Consulting Board takes great pleasure in transmitting to the Commission of the Southern California Coastal Water Research Project Authority the report of the first three years work undertaken by the Project.

As you well know, the Consulting Board has guided the Project and its staff since its inception. The program has now culminated in a creditable report on the characteristics and quality of the waters, creatures, and sediments of a major portion of the Southern California Bight. We believe that the extensive list of specific findings of the Project and the very relevant and timely conclusions and recommendations go far to document existing conditions and to point both the directions for needed improvements and the studies necessary for further understanding and improvement of our local marine environment.

The Consulting Board is most pleased to inform you that the Board unanimously agrees with and endorses the findings, summary and conclusions as enunciated by the Project staff.

We wish to emphasize the practical and relevant nature of several of the report's conclusions concerning present wastewater management practice:

1. The Board concurs that there is no evidence to document that present wastewater disposal practices have had any substantial adverse or irreversible effects on the general ecological characteristics or environmental quality of the Bight.

2. On balance, marine wastewater management practices in the study region have been generally competent and responsive to new findings and developments.

3. Implementation of the recommended changes for marine wastewater discharge (particularly improved control of persistent pesticides, other persistent organics, toxic metals, and floatables) and continuation of research into man's general marine effects are essential for the continued preservation and enhancement of the quality of Southern California's marine environment.

4. The perspective attained by the study on the broad area of man's effects on the Southern California Bight is of major importance, along with the specific findings, for the guidance of future marine related activities.

5. Present disposal regulations designed largely for freshwater and estuarine environments have limited specific applicability to Southern California discharge practice.

The Consulting Board wishes to express their great pleasure in serving the Commission in the unique capacity as scientific and technical consultants to this most interesting and important project. We hope that the findings, conclusions and recommendations will prove to be of substantial benefit to the Commission, its members' agencies and to the general public.

Should you have any questions related to the statement presented in this Report, please do not hesitate to call on the members and chairman of the Consulting Board.

Sincerely,

John D. Isaacs
Chairman, Consulting Board
Southern California Coastal Water
Research Project

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Raymond M. Stewart

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William M. Conn
Roy E. Dodson, formerly Utilities Department
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County of Ventura

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Philip N. Storrs, Engineering-Science, Inc., performed the technical edit of the report and supervised the staff and Consulting Board review of the final draft. In this and several other activities of the project, Mr. Storrs has participated with skill and dedication; we are most grateful for his assistance.

Chapter 1

INTRODUCTION

The southern California coastal region contains one of the most rapidly expanding urban complexes in the United States. Most of this expansion has occurred in Los Angeles and Orange Counties, which in recent years have had high rates of population increase. Two other coastal counties--San Diego and Ventura--are entering periods of similar growth.

Proximity to the Pacific Ocean has been a key factor in southern California's growth. The ocean's influence on the weather of the region results in a temperate, subtropical climate that has drawn people from all parts of the country. Natural resources have made possible the development of such industries as oil, power production, transportation, commercial and sport fishing, mineral extraction, and tourism. The coastland has become a center for science and advanced technology and is valued for its excellent recreational facilities and scenic beauty. At present, it sustains a population of 11 million, and its continued growth seems certain. Inevitably, the demands on ocean resources will also increase.

The waters within a few kilometers of shore are perhaps most directly influenced by the intense development in the coastal region. There are both negative and positive aspects of man's influence on these nearshore waters. On one hand, marine ecosystems may be severely stressed or permanently altered as a result of human exploitation. Conversely, technology and knowledgeable planning and management may enhance the marine environment for its inhabitants and permit replenishment of important marine resources. If the ocean is to continue to satisfy the often conflicting demands of the human population, both of these aspects of the environment quality issue must be considered--the coastal water environment must be both protected and enhanced.

Traditionally, one of the important uses of the coastal waters for man has been as a repository for his wastes. Although the ocean is vast, its ability to assimilate these wastes without significant environmental degradation is limited. Considering the absence of generally accepted criteria for environmental quality control and the complexities of the physical, chemical, and biological systems involved, it is not surprising that there is concern over the adequacy of present-day marine wastewater management practices. Today, particular attention is focused on certain waste constituents--oils and greases, particulates, persistent pesticides, and some trace metals and metallic compounds. These substances may have far-reaching effects on marine ecosystems or the public health, yet their true behavior and effects have not been established to the degree necessary to permit implementation of effective controls. Progress is hampered by several factors. Some substances have been detected in various components of the marine ecosystem; however, in all but a few cases, neither their exact source nor the modes by which they are distribibed in the environment are known, nor are their effects understood. Many suspect

substances are not detectable in the environment with existing technology; the natural levels of other waste constituents are imperfectly appreciated.

In southern California, evaluation of the impact of waste discharge is further complicated by the complex physical, chemical, and biological character of the receiving waters. Geologically, the southern California offshore region has existed essentially in its present form for thousands of years. But, because of the often extreme cyclic and noncyclic changes in weather and currents that characterize the Pacific Ocean in this area, local marine organisms have been subjected to a variety of environmental stresses; ecological changes are thus a part of the natural history of the area. Changes occurring in recent times as a result of man's activities may resemble, blend with, or perturb such natural fluctuations. Alternatively, long-standing effects of man's historical actions may become established as the "natural" state of things. For these reasons, both natural phenomena and man's acts in the recent past and present must be considered in evaluating the impact of present wastewater discharges upon the ecology of the area.

In the last decades, water quality management techniques and wastewater treatment methods have been steadily improving. There is the technical capability (disregarding cost) to remove virtually any constituent from the wastewater stream. However, without adequate understanding of the relative significance of various waste constituents, valuable resources can easily be expended in implementing controls that do not significantly benefit either man or the environment.

There is particular danger of misspent effort in marine water quality control. Because the problems of freshwater pollution have been recognized for some time, treatment systems and controlling regulations are most highly developed in this area. However, these techniques and controls are not always applicable to marine systems as the chemistries of the two realms differ in fundamental and profound ways.

Unquestionably, the protection and enhancement of the marine environment is an important goal in the Nation's environmental quality program. However, it is doubtful that marine waste management systems such as those in southern California can be optimized without improvement in our knowledge of the characteristics of the wastes discharged and the ecosystems of the marine waters that receive them. Only with improved understanding of these two elements and the interactions between them can the limited financial resources available for wastewater control be allocated with assurance of benefit. And, although each particular area and situation must be considered separately, much of the understanding of marine waste disposal problems in southern California will be broadly applicable to planning and improving similar marine systems elsewhere in the world.

1.1 STUDY PURPOSE AND SCOPE

The basic goal of the Southern California Coastal Water Research Project (SCCWRP) is to increase understanding of the ecology of the coastal waters off southern California and of the effects of man's activities (especially municipal wastewater discharge) on the marine environment. The project aims at encouraging the conservation and enhancement of local marine resources by providing broad scientific insight and guidance to agencies affecting these

resources and to the general public. The ultimate goal of the project is to acquire a reservoir of information on the ecology and the nature of wastewaters so that the effects of past and present wastewater discharges can be evaluated and future discharges can be appropriately planned and meaningfully monitored.

SCCWRP was founded in 1969 by the five government agencies[1] responsible for most of the municipal wastewater discharges into the ocean off southern California. Believing that their established research programs could benefit from the addition of a project with regionwide focus, the agencies entered into a joint powers agreement to sponsor SCCWRP. The sponsors delegated control of the project to a commission of local civic leaders and elected officials who could reflect the current public interest in environmental quality, but be free from partisan pressures. This arrangement has given the project freedom from control by other agencies and has fostered a broad and balanced viewpoint.

The project differs from its sponsors' continuing research efforts in the scope of its investigations. The goals of most current and recent studies have been to develop and confirm engineering design criteria for waste treatment and ocean disposal, to demonstrate compliance with regulatory requirements, or to resolve special problems. In the SCCWRP program, studies of specifics--isolated substances, areas, and effects--are balanced by broader investigations of the coastal water region as a whole, its natural history, its large-scale physico-chemical characteristics and functions, its biological communities, and its responses to various human activities. In initiating this project, the sponsors realized that these fundamental investigations are necessary to the development of a sound basis upon which to evaluate the ecological significance of present and proposed wastewater disposal systems.

1.1.1 Objectives

The specific objectives of the study described in this report were:

A. To obtain background information on the general physical, chemical, and biological characteristics of the coastal water ecosystem.

B. To identify and investigate ecologically significant but insufficiently understood physical, chemical, and biological processes and phenomena occurring in the southern California coastal waters.

C. To identify the significant sources of inputs to these waters and to characterize the inputs with respect to the nature and quality of their constituents; to describe the transport and fate of certain constituents that are known or suspected to be potentially hazardous to the environment or the public health.

D. To identify quantifiable species, population, and community responses to environmental stresses.

[1] Ventura County, the Cities of San Diego and Los Angeles, and the County Sanitation Districts of Orange and Los Angeles Counties.

E. To determine the significance of findings to water quality management systems--specifically, to make economically and technologically feasible recommendations on effluent and receiving water standards and monitoring procedures.

F. To identify and define further research that is most urgently needed to ensure that the environment and its resources are adequately protected.

1.1.2 Study Area

The Southern California Bight (Figure 1-1) is defined as the open embayment of the Pacific Ocean bounded on the east by the reach of the North American coastline extending from Point Conception, California, to Cabo Colnett, Baja California, Mexico, and on the west by the California Current. The joint powers agreement creating SCCWRP specified the project's primary study area as the portion of the Bight defined on the east by the strip of California coastline extending from the Santa Barbara/Ventura county line to the United States/Mexico border and on the west by the edge of the mainland shelf. (Waters in the harbors of the Bight and in the tidal prisms of its estuaries were excluded from the primary study area.) However, to provide perspective for the study, the Bight as a whole and those transports across its boundaries pertinent to the fate of wastes introduced into the primary study area were considered in the SCCWRP investigations. Therefore, in this report, no distinction is made between the "Southern California Bight," "southern California coastal waters," and "the study area."

SCCWRP studies of the coastal basin bordering the Bight have focused on the land draining through streams on the United States portion of the coast (shaded area in Figure 1-1); this land is referred to in this report as the southern California coastal basin. The coastal basin of northern Baja California is sparsely populated and generally undeveloped and is drier than the land to the north; hence, inputs to the Bight from this area are generally of less magnitude and significance. However, because Baja California waters are used as a control area for many ecological studies of the waters off southern California, features of the land draining into the Mexican portion of the Bight will be investigated in future SCCWRP programs.

1.2 PLAN AND ORGANIZATION

Some rather extensive background data on the ecology of southern California coastal waters exist as a result of a number of research and survey programs carried out by universities and Federal, State, and local agencies. Much of the data from the local government agencies had been unanalyzed prior to SCCWRP's formation. Thus, one of the first steps in the SCCWRP investigations was to examine and integrate the material collected in these programs.

In connection with this review, SCCWRP designed a research program to supplement and expand the existing data. Laboratory and field studies were conducted both by the SCCWRP staff and by other groups under contract (major contractors are listed in Appendix A). In addition, several programs were carried out in cooperation with local and State agencies.

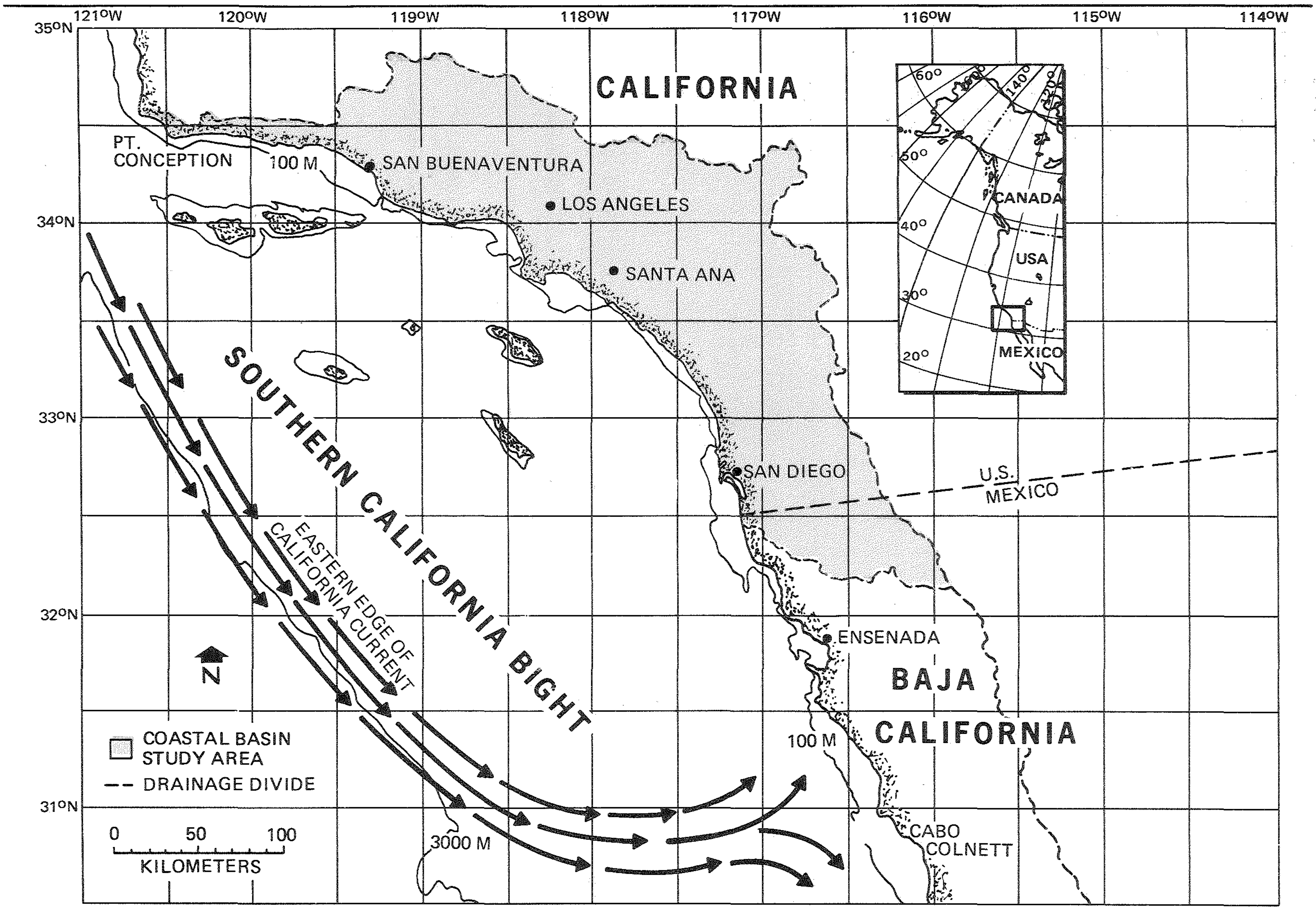

Figure 1-1. The SCCWRP Study Area.

Both the review and research phases of the effort involved the professional disciplines of physical and chemical oceanography, marine biology and ecology, public health, sanitary engineering, and systems engineering. The SCCWRP organization and primary areas of responsibility are shown in Figure 1-2.

1.3 ORGANIZATION OF THE REPORT

The next two chapters (Chapters 2 and 3) provide an overview of the many facets and complexities of ecological study in the Bight and a general description of the characteristics of the coastal basin and the nearshore waters. Chapter 4 deals with quantities and characteristics of municipal wastewater discharges, natural runoff from storm drains and streams, industrial discharges, and other, more diffuse sources of potential pollutants. A brief general discussion of water quality characteristics and current patterns in the nearshore waters is included in Chapter 5; general sediment characteristics are also described in this chapter. SCCWRP investigations of the concentrations of trace metals and chlorinated hydrocarbons in the sediments of the Bight, particularly those around major municipal wastewater outfalls, are discussed in Chapter 6.

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Figure 1-2. SCCWRP Organization and Principal Areas of Responsibility.

SCCWRP investigative and analytical work on fish, benthos, and plankton is described in Chapters 7, 8, and 9, respectively. Chapter 10 is a discussion of the public health aspects of marine wastewater discharges. The final two chapters of the report are devoted to the summary and discussion of the Project's work and to conclusions and recommendations stemming from the work done to date.

Chapter 2

A PERSPECTIVE FOR CONSIDERATION OF THE SOUTHERN CALIFORNIA BIGHT

A long, largely unrelieved portion of the west coast of North America extends from the Strait of Juan de Fuca at the United States/Canada border to Cabo San Lucas at the southern tip of the Baja California peninsula. This 3,200-km reach is almost precisely bisected by Point Conception, which is often called "the Cape Horn of the Pacific" because of the conspicuous change in climates and fauna that it marks. However, it is not the salient Point Conception, per se, that creates this climatic and faunal discontinuity, but rather the sharp eastern break of the coast to the south of the point and the resulting indentation that extends for 575 km to Cabo Colnett on the Baja California coast. This great Southern California Bight describes the immediate milieu of the marine problems attending southern California's human population. The broad geological, physical, and organic processes that set the general conditions of the Bight and cause profound aperiodic fluctuations of all its characteristics are described in this chapter.

Geologically, the Southern California Bight has existed much in its present form since early Pleistocene times, 3 to 4 million years ago. It is a feature of the great crustal movements of the earth circling the Pacific. More locally, it is a result of a complex fault system dominated by the San Andreas Fault. The Bight's comparatively rapid geological evolution has resulted in the development of an unusual sea floor configuration--a series of coastal basins, troughs, and submarine canyons, which, in a more stable environment, would have inevitably been smothered long ago by a heavy blanket of sediments. The rugged underwater topography of the region allows deep, cold bathypelagic waters and attendant nutrients and organisms to encroach shoreward of the island-bearing continental borderland.

This highly irregular continental shelf imposes other conditions on the southern California region. For example, it largely protects the coastland from the heavy winter swells from the North Pacific and effectively reflects the great tsunamis that periodically sweep the Pacific from Alaska to Chile. Conversely, it allows the summer entry of the long southern swell generated by the violent winter storms of the South Pacific, and it can be expected to "trap" and accentuate any tsunamis ever generated within the Bight.

The most important effect of the Bight is to interrupt the ponderous flow of the California Current. This current, the eastern branch of the great North Pacific Gyre, converges off the Washington Coast and sweeps 1,500 km without major perturbations, commonly departing from its coastal flow only at Point Conception. This sudden departure can be viewed as a "stall" in the flow of the current--a hydrodynamic discontinuity that is ordinarily associated with a return eddy, the Southern California Countercurrent.

The effects and importance of the Southern California Countercurrent, the most permanent feature of the variable circulation of the Bight, are innumerable. Appropriate to mention here are (1) its action as a delay or reservoir in the otherwise straight sweep of the California Current, with a consequent warming of the oceanic water in the Bight, an over-all advection of food material into the Bight from farther up the coast, and a net consumption of food material elaborated upstream and (2) its importance as an enclave in which many organisms can maintain a breeding stock. The most notable effect of the countercurrent on the Bight is the creation of a region in which southern, western, northern, and upwelling waters and organisms converge. These four relatively independent regimes, each subject to its own individual fluctuations, meet in southern California in a variable concert.

The oceanographic conditions of the Bight are also influenced by several weather regimes and storm systems. However, the vulnerability of the southern California region to changes in weather does not result solely from its location near the terminus of several atmospheric and oceanic influences. In general, weather moves from west to east. Thus, weather features reaching the Bight have been generated in or transported and modified across the greatest and most featureless expanse of water in the northern hemisphere, a sea spanning one-third the girth of this globe. These weather events are "steered" across the Pacific by their interaction with the varying air and water masses, which are in turn created by the weather events themselves. The course of weather events in their motion across the Pacific is only weakly and peripherally influenced by any permanent features (e.g., the Aleutian Islands) but is strongly affected by impermanent and fluctuating interactions. The results of this changeable steering are indirectly exhibited in the great year-to-year and decade-to-decade variability of storms, rainfall, fog, air and water temperature, and abundance and composition of marine populations in the Southern California Bight.

The direct terminal effect of this weather on oceanic conditions is equally variable. For example, extra-tropical storms may be steered directly to the southern California coast, leading to high runoff and the encroachment of southern or central water and southern organisms. Stronger than normal storms, steered into the northwest coast, greatly impede the flow of the California Current and lead to the development of a strong, narrow countercurrent flowing north from subtropical waters through southern California and, in extraordinary cases, continuing up the coast as far as Vancouver Island. Under other circumstances, strong northwesterly winds intensify the California Current, leading to strong upwelling, cool summers, and the presence of northern fauna in the Bight. A variety of other conditions may also exist. Weak summer northwesterly winds and a sluggish California Current encourage the development of high water temperatures and the invasion of southern California by tropical storms, such as the fierce Mexican chubasco. In some periods in the early 1800's, the southern California coast apparently was affected by these hurricanes several times a year. These conditions were probably accompanied by abnormally high temperatures in autumn and an influx of tropical creatures, an association that has occurred several times in this century. Certain periods, sometimes lasting for years, stand out as quite warm and others as quite cold. For example, warm periods occurred in 1850-70, 1926, 1931, 1939-41, 1957-58, 1968-69, and 1971-72, and cold periods in 1880-90, 1924, 1933, and 1946-56. Some of these extremes extended far across the continent.

It has been estimated that the average upwelling on the California coast involves the continuous input of about 1 million kw of mechanical power and 1 billion kw of thermal power. Since year-to-year upwelling varies by similar amounts, the year-to-year variation in thermal power related to upwelling is of the order of the thermal discharge from all of the electrical generating plants on the continent.

The pelagic regime and its conditions, currents, transport, chemistry, and organisms are of course most directly affected by these large-scale variations. A pelagic creature born into the Bight has only a little assurance of the nature of its food, predators, transport, and associates. Therefore, at least in the pelagic regime, the classical concepts of a complexly balanced ecological system or of steady mixing and stable transport are largely fictional. Instead, the creatures are opportunistic, variable, and resilient and absorb great insults inflicted by an often inconstant nature.

In the other environments of the Bight--those of the littoral, bathypelagic, and benthic creatures--the strength of these fluctuations is variously modified or weakened. Not only are these regimes insulated from the pelagic events by a step of remoteness, but the habitats offer an added degree of insulation. For example, food material in sediment cannot be destroyed by any ordinary short-term event, and benthic organisms can retain a viable breeding population for a substantial time period although their progeny may be largely swept away in extended periods of adverse currents. Thus, in these environments, some real degree of stable, balanced ecological complexity may often exist. However, the substantial, decade-to-decade natural fluctuations observed in littoral and shallow benthic species and populations indicate that the ecological balance of these regimes is also profoundly affected by large-scale fluctuations, although on a longer time scale.

The present-day conditions in the Bight are not solely the result of natural phenomena modified by the effects of contemporary man's actions, for man has been involved in the ecology of the Bight for millenia. In some areas, he has exerted more profound influence in the past than at present. For example, over a century ago, Russian and American hunters and whalers nearly exterminated the sea otter and the gray whale in the region. Although both of these species are now returning, the imbalances engendered by their 100-year or more absence have not been evaluated fully. The decline of some southern California kelp beds are perhaps more readily attributable to the absence of the sea otter (a predator of the sea urchin, which feeds on the kelp) than to other causes.

In the more remote past, burning of the backcountry by the Spanish and Indians, local overgrazing, and, most particularly, cessation of the centuries of harvesting of littoral and rocky shore animals by the Indians have been shocks to the nearshore environment--shocks that we are apt to consider as being within the natural order of things. The cliff-high layers of shells in the kitchen-middens of southern California Indians indicate the extent of their daily cropping, to which the littoral creatures had adjusted over 40 centuries. In the accessible coastal areas where the cropping occurred, an ecological imbalance may have followed its sudden discontinuance.

More recent historical effects of man must also be considered in ecological studies. Major rivers and streams, with their associated loads of sediment and debris, have been regulated. Commercial fisheries have blossomed and then been legislated out of existence. For example, the bottom trawl fishery within 5 km of the southern California shoreline became illegal in 1925; ecological adjustments to this fishery and its sudden demise must still reverberate through the communities of benthic creatures.

The most profound effects of sport and commercial fisheries may stem from their selectivity. For example, the fisherman's pursuit of the large predators has probably imposed an important background condition on the Southern California Bight. In a marine biological community, sick, injured, or abnormal fish (or even those that are merely behaving erratically) are usually quickly removed by large predators; abnormal prey can only be present in a community in which the populations of major predators have been selectively reduced. Thus, an equivocation of evidence arises with a report of abnormal fish: Abnormality or disease in a population indicates a preexisting imbalance or scarcity of the species' predators. This is a particularly apt example of the importance of conducting research on the influence of one of man's contemporary acts in the context of other preexisting and often unassociated man-related activities.

This brief description of the Southern California Bight abstracts from the great and increasing store of knowledge and understanding that has been gathered by many marine scientists. The intent of this summary is to emphasize a number of vital features of the Bight that are now understood with considerable certainty. Particularly important are the facts that the fluctuating conditions in the Bight result from processes involving at least the entire North Pacific; that, as a consequence, study of the oceanographic conditions of the Bight alone cannot provide an adequate picture of events occurring within its boundaries; that the Bight constitutes a unique biological and climatic discontinuity and enclave in the California Current; that waterborne pollutants in the Bight comprise not only those from local sources, but also a substantial fraction of those introduced along the entire west coast of North America; that the natural fluctuations of physical conditions and organisms occurring in the Bight are driven by energy fluxes involving millions of megawatts of power; that only a partial stability exists in the circulation and pelagic populations of the Bight; and that the present-day conditions of the Bight are influenced by over 40 centuries of man's activities in the region.

Chapter 3

THE GEOGRAPHY OF THE SOUTHERN CALIFORNIA BIGHT AND THE ADJACENT COASTAL REGION

3.1 INTRODUCTION

The structure, topography, climatology, hydrology, and water movements of the southern California and northern Baja California region contribute to the uniqueness and coherence of the Southern California Bight. These elements and their interrelationships are briefly discussed in this chapter. As human activities in the region are related to some extent to all of the physical features and conditions described here, the chapter also contains general data on the southern California population and its use of land and water resources. Three other physical parameters--sediments, water characteristics, and nearshore circulation, which are particularly relevant to the SCCWRP studies, are treated separately in Chapter 5.

3.2 LAND AND SUBMARINE PHYSIOGRAPHY

The Southern California Bight (Figure 3-1) is the open embayment of the Pacific Ocean extending from Point Conception on the north to Cabo Colnett, Baja California, on the south. The California Current roughly defines the Bight on the west. As the Bight's current system usually extends westward to the area with water depth in the order of 3,000 m, a more precise western boundary is the continental slope off southern California and northern Baja California. Within these boundaries, the Bight is approximately 500 km long and 200 km wide, covering a surface area of 100,000 sq km.

The Bight is located in a region that is carved and sliced extensively by faults (Figure 3-2). This fault system, which has been intermittently active during long periods of Cenozoic time, has been fundamental to the geomorphic development of the area.

The fault system has a number of immediate influences on the inputs into the Bight. For example, the larger active faults are effective in continuously reducing their flanking rocks into particles much finer than those produced by ordinary weathering. Thus faults often become water courses, bearing the fine sediment to the sea. Faults also contribute significant amounts of oils and tars through natural seeps, particularly at times of high seismic activity.

Faults are also commonly associated with highly mineralized ponds, geothermal springs, and mineral deposits and thus undoubtedly contribute disproportionately to the mineral input from stream flow. Possible geothermal power-plant developments will be related to faults.

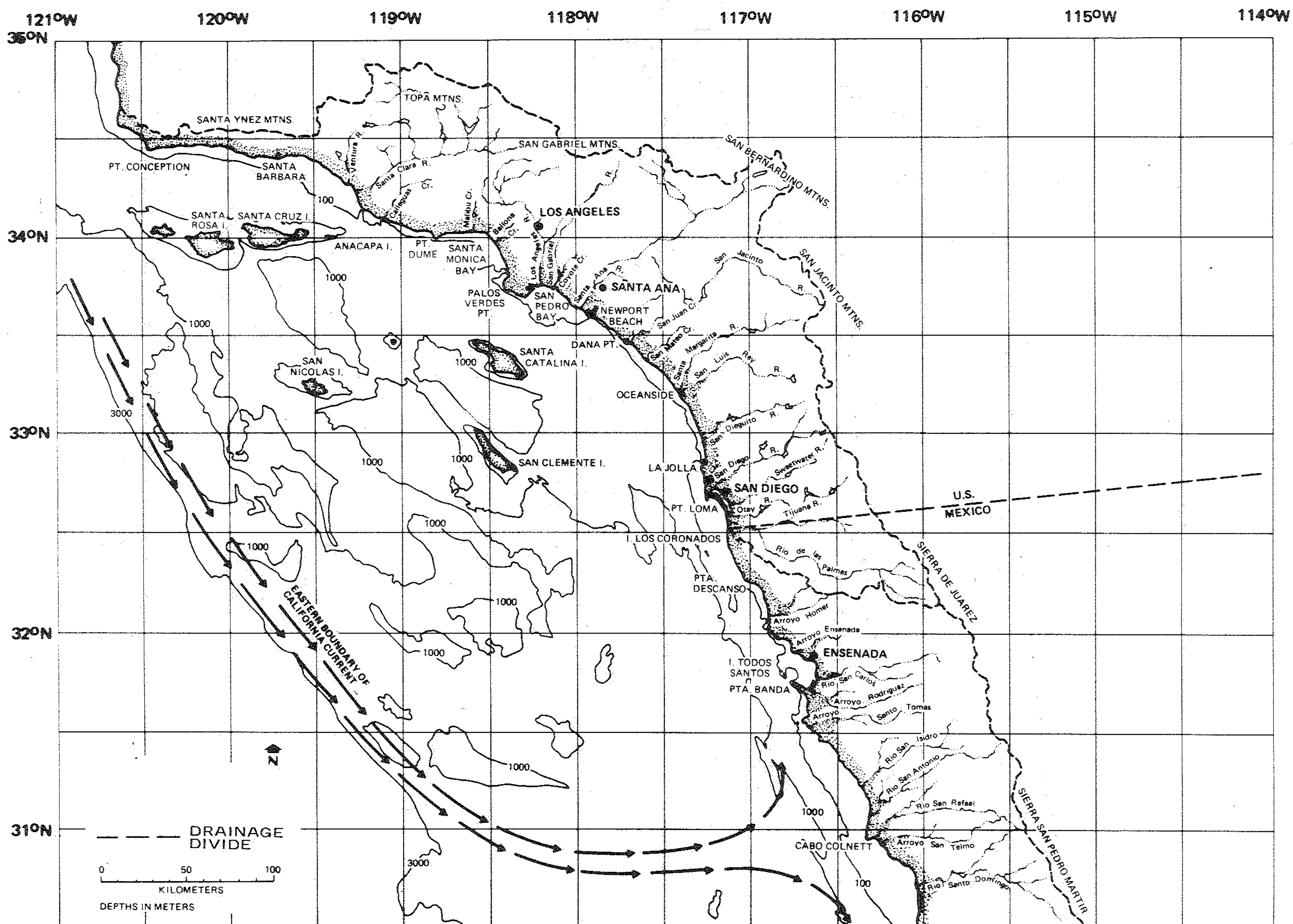

Figure 3-1. The Southern California Bight and the Adjacent Coastal Basin.

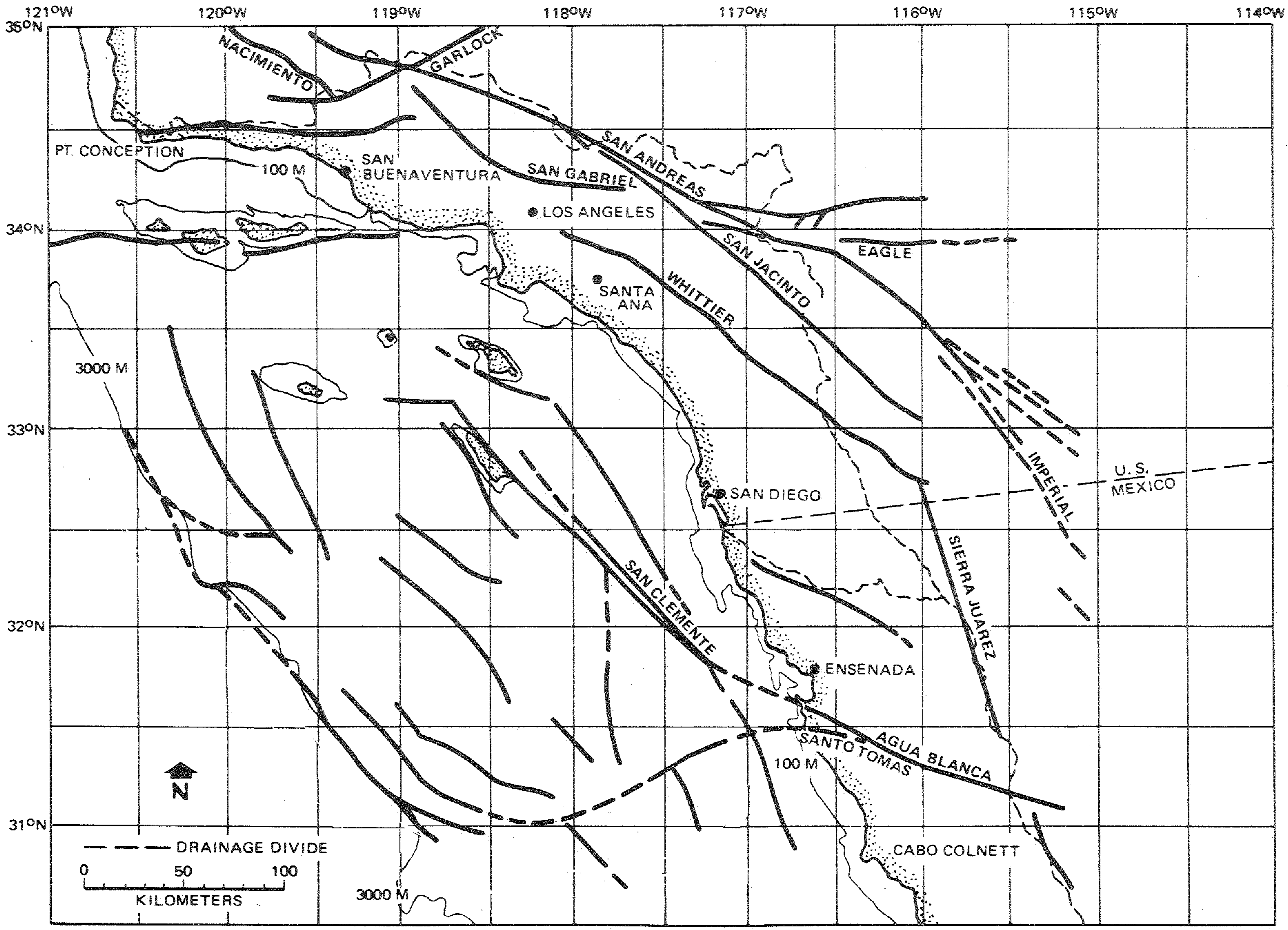

Figure 3-2. Major Faults in Southern California and Northern Baja California. From Moore 1969, Plate 13.

Undersea faults in other geologically active regions of the world recently have been shown to be immense producers of metallic inputs. The Red Sea brines and associated Red Sea sediments and the sediments of the East Pacific Rise are so heavily mineralized as to be potentially minable. Brines of this type have been tapped in the Imperial Valley. Although no similar flows have been demonstrated in the floor of the Bight, they have not been sought, and it would be surprising if, in so complex and active a fault system, submarine inputs of metals were not important. It is probable that any such inputs are rapidly mixed into the waters of the Bight rather than pooled as they are in the weakly circulating Red Sea. Materials in such geothermal brines include silver, copper, arsenic, radium, zinc, selenium, lead, and mercury as well as many other ecologically significant substances.

There are two natural geologic provinces in the southern California and northern Baja California coastal area (Figure 3-3). The Transverse Ranges, which have a west-to-east trend, stretch from Santa Rosa Island inland to within 100 km of the Colorado River. The province formed by these ranges is about 475 km long and from 25 to 100 km wide. It is marked by topographic contrasts ranging from broad river valleys to high mountain chains (highest elevation: 3,073 m at San Antonio Mountain) dissected by deep, narrow canyons. Several large, low-angle thrust faults are major elements in the structure of the Topatopa Mountains, and the Transverse Province is intersected in that area by the San Andreas and associated northwest-to-southeast faults.

The Peninsular Ranges parallel the northwest-to-southeast trend of most of the major ranges of California. The province extends southward from the foot of the southern slopes of the Transverse Ranges to the tip of Baja California and westward to the continental slope. The exposed portion is 1,450 km long, from 90 to 220 km wide, and 3,294 m at its highest point, San Jacinto Peak. (The continental borderland, the submerged part of the province, is described later in this section.) The profile of the province is asymmetric, with the eastern slopes rising steeply from the desert and the western slopes long and gentle, broken locally by a wide variety of features. The coastal zone is irregular, ranging in width from a few meters to about 50 km.

3.2.1 The Coastline

The coastline, which comprises the beaches, cliffs, coastal terraces, and other land features immediately affected by the ocean, is a region sensitive to the phenomena occurring on land as well as to the sea's erosional and depositional processes. In southern California, the human activity on the land is intense: A significant portion of the shoreline has been dredged, filled, or reshaped for the development of ports, harbors, marinas, and jetties and for other purposes. These and other human activities, some occurring far inland, combine and interact with natural processes to change the existing coastline and to affect the character of the adjacent coastal waters and sea floor.

A rough but useful classification of the shoreline can be made in terms of rocky and sandy. In general, rocky shorelines have been shaped by erosional processes, whereas sandy beaches backed by deltas, alluvial fans, or mudflats are depositional. Sandy shorelines backed by cliffs are influenced by both processes; i.e., they are erosional on a long-term basis, although the beach indicates temporary depositional characteristics. The lengths of southern California

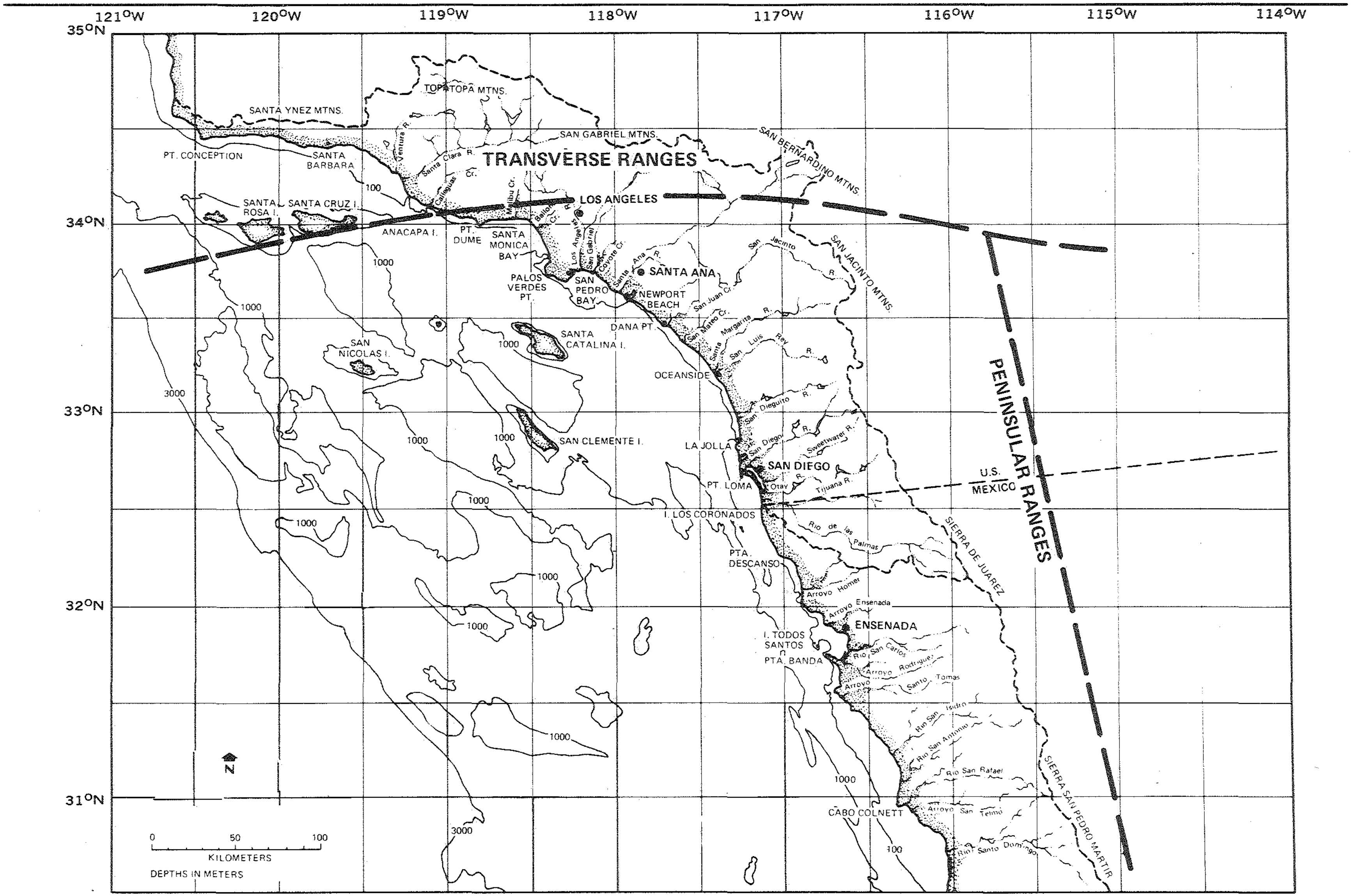

Figure 3-3. The Natural Geologic Provinces of Southern California and Northern Baja California.

shoreline that fall into each of these categories are given in the following table:[1]

		Sandy		
	Rocky (Erosional)	Backed by Cliffs (Erosional)	Backed by Lowlands (Depositional)	Total
Mainland	81 km	278 km	129 km	488 km
Islands	410	92	0.5	502
Total	491 km	370 km	129 km	990 km

As the table shows, almost 87 percent of the coastline of southern California (including the islands, where most shorelines are rocky) is erosional. It is also interesting to note that the total length of island coastline exceeds that of the mainland.

Erosional Coasts

Most erosion at the coastline occurs through mechanical processes, such as abrasion by suspended sands and gravel or by runoff. Substantial quantities of debris also enter the sea through the activities of boring and shell-bearing organisms. Overall, the erosion of rocks other than by surface runoff is occurring at an extremely slow rate in southern California.

The cliffs of the erosional coasts of southern California range in height from 2 to more than 150 m. Direct erosion at the shore occurs only at the level between high and low tides. Thus the bulk of erosion of high cliffs is caused indirectly by the undercutting that finally results in landslides. About 12 percent of the total length of shoreline in southern California has been affected by such landslides.

Land-form erosion is a perennial and variable process. For example, the presence of a talus or gravel rampart at the foot of many southern California coastline cliffs usually affords protection against marine erosion. However, during severe storms, waves may reach the cliffs, and considerable erosion may result. More significantly, storms greatly increase the amount of erosion through surface runoff. As the rate of input of natural particulates by erosional processes is far from constant, the offshore deposition of the particulate material (which sometimes greatly alters the character of offshore habitats) also varies. In addition, the input of various minerals to the Bight fluctuates, depending upon the amount of erosion and the geological nature of the source material.

Depositional Coasts

Most of southern California depositional coasts are sandy beaches along the mainland. About 30 percent of the sandy beaches of the area are backed by lowlands (marshes or mudflats) and are thus truly depositional. The remainder are found at the base of sea cliffs in coastal areas that must be considered only temporarily depositional.

1. From Emery 1960, tab. 2.

Beach Sand Transport. The role of waves and tides in the transport of beach materials is an important indication of the natural transport processes available for pollutants. Waves at the shoreline and related nearshore water movements initiated by waves move sediment in three directions--onshore, offshore, and alongshore. Most of the waves in the Bight come from the southwest in the summer and from the west and northwest in winter, with a resultant concentration of sand in the central part of the Bight, i.e., between Ventura and San Diego. The estimated rate of transport of sand along the coastline toward the middle of the Bight is about 250,000 cu m/yr.

Net offshore transport of sand may occur where submarine canyons intercept the sand transport zone. Four submarine canyon systems fall into this category: The Hueneme-Mugu-Dume group, Redondo, Newport, and the Scripps-La Jolla group. These divide the region into five nearly independent beach units.

There is a natural annual onshore-offshore movement of sand on most beaches, resulting in a lowering of the intertidal portion of beaches during the winter and a buildup during the summer. The lunar tidal cycle of low neap and high spring tides (each event occurring about once a month) also causes a periodic variation in beach level. Another cycle of beach sand movement occurs because of changing water levels during the tides, and other changes are observed with changing wave height, length, and angle of approach.

Finally, the longshore transport of sand by littoral currents causes changes in erosion and deposition along the shoreline. The average size of the grains on a beach, as well as the thickness and extent of the sand, varies with changes in the currents and the characteristics of the waves that supply the transport energy to the system. The interposition of breakwaters, groins, piers, and other structures across this transport system has serious consequences. Erosion occurs downcurrent from a structure such as a groin, while deposition occurs on the upcurrent side (Figure 3-4). This sequence of events has occurred with the building of almost every structure across southern California beaches, sometimes with far-reaching effects on the character of the coastline. For example, the section of shoreline from Santa Monica to Redondo Beach formerly received sediment from river drainage, but this beach area has been so extensively altered by development of piers, groins, breakwaters, flood controls, and buildings that the present configuration only vaguely resembles that which existed around 1850. Beach erosion now occurs where formerly this coastline was depositional, and sand must be brought from inshore sand dunes to replenish losses to the sea.

Marine Terraces

One of the more impressive features of the southern California coastal area is the mesaland topography of some sections of the coastline. The marine terraces, which may appear as steps on the coastal hills, were cut from the sedimentary rocks of the coastal zone by waves at other stands of sea level. Terraces are exposed on all the southern California islands, in the San Diego area, and at many other places along the coast. Most are under 150 m in elevation, but some on the islands reach over 600 m. Widths range from a few meters to over 8 km.

The terraces display a unique fossil record of prehistoric marine life, but are primarily of significance to man because of their suitability for construction. In many hilly areas adjacent to the coast, virtually all works of man are located on the terraces, and the characteristics of surface runoff in these areas is thereby affected.

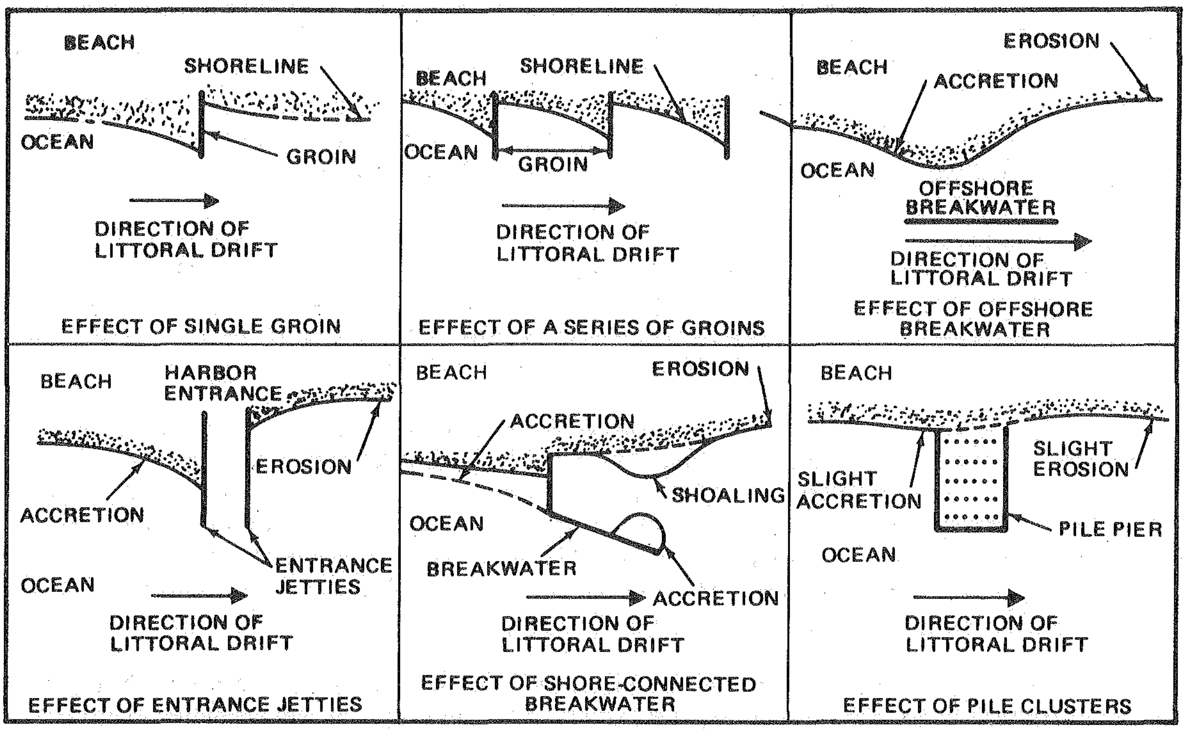

Figure 3-4. The Effect of Man-Made Structures on Littoral Drift. (From Peel and Kaplan 1953, figs. 40-45

Beach Sand Supply. Sand and gravel are supplied through local erosion of sea cliffs and through surface runoff in streams. The latter is by far the more important source of sediment (but probably not of erosional trace minerals). An average of nearly 2 million cu m of sediments (including silt and clay) are contributed to the Bight annually (Table 3-1). On a long-term basis, most of the input occurs during large, infrequent floods (a pattern typical of semiarid regions). For example, 6.2 million cu m of sand alone were deposited at the mouth of the Los Angeles River during the flood of 2 March 1938.

As surface runoff is the major source of beach sand, man's obstruction and modification of stream courses has had a significant impact on the coastline. Channeling of stream beds and dam construction for soil erosion prevention or flood control have reduced beach sand supply and changed prograding river deltas into tidal inlets, consequently inducing beach erosion.

3.2.2 The Offshore Islands

There are eight islands off the coast of southern California, commonly called the Channel Islands. The northernmost group consists of San Miguel, Santa Rosa, Santa Cruz, and Anacapa; these islands are the exposed extensions of structural features found on the mainland. The others--San Nicolas, Santa Barbara, Santa Catalina, and San Clemente--which are dispersed widely through the center of the Bight, are the emergent peaks of undersea ridges. The dimensions and elevations of the islands are given in Table 3-2.

Table 3-1
ESTIMATE OF LONG-TERM BEACH SAND SUPPLY
FROM MAJOR SOUTHERN CALIFORNIA STREAMS*

Streams	Mean Sediment Load (1,000 cu m/yr)
Santa Ynez Mtn. Group	28
Ventura River	77
Santa Clara River	344
Santa Monica Mtn. Group	12
Ballona Creek	35
Redondo-Palos Verdes Group	46
Santa Ana River	22
Aliso Creek	8
San Juan Creek	44
San Mateo Creek	25
Santa Margarita River	12
San Luis Rey River	269
San Dieguito River	3
San Diego River	84
Tijuana River	694
TOTAL	1,703

*Based on California Depart. of Water Resources 1969.

Beach sand transport and other shoreline processes discussed in the preceding subsection are strongly influenced by the islands, which have a "shadowing" effect on the mainland. The islands are spawning grounds for some species and thus affect the operations of local sport and commercial fisheries. In addition, the islands are a determinant of water circulation and shipping lane patterns in the Bight.

Over half the coastline of southern California belongs to the islands, and they are an important source of erosional inputs. As on the mainland, the character of these and other inputs to the Bight from the islands is influenced by the human activities found there as well as by the rock and soil types. Santa Rosa and Santa Cruz are devoted to ranching; Santa Catalina has several natural harbors and coves used extensively by pleasure craft and a public resort at

Table 3-2
DIMENSIONS AND ELEVATIONS OF THE CHANNEL ISLANDS

Island	Length (km)	Maximum Width (km)	Highest Elevation (m)
San Miguel	13	6.5	254
Santa Rosa	21	13	466
Santa Cruz	34	8	740
Anacapa			
West	2.5	0.3	294
Middle	2.5	0.3	99
East	1.5	0.3	76
Santa Barbara	2.5	1.5	194
Santa Catalina	30	11	648
San Nicolas	14.5	5	277
San Clemente	29	6.5	598

Avalon; and San Miguel, San Nicolas, and San Clemente are U.S. Naval reservations. All, including the uninhabited Anacapa and Santa Barbara, are used heavily by sports fishermen and scuba divers.

3.2.3 The Sea Floor

The classic continental slope-abyssal sea floor sequence outward from the coastline does not appear in southern California. Instead, the mainland shore is bordered by a narrow continental shelf, followed by a narrow slope region. Next comes a wide, complex region of basins and troughs interspersed with ridges locally piercing the surface as offshore islands. This is the continental borderland (Figure 3-5). Finally, the continental slope, the transition feature between the borderland and the deep-sea floor, is found as much as 250 km from the coast (Figure 3-6).

While the borderland is a distinct physiographic province, it is readily subdivided into its component features--mainland and island shelves, basin and trough slopes, submarine canyons, basins and troughs, and continental slope.

Mainland and Island Shelves

Shelf profiles are generally smooth and regular, except where extensive rock outcrops are exposed on the sea floor. The submerged terraces are generally wider and flatter than most of the emergent shelves exposed on land. The outer terrace is generally regarded as the true outer edge of the shelf. The depth of this edge in the Southern California Bight ranges from about 76 m on the shelf off the Palos Verdes Hills to about 140 m to the south and west.

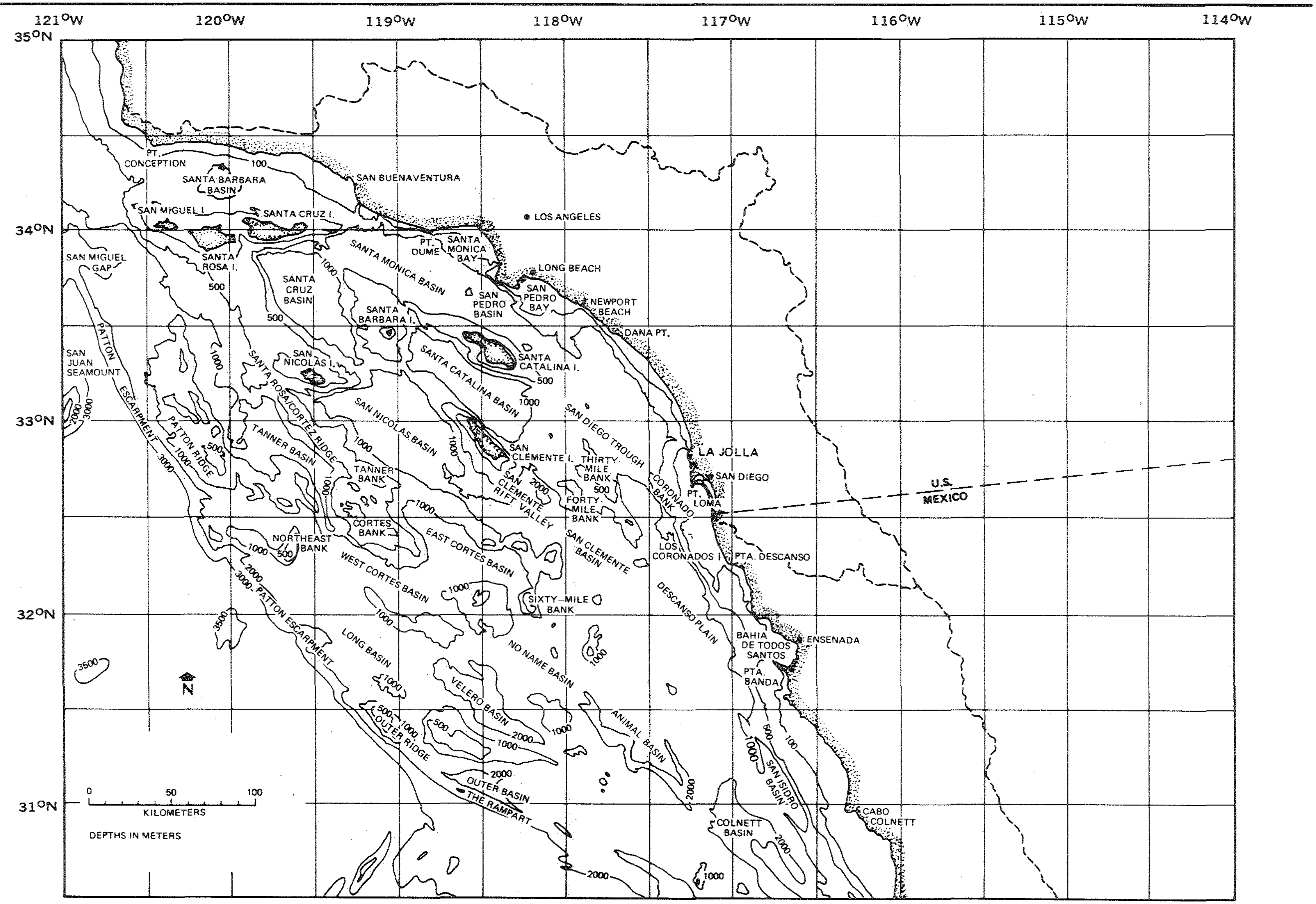

Figure 3-5. The Sea Floor of the Southern California Bight. From Moore 1969, Plate 1

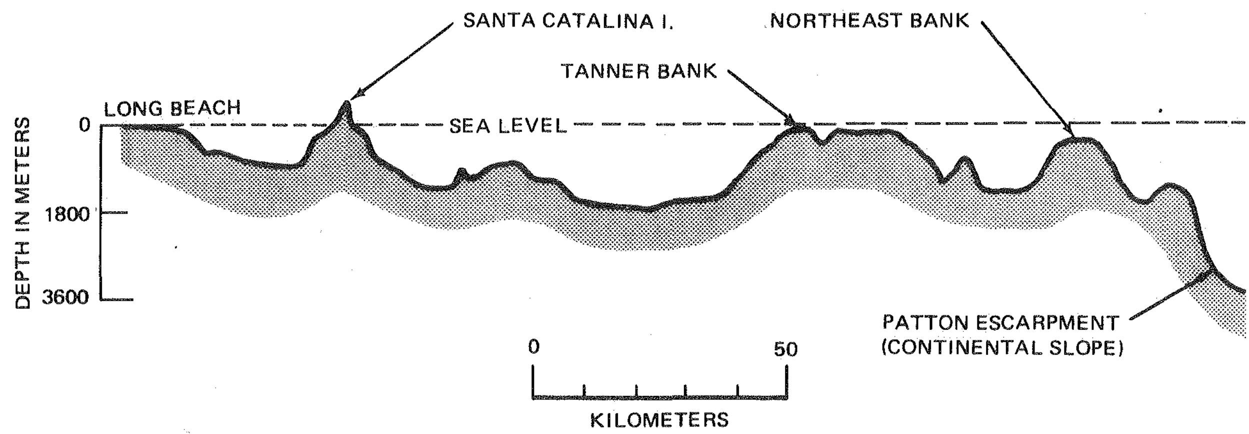

Figure 3-6. A Typical Profile of the Sea Floor Off Southern California. From Shepard 1963, fig. 130.

Basin and Trough Slopes

The slopes that border shelves and bank tops of the Bight and lead down into the adjoining offshore basins and troughs are commonly long and straight; several extend for more than 80 km in nearly straight lines. The slopes, which are generally steeper near the top than near the bottom average 8° in steepness (Figure 3-7). The most prominent departures from the average are slopes that exceed 15 to 20° for long distances on the Coronado, San Pedro, San Clemente, and Santa Catalina escarpments and on the scarps east of Thirty-Mile Bank and west of Forty-Mile Bank; these are believed to be closely related to recent active faulting. Irregularly sloped bottoms usually coincide with (1) partial sediment cover of a rocky bottom (e.g., off Santa Catalina Island) or (2) land-sliding (e.g., off the Palos Verdes Hills). Step-like irregularities on some slopes are possibly due to local faulting of a minor nature. An apron of sediment is commonly found at the base of slopes bordering the mainland shelf; this feature is rare for slopes below insular shelves and banks. The greater geomorphic maturity of these nearshore slopes and their proximity to the mainland source of sediment is the most probable explanation.

Submarine Canyons

The submarine canyons off southern California are among the most famous in the world. Although the canyons may not appear impressive as shown on hydrographic charts, several are comparable in size to the Grand Canyon of the Colorado River.

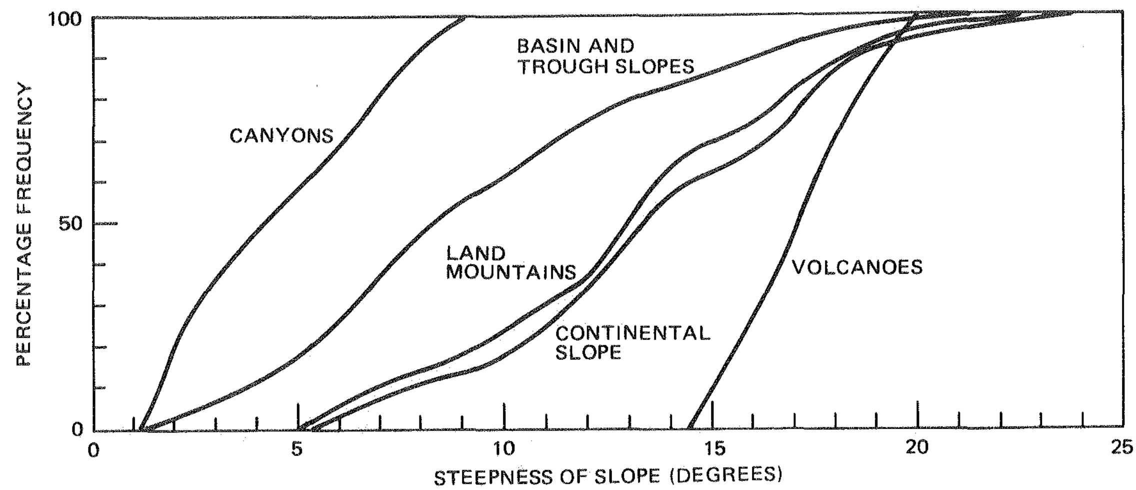

Figure 3-7. Cumulative Curves of Measurements of Steepness of Basin and Trough Slopes and Other Land and Submarine Features of the Southern California Area. From Emery 1960, Fig. 39.

Emery (1960) identifies 32 submarine canyons in the United States portion of the Bight; 20 of these indent the mainland shelf, 10 are located near the Channel Islands, and 2 are adjacent to offshore banks. Several hundred other canyons no doubt exist--many so small as to be best classified as sea gullies, others buried and thus concealed from ready identification. None cross the true continental slope, the transition from the continental borderland to the abyssal sea floor.

Of the 14 major canyons in the Bight that have been identified and named (Figure 3-8), all but Tanner Canyon cross at least the outer third of the mainland or island shelves. La Jolla, Newport, Redondo, Dume, Mugu, and Hueneme Canyons penetrate the mainland shelf to within hundreds of meters of the shoreline and thus trap and funnel littoral-borne material into the offshore sediments.

Although the submarine canyons of the northern and central California coast have been most often associated with upwelling, southern California canyons also provide avenues for the occasional movement of upwelling water or organisms of mid-depth or deep-water origin into the shallow nearshore environment. Partial, temporary filling by sediments takes place; however, these canyons are generally sites of long-term, often very active erosion.

Multiple heads are common features of the canyons that penetrate the shelf to the vicinity of the coastline. Detailed examination of the area around the head of Santa Monica Canyon by the City of Los Angeles prior to construction of the 7-mile Hyperion Treatment Plant sludge outfall revealed the presence of at least three small tributary canyons at the head, where only one had been

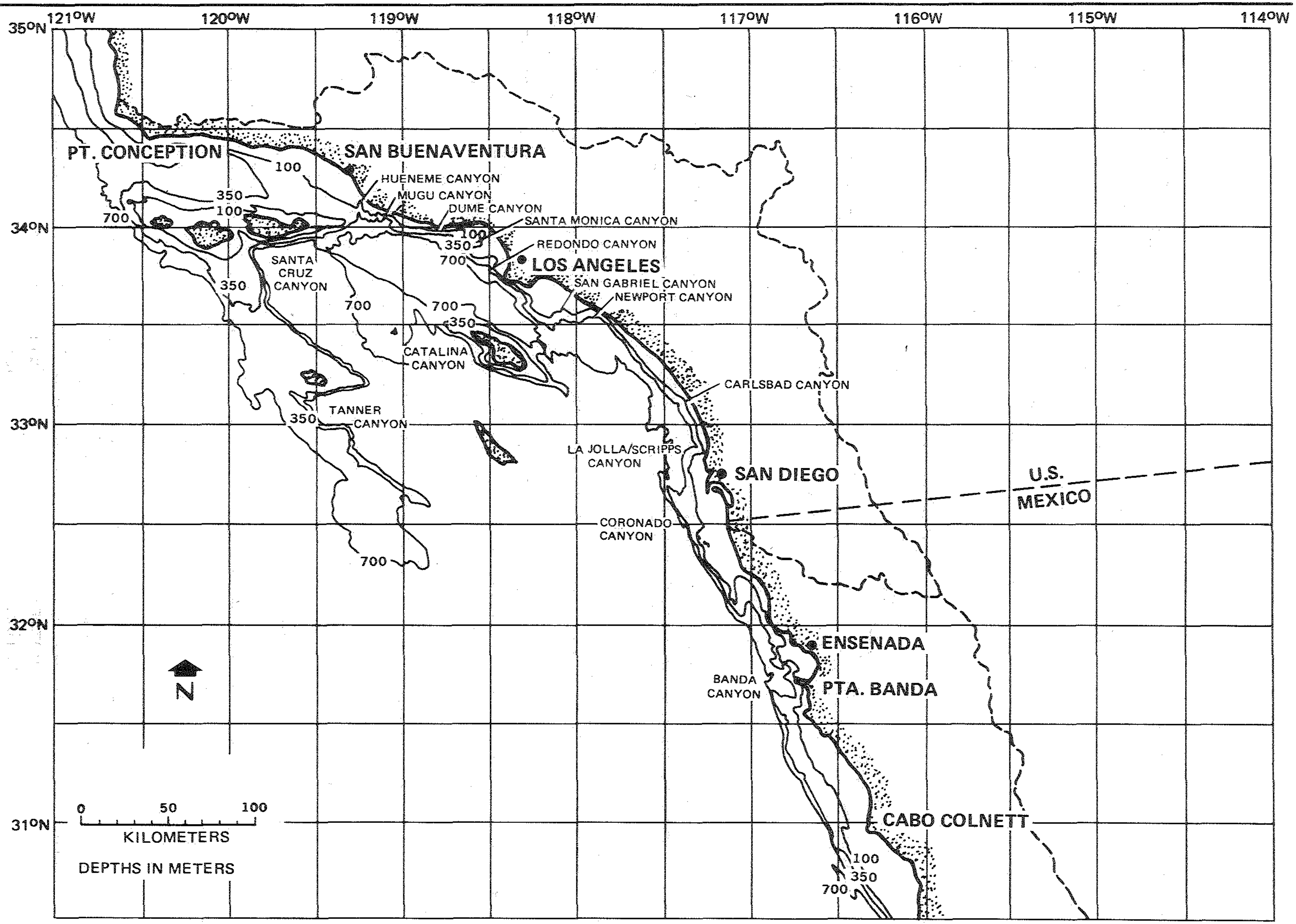

Figure 3-8. Submarine Canyons of the Southern California Bight.

believed to exist. Slopes near the heads are greater than those farther offshore. Like canyons on land, these features also become wider with increasing distance from the head.

Basins and Troughs

Marine geologists generally define a basin as a closed depression, deeper than its surroundings, approximately equidimensional in plan view. A trough is an elongated basin with two sides roughly parallel to each other. A low point on the basin rim is a sill; multiple sills may occur. There is an inverse relationship of shoaling, broadening, and flattening of basins with distance from the mainland shore (Figure 3-9): The nearshore basins are generally shallower, broader, and have more regular floors than those farther offshore. These observations, augmented by measurements of rates of deposition and some seismic data, support the conclusions that the nearshore basins are receiving the most sediment and that this has been occurring for a long time. However, these regions have been virtually ignored in marine pollution monitoring efforts.

The longer dimensions of basins are generally parallel to associated land features. Thus, the Santa Barbara Basin and the filled Ventura Basin have an east-west trend parallel to the Transverse Ranges. The other submarine basins have a northwest-southeast trend parallel to the Peninsular Ranges of southern

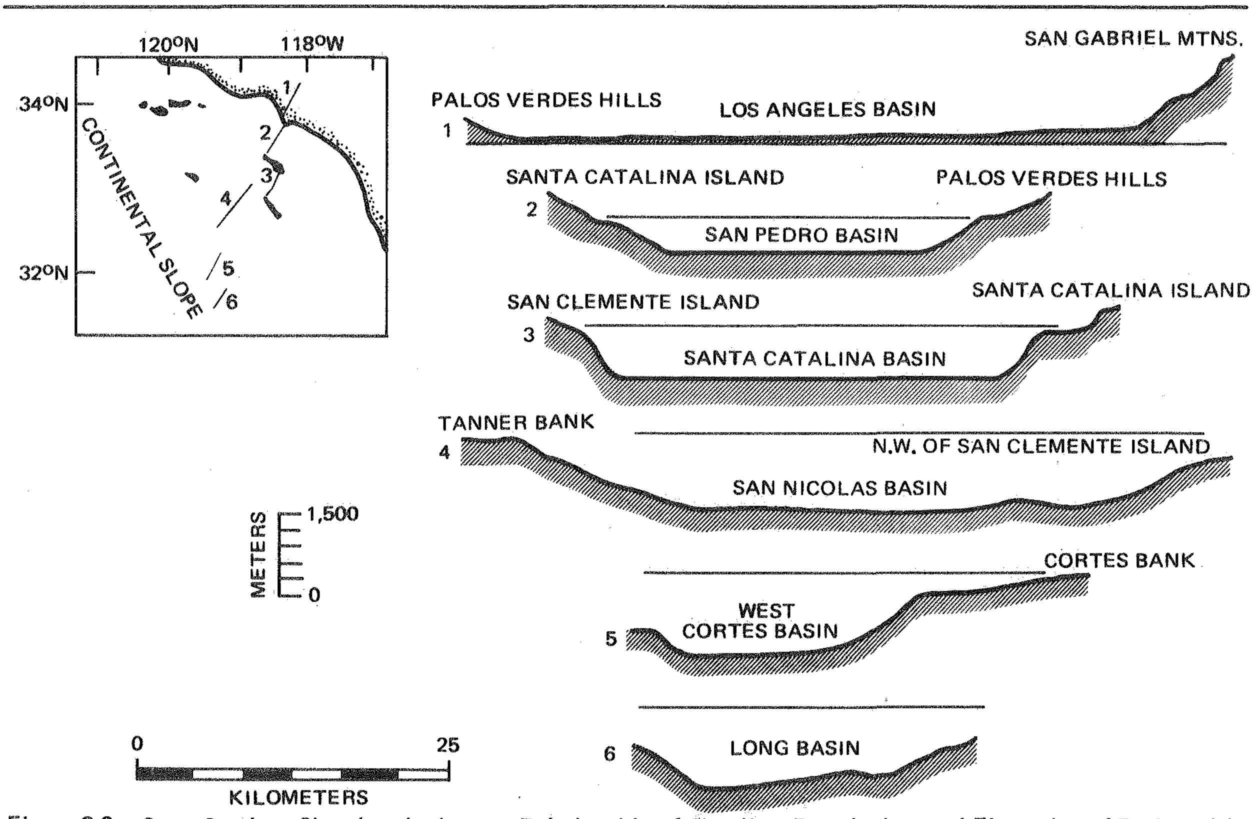

Figure 3-9. Cross Sections Showing the Inverse Relationship of Shoaling, Broadening, and Flattening of Basins with Distance from the Mainland Shore. From Emery 1960, Fig. 50.

California. The remaining filled basins on land have an east-west trend like the mountains that enclose them.

The Continental Slope

The continental slope off southern California lies 90 to 300 km from the coastline. The average width of the slope is about 19 km, and its base on the abyssal sea floor is at a depth on the order of 3,000 m. The average slope is about 8 to 9°. The profile is nearly straight, interrupted only by small irregularities. Five gaps in the slope are believed to be of structural origin; no submarine canyons have been recognized.

3.3 CLIMATOLOGY AND HYDROLOGY

The mild "Mediterranean" climate of the southern California coastal basin has always been considered one of its strongest attractions. Summers are warm and almost rainless; winters are pleasant with occasional mild storms, although heavy rains and rapid runoff from the mountains and coastal slopes have sometimes caused serious flooding and large aperiodic inputs to the ocean.

In the southern California coastal basin, there are 18 major watersheds, with a combined land area of some 33,000 sq km, through which water and silt (as well as the dissolved substances and particle-borne materials associated with them are introduced into the Pacific Ocean. These watersheds, designated Hydrologic Units H1 to H18,[2] are shown in Figure 3-10. Some of the hydrologic units are integrated river systems; others are smaller watersheds in coastal areas that drain by one or more streams directly into the sea. The major river systems are those of the Santa Clara, Los Angeles-San Gabriel, Santa Ana, and Tijuana Rivers.

3.3.1 Precipitation

Annual precipitation in the southern California coastal basin strongly depends on distance from the coast, elevation, and topography. Twenty-two U.S. Weather Bureau stations have been selected to present a general description of precipitation distribution in the coastal region; station names and locations are shown in Table 3-3 and Figure 3-11, respectively.

Precipitation in the coastal basin occurs as rainfall on the coastal lowlands and as snow and rainfall in the mountains. Table 3-3 presents normal annual precipitation data as well as precipitation data for two relatively abnormal years. The large variations in rainfall are evident even on this annual basis. Approximately 90 percent of the precipitation occurs during the period November through April. Figure 3-12 illustrates the large seasonal variation of annual precipitation in the region.

2. This drainage basin division is essentially that adopted by the California Department of Water Resources (1971).

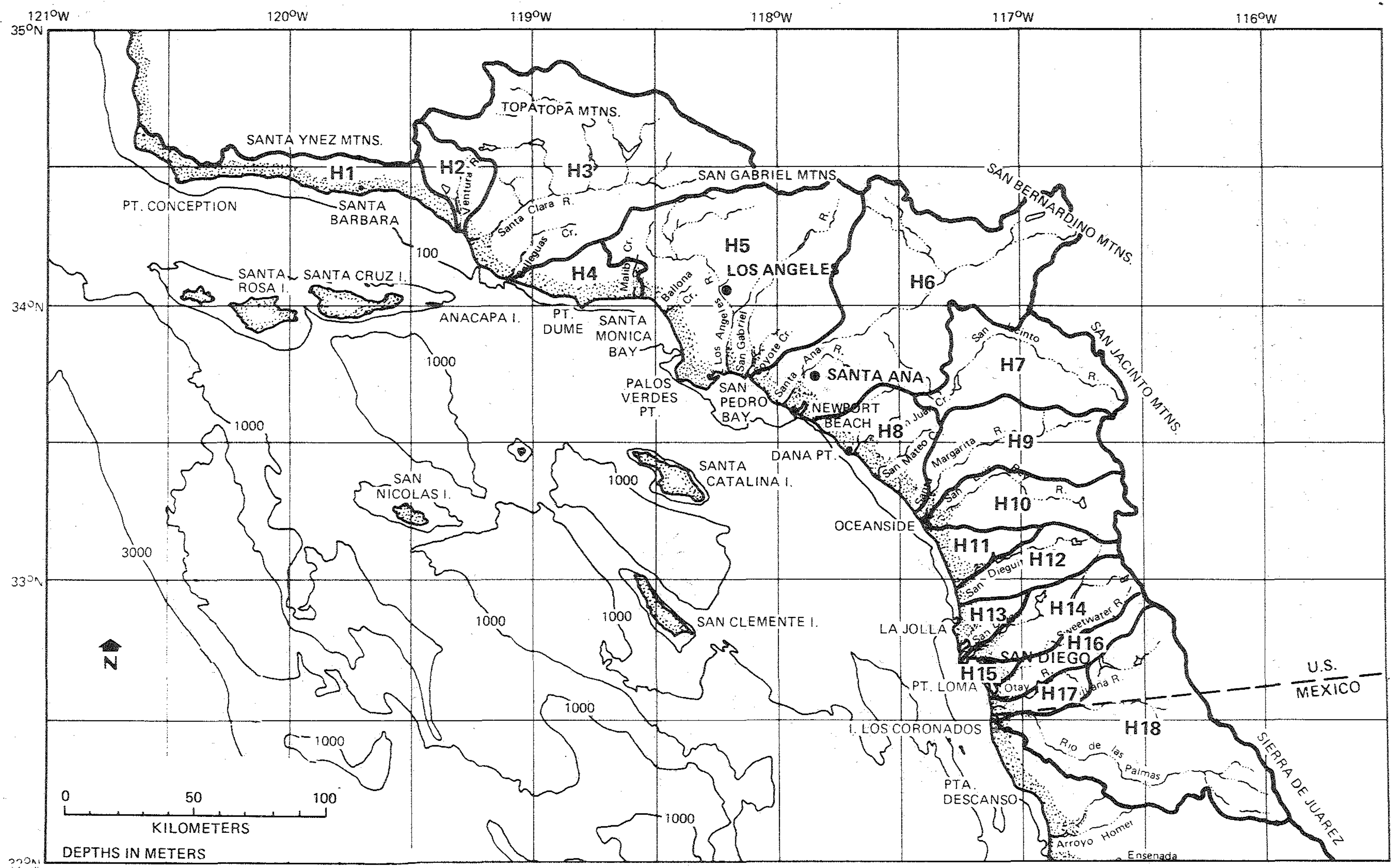

Figure 3-10. Hydrologic Units in the Southern California Coastal Basin.

Table 3-3
ANNUAL PRECIPITATION AT SELECTED STATIONS
IN THE SOUTHERN CALIFORNIA COASTAL BASIN

Ref. No.*	Station	Annual Precipitation (cm) Normal	1968	1969
1	Santa Barbara	43.4	29.7	74.9
2	Ojai	51.6	30.7	116.1
3	Oxnard	37.3	25.4	53.3
4	Sandberg Weather Serv. Off.	30.7	11.9	42.9
5	Los Angeles Weather Serv. Off.	32.8	18.8	40.1
6	San Fernando	43.7	18.3	70.6
7	Pasadena	51.3	19.8	82.3
8	Mt. Wilson	78.0	30.7	166.9
9	Long Beach Weather Serv. Off.	25.1	14.5	51.1
10	Pomona (Calif. State Polytechnic College)	47.5	23.9	73.9
11	Corona	31.2	17.5	62.2
12	San Bernardino Co. Hosp.	45.0	19.6	81.3
13	Big Bear Lake	81.5	31.5	141.7
14	Beaumont Pumping Station	52.1	28.7	83.3
15	San Jacinto	32.8	16.5	43.4
16	Elsinore	25.4	14.5	55.9
17	Laguna Beach	32.0	14.7	56.6
18	Warner Springs	40.1	24.1	60.5
19	Escondido	41.1	15.5	47.2
20	Cuyamaca	96.3	41.7	118.1
21	San Diego Weather Serv. Off.	27.2	9.4	29.7
22	Barrett Dam	43.9	21.1	57.4
	Average of 22 Stations	45.0	21.8	73.2

*Key to location on Figure 3-11.

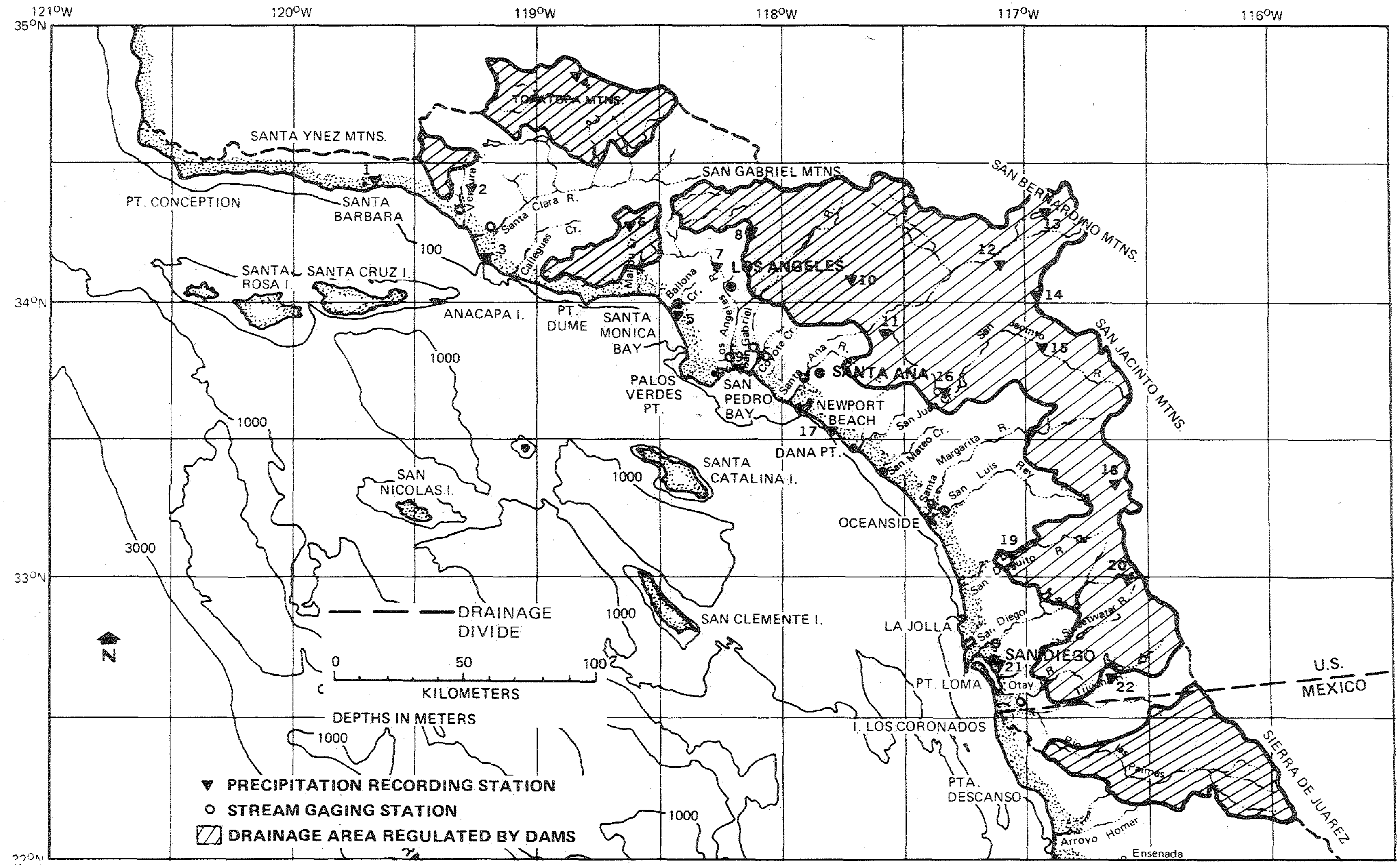

Figure 3-11. Regulated Watersheds and River Gauging and Rainfall Recording Stations in the Southern California Coastal Basin.

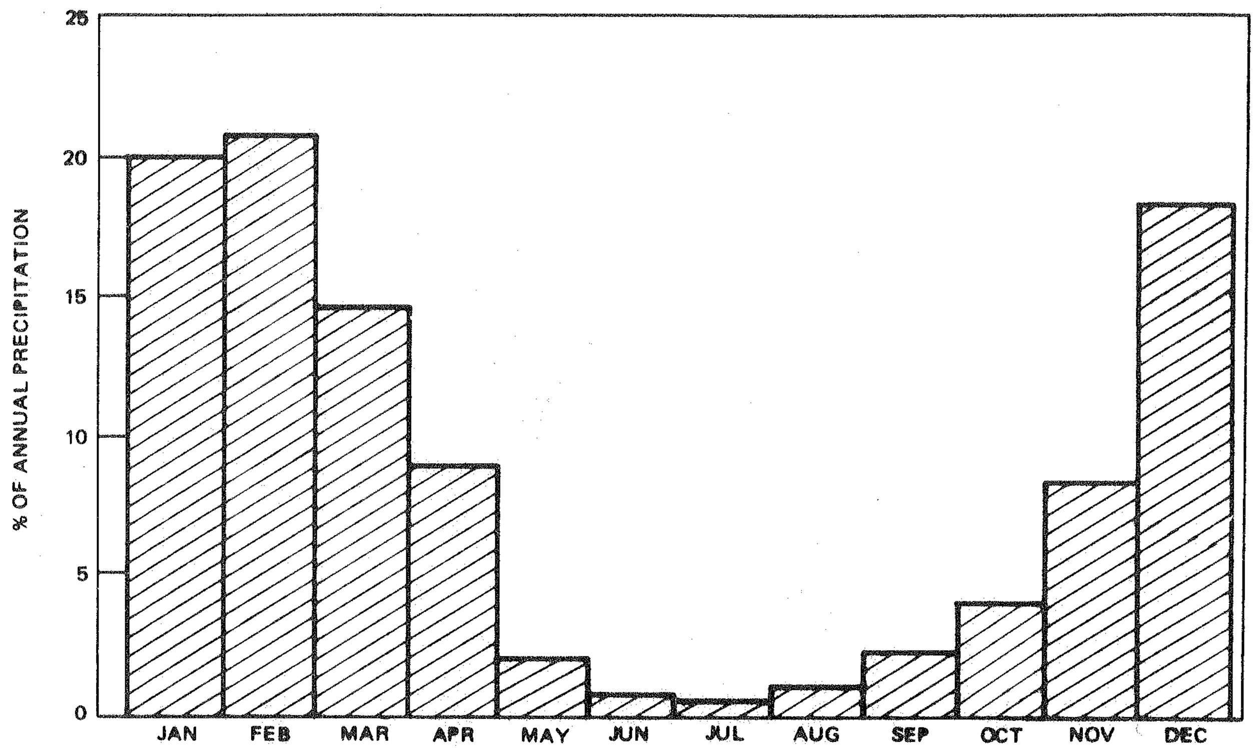

Figure 3-12. Monthly Variation of Precipitation in the Southern California Coastal Basin (Average of 22 Stations).

In the lowlands along the Pacific coast, precipitation varies from north to south. For example, Santa Barbara has a normal annual precipitation of approximately 43 cm, Los Angeles has 33 cm, but San Diego (the southernmost point) receives only about 27 cm. The wetter locations in the interior lowlands are usually on the seaward side of the mountains and at elevations above 300 m. Typical rainfall amounts in these areas are 25 to 50 cm (Ojai, Pasadena, San Fernando, San Bernardino, and Elsinore). As the valley floor rises to the mountains, annual precipitation increases to as much as 78 to 96 cm (Mount Wilson, Big Bear Lake, and Cuyamaca).

1968 was a relatively dry year for the entire coastal basin--as little as 40 percent of the normal annual precipitation was recorded. Conversely, 1969 was a relatively wet year, with up to 220 percent of normal annual average precipitation.

3.3.2 Stream Runoff

Stream runoff, one of the major inputs to the ocean, is controlled by regional hydrology. Within the southern California coastal basin, there are more than 150 streams discharging at points along the coastline, excluding the storm drains in the urbanized areas. Table 3-4 lists 19 major streams for which there are relatively long flow records. The total area tributary to the gauging stations on these streams is about 22,500 sq km, or 70% of the total land area of southern California coastal basin. As already mentioned, 1968 and 1969 are two of the most recent atypical years in southern California hydrologic history. The annual discharges in 1968 and 1969 from these streams are pre-

sented in Table 3-4, along with the mean annual flow rate during the record years up to 1970; these data and those in Table 3-3 are summarized as follows:

	Long-Term Average	1968	1969
Precipitation			
Average of 22 selected stations (cm)	45	22	73
Percent of long-term average		49	162
Stream Runoff			
Total flow of 19 gauged streams (10^6 cu m/yr)	566	173	3,846
Percent of long-term average		31	680
Ratio of total runoff to total annual precipitation (10^6 cu m/cm)	12.6	7.9	52.7

This comparison illustrates that the natural fluctuations in storm pattern and rainfall intensity/duration relationships preclude close estimates of stream flow from annual precipitation data.

Most of the stream flows in the southern California coastal area have been considerably altered by regulation and impoundment, either for flood control or

Table 3-4
ANNUAL FLOW RECORDS OF MAJOR RIVERS
IN THE SOUTHERN CALIFORNIA COASTAL BASIN*

Ref No.**	Hydrologic Unit	Stream	Gauge Location	Area of Basin Above Gauge (sq km)	Years Kept	Records of Flow: Mean Annual Average (10^6 cu m/yr)	1968 Flow (10^6 cu m/yr)	1969 Flow (10^6 cu m/yr)
H1	Santa Barbara/ Rincon	Jalama Cr.	Lompoc	53	5	3.1	0.2	7.4
		San Jose Cr.	Goleta	14	29	1.7	0.4	5.7
		Atascadero Cr.	Goleta	49	29	3.5	1.0	26.0
		Carpinteria Cr.	Carpinteria	34	29	2.6	0.2	30.1
			Total H1	150		10.9	1.8	69.2
H2	Ventura	Ventura R.	San Buena-ventura	487	43	52.3	5.0	310.6
H3	Santa Clara/ Calleguas	Santa Clara R.	Montalvo	4,175	26	102.8	5.0	1,099.6
H4	Malibu	Malibu Cr.	Crater Camp	272	39	19.6	9.4	148.6
		Topanga Cr.	Topanga Beach	47	39	5.1	1.2	36.4
			Total H4	319		24.7	10.6	185.0
H5	Los Angeles/ San Gabriel	Ballona Cr.	Culver City	232	20	38.9	28.4	89.9
		Los Angeles R.	Long Beach	2,155	41	148.5	87.6 50.6%	961.4 25%
		Coyote Cr.	Los Alamitos	352	7	30.2	17.5	79.7
		San Gabriel R.	Los Alamitos	1,222	42	25.2	3.8	257.4
			Total H5	3,961		242.8	137.3	1,388.4
H6	Santa Ana	Santa Ana R.	Santa Ana	4,375	30	28.1	6.5	479.9
H8	San Juan	San Diego Cr.	Irvine	104	21	2.7	1.5	19.7
		San Juan Cr.	San Juan Capistrano	275	42	12.3	1.6	95.8
			Total H8	379		15.0	3.1	115.5
H9	Santa Margarita	Santa Margarita Cr.	Ysidora	1,914	47	25.9	0	144.1
H10	San Luis Rey	San Luis Rey R.	Oceanside	1,445	38	13.8	2.4	31.4
H14	San Diego	San Diego R.	Santee	976	57	20.7	1.3	17.9
H18	Tijuana	Tijuana R.	Nestor	4,377	35	28.7	0.1	4.6
			TOTAL	22,549		565.7	173.1 1/3	3,846.2 6.8

*Based on U.S. Geological Survey 1968, 1969, 1970
**Key to location on Figure 3-11.

Table 3-5
MAJOR DRAINAGE AREAS CONTROLLED BY DAMS
IN THE SOUTHERN CALIFORNIA COASTAL BASIN*

Stream	Total Drainage Area (sq km)	No. of Dams	Drainage Area Controlled by Dams	
			Sq km	% of Total
Ventura R.	590	7	240	41
Santa Clara R.	4,250	4	1,450	34
Malibu Cr.	310	4	280	90
Los Angeles R.	2,180	23	1,470	67
San Gabriel R.	1,610	21	1,160	72
Santa Ana R.	7,200**	42	5,860	81
Santa Margarita R.	1,920	3	830	43
San Luis Rey R.	1,450	2	530	37
San Dieguito R.	850	4	780	92
San Diego R.	1,130	3	700	62
Sweetwater R.	470	2	380	81
Otay R.	390	2	260	67
Tijuana R.	4,490	4	3,200	71
TOTAL	26,840	121	17,140	64

*Based on Calif. Dept. of Water Resources (1969) and Norris (1964).
**Including 1,990 sq km upstream of Lake Elsinore.

water conservation purposes. At present, there are 121 dams on 13 of the major streams (Table 3-5). As of 1970, stream runoff from approximately 17,100 sq km of drainage area was controlled or regulated by dams; this controlled area is about 64 percent of the combined drainage area tributary to the 13 major streams listed on Table 3-5 and is more than 50 percent of the land area of the southern California coastal basin. The extent of the controlled area, illustrated in Figure 3-11, is expected to increase.

3.3.3 Wastewater

Another important source of freshwater to the Bight, especially during the dry season of the year, is the continuous discharge of various municipal and industrial wastewaters. Besides drawing water from local surface and ground sources, the southern California coastal area has been dependent on imported waters (from Hoover Dam via the Colorado Aqueduct, from the Sierra Nevada via the Los Angeles Aqueduct, and from northern California via the California Aqueduct) for its domestic, industrial and agricultural uses. Most of the waters used for domestic and industrial purposes and some of the agricultural waters find their way into the municipal wastewater treatment plants and eventually enter the coastal waters. At present, the total amount of municipal and industrial wastewaters

discharged directly into the coastal waters is estimated to be more than 1,100 mgd (1.5 x 10^9 cu m/yr)--more than twice that of the long-term average input via stream runoff from the gauged drainage area described in Table 3-4. At present, five major ocean outfalls discharge about 940 mgd (1.3 x 10^9 cu m/yr) of treated municipal wastewaters into the coastal waters. The distribution of this freshwater inflow and the mass emission rates of associated constituents are examined in Chapter 4.

3.3.4 Input of Solar and Atmospheric Radiation

The heat budget of a natural water body simply states that the time rate of change of heat content (and hence, temperature) of the water body is equal to the sum of the fluxes of heat added to the body minus the sum of the fluxes of heat lost from the body. In utilizing such heat budgets, it has been usual to consider the shortwave solar radiation as the only input term acting through the surface, and to combine the incoming longwave radiation from the atmosphere with the outgoing longwave radiation from the water surface into a single loss term, often called the net back radiation.

The incoming longwave radiative flux from the atmosphere depends upon the water vapor content and temperature of the atmosphere, while the outgoing longwave radiative flux from the water surface depends only upon the surface water temperature. The two terms are quite independent, and the incoming longwave radiative flux of heat from the atmosphere is just as much a source term in the heat budget as is the incoming shortwave radiative solar flux. Any comparison of the relative size of a man-made heat source to the waters of the Southern California Bight should be made against the sum of the natural heat sources.

The amount of shortwave radiation reaching the earth surface varies with latitude, time of day, season, cloud cover, and other atmospheric conditions. To illustrate the regional characteristics of this fundamental ecological force, monthly mean values of solar radiation at Fresno, Riverside, and La Jolla are shown in Figure 3-13 and the arithmetic mean for these three locations is plotted as Curve 5.

Along the coast, the clear sky solar radiation ranges from 380 cal/sq cm-day during the winter to as high as 785 cal/sq cm-day during the summer, with an annual average of 575 cal/sq cm-day (Curve 1, Figure 3-13). The annual net solar radiation energy absorbed by the earth surface is estimated as 388 cal/sq cm-day, a value typical of sunny climates.

The incoming longwave radiative flux from the atmosphere to the water surface varies with latitude and with season, but this variation is relatively much less than in the case of the solar radiation. The variation in the longwave radiation from the atmosphere with season results from variations in the weighted vertical mean air temperature; the dependence being to the fourth power of the absolute temperature. The mean temperature of the lower layers of the atmosphere over the Bight varies from about 7°C (280°K) in winter to about 22°C (295°K) in summer, and consequently the incoming longwave radiation from the atmosphere to the water surface varies seasonally by only about 10 percent above and below its annual average.

The annual average flux of incoming longwave atmospheric radiation to the surface waters of the Bight is about 710 cal/sq cm-day, or slightly less than twice the annual average solar radiative flux. The annual average sum of solar and atmospheric radiative flux input to the waters of the Bight is then about 1,100 cal/sq cm-day.

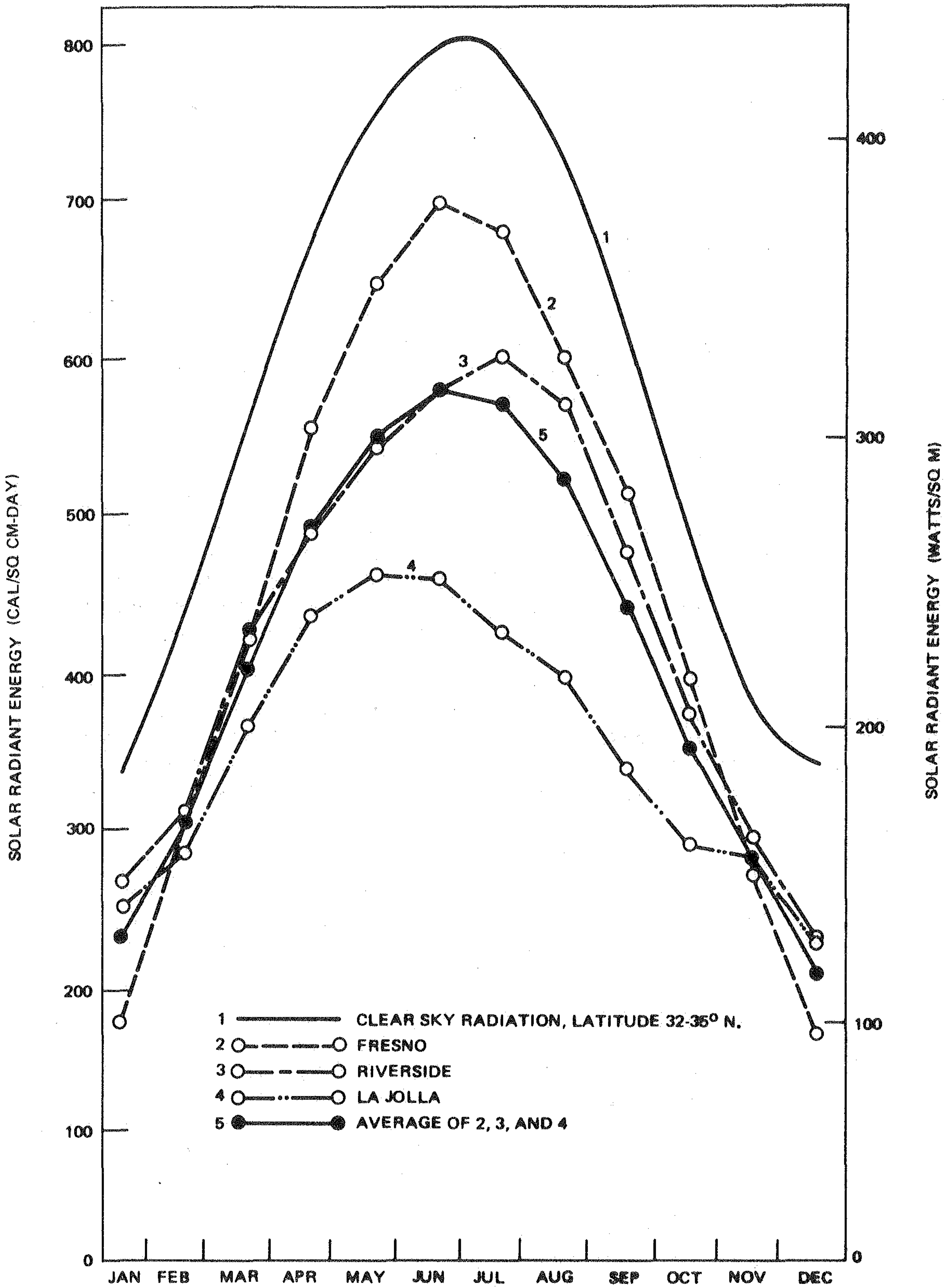

Figure 3-13. Average Monthly Solar Radiation Received on the Horizontal Surface in Southern and Central California. From Young 1971, Fig. 4.

3.4 PHYSICAL AND DYNAMIC OCEANOGRAPHY

There are three principal types of currents present in the Bight: (1) those related to the distribution of mass, (2) those caused directly by the stress of the wind on the sea surface, and (3) those produced by tidal forces.

The first type--called geostrophic currents--results from the fact that, in the presence of a horizontal density gradient, surfaces of equal pressure (called isobaric surfaces) slope relative to geopotential surfaces (surfaces along which no component of gravity acts). There is a force directed down the slope of the isobaric surfaces due to gravity. In the sea, this pressure force is very nearly balanced by the Coriolis force resulting from the rotation of the earth. The Coriolis force is directed at right angles to the current direction (to the right--as viewed "downstream"--in the northern hemisphere, to the left in the southern hemisphere). The resulting geostrophic current in the Southern California Bight is therefore directed in such a manner that the downslope of the isobaric surfaces is to the left of the current and the upslope to the right. Isobaric surfaces slope in a direction opposite to surfaces of equal density. Consequently, the direction of the geostrophic current is such that lower density water is to the right of the flow and higher density water to the left. Since the horizontal variation in density in the Southern California Bight is related more to variations in temperature than to salinity, the flow of the geostrophic current is generally such that the warmer water is to the right of the current and colder water to the left. Geostrophic currents can be computed from the observed density distributions.

The second type of current is due to wind stress on the sea surface. The wind moves the surface water, which is then subject to both friction and the Coriolis force. In offshore areas, the surface water moves at an angle of about 45° to the right of the wind direction. This motion is transferred to the underlying layer of water, causing it to move at a lower speed and slightly to the right of the flow of the overlying layer. At the greatest depth in the layer affected by the wind, the water is moving very slowly in a direction opposite to the surface current. This current profile is called the Ekman Spiral. The angle between the surface current and wind direction depends on latitude and interference from water piled up by the wind against a boundary. The integrated effect over the entire layer under the influence of the wind is an average transport at right angles to the wind. A second effect is the redistribution of mass, which produces a geostrophic flow, the first type of current described.

Off southern California, as a result of these processes, the onset of strong, steady, northerly winds blowing in the late winter moves the warmer surface water to the west and permits colder (denser) water to well up near the coast. This water brings up nutrients, which support heavy plankton blooms and cause the area to be one of high organic production. The resulting redistribution of mass maintains a geostrophic current directed southward.

Tidal currents are produced when the tide rises and falls in the ocean as a result of the gravitational attraction between earth, moon, and sun and the centrifugal force that balances the attractions. Although lunar and solar tides produce a rhythmic wave motion, irregular sea-bottom and shoreline topography cause many secondary effects.

The California Current, typical of eastern boundary currents, is best described as a meandering, diffuse southeastward flow, with short-term variations in speed that are of the same order as the mean speed itself. The current, which is a continuation of the westerly drift in the North Pacific, starts its southward flow near the Canadian border and initially contains water characteristic of the subarctic. As this water moves southward, the surface characteristics are modified by solar heating, by upwelling, and by the effects of river inflow and exchange with estuaries and embayments. The flow generally follows the coastline until it reaches the northern limit of the Southern California Bight--Point Conception. Here, the coastline turns abruptly eastward, and the flow of water departs from the coast, generally continuing in a southeastward direction (Figure 3-14). Further south, off the coast of northern Baja California, the main portion of the current turns toward the land, and the flow divides into two branches. One branch, known as the Southern California Countercurrent, turns northward and flows through the Channel Islands, forming the inshore side of the Southern California Eddy. The second branch turns southward and continues down the coast of Baja California, where it eventually turns westward and contributes to the North Equatorial Current.

The Southern California Eddy, a nearly permanent feature of the flow pattern, is seasonal in character. The Eddy is usually well developed in summer and autumn and weak (and occasionally absent) in winter and spring (Figure 3-15).

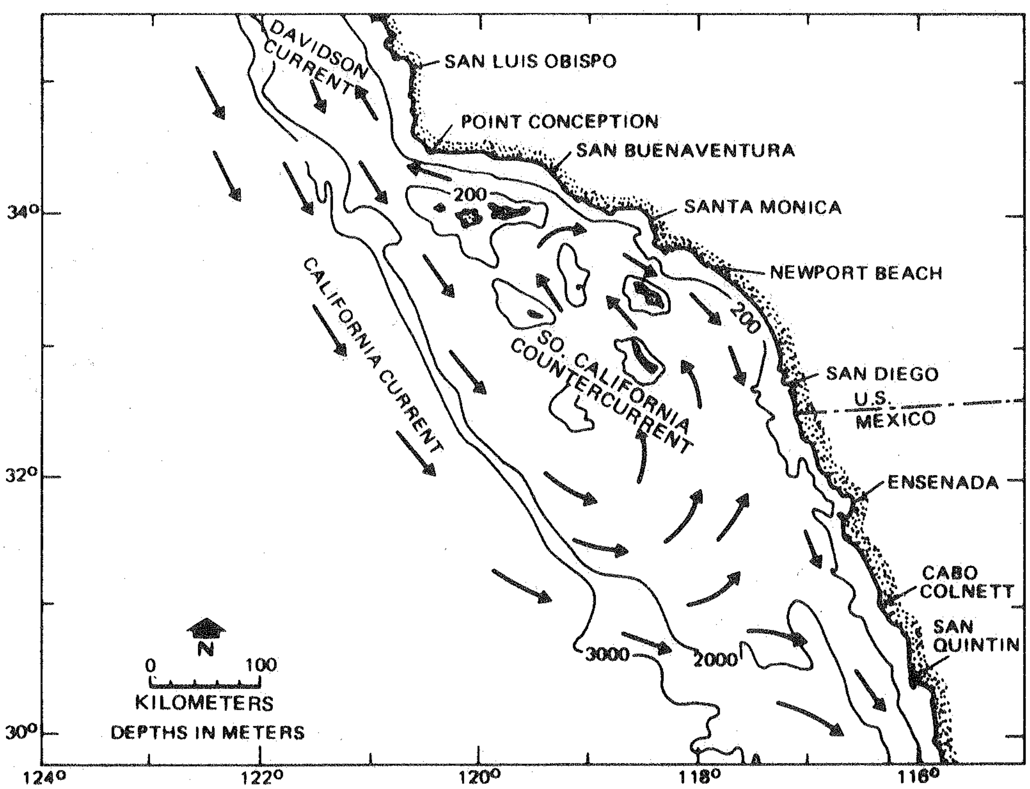

Figure 3-14. Surface Circulation (0—100 m) in the Southern California Bight. (Arrows Indicate Approximate Direction of Flow). From Jones 1971, Fig. 1.

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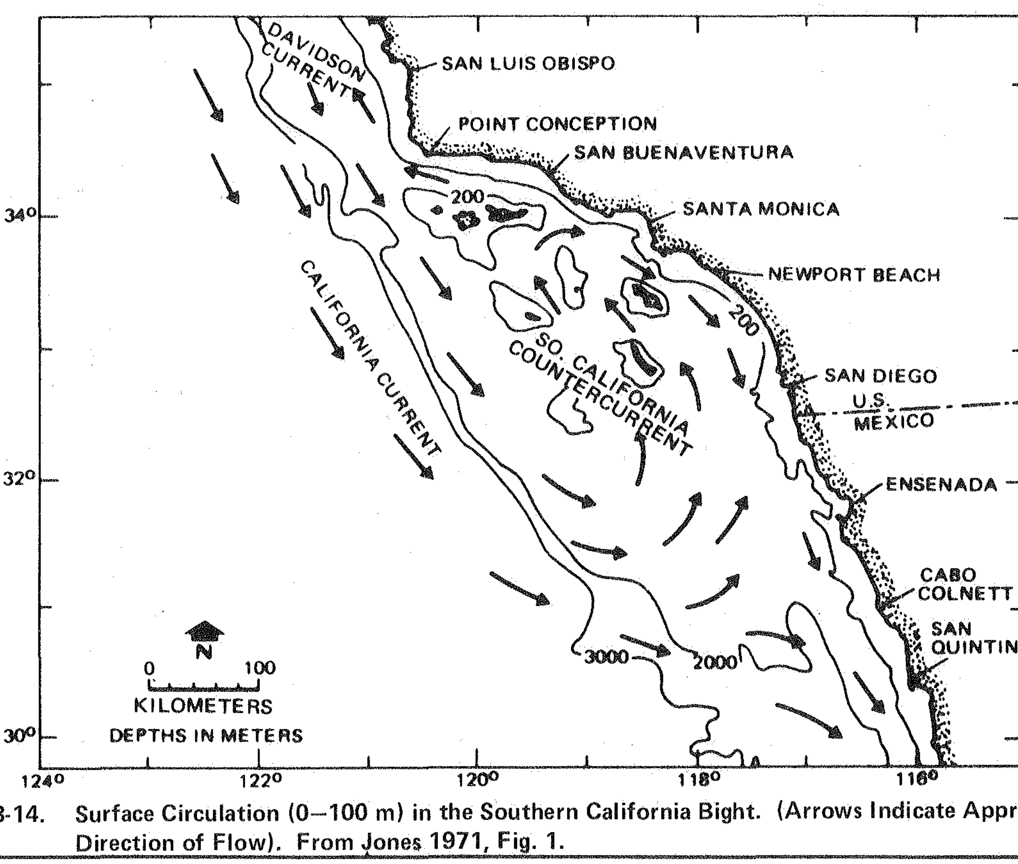

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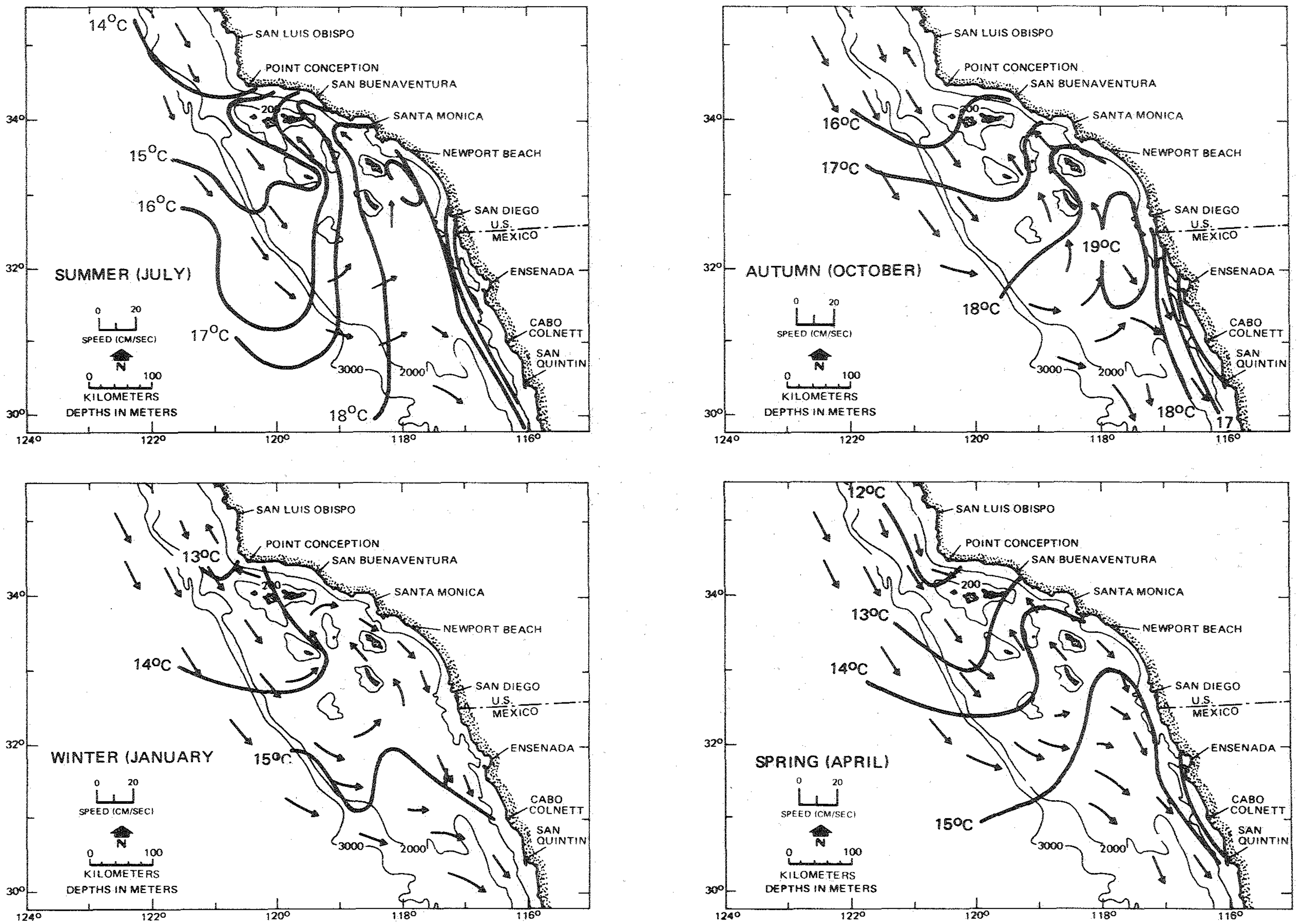

Figure 3-15. Average Geostrophic Surface Flow (Arrows) and Surface Isotherms (Degrees C) in the Southern California Bight. From Jones 1971, Figs. 5-8.

The presence of the coastal countercurrent, known as the Davidson Current (Figure 3-14), north of Point Conception may be considered the antithesis of upwelling. When the dynamics of the circulation are such that a strong Davidson Current is in evidence, no upwelling is likely to occur in the Point Conception area. The Davidson Current is strongest in autumn and winter--the seasons of the weakest northwest winds (Figure 3-16).

Most of the present knowledge about the circulation in the Southern California Bight is based upon information from programs not specifically intended to deal with the dispersion of pollutants as they enter the ocean environment. We have knowledge of the average seasonal variations of some oceanographic parameters, and some data on the monthly variations are available. However, pertinent information is missing regarding the small-scale, horizontal eddy structures, which are important in describing lateral mixing as well as in determining the residence time of a parcel of water or the half-life of a substance in the Bight. Valid estimates of these parameters must await specialized oceanographic field programs and dynamic models of the circulation in the Southern California Bight.

Evidence has indicated that the flow in the California Current is highly responsive to the influence of the winds. Much of the information necessary to document the response of the current to changes in the wind is available. However, no adequate study aimed at predicting changes in the flow pattern has been attempted to date.

The nature of the California Undercurrent (Figure 3-17), especially off southern California, is not at all well understood. It has been suggested that the Davidson Current is a surface manifestation of this flow occurring north of Point Conception. Further understanding of the vertical properties and the northward transport of biota into the region of the Bight is necessary.

3.5 HUMAN POPULATION AND INDUSTRY

Population data for the southern California coastal basin have been compiled from many sources, including reports from the U.S. Bureau of Census, the California State Department of Finance, and the Southern California Association of Governments. Table 3-6 shows the estimated population of seven southern California counties for 1960 and 1970. As the county lines do not match the coastal basin drainage divide, estimates have been made for the portion of each county within the coastal basin proper as well as for the total county. Land areas are also given in Table 3-6 for reference. In 1970, the total resident population in the southern California coastal basin was approximately 11 million, a 29 percent increase from the 1960 population.

3.5.1 Land Use

Data on the uses of land in the southern California coastal basin are essential to the estimation and prediction of runoff-associated waste loads. Land use data have been compiled from a wide variety of sources, each with its own hydrologic or operational units and time bases. Therefore, the data have been updated to 1970 and integrated into six selected land use categories by hydrologic unit. These six categories are defined below.

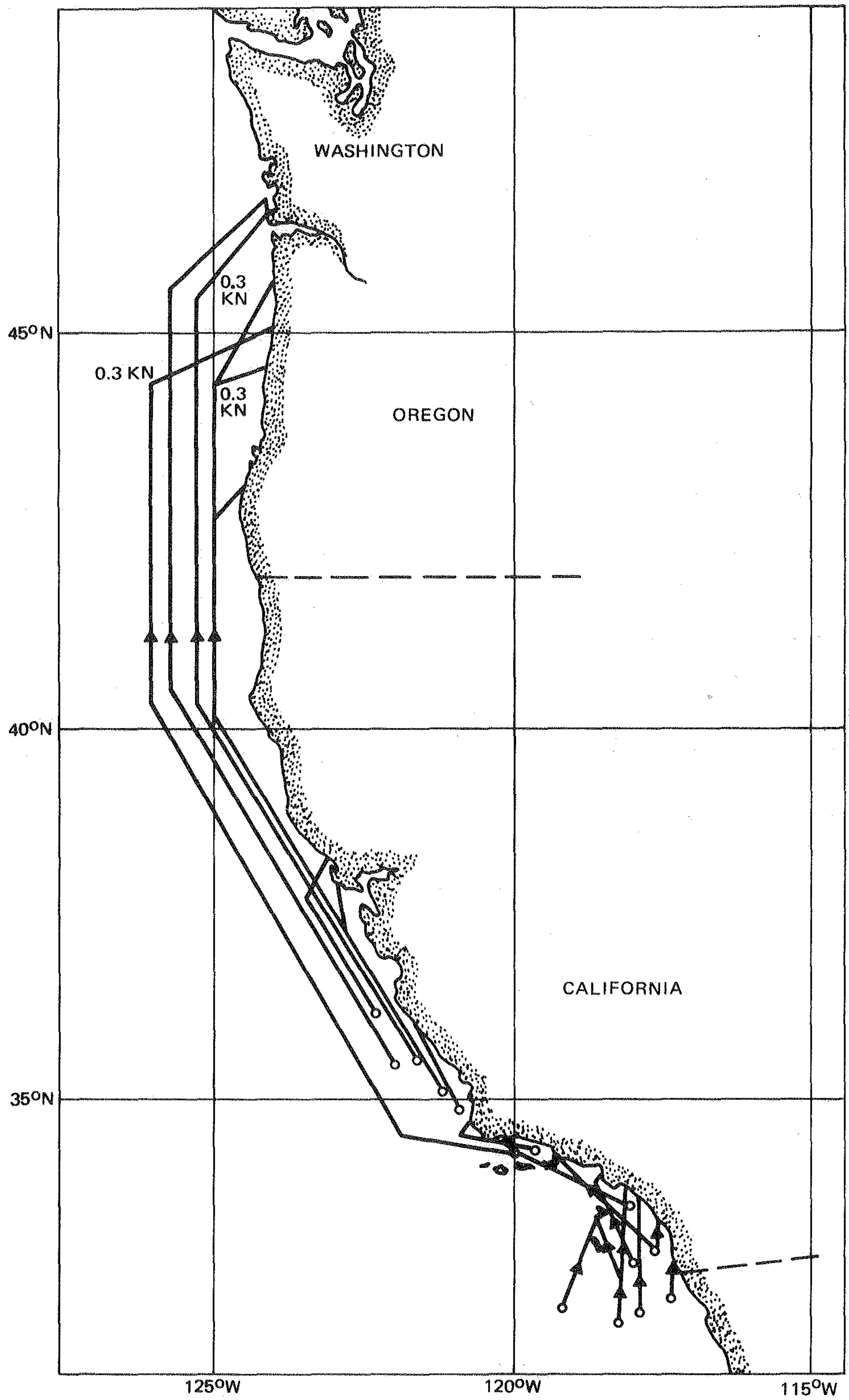

Figure 3-16. An Unusually Strong Coastal Countercurrent During November 1957 (Direction and Speed of Flow Indicated by Drift Bottles). From Schwartzlose 1963, Fig. 1.

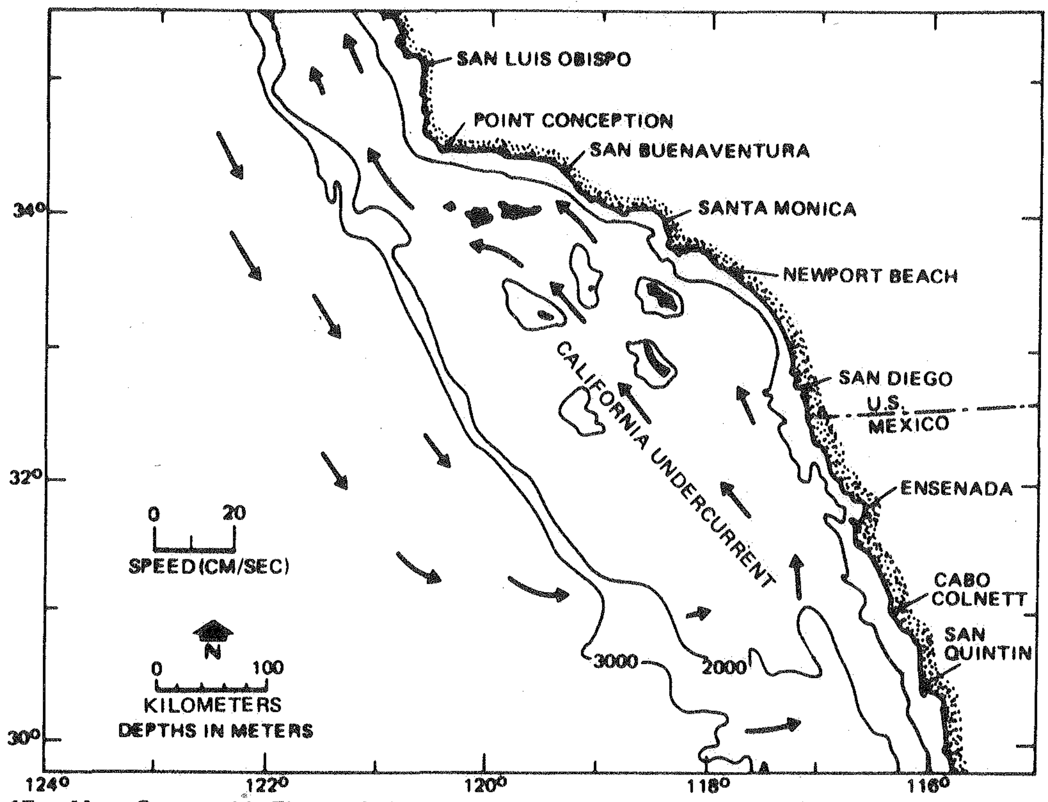

Figure 3-17. Mean Geostrophic Flow at 200 m Depth in the Southern California Bight (Arrows Show Direction and Magnitude of Flow). From Jones 1971, Fig. 11.

Table 3-6
LAND AREA AND POPULATION OF
SOUTHERN CALIFORNIA COUNTIES, 1960-1970

	Land Area (sq km)		Population (thousands)			
		In Coastal	Total		In Coastal Basin	
County	Total	Basin	1960	1970	1960	1970
Los Angeles	10,540	7,410	6,039	7,032	5,979	6,949
Orange	2,020	2,020	704	1,420	704	1,420
Riverside	18,590	4,980	306	459	216	319
San Bernardino	52,100	2,640	504	684	408	548
San Diego	11,040	7,840	1,033	1,358	1,020	1,320
Santa Barbara	7,090	750	169	264	91	150
Ventura	4,830	4,150	199	376	198	374
TOTAL	106,210	29,790	8,954	11,593	8,616	11,080

A. Residential. Land used for residences, including single and multiple-unit buildings.

B. Commercial. Area used for retail trade and general office buildings, such as shopping centers; includes strip commercial buildings and central business districts.

C. Industrial. Manufacturing, industrial nonmanufacturing, and wholesale trade areas.

D. Public. Sites of public buildings, schools and educational and recreational facilities, parks, military bases, transportation and public utilities facilities.

E. Agricultural. Cultivated areas, including crop lands, orchards, grazing and dairy lands.

F. Wilderness. Land that is undeveloped or unsuitable for development.

Table 3-7 summarizes the 1970 land use characteristics of the southern California coastal basin by hydrologic unit. The table illustrates the large proportion (62 percent overall) of wilderness area throughout the basin (with the exception of the Ventura, Los Angeles/San Gabriel, Santa Ana, and Coronado hydrologic units).

Figure 3-18 shows the 1970 distribution of developed area among the five uses for the entire coastal basin. About 27 percent of the developed land area in 1970 was in agricultural use. More than 30 percent was urbanized, and the remainder was in public ownership for various uses.

3.5.2 Recreational Activities in the Coastal Zone

The sandy beaches, scenic shorelines, and marinas are major recreational resources in the southern California coastal area. There are approximately 180 km of improved public beaches fronting the Pacific Ocean in southern California. It has been estimated that more than 85 million recreation-days are spent at southern California beaches each year. Uses of the public beaches and adjacent coastal waters involve swimming, wading, surfing, skin and scuba diving, sunbathing, picnicking, camping, fishing, and aesthetic enjoyment of the view of land and ocean and of bird life. Most of these recreational activities are limited to relatively shallow waters. For example, skin divers normally remain within the 10-m contour, scuba divers may venture to depths up to 30 m, but over 90 percent of all diving activities is reportedly done within the 20-m contour. These extensive recreational uses are the basis for the long-standing constant surveillance of the beaches and near shore waters for bacteriological safety and account for the high public interest in the aesthetic qualities of the coastal zone.

There are presently 14 marinas and small boat harbors in southern California, each with capacities for more than 600 boats. The populations of boats in these facilities are given in Table 3-8; the locations of major marinas are shown in Figure 3-19. The estimated total number of boats is 34,860, which represents an average of 3.5 boats per 1,000 dwellers in the entire coastal basin. However, Orange County has an ownership ratio of as high as 25 to 30 boats per 1,000 dwellers.

Table 3-7
LAND USE CHARACTERISTICS BY HYDROLOGIC UNIT, 1971 (IN SQ KM)

Ref. No.*	Hydrologic Unit	Residential	Commercial	Industrial	Public	Agricultural	Total Developed	Wilderness	Total Land Area
H1	Santa Barbara/ Rincon	27	7	13	140	27	214	620	834
H2	Ventura	28	6	37	63	188	322	269	591
H3	Santa Clara/ Calleguas	114	55	24	1,498	426	2,117	2,882	4,999
H4	Malibu	12	2	2	100	1	117	510	627
H5	Los Angeles/ San Gabriel	1,498	194	320	1,501	291	3,804	1,262	5,066
H6	Santa Ana	720	83	167	591	1,114	2,675	2,536	5,211
H7	San Jacinto	22	8	8	320	389	747	1,242	1,989
H8	San Juan	27	4	1	506	23	561	786	1,347
H9	Santa Margarita	4	2	0	37	91	134	1,809	1,943
H10	San Luis Rey	15	6	0	90	157	268	1,195	1,463
H11	Carlsbad	44	21	1	13	88	167	398	565
H12	San Dieguito	13	10	1	33	146	203	696	899
H13	Penasquito	46	9	1	27	8	91	323	414
H14	San Diego	68	10	2	81	66	227	900	1,127
H15	Coronado	138	34	28	142	2	344	3	347
H16	Sweetwater	50	7	8	78	74	217	490	707
H17	Otay	6	1	3	4	107	121	273	394
H18	Tijuana	55	47	5	39	155	301	4,193	4,494
	TOTAL	2,887	506	621	5,263	3,353	12,630	20,387	33,017

*Key to location on Figure 3-10.

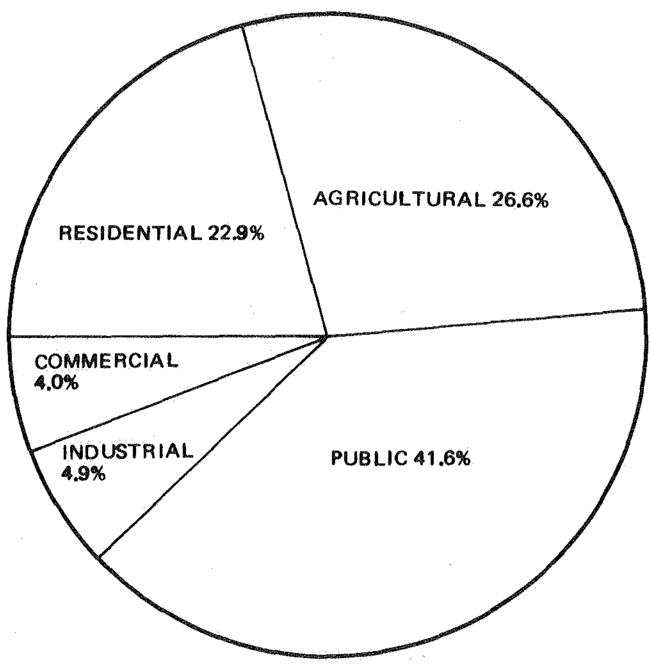

Figure 3-18. Distribution of the Use of Developed Land in the Southern California Coastal Basin, 1970.

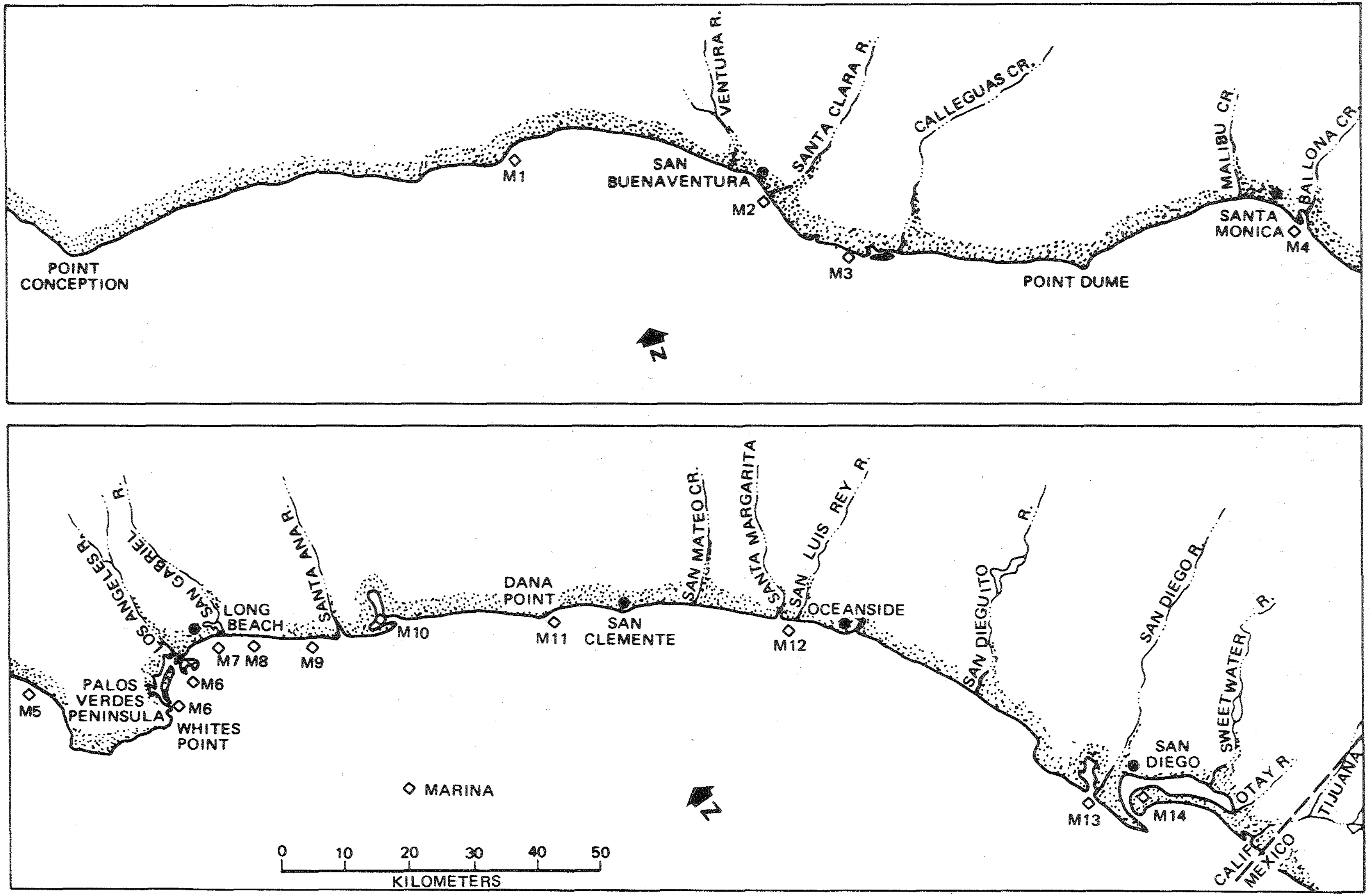

Figure 3-19. Southern California Marinas.

The extensive recreational boating activities have an influence on the quality of coastal waters. Potential water quality problems arise from disposal of human and fish wastes, the loss of anti-fouling and other boat paint, fuel spills, and exhausted fuel residues. Some of these influences are examined in detail in Chapter 4.

Table 3-8
NUMBER OF BOATS HARBORED IN
SOUTHERN CALIFORNIA MARINAS, 1971

Ref. No.*	Marina	No. of Boats**
M1	Santa Barbara Harbor	750
M2	Ventura Harbor	930
M3	Oxnard, Channel Islands Harbor	930
M4	Los Angeles, Marina del Rey	5,500
M5	Redondo Beach, King Harbor Marina	1,400
M6	San Pedro Bay, Los Angeles Harbor	3,400
M7	San Pedro Bay, Long Beach Harbor	2,530
M8	San Pedro Bay, Long Beach Marina	2,300
M9	Huntington Beach, Huntington Harbor	3,200
M10	Newport Bay, Newport Beach Harbor	8,000
M11	Dana Point Harbor	550
M12	Oceanside Harbor	550
M13	San Diego, Mission Bay	1,500
M14	San Diego Bay	3,320
	TOTAL	34,860

*Key to location on Figure 3-19.
**Includes only 16- to 65-ft boats corresponding to U.S. Coast Guard Classes 1, 2, and 3. Boats smaller than 16 ft, which are U.S. Coast Guard Class A, are not included in this inventory.

3.5.3 Offshore Oil Production and Oil Transport

Extensive oil and natural gas resources are additional valuable assets of the southern California offshore zone, but their extraction and natural seepage can result in pollution of the coastal waters. At present, approximately 26,500 bbl/day of oil are produced at the offshore production facilities in southern California. The facilities are described in Table 3-9, and their locations are shown in Figure 3-20. Although new offshore exploration has been steadily declining in recent years (in spite of growing State and National oil demands), the visible impact of offshore oil production activities and the less visible effects of oil transport and refinery activities are considerable. Petroleum discharges and spills are a source of very undesirable contamination of beaches and offshore waters. Although the effects apparently are reversible, oil spills (natural and otherwise) have resulted in the wide-scale death of seabirds and invertebrates and in severe aesthetic damage.

There are 12 oil tanker mooring facilities along the southern California coast (Figure 3-20), excluding the facilities inside the San Pedro and San Diego Bays As shown in Table 3-10, these facilities serve various functions from crude oil and refined-product loading to fuel oil unloading with a mixed capacity of some 23,000 bbl/day (or 1.35 X 10^6 cu m/yr). Although the risk of oil spills from oil transport is relatively low, one spill can result in considerable damage; the potential of oil mishaps should therefore not be overlooked. A record of 36 major world oil spills (2,000 bbl or more) that occurred during the period of 1956 to 1969 indicates that 75 percent of these spills were related to oil transport and approximately 50 percent of these occurred within 2 km of shore. There have been three major spills originating from oil tankers off the California coast since February 1969.

While the risk of oil leaks or oil spills from production or transport facilities is a matter of probability, the disposal of oil field brine and refinery wastes into the coastal water is a matter of certainty. Within the southern California coastal area, there are 21 refineries with a total capacity of more than 1 million bbl/day (or 58 X 10^6 cu m/yr). The constituent mass emission rates of the refinery waste and oil field brine waste discharging into the coastal waters are discussed in Chapter 4.

3.5.4 Mining

Mining in the southern California coastal basin has virtually ceased, with two significant exceptions: Recently, a mercury mine north of Lake Cachuma in Santa Barbara County has produced a few flasks of mercury; also, a tungsten mine on Mount Palomar in San Diego County is being activated.

Nevertheless, mining has been an important activity in the past in southern California, and it is possible that diggings could contribute to the surface runoff transport of trace minerals. Figure 3-21 illustrates the locations of the principal metallic deposits in the coastal basin.

3.6 SUMMARY

The Southern California Bight is located in an area of topographic and geologic diversity. Both the topography and faulting of the region affect the

Table 3-9
OFFSHORE OIL PRODUCTION FACILITIES
IN SOUTHERN CALIFORNIA*

Ref. No.**	Operator	Facility	Function††	Oil Pipelines† Diameter (in.)	Length (ft)	Volume (bbl)
E1	Phillips	Platform Harry	Crude oil	6	10,000	330
E2	Texaco	Platform Herman;	Crude oil	6	12,000	440
		20 ocean floor wells	Flow lines	2-1/2	39,000	200
E3	Texaco	Platform Helen	Crude oil	6	11,500	420
E4	Atlantic-Richfield	1 ocean floor well	Flow lines	3	22,500	180
E5	Standard-Shell	2 ocean floor wells	Flow lines	3	24,000	Condensed Gas
E6	Standard-Shell	1 ocean floor well	Flow lines	4	13,000	Condensed Gas
E7	Standard-Shell	5 ocean floor wells	Flow lines	4	13,000	Condensed Gas
E8	Phillips-Pauley	4 ocean floor wells	Flow lines	4	57,600	Condensed Gas
E9	Atlantic-Richfield	Platform Holly	Crude oil	6	26,400	960
E10	Atlantic-Richfield	3 ocean floor wells	Flow lines	2	34,700	140
E11	Standard	Platform Hilda	Crude oil	6	26,400	960
		Platform Hazel	Crude oil	6	26,000	960
		2 ocean floor wells	Flow lines	4	9,200	130
E12	Union	Platforms A & B	Crude oil	12	62,000	8,700
E13	Phillips	Platforms Houchin & Hogan	Crude oil	10	32,500	3,150
E14	Standard	Platforms Hope & Heidi	Crude oil	10	21,500	2,090
E15	Atlantic-Richfield	Rincon Island	Crude oil	6	3,000	110
E16	THUMS Long Beach Co.	Islands Grissom,		6	3,700	130
		White, Chaffee, &		8	21,300	1,320
		Freeman	Crude oil	12	20,400	2,860
				14	4,400	840
E17	Humble	Monterey Island	Crude oil	3	8,700	80
E18	Standard	Island Ester	Crude oil	12	8,000	1,120
E19	Union	Platform Eva	Crude oil	8	18,000	1,120
E20	Signal	Platform Emmy	Crude oil	14	7,000	1,190

*Based on Calif. Dept. of Conservation 1971.
**Key to location on Figure 3-20.
†There are other submarine pipelines connecting the offshore production facilities to shore and serving various functions. For example, each THUMS Island in San Pedro Bay has 5 additional pipeline connections to Pier J. The production lines are an emergency line, a clean oil line and a gas line; the supply lines from shore carry fresh water and water to be injected into water-flood wells.
††Flow lines from E5, E6, E7, and E8 carry condensed gas; flow lines from other facilities carry a combination of gas and crude oil (the volumes given are for the crude oil portion only).

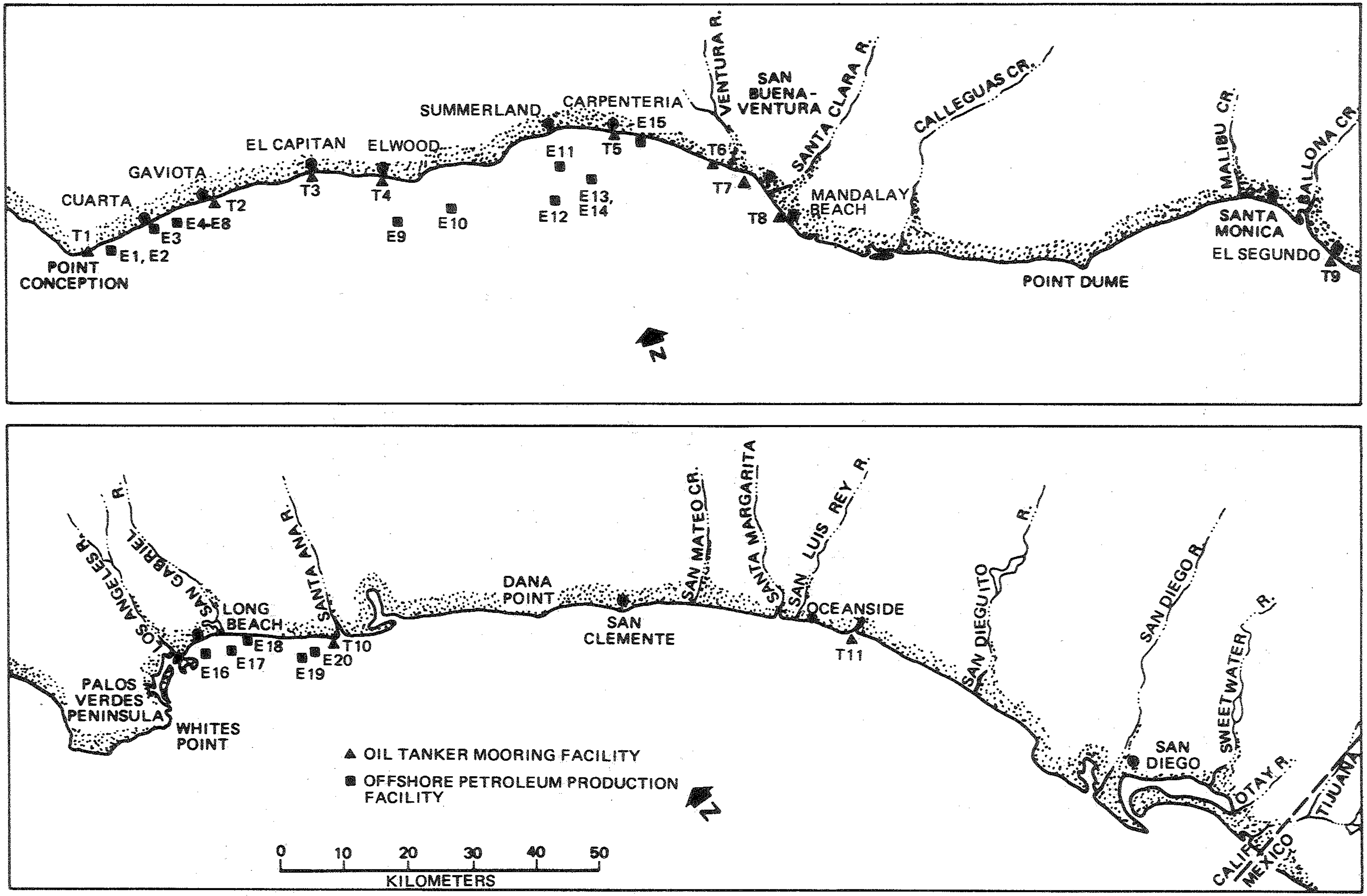

Figure 3-20. Offshore Oil Production and Oil Transport Facilities in Southern California.

Table 3-10
OIL TANKER MOORING FACILITIES IN
SOUTHERN CALIFORNIA COASTAL AREA*

Ref. No.**	Operator	Function	Oil Pipelines Diameter (in.)	Length (ft)	Volume (bbl.)
T1	Phillips	Crude oil loading	10	2,000	200
T2	Getty	Crude oil loading	12	4,800	680
T3	Shell	Crude oil loading	16	2,890	700
T4	Signal	Crude oil loading	11	2,530	300
T5	Standard	Crude oil & refined products loading & unloading (3-ship facility)	20 10	2,550 2,500	970 240
T6	Union	Crude oil loading	10 & 20	9,120	2,050
T7	Getty	Crude oil loading	18	4,300	1,350
T8	So. Calif. Edison	Fuel oil unloading	24	4,480	2,520
T9	Standard	Crude oil & refined products loading & unloading (3-ship facility)	8 12 14 16 20 26	5,300 7,780 7,900 2,100 3,200 7,780	330 1,090 1,470 530 1,250 5,100
T10	Gulf	Crude oil unloading	24	5,950	3,320
T11	San Diego G & E	Fuel oil unloading	20	3,000	1,160

*Excluding Los Angeles and Long Beach Harbors; based on Calif. Dept. of Conservation 1971.
**Key to location on Figure 3-20.

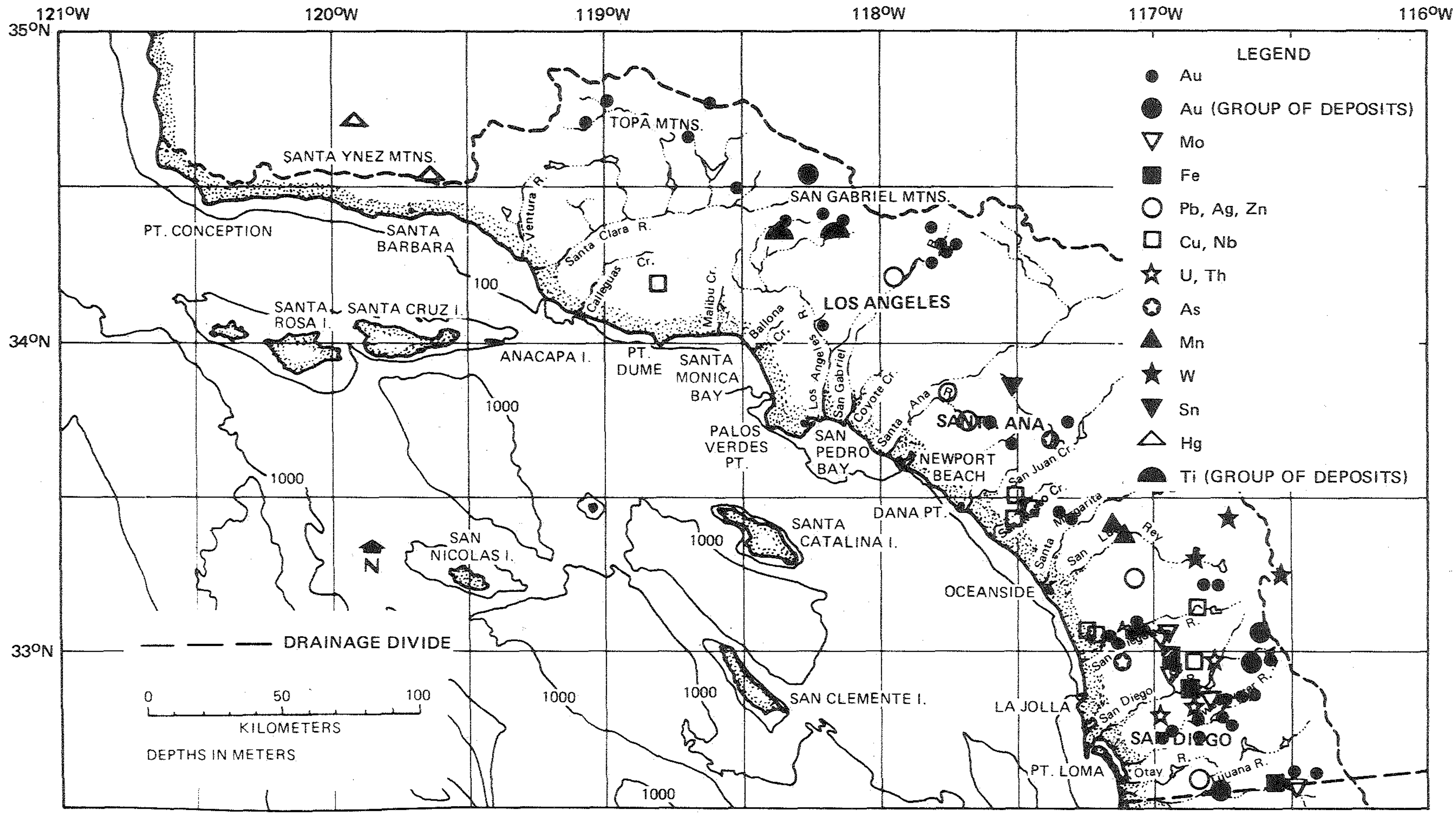

Figure 3-21. Metallic Deposits in the Southern California Coastal Basin.

processes involving the Bight. For example, the Transverse and Peninsular Ranges that enclose the Southern California basin cause the tropospheric entrapment of airborne pollutants generated in the basin and contribute to the eventual deposition of a portion of this material into the waters of the Bight. The tilting and fissuring of these geologic provinces affect ground water flow and mineral input into the waters of the region as well as the human development of the land.

The shelves, banks, basins, and canyons of the floor of the Bight reflect the character of the adjacent land more than they do typical seafloor configurations. These features constrain water flow at depth, and their influence on the paths and fates of dissolved and particulate materials must be taken into account in ecological monitoring.

The water movements in the Bight are strongly affected by the California Current and the Southern California Eddy, a northeastward flowing branch of the major current. Although the action of these and other offshore surface and subsurface currents in the Bight is fairly well understood, small-scale phenomena, which are important determinants of dilution, mixing, and water and waste residence time in the Bight, are not well known.

The Bight receives significant inputs from the United States portion of the coastal basin forming its eastern boundary. In the last 10 years, the population of this region has increased 29 percent; there is no reason to believe that this growth trend will not continue. Although the basin contains extensive urban development, a large portion of the total land area is wilderness, and a substantial portion of the developed land is devoted to agriculture. These contrasts give an unusual diversity to the character of inputs from the land.

Although the climate of southern California is mild, occasional heavy rains and rapid runoff from the mountains have sometimes caused serious flooding and large aperiodic inputs to the ocean. To control flooding and to conserve water and soil, a number of dams have been built in the United States portion of the basin; these block the water in more than half of the total watershed area of southern California. The consequences of such modifications are far-reaching. Sand supply to the coastline, which is already primarily erosional, is reduced, as are freshwater inputs to the Bight. Offshore habitats are also affected--both the nature and volume of their sediment blankets are changed. In addition, the mineralogic character of runoff, and thus the total mineralogic input to the Bight, may be changed. Other man-related influences on surface runoff have not yet been evaluated. For example, the combination of uptake of lead (from automobile exhausts) into the plants of the Bight, extensive brush fires, and subsequent runoff from the burned-over area may result in significant amounts of lead entering the Bight.

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Chapter 4

SOURCES AND MAGNITUDES OF CONSTITUENT INPUTS

4.1 INTRODUCTION

Each year, approximately 1.4 x 10^9 cu m (1,000 mgd) of treated municipal wastewaters, 0.25 x 10^9 cu m (180 mgd) of discrete industrial wastes, 7.7 x 10^9 cu m (5,600 mgd) of returned cooling waters, and 0.6 x 10^9 cu m (500,000 acre-ft/yr) of surface runoff enter the coastal waters of southern California. In addition, about 20,000 x 10^9 cu m/yr of advected ocean water enter the Bight, a flow about 2,000 times as great as the combined flows listed above. These inflows, fresh or saline, carry a wide spectrum of constituents to the ocean. Such constituents are also introduced through man's physical contact with the waters and exploitation of marine resources. The purpose of this chapter is to identify and quantify, to the extent possible, the ecologically important parameters of these significant external sources of influence on the Bight.

4.1.1 Approach to Consideration of Influences

To simplify description of the inventory effort, the entire coastal water system can be considered as a reactor bounded by interfaces with the atmosphere, land masses, and neighboring oceanic waters and made up of three components with various constituent reservoirs, namely:

A. The hydrosphere--the water mass with its interfaces with the atmosphere and the sediments.

B. The lithosphere--the bottom sediment.

C. The biosphere--microorganisms, plankton, plants, invertebrates, and vertebrates.

Physical changes, chemical reactions, and biological conversions occurring within this system affect the distribution of material between the reservoirs. However, it is the external sources of constituent inputs to this dynamic system that are considered in this chapter.

4.1.2 External Sources -- Discrete vs. Diffused Sources

The Southern California Bight receives a substantial portion of the waste material and energy of man-induced or natural origin that is generated within the southern California coastal basin. Other waste products generated outside of the coastal basin may also find their way to the Bight. By considering

the paths by which materials enter the Bight, the external sources can be divided into two categories:

A. Discrete Sources--Sources of materials that reach the Bight through direct and generally discrete land based pathways; include municipal wastewaters, industrial wastes, and surface runoff.

B. Diffused Sources--Sources of materials that enter the Bight by other than direct land based pathways; include aerial fallout (dry or washout), ocean dumping, vessel wastes, and advective transport.

In general, the discrete sources can be identified and characterized more easily than the diffused sources. Consequently, there are more reliable data and information regarding the nature and magnitude of discrete sources than for diffused sources.

4.1.3 Parameters Selected for Study

No single parameter can serve as the sole indicator of the condition of a complex aquatic ecosystem such as that of the Southern California Bight. Because of the intensity and diversity of human uses of the coastal waters, the rising concern for protection of marine resources, and the complexity and uncertainty of the cause-effect relationships within the Bight, the number of parameters selected for study must be extensive. In addition, it is desirable to incorporate parameters that are indicators of the effectiveness of waste treatment processes or other control measures.

Parameters selected for study can be grouped into the following categories according to their potential effects on the aquatic environment:

A. Oxygen Consumption--Parameters such as biochemical or chemical oxygen demand (BOD or COD) or total organic carbon (TOC), which serve as indicators of the oxygen consumption potential.

B. Biostimulation--Parameters such as various forms of nitrogen (ammonia, nitrite, and nitrate), phosphorus (phosphate), and dissolved silica, which are biostimulatory.

C. Toxic Effects--Parameters such as trace metals, chlorinated hydrocarbons, cyanide, and phenols, which have acute or chronic toxic effects.

D. Aesthetic Effects--Parameters such as total and volatile suspended solids (TSS and VSS), oil and grease, floatables, and settleable solids.

E. Thermal Effects--Waste heat that will result in temperature changes in the receiving environment.

4.2 DISCRETE SOURCES

Discrete sources of pollutants to the Southern California Bight may be grouped into three categories:

A. Municipal wastewaters (including industrial wastes tributary to municipal systems).

B. Discrete industrial wastes.

C. Surface runoff.

Figure 4-1 shows the locations of the municipal and industrial entities that discharge directly into the Pacific Ocean. Natural drainage boundaries and major surface runoff discharge points are shown in Figures 3-10 and 3-11. At present, a complete inventory of inputs from all of these sources of pollutants is not possible because many sources are poorly characterized or not recorded.

For the purpose of the following discussion of the relative significance of various sources, the coastal zone has been divided into subareas. The subarea divisions, shown in Figure 4-1, are as follows:

Area I: Point Conception to Las Pitas Point

Area II: Las Pitas Point to Point Mugu

Area III: Point Mugu to Palos Verdes Point

Area IV: Palos Verdes Point to Point Fermin

Area V: Point Fermin to Newport Bay

Area VI: Newport Bay to Del Mar

Area VII: Del Mar to the Mexican border

4.2.1 Municipal Wastewaters

In 1969, there were 174 municipal wastewater treatment plants serving the southern California coastal basin (Table 4-1). The combined total effluent of these plants has been estimated to be about 1,111 mgd, of which 75 mgd was being reused directly. Another 97 mgd was discharged at various inland locations and possibly carried by surface runoff or other pathways to the ocean. The remaining 937 mgd (84 percent of the total) was discharged directly into the coastal waters of Southern California.

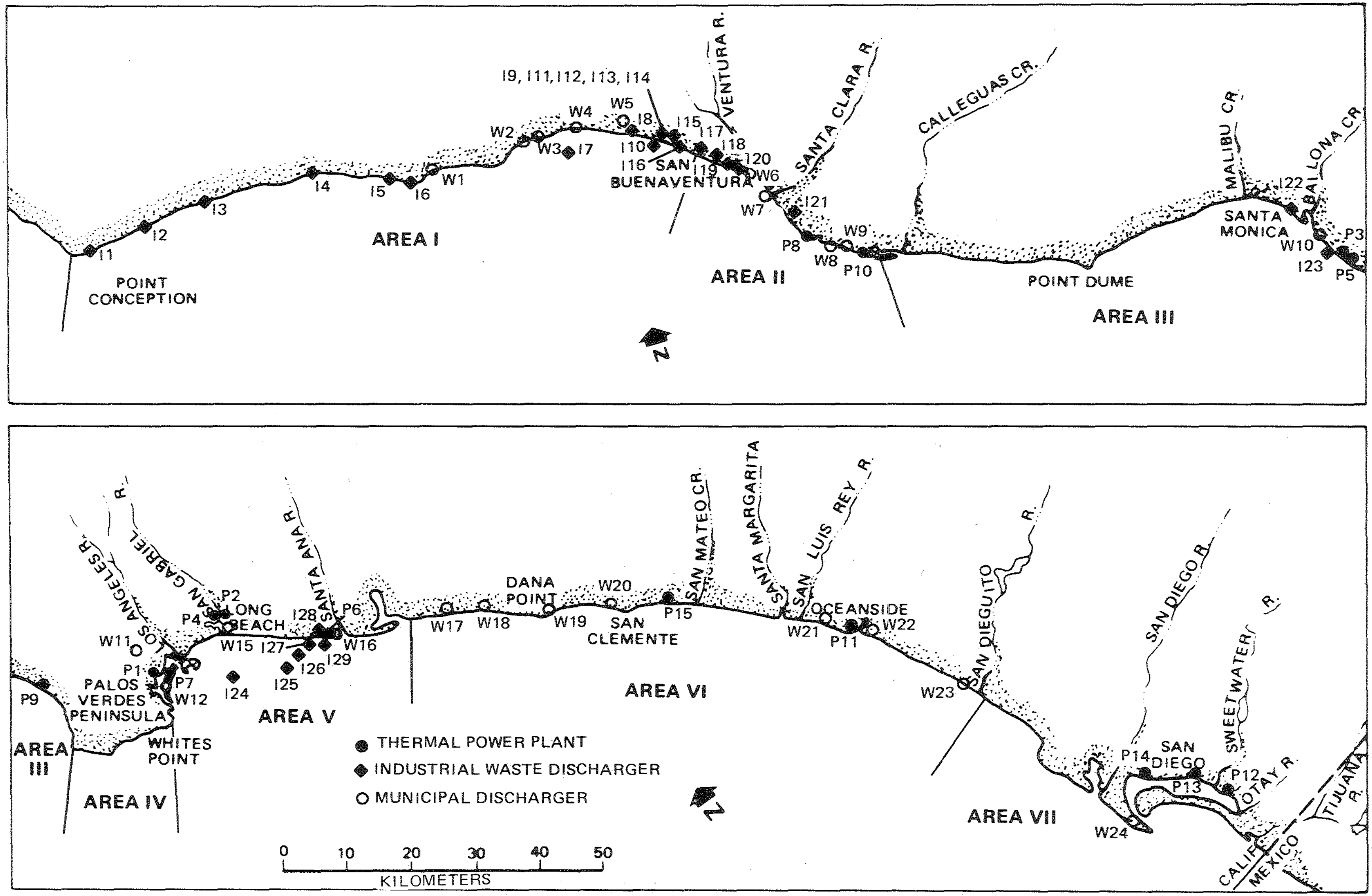

Figure 4-1. Municipal and Industrial Waste Discharges Along the Southern California Coast.

Table 4-1

SUMMARY OF MUNICIPAL WASTEWATER DISCHARGED AND REUSED IN THE SOUTHERN CALIFORNIA COASTAL BASIN AS OF 1969*

	Reused			Discharged to Land or Water Course			Discharged into Saline Waters			Total		
Region No. and Name**	Sources (No. of Plants)	Amount Yearly (10^6 cu m)	Amount Daily (mgd)	Sources (No. of Plants)	Amount Yearly (10^6 cu m)	Amount Daily (mgd)	Sources (No. of Plants)	Amount Yearly (10^6 cu m)	Amount Daily (mgd)	Sources (No. of Plants)	Amount Yearly (10^6 cu m)	Amount Daily (mgd)
Region 3:† Central Coastal	0	-	-	0	-	-	5	20.6	15	5	20.6	15
Region 4: Los Angeles	14	61	44	27	43.4	31	8	979	707	41	1,083	782
Region 8: Santa Ana	23	29.4	21	27	75.1	54	5	174	126	45	279	201
Region 9: San Diego	30	13.3	10	29	16.2	12	8	126	91	55	156	113
TOTAL	67	104	75	83	135	97	26	1,300	939	146	1,539	1,111

*Source: Calif. Dept. of Water Resources, 1971.
**Regional Water Quality Control Boards of the State of California.
†Portion in southern California coastal basin only.

As of 1971, there were 25 direct discharges of treated municipal wastewater into the coastal waters of Southern California. These discharges, described in Table 4-2, have a combined total flow rate of about 1,000 mgd.

It should be noted that most of the major municipal wastewater treatment facilities receive a substantial amount of industrial wastes, with or without treatment, generated within their service areas. The Joint Water Pollution Control Plant (JWPCP) of the Los Angeles County Sanitation Districts has the greatest industrial waste contributions, followed by the City of Los Angeles (Hyperion Sewage Treatment Plant), the Orange County Sanitation District, the City of San Diego (Point Loma Sewage Treatment Plant), the City of Oxnard, and the City of Los Angeles (Terminal Island Sewage Treatment Plant). At present, less than 20 percent of the municipal wastewaters discharged into the coastal waters of southern California receives secondary (biological) treatment; the remainder receives primary treatment. Depending on receiving water conditions, some effluents have been chlorinated during certain seasons of the year. Most dischargers employ land disposal for digested or dewatered digested sludge, with the exception of the Hyperion Treatment Plant, which discharges digested sludge (after dilution with plant effluent) by a separate 7-mile outfall into the Santa Monica Canyon at a water depth of approximately 100 m.

Five major dischargers--JWPCP (371 mgd), Hyperion (340 mgd), Orange County Sanitation District (130 mgd), Point Loma (90 mgd), and Oxnard (12 mgd)--contribute 943 mgd, or 94 percent of the total municipal wastewater currently discharged into the coastal waters of southern California. The service areas of these five major municipal wastewater treatment plants are shown in Figure 4-2.

Effluent Monitoring Programs

Almost all the municipal wastewater dischargers in southern California conduct a routine effluent monitoring program and report effluent quality data to the regulatory agencies. Table 4-3 is a partial list of the minimum routine effluent monitoring requirements prescribed by the Stage Regional Water Quality Control Boards. In implementing the monitoring requirements, some dischargers have expanded their programs substantially beyond the minimum requirements to incorporate more parameters and to sample at more frequent intervals. The data generated by these routine monitoring programs constitute one of the major sources for this effluent inventory.

Major difficulties in monitoring a waste stream for trace constituents (chlorinated hydrocarbons and trace metals) have been experienced, both in establishing reliable analytical procedures and in obtaining representative samples. Hyperion and JWPCP were among the first dischargers to establish routine chlorinated hydrocarbon monitoring programs for their final effluent. However, these programs did not start until January 1971. Routine chlorinated hydrocarbon monitoring programs for other major dischargers either are being implemented or are not yet developed. Available data concerning the trace metal concentrations in major municipal wastewater treatment plant effluent has been fragmented, ranging from an occasional grab sample for a few metals to programs described in Table 4-3.

Table 4-2
MUNICIPAL WASTE WATER DISCHARGES TO
SOUTHERN CALIFORNIA COASTAL WATERS, 1971

Area*	Ref No.*	Discharger Name	Flow (mgd)	Type of Treatment	Ocean Outfall Length (m)	Ocean Outfall Depth (m)
I	W1	Goleta San. Dist.	5.0	Primary	1,800	28
	W2	City of Santa Barbara	8.0	Primary	1,100	14
	W3	Montecito San. Dist.	0.8	Secondary	440	11
	W4	Summerland San. Dist.	0.1	Secondary	240	6
	W5	Carpinteria San. Dist.	1.3	Secondary	920	9
II		City of San Buenaventura				
	W6	Seaside Plant	2.7	Primary	800	11
	W7	Eastside Plant	4.0	Secondary		
	W8	Port Hueneme San. Dist.	3.5	Primary	1,900	18
	W9	City of Oxnard	12	Primary	1,750	16
III	W10	City of Los Angeles				
		Hyperion Plant	235 100	Primary Secondary	8,000 (effluent)	60
			5		11,000 (sludge)	100
IV	W11	Los Angeles Co. San. Dist.				
		Joint Water Pollution Control Plant	371	Primary	2,000	50
					2,600	65
					3,600	60
V	W12	City of Los Angeles				
		Terminal Island	8.1	Primary	730	18
	W13	City of Avalon	0.2	None	120	26
	W14	U.S. Navy (San Clemente Island)	0.1	None		
	W15	Sunset Bch. San. Dist.	0.2	Primary	520	
	W16	Orange Co. San. Dist.			8,300	60
		Plant No. 1	45 10	Primary Secondary		
		Plant No. 2	75	Primary		
VI	W17	City of Laguna Bch.	2.3	Primary	980	25
	W18	So. Laguna Bch. San. Dist.	1.2	Secondary	520	18
	W19	Dana Point San. Dist.	2.3	Secondary	1,200	12
	W20	City of San Clemente	1.8	Secondary	210	9
	W21	City of Oceanside	4.0	Secondary Oxidation Pond		
		County of San Diego				
	W22	Encina (Vista-Carlsbad)	4.7	Primary	5,300	30
	W23	San Elijo (Cardiff-Solana Beach)	1.1	Primary	3,700	15
VII	W24	City of San Diego				
		Point Loma Plant	90	Primary	3,200	64
	W25	Joint International Outfall	6.0	Chlorination	43	0

*Areas and discharger locations are shown by number on Figure 4-1.

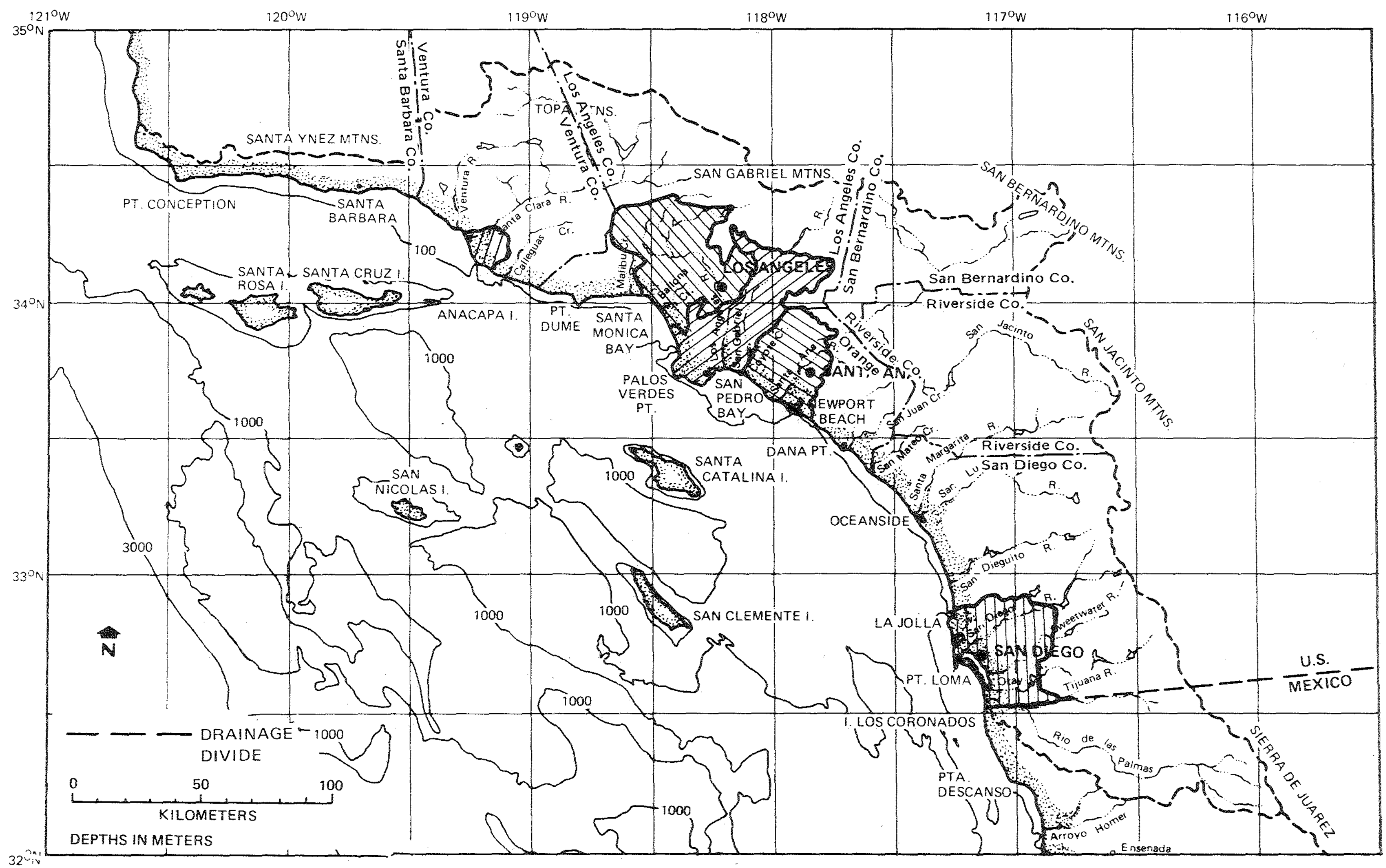

Figure 4-2. Major Ocean Outfall Service Areas in the Southern California Coastal Basin.

Table 4-3

PARTIAL LIST OF FINAL EFFLUENT MONITORING REQUIREMENTS FOR MUNICIPAL WASTEWATER DISCHARGERS

	Frequency of Sampling and Analysis*					
		W10 Hyperion			W16	W24
Parameter	W9 Oxnard	Effluent	Sludge	W11 JWPCP	Orange Co. San. Dist.	Pt. Loma
Flow	W	C		C	C	
Suspended solids	W	D	D	D	2W	2W
Oil and grease						
Detergent (MBAS)	W	M		M		M
5-day biochemical oxygen demand	W	D		D	2W	2W
Chemical oxygen demand		M		M		
Nitrate nitrogen		M		M		
Ammonia nitrogen		M		M		
Organic nitrogen		M		M		
Phosphate		M		M		
Cyanide	6M	M	M	M		
Phenols	M	M		M	M	
Fish Bioassay		2M		2M		12M
Arsenic (As)	6M	M	M	M		
Cadmium (Cd)	6M	M	M	M	M	2W
Chromium (Cr)	6M	M	M	M	M	2W
Copper (Cu)	6M	M	M	M	M	2W
Lead (Pb)	6M	M	M	M		
Mercury (Hg)		M	M	M		
Nickel (Ni)		M	M	M	M	2W
Selenium (Se)		M	M	M		
Silver (Ag)	6M	M	M	M		
Zinc (Zn)	6M	M	M	M	M	2W
Iron (Fe)		M	M	M		
Manganese (Mn)	6M	M	M	M		
Chlorinated hydrocarbons		M	M	M	M	
Radioactivity, β		W	W	W	M	2W

*Code: C = continuous, D = daily, W = weekly, 2W = every 2 weeks, M = monthly, 2M = every 2 months, 6M = every 6 months, and 12M = every 12 months.

Because of the scarcity and nonuniformity of existing data, SCCWRP, with the assistance of major dischargers, initiated a short-term trace metal survey during the summer of 1971 and a short-term chlorinated hydrocarbon survey during the spring of 1972. A series of representative samples of final effluent was collected at intervals during each of 7 consecutive days and composited proportionally to the flow rate. Replicate samples were analyzed by two independent laboratories. The 1-week composite samples for chlorinated hydrocarbons were analyzed for:

A. Total DDT--The sum of p,p'- and o,p'-DDT, p,p'- and o,p'-DDE and p,p'- and o,p'-DDD.

B. Total PCB--The sum of Arochlors 1242, 1254, and 1260.

C. Other chlorinated hydrocarbons such as aldrin, dieldrin, endrin, BHC, heptachlor, heptachlor epoxide, methoxychlor, chlordane, lindane, toxaphene, etc.

The 1-week composite samples for trace metals (both filtrates and residues) were analyzed for:

Silver	Nickel
Cadmium	Lead
Chromium	Zinc
Cobalt	Iron
Copper	Manganese

Historical Records of Municipal Wastewater Discharges

A historical record of wastewater flow rates from six major discharges is presented in Figure 4-3. Note that San Diego's Point Loma Sewage Treatment Plant and its outfall system did not become operative until late 1963; the others started discharge prior to 1961. With the exception of the City and the County of Los Angeles (Hyperion and JWPCP), all treatment plants experienced a steady increase in flow rates, reflecting a constant expansion of service areas and a steady growth of both population and industries within the service areas. The slight decrease in flow rates for the period of 1969 to 1971 from Hyperion and JWPCP may be attributable to the exceptionally wet year of 1969 and the interception of part of their influent by new treatment plants upstream.

As an example, a historical record of Hyperion effluent constituent mass emission rates is presented in Figure 4-4. This figure indicates that, with the exception of total suspended solids and BOD, effluent constituent mass emission rates do not always increase steadily and proportionately with volumetric flow rates; the volumetric flow rate should not be considered as the sole indicator of the potential influence of wastewater discharges on the receiving environment.

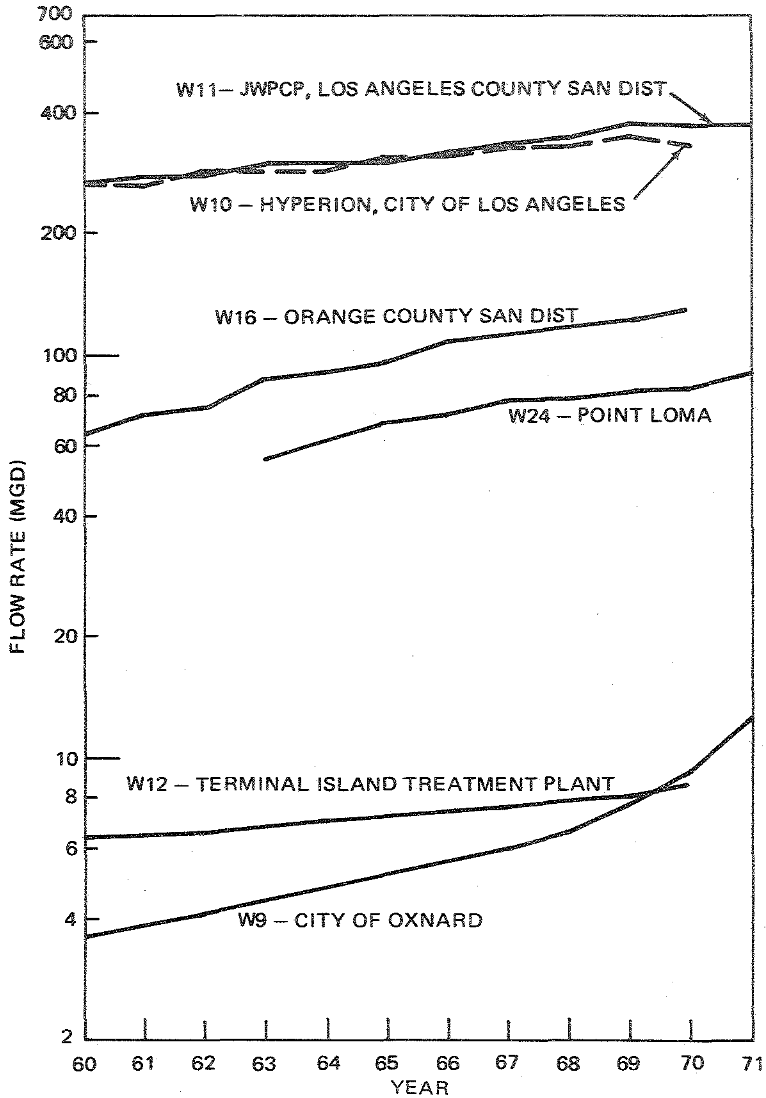

Figure 4-3. Effluent Flow Rates from Six Major Municipal Wastewater Treatment Plants, 1960-71.

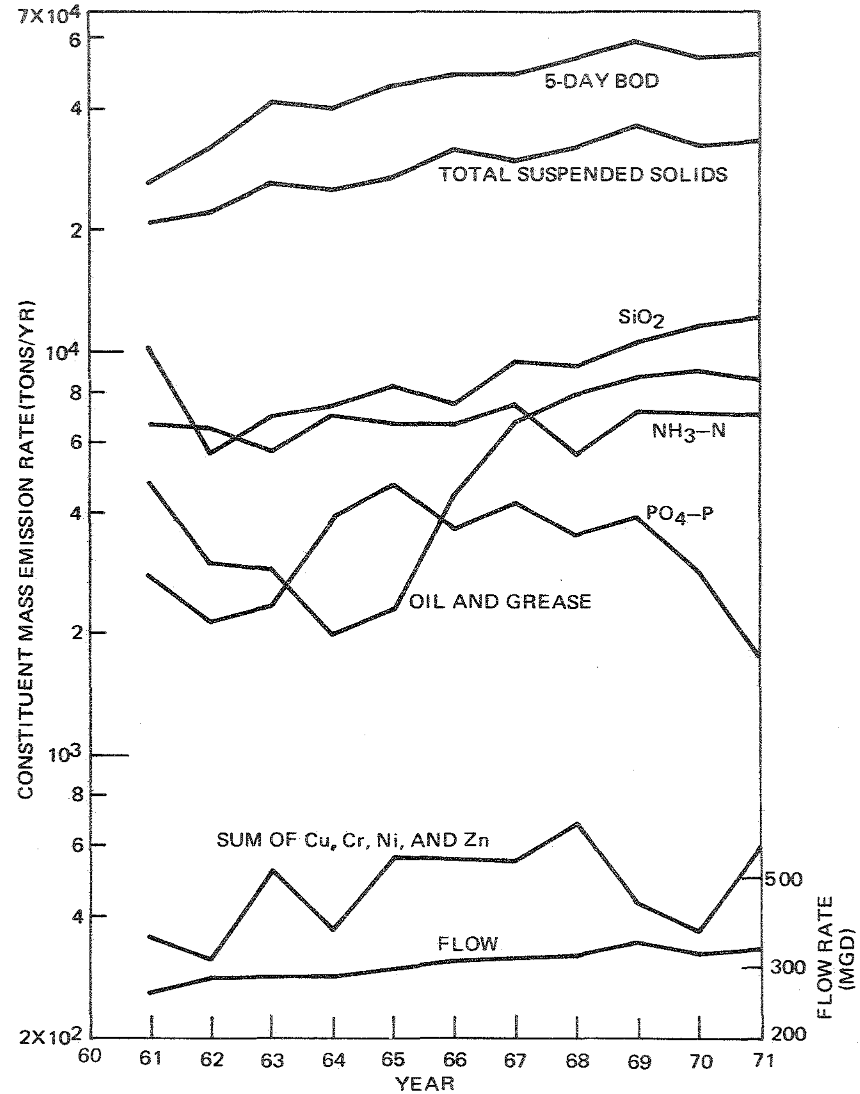

Figure 4-4. Constituent Mass Emission Rates from the Hyperion 5-Mile Effluent Outfall, 1961-71.

Present Effluent Quality and Constituent Mass Emission Rates

General Characteristics. A summary of the effluent constituent concentrations of the six major municipal wastewater dischargers is given in Table 4-4. It is of interest to note that, apparently due to the number of industrial discharges in the service area, the discharge of waste sludge from upstream water reclamation plants, and the return of sludge centrate to the effluent, the final effluent of the JWPCP has the highest concentrations for almost all parameters examined. For example, the concentrations of 330 mg/ℓ total suspended solids, 210 mg/ℓ volatile suspended solids, 320 mg/ℓ 5-day BOD, 610 mg/ℓ COD, and 70 mg/ℓ oil and grease in the JWPCP final effluent are equal to or higher than those of normal, untreated municipal wastewaters; the high concentrations of ammonia nitrogen (80 mg/ℓ), total nitrogen (107 mg/ℓ), and phenols (3.2 mg/ℓ) are higher than those of most other municipal wastewaters. The Hyperion Treatment Plant also receives substantial amounts of industrial wastes; however, about 100 mgd (or one-third of the total) of the Hyperion effluent receives secondary treatment. Consequently, the combined effluent discharging through the 5-mile outfall has relatively lower constituent concentrations than the final effluents of other dischargers.

As shown in Table 4-4, some constituent concentrations are not available from the routine monitoring programs, and data were not collected from the smaller dischargers (flow rates less than 10 mgd). It was necessary to use constituent concentrations of similar dischargers in southern California or in other areas for estimation of constituent mass emission rates for the smaller discharges. For this purpose, average constituent concentrations and unit mass emission rates developed for various types of municipal wastewater treatment plant effluents by the Comprehensive Study of San Francisco Bay, University of California, Berkeley (Pearson 1968) were used.

A summary of constituent mass emission rates for each major discharger (flow rate of 10 mgd or higher) and for all other minor dischargers combined is presented in Table 4-5. These values represent a combination of measured and "best estimate" constituent mass emission rates for 1971. Based upon mass emission rates, the JWPCP, with the highest volumetric flow rates (371 mgd or 37% of the total) and high constituent concentrations in the final effluent, is the most significant contributor.

The combined discharges from Hyperion and the JWPCP contribute between 68 and 83 percent of the total constituents discharged in municipal wastewaters to the Bight. Within the coastal basin, approximately two-thirds of the population resides in Los Angeles County. The somewhat disproportionate amounts of waste constituents discharged in this area is due, in part, to the industrial waste contribution to the municipal sewerage systems.

Chlorinated Hydrocarbons. Measurement of chlorinated hydrocarbons at the levels normally found in the environment requires extreme care and skill. Analytical results should be regarded with some degree of skepticism until a given laboratory and its procedures have been thoroughly checked. Replicate samples collected during a 1-week survey in the spring of 1972 were analyzed for chlorinated hydrocarbons by two laboratories for comparison. The results are presented in Table 4-6. The comparison of these data indicates that, for the total DDT measurements, there is a general agreement between the two

Table 4-4

GENERAL CHARACTERISTICS (MG/L) OF FINAL EFFLUENTS
FROM SIX MAJOR MUNICIPAL WASTEWATER DISCHARGERS, 1971*

Parameter	W9 Oxnard	W10 Hyperion Effluent	W10 Hyperion Sludge	W11 JWPCP	W12 Terminal Island	W16 Orange Co. San. Dist.	W24 Pt. Loma
Flow (mgd)	12	335	5	371	8	130	90
Total suspended solids	80	73	3,000	330	120	145	110
Volatile suspended solids	38	55	1,600	210	75	110	85
5-day biochemical oxygen demand	150	120	-	320	160	190	220
Chemical oxygen demand	-	240	-	610	-	-	-
Oil and grease	17	19	760	70	23	-	37
Dissolved silica (SiO_2)	11	26	-	-	15	-	-
Nitrate nitrogen	2.4	0.6	-	0.2	-	-	-
Ammonia nitrogen	-	15	160	80	23	31	-
Organic nitrogen	-	7.5	430	27	-	14	-
Total nitrogen	-	23	590	107	-	45	-
Phosphate phosphorus	15	5	130	15	12	-	-
Detergent (MBAS)	1.1	4.8	-	7.0	4.5	-	5.3
Cyanide (CN)	-	0.25	-	0.11	0.01	0.08	-
Phenols	0.06	0.01	-	3.2	0.06	0.2	-

*All concentrations are flow-weighted annual averages.

Table 4-5

CONSTITUENT MASS EMISSION RATES (1,000 M TONS/YR)
FROM MUNICIPAL WASTEWATER DISCHARGERS, 1971

Parameter	W9 Oxnard	W10 Hyperion*	W11 JWPCP	W16 Orange Co. San. Dist.	W24 Pt. Loma	Sum of Minor Discharges	Total
Flow (mgd)	12	340	371	130	90	57	1,000
Total suspended solids	1.2	61	169	27	13	7	278
Volatile suspended solids	0.5	37	106	20	11	4.5	179
5-day biochemical oxygen demand	2	59	160	35	26	9	291
Chemical oxygen demand	6	154	311	110	74	20	675
Oil and grease	0.2	14	35	7	5	4	65
Dissolved silica (SiO_2)	0.2	12	9	5	3	4	33
Nitrate nitrogen	0.036	0.29	0.11	0.046	0.031	0.007	0.53
Ammonia nitrogen	0.3	8.1	41	5.7	3	1.3	59.4
Organic nitrogen	0.12	6.4	13.7	2.5	1.7	0.38	24.8
Total nitrogen	0.46	14.8	55	8.2	4.8	2.1	85.4
Phosphate phosphorus	0.23	3.2	7.3	1.1	0.75	0.67	13.3
Detergent (MBAS)	0.02	2.2	3.5	0.91	0.66	0.34	7.6
Cyanide (CN)	0.001	0.117	0.058	0.015	0.012	0.007	0.21
Phenols	0.001	0.046	1.62	0.038	0.015	0.008	1.73

*Effluent and sludge combined.

Table 4-6

CONCENTRATION OF CHLORINATED HYDROCARBONS (μG/L) IN 1-WEEK COMPOSITE SAMPLES OF FINAL EFFLUENTS FROM MUNICIPAL WASTEWATER DISCHARGERS, SPRING 1972

	Laboratory A*			Laboratory B**			
Discharger	Total DDT	Total PCB	Dieldrin	Total DDT	Total PCB	Dieldrin	Period Sampled
W9 Oxnard	0.16	0.21	0.01	0.06	0.20	0.04	22-29 May
W10 Hyperion							
Effluent	0.21	0.28	0.03	0.13	0.30	0.06	1-7 May
Sludge	5.0	280	1.3	2.4	63	1.9	1-7 May
W11 JWPCP	9.6	24	0.14	12	3.6	0.12	31 Mar-7 Apr
W16 Orange Co. San. Dist.	0.36	27	0.03	0.36	6.6	0.18	21-27 May
W24 Pt. Loma	0.26	0.92	0.02	0.12	0.92	0.02	7-13 Mar

*University of California, Bodega Bay Institute of Pollution Ecology

**San Jose Creek Pesticide Laboratory of Los Angeles County Sanitation Districts

laboratories, within a factor of two. With respect to the total PCB data, the agreement between the two laboratories is quite good at low concentrations (less than 1 μg/ℓ). However, for samples with higher concentrations, such as those from Hyperion sludge and the JWPCP and Orange County final effluents, a significant discrepancy exists. The Bodega Bay laboratory reported values three to five times those reported by Los Angeles County Sanitation Districts. The difficulty in measuring PCB in sewage and natural water samples is well recognized, and, at present, the cause of the discrepancy is not known.

Table 4-7 summarizes chlorinated hydrocarbon concentrations in the effluents of four major dischargers. These data are based on values reported by the individual dischargers. The values for total identified chlorinated hydrocarbons were calculated by the dischargers from the sum of total DDT, total PCB, and other identified chlorinated hydrocarbons. Only the DDT and PCB concentrations making up the total are listed in Table 4-7. Note also that, for the JWPCP the sum of DDT and PCB exceeds the total concentration (44.8 μg/ℓ). The reason for this apparent anomaly is evident from the data shown in Table 4-8, which presents the monthly average concentrations reported by the JWPCP for 1971. The table shows that the mean values for DDT, PCB, and total identified hydrocarbons are based on differing sets of monthly values.

Examination of Tables 4-6, 4-7, and 4-8 yield the following observations of particular interest:

A. The Hyperion sludge outfall reports total PCB concentrations much higher than all other waste streams examined.

B. The Orange County Sanitation District effluent contains about the same concentration of PCB as found in effluent from the JWPCP, both of which are higher than that found in the Hyperion or Point Loma effluent.

C. The effluent from the JWPCP contains a concentration of total DDT at least 10 times that of all other treatment plant effluents, including the computed concentrations for the combined Hyperion effluent and sludge.

D. For the JWPCP, the low total DDT concentration in the 1-week composite sample (as compared with the 1971 annual average) may be attributed in part to an extensive clean-up operation to remove the deposits in the sewer lines during the spring and summer of 1971. During the clean-up period, there was a substantial increase in chlorinated hydrocarbons in the plant influent. The clean-up effort, together with source control measures adopted in late 1970, resulted in a marked reduction of chlorinated hydrocarbon concentrations in the plant influent in the subsequent months. The combined efforts are clearly reflected by the changes of chlorinated hydrocarbon concentrations with time in the final effluent (Table 4-8). During the clean-up period, the total DDT concentration in the final effluent was about 60 to 70 μg/ℓ, a substantial increase from the previous 40 μg/ℓ. In the subsequent months, the concentrations decreased to about 10 μg/ℓ.

Table 4-7

AVERAGE CONCENTRATIONS OF CHLORINATED HYDROCARBONS (μG/ℓ) IN FOUR MAJOR MUNICIPAL WASTEWATER TREATMENT PLANT EFFLUENTS, 1971*

Discharger	Flow (mgd)	Total DDT	Total PCB	Total Identified Chlorinated Hydrocarbons	Remarks
W10 Hyperion Effluent	335	0.16	0.08	1.26	Average of 12 monthly values
Sludge	5	2.07	28.7	39.0	Average of 12 monthly values
W11 JWPCP	371	36.3	11.7	44.8	See Table 4-8
W12 Terminal Island	8.1	0.96	0.38	1.37	Average of Feb and Aug values
W24 Pt. Loma	90	0.2	-	-	Average of 3 samples

*Data from municipal wastewater treatment plant monitoring reports.

Table 4-8

1971 MONTHLY AVERAGE CONCENTRATIONS OF CHLORINATED HYDROCARBONS (μG/ℓ) IN FINAL EFFLUENT FROM THE LOS ANGELES COUNTY SANITATION DISTRICTS JWPCP

Month (1971)	Total DDT	Total PCB	Total Identified Chlorinated Hydrocarbons
January	42.0	---	44.0
February	38.1	---	38.8
March	63.6*	---	64.7
April	64.0*	42.5**	107
May	57.2*	---	58.0
June	71.9*	2.0	75.2
July	44.0*	12.2	56.5
August	18.2	5.6	23.8
September	11.6	9.1	21.0
October	10.5	10.4	21.1
November	7.9	6.6	14.8
December	7.1	5.2	12.4

*Note the effect of a trunk sewer clean-up operation during the spring and summer of 1971.

**Value is suspect because of analytical problems.

Based on the available concentration data, chlorinated hydrocarbon mass emission rates have been estimated for the major dischargers and are shown in Table 4-9. These data indicate that, during 1971, more than 19 M tons DDT and 10 M tons of PCB were discharged by the municipal wastewater dischargers. The JWPCP, with a mass emission rate of approximately 19 M tons/yr, was the major source of DDT, and the JWPCP (6 M tons/yr) and Orange County Sanitation District (3 M tons/yr) were the two major sources of PCB among the municipal wastewater dischargers in southern California. It is expected that future chlorinated hydrocarbon mass emission rates will be reduced markedly because of stricter control of these substances.

Table 4-9

CHLORINATED HYDROCARBON MASS EMISSION RATES (KG/YR)
FROM MUNICIPAL WASTEWATER DISCHARGERS, 1971

Discharger	Flow (mgd)	Total DDT	Total PCB	Total Identified Chlorinated Hydrocarbons
W9 Oxnard*	12	2	3	5
W10 Hyperion**	340	88	570	860
W11 JWPCP**	371	19,000	6,000	25,000
W12 Terminal Island**	8	10	4	15
W16 Orange Co. San. Dist.*	130	65	3,000	3,100
W24 Pt. Loma*	90	24	110	140
TOTAL	951	19,200	9,700	29,000

*Derived from average concentration values reported by Laboratories A and B (Table 4-6).

**Based on 1971 average concentration reported by dischargers (Table 4-7).

Trace Metals. A summary of trace metal concentrations in the final effluents of municipal wastewater dischargers is shown in Table 4-10. Composite samples collected from major dischargers during a 1-week trace metal survey were analyzed by two laboratories. These results are shown in Table 4-11. In general, there is a fair agreement between the two sets of results, with a few discrepancies. The variation, in terms of ratios, of the two sets of data is generally within the range of 0.5 to 2 and does not appear to show any definite trend.

It was found that, for 7 of the 10 trace metals analyzed (silver, cadmium, chromium, copper, iron, lead, and zinc), approximately 64 to 93 percent of the metal was retained with the residues on 0.45-μ filters. For cobalt, manganese, and nickel, the percentages were relatively lower (ranging from 42 to 58 percent). It should be noted that some particles considerably smaller than 0.45μ may be retained with the filter residues. With the limited data available at present, it is not possible to establish a relationship between the distribution of trace metals and the characteristics (such as organic content or particle size distribution) of suspended solids.

Based on the average trace metal concentrations and flows, mass emission rates from major municipal wastewater dischargers can be calculated as shown in Table 4-12. Except for cadmium, cobalt, mercury, and nickel, the JWPCP is the single most important source of trace metals, contributing 50 to 85 percent of the total from municipal wastewater dischargers. Hyperion is the major contributor of mercury (72 percent), nickel (48 percent), and cadmium (46 percent).

4.2.2 Discrete Industrial Wastes

There are three groups of discrete industrial wastes discharged into the coastal waters of southern California:

A. Thermal discharges from power plants.

B. Industrial wastes discharged directly to coastal waters.

C. Industrial wastes discharged into San Pedro Bay.

There are limitations to interpretation of reported flow rates and constituent concentrations of industrial waste discharges, as these parameters vary with changes in production schedules, properties of raw material, and operational and housekeeping procedures. However the data presented here provide a reasonable estimate of the magnitude of discrete industrial waste discharges in the coastal area.

Waste Heat Discharges and Cooling Water Flows

Fifteen major thermal power-generating stations (Figure 4-1), with a total capacity of 11,855 mw, discharge cooling water into the southern California coastal waters, bays, and estuaries. Of these, only San Onofre is a nuclear power-generating station. The remainder are conventional thermal power plants that use fossil fuels such as gas and oil.

Table 4-10

AVERAGE CONCENTRATIONS OF TRACE METALS (MG/L) IN FINAL EFFLUENTS OF MUNICIPAL WASTEWATER DISCHARGERS, 1971

Discharger	Silver	Cadmium	Cobalt*	Chromium	Copper	Mercury	Nickel	Lead	Zinc	Iron	Manganese	Remarks (note exceptions in footnotes)
W9 Oxnard	-	0.02	-	0.06	0.09	-	0.06	-	0.28	0.5	0.12	Avg. of Jan 71 & Mar 72 values
W10 Hyperion												
Effluent	0.002**	0.05	0.006	0.29	0.23	0.003	0.28	0.06	0.46	0.7	0.01**	Avg. of 12 monthly values
Sludge	0.03**	0.23	0.03	2.1	12.2	0.10	2.6	0.51	16.5	47	1.6	
W11 JWPCP	0.02	0.03	-	0.86	0.56	0.001	0.24	0.25†	2.4	9.9	0.13	Avg. of 12 monthly values
W12 Terminal Island	0.002††	0.01	-	0.11	0.26	0.001	0.42	0.00	0.36	0.9	0.05	Avg. of Jan & Jul values
W16 Orange Co. San. Dist.	0.02	0.06	-	0.22	0.35	0.001§	0.16	0.22	0.54	1.2	0.09	Avg. of Oct-Dec values
W24 Pt. Loma	--	0.02	-	0.15	0.16	-	0.06	0.10	0.18	-	-	Avg. of Jul-Sep values

*All cobalt concentrations are averages of 24-hr composite samples collected 24 Aug and 9 Dec 70.
**Hyperion effluent and sludge silver concentrations are averages of 4 monthly values; effluent manganese concentration is average of 11 monthly values.
†JWPCP lead concentration is average of 10 monthly values.
††Terminal Island silver concentration is average of Aug and Sep 71 values.
§Orange Co. mercury concentration is estimated from analysis of 22 grab samples, 15-21 Jun 72.

Table 4-11

TRACE METAL CONCENTRATIONS (mg/ℓ) IN 1-WEEK COMPOSITE SAMPLES OF FINAL EFFLUENTS FROM MUNICIPAL WASTEWATER DISCHARGERS, SUMMER 1971*

Discharger and Date Sampled	Silver		Cadmium		Cobalt		Chromium		Copper		Nickel		Lead		Zinc		Iron		Manganese	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
W9 Oxnard (15-21 Aug)	-	0.004	-	0.01	-	0.002	-	0.04	-	0.11	-	0.02	-	0.03	-	0.16	-	0.99	-	0.02
W10 Hyperion (26 Jul - 1 Aug)																				
Effluent	0.01	0.02	0.01	0.01	-	0.008	-	0.22	0.09	0.18	-	0.15	0.06	0.04	-	0.27	-	0.68	-	0.03
Sludge	0.07	0.79	0.47	0.57	-	0.065	-	0.55	4.4	7.5	-	2.0	3.6	3.1	-	14.0	-	40.0	-	0.47
W11 JWPCP (13-19 Aug)	0.01	0.01	0.02	0.02	-	0.004	1.3	0.61	0.40	1.1	0.18	0.16	0.16	0.19	2.4	1.4	7.3	7.3	0.12	0.08
W16 Orange Co. San. Dist. (27 Aug - 2 Sep)	0.01	0.01	0.04	0.04	-	-	0.28	0.26	0.24	0.31	0.14	0.06	0.20	0.15	0.54	0.39	0.78	1.2	0.06	0.04
W24 Pt. Loma (1-7 Aug)	-	0.01	-	0.01	-	0.002	-	0.12	-	0.18	-	0.04	-	0.06	-	0.32	-	1.2	-	0.07

*Column 1: concentrations reported by dischargers laboratory;
Column 2: concentrations reported by Galloway 1972.

Table 4-12

TRACE METAL MASS EMISSION RATES (M TONS/YR)
OF MUNICIPAL WASTEWATER DISCHARGERS, 1971

Discharger	Flow (mgd)	Silver	Cad-mium	Cobalt	Chro-mium	Copper	Mer-cury	Nickel	Lead	Zinc	Iron	Manga-nese
W9 Oxnard	12	-	0.3	-	1	1	-	1	-	4	8	2
W10 Hyperion	340	1.1	25	3.0	150	190	2.1	150	31	330	661	16
W11 JWPCP	371	10	15	-	440	290	0.5	120	130	1,220	5,100	67
W12 Terminal Island	8	-	0.1	-	1	3	-	5	-	4	11	1
W16 Orange Co. San. Dist.	130	3.6	11	-	40	63	0.2	29	40	97	220	16
W24 Pt. Loma	90	-	2.5	-	19	20	0.1	8	12	22	-	-
TOTAL	951	15	54	3.0	651	567	2.9	313	213	1,677	6,000	102

Operating data for 1970-71 obtained from the various power companies are reported in Table 4-13. The total annual thermal power generated by the 15 power stations is estimated to be 58 x 10^9 kwh. This represents about 75 percent of the annual total energy requirements in southern California.

The annual average load factor for the 14 fossil-fuel stations was about 55 percent for the year 1970-71. This value is much lower than the annual average load factor for all power plants in the United States, which has been estimated by Edison Electric Institute to be 64 percent. A load factor of 80 percent for 1970 has been reported for the San Onofre nuclear power plant.

In a steam thermal power plant, the steam cycle converts part of the heat from the furnace or the reactor into electric power, and the remaining heat is discharged to the environment. When cooling water is used to convey the waste heat away, the water temperature is raised as it flows through a condenser, where the steam that drives the turbine is cooled. Thus, the amount of waste heat discharged through cooling water depends on the operating conditions and efficiency of the power plant. Actual thermal efficiencies of southern California power plants vary from 25 to 36 percent for the conventional type and 32 percent for the San Onofre nuclear power plant.

The waste heat discharge from each power station in the southern California coastal area for the year 1970-71 is shown in Table 4-13. When the capacity-weighted mean efficiency is considered, the conventional thermal power plants in this area have an overall efficiency of about 34 percent. Thus, the average fuel energy requirement is 2.94 units per unit of electrical energy produced. Part of the waste heat is dissipated into the atmosphere through the stacks. If 15 percent is assumed to be lost through the stacks, approximately 1.65 (0.85 x 1.94) units of the heat will be removed by cooling water and discharged into the receiving waters. (Data from San Onofre show a total heat loss of 2.1 units of energy per unit of electrical energy produced).

Based on estimates of the heat wastage, the total maximum instantaneous waste heat discharge is calculated to be 1.96 x 10^7 kw (4.1 x 10^{14} g-cal/day) for all southern California power plants. Using the load factors reported for each station, the annual average waste heat can be estimated to be 1.07 x 10^7 kw (8 x 10^{16} g-cal/yr) for the year 1970-71. Compared with the rate of net solar plus atmospheric radiation energy absorbed by the water surface, which has been estimated to be about 1,100 g-cal/sq cm-day or 4.0 x 10^9 g-cal/sq m-yr (Section 3.3.4), the amount of waste heat from power plants is equivalent to absorbed radiation from 20 sq km of coastal water.

The amount of cooling water required for a thermal power plant to remove a unit of waste heat is dependent upon the temperature rise. The normal temperature increase for the cooling water flow in southern California power plants is about 7°C in the San Diego Bay area and about 10 to 12°C in the other coastal areas. On an annual average basis, approximately 7.7 x 10^9 cu m/yr of saline water is being used for power-plant cooling purposes. The cooling water temperature is raised an average of 10.5°C, and it is subsequently returned to the coastal environment. The present maximum rate of instantaneous cooling water flow for the power stations in the southern California coastal area is 38.6 x 10^6 cu m/day.

Table 4-13

THERMAL DISCHARGES AT POWER GENERATING STATIONS IN THE SOUTHERN CALIFORNIA COASTAL AREA AS OF 1970-71[a]

	Plant Operation			Estimated Waste Heat to Cooling Water[d]				Estimated Cooling Water Flow[d]		
	1	2	3	4	5	6 Plant Waste Heat, H		7	8 Cooling Water Flow, R	
Fuel STATION-Location	Capacity, MW_e (mw)	Load Factor, F (%)	Overall Efficiency, E (%)	Waste Heat per unit of Electrical Output, Q	Waste Heat to Cooling Water per Unit Output, Q_w	6A Maximum, H_{max} (10^6 kw)	6B Average, H_{avg} (10^6 kw)	Normal Average Temp Rise, T (°C)	8A Maximum, R_{max} (10^6 cu m/day)	8B Annual, R_{avg} (10^8 cu m/year)
FOSSIL-FUEL TYPE										
L.A. Dept. of Water and Power										
P1 Harbor, Wilmington	445	14	25	3.00	2.55	1.1	0.2	11	2.1	1.1
P2 Haynes, Seal Beach	1,625	60	36	1.78	1.51	2.5	1.5	10.5	4.8	10.5
P3 Scattergood, Playa del Rey	350	59	34	1.65	1.65	0.5	0.3	10	1.2	2.5
Subtotal	2,420					4.1	2.0		8.1	14.1
Southern California Edison Co.										
P4 Alamitos, Seal Beach	1,950	58	36	1.78	1.51	2.9	1.7	11	5.5	11.6
P5 El Segundo, El Segundo	1,020	50	35	1.86	1.58	1.6	0.8	12	2.7	5.0
P6 Huntington, Huntington Beach	990	65	35	1.86	1.58	1.6	1.0	12	2.8	6.5
P7 Long Beach, Long Beach[b]	210	20	25	3.00	2.55	0.5	0.1	10.5	1.0	0.8
P8 Mandalay, Oxnard	430	73	36	1.78	1.51	0.6	0.5	11	1.2	3.2
P9 Redondo, Redondo Beach	1,600	52	33	2.03	1.72	2.8	1.4	11	5.1	9.8
P10 Ormond, Ormond Beach	1,580	55	34	1.94	1.65	2.6	1.4	10.5	5.1	10.2
Subtotal	7,780					12.6	6.9		23.4	47.1
San Diego Gas and Electric Co.[b]										
P11 Encino, Carlsbad	345	55	34	1.94	1.55	0.5	0.3	10.5	1.1	2.2
P12 Silver Gate, San Diego Bay	235	55	34	1.94	1.65	0.4	0.2	7	1.1	2.2
P13 South Bay, San Diego Bay	530	55	34	1.94	1.65	0.9	0.5	7	2.5	5.0
P14 Station "B," San Diego Bay	95	55	34	1.94	1.65	0.2	0.1	7	0.5	0.9
Subtotal	1,205					2.0	1.1		5.2	10.3
Total, Fossil-Fuel Type	11,405					18.7	10.0			71.5
Weighted Mean[c]		55	34	1.94	1.65			10.5		
NUCLEAR										
P15 San Onofre, San Clemente	450	80	32	2.12	2.02	0.9	0.7	10	1.9	5.5
TOTAL	11,855					19.6	10.7		38.6	77.0

a. Station operating data provided by power companies, except as noted in Note b below.
b. Estimated values for the year 1971.
c. All mean values are weighted by plant capacity.
d. Calculations:
(i) Column (4): $Q = (1 - E)/E$
(ii) Column (5): Assume 15% of heat wastage lost through stack for fossil-fuel-type plant; 5% for nuclear power plant.
(iii) Column (6A): $H_{max} = (MW_e) \times (Q_w) \times 10^3$
(iv) Column (6B): $H_{avg} = (H_{max}) \times F$
(v) Column (8A): $R_{max} = (H_{max}) \times 20.7/(T)$
(vi) Column (8B): $R_{avg} = (R_{max}) \times (F) \times 365$

Industrial Waste Discharges Along the Southern California Coast

This group includes major discrete waste dischargers from nonpower industries discharging directly into the coastal waters; the discharges are described in Table 4-14. Note that with the exception of one discharger (I22), the entire group is from petroleum-related industries, including onshore and offshore oil production, transport, and processing and oil tanker mooring facilities (see Tables 3-9 and 3-10). The locations of these industrial waste dischargers are shown in Figure 4-1. All discrete industrial waste dischargers are clustered around the Santa Barbara Channel (Areas I and II), in Santa Monica Bay (Area III), and off the northern Orange County coast (Area V).

Available constituent concentration data from individual dischargers have been summarized, and average constituent concentrations for oil field brines and oil tanker and line ballast, the two main types of discrete industrial wastes in the coast, have been calculated. The estimated average concentrations are as follows:

	Average Concentration (mg/ℓ)		
Type of Waste	Total Suspended Solids	Oil and Grease	Chemical Oxygen Demand
Oil field brine	60	12	3,000
Tanker and line ballast	50	14	1,100

Assuming these characteristics are representative of all similar industrial wastes, the total constituent mass emission rates have been estimated (Table 4-15). Altogether, approximately 3,400 M tons suspended solids, 1,400 M tons oil and grease, and 45,000 M tons chemical oxygen demand per year are contributed by discrete industrial waste discharges into the Pacific Ocean. The mass emission rates for total suspended solids and oil and grease are approximately 2 percent of that contributed by municipal dischargers and chemical oxygen demand is about 7 percent of that of municipal dischargers.

Industrial Waste Discharges Tributary to San Pedro Bay

As shown in Table 4-16, there are 156 discrete industrial waste dischargers in the San Pedro Bay area (Calif. Reg. Water Qual. Control Bd., Los Angeles Reg. 1969) that discharge either directly or through storm drains into the Los Angeles-Long Beach Harbors and their tributary tidal prisms. The combined flow rate is about 102 mgd, not including a municipal wastewater treatment plant effluent (W12, Terminal Island), nor cooling waters from four power plants (P1, P2, P3, or P7). Considering the types of industry and the nature of the waste streams, these dischargers can be classified into the following groups:

Type		Total Flow (mgd)
A	Oil field brine	34
B	Oil tanker and line ballast	6.5
C	Refinery and petrochemical	36

Table 4-14

DISCRETE INDUSTRIAL WASTE DISCHARGERS ON THE SOUTHERN CALIFORNIA COAST

Area		Discharger	Type of Waste	Flow (mgd)	Pipe Length (m)	Pipe Depth (m)	Reference to Tab. 3-9 & 3-10
I	I1	Phillips Petroleum--Point Conception	Oil brine Tanker ballast	0.2			T1, E1
	I2	Texaco, Inc.--San Augustin	Oil brine	0.2			E2, E3
	I3	Getty Oil--Gaviota	Oil brine Tanker ballast	0.16			T2
	I4	Shell Oil--El Capitan	Oil brine Tanker ballast	0.2			T3
	I5	Signal Oil & Gas--Ellwood	Oil brine Tanker ballast	0.29			T4
	I6	Atlantic Richfield--Coal Oil Point	Oil brine	0.06			E9, E10
	I7	Standard Oil-Summerland	Oil brine	0.4		32	E11
	I8	Standard Oil--Carpinteria	Oil brine Tanker ballast	0.4	120	3	T5
	I9	Atlantic Richfield--Rincon	Oil brine	0.01	76	6	
	I10	Atlantic Richfield--Rincon Island	Oil brine	0.04	800	18	E15
	I11	Western Oil & Dev.--Rincon	Oil brine	0.36		3	
	I12	Petrol Industries--Rincon	Oil brine	0.01			
	I13	Continental Oil--Rincon	Oil brine	0.49	150	4	
	I14	Norris Oil Co.--Rincon	Oil brine	0.05	670	3	
	I15	Phillips Petroleum--La Conchita	Oil brine	0.36	270	6	
	I16	Phillips Petroleum--Punta Garda	Oil brine	0.4	150	6	
	I17	Mobil Oil--Sea Cliff	Oil brine Tanker ballast	0.18	950	9	
II	I18	Continental Oil--Pitas Point	Oil brine	0.27	150	4	
	I19	Continental Oil--Grubb Lease	Oil brine	0.75	150	2	
	I20	Getty Oil--Ventura	Oil brine Tanker ballast	0.06		3	T7
	I21	Standard Oil--McGrath Beach	Oil brine	0.14		1	
III	I22	McDonnell Douglas Corp.--Venice	Cooling tower bleedoff	0.65			
	I23	Standard Oil--El Segundo	Cooling water Refinery Waste	72.0	170	5	T9
V	I24	Standard Oil--Island Esther	Oil brine	1.0			E18
	I25	Union Oil--Platform Eva	Oil brine	0.02			E19
	I26	Signal Oil and Gas--Platform Emmy	Oil brine	0.08			E20
	I27	Signal Oil and Gas--Huntington Beach	Oil brine	0.6	300	3	
	I28	Standard Oil--Huntington Beach	Oil brine	0.8	310	4	
	I29	Gulf Oil--Huntington Beach	Oil line ballast	0.01	300		T10

Table 4-15

CONSTITUENT MASS EMISSION RATES (M TONS/YR) FROM DISCRETE INDUSTRIAL WASTE DISCHARGERS ON THE SOUTHERN CALIFORNIA COAST

Type of Waste	Flow (mgd)	Total Suspended Solids	Oil and Grease	Chemical Oxygen Demand
Oil field brine	6	500	100	24,800
Tanker and line ballast	1.5	103	29	2,300
I22 Cooling tower bleedoff	0.65	31	10	210
I23 Cooling and refinery waste	72	2,800	1,290	17,800
TOTAL	80	3,434	1,429	45,110

Table 4-16

DISTRIBUTION OF DISCRETE INDUSTRIAL WASTE DISCHARGERS IN SAN PEDRO BAY AREA

Discharge Area	No. of Dischargers		Combined Flow (mgd)	
Los Angeles Harbor				
Outer Harbor	4		7.8	
Fish Harbor	7		1.9	
Main Channel	6		1.5	
West Basin—Southwest Slip	15		29.2	
East Basin—Slips 1 and 5	25		6.1	
Consolidated Slip	34		0.25	
Cerritos Channel	5		0.14	
Subtotal		96		46.9
Long Beach Harbor				
Cerritos Channel	3		11.3	
Channel Two	5		16.5	
Channel Three	7		1.5	
Southeast Basin	4		4.6	
Subtotal		19		33.9
Dominguez Channel		23		10.3
Los Angeles River Tidal Prism		3		7.0
Los Cerritos Channel		7		0.2
San Gabriel River Tidal Prism		8		3.6
TOTAL		156		102

Type		Total Flow (mgd)
D	Metallic	3.8
E	Fish cannery	9.6
F	Miscellaneous chemical	12

Table 4-17 summarizes the spatial distribution of each type of waste discharge in the San Pedro Bay system. As shown, the fish canneries are clustered around the Fish Harbor in Los Angeles Harbor; oil tanker mooring facilities are limited to Los Angeles and Long Beach Harbors; refinery and petrochemical industries are concentrated in Los Angeles Harbor and along Dominguez Channel and Los Angeles River tidal prisms; and oil field, metallic and other chemical industries are distributed throughout the bay area.

From available data collected from the California Regional Water Quality Control Board, Los Angeles Region, average constituent concentrations for each type of waste in the San Pedro Bay area were computed and are presented in Table 4-18. It is interesting to note that the concentrations of total suspended solids, oil and grease, and chemical oxygen demand in oil field brines and oil tanker ballasts discharged to San Pedro Bay are significantly lower than those in similar types of waste discharged directly to the Pacific Ocean.

Based on the average constituent concentrations, the mass emission rates from discrete industrial waste dischargers in San Pedro Bay area were estimated and are reported in Table 4-19. At present, approximately 12,500 M tons suspended solids, 6,000 M tons 5-day biochemical oxygen demand, 33,000 M tons chemical oxygen demand, 800 M tons oil and grease and 9,500 M tons ammonia nitrogen per year are discharged to the San Pedro Bay system from discrete industrial waste dischargers. With a combined flow rate of 102 mgd, or approximately 10 percent of the combined municipal wastewater flow rate in Southern California, the estimated annual mass emission rates from discrete industrial waste dischargers in San Pedro Bay area appear to be very low. In terms of the total mass emission rates from municipal dischargers (Table 4-6), the discrete industrial wastes contribute about 5 percent of the suspended solids, 5-day biochemical oxygen demand, and chemical oxygen demand, 12 percent of the oil and grease, and 16 percent of the ammonia nitrogen.

4.2.3 Surface Runoff

Runoff associated pollutant inputs can be conveniently grouped into two categories: dry weather flow and storm waters. There are approximately 200 to 300 major rivers, streams, and storm drains discharging into the coastal waters of southern California. It is a major undertaking to sample and analyze all significant storm waters and dry weather flows for ecologically significant parameters, yet this type of information is needed urgently and is not available. Thus it was necessary for SCCWRP to undertake a limited-scale runoff characterization program during the water year 1971-72.

Table 4-17

COMBINED FLOW RATES (MGD) OF DISCRETE INDUSTRIAL WASTE DISCHARGERS
IN SAN PEDRO BAY AREA BY TYPE OF WASTE

Discharge Area	Type A Oil Field Brine	Type B Oil Tanker and Line Ballast	Type C Refinery Petrochemical	Type D Metallic	Type E Fish Cannery	Type F Chemical Miscellaneous	Total
Los Angeles Harbor	0.43	0.82	28.4	2.03	9.6	5.6	46.9
Long Beach Harbor	24.3	5.7	-	0.03	-	3.8	33.8
Dominguez Channel	0.05	-	6.5	1.4	-	2.3	10.3
Los Angeles River Tidal Prism	5.9	-	1.1	-	-	-	7.0
Los Cerritos Channel	-	-	-	0.12		0.04	0.2
San Gabriel River Tidal Prism	3.4	-	-	0.19	-	-	3.6
TOTAL	34.1	6.5	36.0	3.8	9.6	11.7	102

Table 4-18

AVERAGE CONSTITUENT CONCENTRATIONS (MG/L) OF INDUSTRIAL WASTE DISCHARGERS TO SAN PEDRO BAY, BY TYPE OF WASTE

Type of Waste	Combined Flow Rate* (mgd)	Total Suspended Solids	5-day Biochemical Oxygen Demand	Chemical Oxygen Demand	Oil and Grease	Ammonia Nitrogen	Phenols
A. Oil Field Brine	8.5	18	110	410	6	200	0.3
B. Oil Tanker and Line Ballast	6.3	460	11	430	4		1.6
C. Refinery and Petrochemical	10.3	28	13	180	9	8	0.3
D. Metallic	1.6	44	7	150	6	21	0.01
E. Fish Cannery	2.0				32		
F. Miscellaneous Chemical	5.3	16	1	50	1		

*Combined flow rates of dischargers for which concentration data are available.

Table 4-19

CONSTITUENT MASS EMISSION RATES (M TONS/YR) FROM DISCRETE INDUSTRIAL WASTE DISCHARGERS IN SAN PEDRO BAY AREA

Area	Flow (mgd)	Total Suspended Solids	5-day Biochemical Oxygen Demand	Chemical Oxygen Demand	Oil and Grease	Ammonia Nitrogen	Phenol
Los Angeles Harbor	46.9	1,880	620	8,300	370	120	14
Long Beach Harbor	33.8	9,900	3,800	17,600	230	6,800	22
Dominquez Channel	10.3	390	140	1,860	92	14	3
Los Angeles River Tidal Prism	7.0	190	910	3,600	59	1,640	3
Los Cerritos Channel	0.2	8	1	5	1	-	-
San Gabriel River Tidal Prism	3.6	96	510	1,920	28	940	1
TOTAL	102	12,500	5,980	33,300	780	9,510	43

Four major rivers were studied in the program. In addition 11 perennial streams were sampled once during the dry weather period. For each time-sample, at least eight subsamples were collected for the following groups of analyses:

A. Filtered Samples--Residue on evaporation, nitrogen (organic, ammonia, nitrite and nitrate), phosphate, dissolved silica, and total organic carbon.

B. Unfiltered Samples--Chemical oxygen demand, oil and grease, detergents (MBAS), phenols, and cyanide.

C. Suspended Silt--Dry weight, particle size distribution, organic carbon, organic nitrogen, and phosphate.

D. Chlorinated Hydrocarbons--DDT, PCB, dieldrin, etc.

E. Trace Metals--Silver, cadmium, cobalt, chromium, copper, lead, mercury, nickel, zinc, iron, and manganese.

The firm of Pomeroy, Johnston, and Bailey of Pasadena, California, conducted the field sampling and laboratory analyses for parameters in Groups A, B, and C. Chlorinated hydrocarbons were analyzed at the University of California, Bodega Bay Institute of Pollution Ecology. Heavy metal determinations were conducted by the California Institute of Technology, Keck Laboratory of Environmental Engineering, Pasadena.

Surface Runoff Sampling Activities

One of the important considerations in selecting the basins to be studied was the objective of characterizing the largest possible amount of flow during the storm season, while relating the storm water quality to land use characteristics and rainfall patterns. As the concentrations of some constituents vary significantly over the period of a storm, it was necessary to examine a series of samples at appropriate intervals. During the peak flow period, samples were taken at approximately 2-hr intervals. Sampling frequencies were modified as the storm flow progressed. Altogether, 77 time-samples were obtained from four selected study basins during the storm season of 1971-1972.

During an unusually dry year, such as 1971-72, the dry weather flow and its associated constituent mass emission rates constitute a significant portion of the total annual values for a perennial river. Most of the dry weather flows in southern California result from controlled release of reservoirs, discharge of industrial wastes and treated sewage effluents, casual collection of water from lawn sprinklers, and collection of irrigation return waters. It is believed that if the dry weather flows could be isolated, they would not show wide seasonal variation in most quality parameters, except for fertilizers and pesticides in irrigation percolates. Consequently, one sample from each of the 11 streams, designated as R11 to R21, was collected for analysis during periods of significant dry weather flow.

At the time of sampling, an instantaneous volumetric flow rate was measured. This flow rate was used in conjunction with previous flow records to estimate the median annual flow rate.

Table 4-20 summarizes the storm water and dry weather flow sampling activities during the water year 1971-72. Approximately 61 percent of the storm water has been sampled and analyzed. The amount of surface runoff reaching the Pacific Ocean for the water year 1971-72 is estimated to be 167 x 10^6 cu m from storm flow and 75 x 10^6 cu m from dry weather flow. The total surface runoff (242 x 10^6 cu m/yr) was equivalent to about 43 percent of the long-term average shown in Table 3-4.

General Characteristics of Storm and Dry Weather Flows

The amount of constituent mass emitted between two sampling times has been calculated by multiplying the mean concentration of the two samples and the total volume of flow during that time period. The estimated total mass emission rates for a storm is the sum of all sampling periods. The average concentration is then calculated by dividing the total mass emitted by the total volume of flow. Table 4-21 reports the average constituent concentrations in storm waters in the four selected study basins for the year 1971-71.

There appear to have been some distinct differences in constituent concentrations among the storm flow samples from the selected study basins. One of the most significant differences is that of suspended silt. The highest suspended silt concentration observed was 7,600 mg/ℓ in samples from the Santa Clara River, followed by 1,800 mg/ℓ in samples from the Santa Ana River. The suspended silt concentrations reported for Ballona Creek and the Los Angeles River were in the order of 300 to 400 mg/ℓ, values significantly lower than those for the other two rivers. On the other hand, storm water samples from Ballona Creek and Los Angeles River carried relatively higher concentrations of soluble organic carbon, nitrogen, and oil and grease than the samples from Santa Clara and Santa Ana Rivers. The distinct contrast in these constituent concentrations may be a reflection of differences in waste generating activities, such as land use characteristics, among the drainage basins studied.

The general characteristics of dry weather flow samples are shown in Table 4-22. As with storm water samples, the suspended silt concentrations were higher in the Santa Clara River (930 mg/ℓ) and in another southerly stream, San Diego River (1,620 mg/ℓ), than in other streams (5 to 65 mg/ℓ). There also appears to be a distinct distribution pattern for oil and grease concentrations. The concentrations of oil and grease reported in samples from Los Angeles-Santa Ana River basins (24 to 49 mg/ℓ) were significantly higher than the concentrations reported for the Ventura-Santa Clara River basins (4 mg/ℓ).

Comparisons of these values with those of average storm flow concentrations, indicate that, with the exception of silt and silt-associated constituents, there is no definite tendency for storm water in these basins to carry significantly higher or lower constituent concentrations than does the dry weather flow.

As indicated previously, some storm flows were not sampled in the runoff characterization program; thus, it was necessary to extrapolate concentration data to complete the mass emission estimates. The estimated surface runoff associated constituent mass emission rates from 11 streams in southern California are presented in Table 4-23.

Table 4-20

SUMMARY OF STORM WATER AND DRY WEATHER FLOW SAMPLING EFFORT, 1971-72

Area		Storm Flow			Dry Weather Flow		
			Estimated Flow (1,000 cu m/yr)				
	Stream	Sample Designation	Sampled	Not Sampled	Sample Designation	Date Collected (1972)	Estimated Flow (1,000 cu m/yr)
I	Santa Barbara Group			2,500			1,200
II	Ventura River			3,000	R11	6 Apr	11,700
	Santa Clara River	R1	26,000		R12	2 May	– *
	Calleguas Creek			700	R13	29 Mar	2,700
III	Malibu Creek			3,400			–
	Pico Drain			1,200	R14	11 Apr	3,600
	Ballona Creek	R2	26,000		R15	28 Mar	15,700
V	Dominguez Channel			5,300	R16	28 Mar	5,400
	Los Angeles River	R3	48,000		R17	28 Mar	20,000
	San Gabriel River			10,300	R18	28 Mar	300
	Coyote Creek			27,000	R19	2 May	4,000
	Santa Ana River	R4	1,800	8,600			–
VI	San Diego River			2,500	R20	2 May	8,000
	San Juan Creek			200	R21	2 May	2,100
	APPROX. TOTAL		102,000	65,000			75,000

*Dry weather flow diverted by percolation.

Table 4-21

AVERAGE CONSTITUENT CONCENTRATIONS (MG/L) OF STORM WATERS IN SELECTED STUDY BASINS

	R1 Santa Clara River	R2 Ballona Creek	R3 Los Angeles River	R4 Santa Ana River
Soluble Constituents				
Organic nitrogen	1.1	3.9	3.0	1.1
Ammonia nitrogen	0.4	1.6	1.1	0.2
Nitrite nitrogen	0.1	0.4	0.5	0.1
Nitrate nitrogen	2.3	5.2	3.7	1.3
Phosphate phosphorus	0.43	0.52	0.85	0.82
Dissolved Silica (SiO_2)	11	9.6	11	5.3
Total organic carbon	22	45	45	30
Soluble Plus Insoluble Constituents				
Chemical oxygen demand	180	260	120	62
Oil and Grease	1.5	23	12	7
Detergents (MBAS)	0.1	0.4	0.3	0.06
Phenols	0.03	0.09	0.09	0.05
Cyanide (CN)	0.09	0.16	0.04	0.03
Silt Constituents				
Silt	7,600	390	300	1,800
Organic carbon	100	64	31	28
Organic nitrogen	3.9	3.0	2.0	1.5
Phosphate phosphorus	2.0	0.84	0.65	0.71

Table 4-22

GENERAL CHARACTERISTICS OF DRY WEATHER FLOWS (MG/L) IN SOUTHERN CALIFORNIA, 1971-72

	R11 Ventura River	R12 Santa Clara River	R13 Calleguas Creek	R14 Pico Drain	R15 Ballona Creek	R16 Dominguez Channel	R17 Los Angeles River	R18 San Gabriel River	R19 Coyote Creek	R20 San Diego Creek	R21 San Juan Creek
Soluble Constituents											
Organic nitrogen	2.9	2.2	2.4	2.4	1.9	1.2	2.9	1.7	2.2	1.7	0.7
Ammonia nitrogen	9.1	0.0	6.3	0.0	3.5	0.0	0.0	10.2	0.0	3.5	0.0
Nitrite nitrogen	0.1	0.1	0.1	0.2	0.2	0.0	0.2	0.3	0.7	5.9	0.0
Nitrate nitrogen	6.3	4.1	2.4	2.2	1.7	0.1	0.5	1.2	2.2	10.7	2.5
Phosphate phosphorus	3.7*	0.06*	4.2*	1.6	0.49	0.33	0.55	0.69	0.14	1.83	0.03
Dissolved silica (SiO_2)	17	26	32	28	27	10	18	25	12	21	17
Soluble plus Insoluble Constituents											
Chemical oxygen demand	39	120	100	62	33	190	36	58	46	110	13
Oil and grease	4	4.	4	49	34	34	39	24	34	36	30
Detergent (MBAS)	0.14	0.02	0.08	0.32	0.26	0.72	0.16	0.34	0.74	0.28	0.13
Phenols	0.002	0.001	0.001	0.01	0.00	24	0.0	0.00	0.00	0.01	0.00
Cyanide (CN)	0.004	0.007	0.018	0.00	0.08	0.00	0.009	0.000	0.032	0.004	0.004
Silt Constituents											
Silt	64	930	50	54	51	14	60	32	14	1,620	4.4
Org. Nitrogen	1.0	6.8	1.1	0.16	1.2	1.3	0.42	1.6	0.57	2.9	0.57
Phosphate phosphorus	---	---	---	0.29	0.42	0.09	0.07	0.59	0.15	1.3	0.10

*Determined on unfiltered samples.

Table 4-23

CONSTITUENT MASS EMISSION RATES (M TONS/YR) FROM SURFACE RUNOFF IN SOUTHERN CALIFORNIA, 1971-72

Stream	Flow (10^6 cu m/yr)	Silt	Total Organic Carbon*	Chemical Oxygen Demand	Oil And Grease	Dissolved Silica (SiO_2)	Nitrate Nitrogen*	Ammonia Nitrogen	Organic Nitrogen	Total Nitrogen	Phosphate Phos-phorus*	Detergent (MBAS)	Cyanide (CN)	Phenols
Santa Barbara Gp.														
Storm	2.5	200	200	100	<50	50	16	23	10	49	9	0.4	<0.1	<0.1
Dry Weather	1.2	100	100	<100	<50	<50	8	11	5	24	4	0.2	<0.1	<0.1
Ventura R.														
Storm	3	200	200	100	<50	50	20	27	12	59	11	0.4	<0.1	<0.1
Dry Weather	11.7	700	900	500	<50	200	75	107	46	230	43	1.6	0.1	<0.1
Santa Clara R.														
Storm	26	199,000	2,800	4,800	50	300	63	11	132	206	64	2.6	2.4	0.8
Calleguas Cr.														
Storm	0.7	<100	<100	100	50	<50	2	4	2	8	3	0.1	<0.1	<0.1
Dry Weather	2.7	100	100	300	50	80	7	17	9	33	11	0.2	0.1	<0.1
Malibu Cr.														
Storm	3.4	1,000	300	400	50	<50	15	4	17	36	5	1.0	0.1	0.3
Pico Drain														
Storm	1.2	500	100	300	<50	<50	7	2	8	17	2	0.5	0.2	0.1
Dry Weather	3.6	200	100	200	180	100	9	1	9	19	7	1.2	<0.1	<0.1
Ballona Cr.														
Storm	26	10,000	2,800	6,600	600	250	151	42	180	370	36	10.3	4.1	2.3
Dry Weather	15.7	800	200	500	530	420	30	55	49	134	14	4.1	0.1	<0.1
Dominguez Ch.														
Storm	5.3	100	100	1,000	180	50	1	<1	13	14	2	3.8	<0.1	127
Dry Weather	5.4	100	100	1,000	190	50	1	<1	13	14	2	3.9	<0.1	130
Los Angeles R.														
Storm	48	14,000	3,600	5,700	590	50	204	53	242	500	72	14.5	1.9	4
Dry Weather	20	1,200	200	700	790	36	14	<1	67	81	13	3.2	0.2	<0.1
San Gabriel R.														
Storm	10.3	3,000	800	1,300	130	110	44	11	52	107	16	3.1	0.4	1
Dry Weather	0.3	<100	<100	<100	<50	50	1	3	1	5	3	0.1	<0.1	<0.1
Coyote Cr.														
Storm	27	8,000	2,000	3,200	330	290	110	30	140	280	40	8.1	1.1	2
Dry Weather	4	100	100	200	140	50	12	<1	11	23	1	3.0	0.1	<0.1
Santa Ana R.														
Storm	10.4	18,000	600	600	70	50	15	2	27	44	16	0.6	0.3	1
San Diego Cr.														
Storm	2.5	4,000	100	300	90	50	42	9	12	63	8	0.7	<0.1	<0.1
Dry Weather	8	13,000	400	900	290	170	133	28	37	198	27	2.2	<0.1	<0.1
San Juan Cr.														
Storm	0.2	<100	<100	<100	<50	<50	1	<1	<1	1	<1	<0.1	<0.1	<0.1
Dry Weather	2.1	<100	<100	<100	60	50	5	1	<3	8	<1	0.3	<0.1	<0.1
Total														
Storm	167	258,000	13,000	24,500	2,100	1,330	690	218	840	1,750	283	46	10.4	139
Dry Weather	75	16,000	2,200	4,400	2,300	1,510	290	224	250	760	126	20	0.6	130
TOTAL	242	274,000	15,200	28,900	4,400	2,840	980	442	1,090	2,510	409	66	11.0	269

*Combined mass emission rates of soluble and suspended silt fractions

As indicated in Chapter 3, surface runoff is the primary source of beach sand supply, and any flood control or flow regulation measure will have a profound effect on the shoreline processes. At present, approximately 274,000 M tons of suspended silt per year are carried by surface runoff to the coastal waters of southern California. Of this total, 199,000 M tons are from the Santa Clara River. This indicates that the Santa Clara River is the single most important source of suspended silt from surface runoff in southern California, although it discharged less than 11 percent of the total surface runoff flows from the coastal basin. Apparently, the extensive flood control measures have greatly reduced the suspended silt mass emission rates from other major streams, such as the Los Angeles River, San Gabriel River, Coyote Creek, and Santa Ana River.

The data also indicate that approximately 70 percent of the total surface runoff (167×10^6 cu m out of 242×10^6 cu m) can be considered as storm flows and that a great portion of suspended silt (258,000 out of 274,000M tons), total organic carbon (13,000 out of 15,200M tons), chemical oxygen demand (24,500 out of 28,000 M tons),organic nitrogen (840 out of 1,090M tons), nitrate nitrogen (690 out of980 M tons),and phosphate (283 out of 409M tons) are discharged during the storm season. Other constituent mass emission rates--such as those of oil and grease, ammonia nitrogen, and dissolved silica--appear to be contributed in approximately equal amount by the storm flow and dry weather flow.

Chlorinated Hydrocarbons. Figure 4-5 shows, as an example, the chlorinated hydrocarbon concentrations in samples taken from the Los Angeles River during the storm flow period, 22-23 December 1971. There appears to be a correlation between silt concentration and chlorinated hydrocarbon concentrations: Both appear to increase when the storm flow reaches its peak and decrease when the storm flow subsides.

The flow-weighted mean concentrations of total DDT, total PCB, and dieldrin in the selected storm flows are shown in Table 4-24. These data indicate that the total chlorinated hydrocarbon concentration of 3.5 μg/ℓ in the Los Angeles River waters is significantly higher than the concentration of 0.39 to 1.0 μg/ℓ in other storm waters studied. It is also interesting to note that the concentrations of 0.88 μg DDT/ℓ and 2.5 μg PCB/ℓ in the storm waters of the Los Angeles River are greater than the DDT concentrations in the Oxnard, Hyperion, Orange County Sanitation District, and Point Loma wastewater effluents and greater than the PCB concentrations in the effluent from Oxnard, Hyperion, and Point Loma (see Table 4-6).

Assuming the chlorinated hydrocarbon concentrations shown in Table 4-24 can be used to estimate concentrations in other storm watersthat were not studied and in dry weather flows, the mass emission rates of chlorinated hydrocarbons carried by surface runoff have been estimated and are reported in Table 4-25. These data indicate that approximately 120 kg DDT, 250 kg PCB, and 400 kg total chlorinated hydrocarbons were carried by surface runoff to the coastal waters of southern California in 1971-72. These mass emission rates amount to roughly 1 percent of those from municipal wastewater discharges (see Table 4-9).

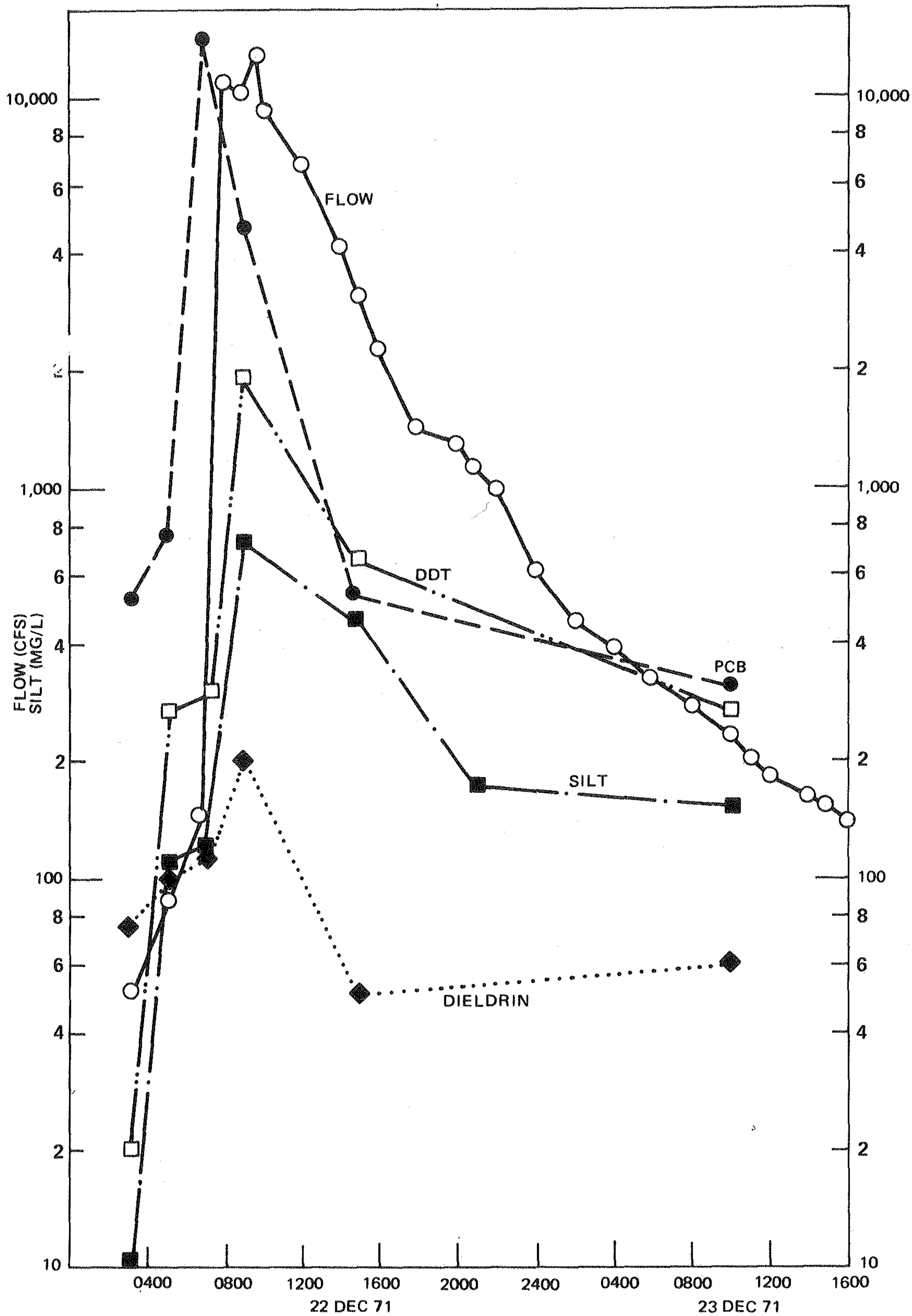

Figure 4-5. Concentrations of Chlorinated Hydrocarbons in Los Angeles River Stormwaters, 22-23 December 1971.

Table 4-24

AVERAGE CONCENTRATION OF CHLORINATED HYDROCARBONS (μG/ℓ) IN STORM WATERS, 1971-72*

Stream	Volume** (10^6 cu m)	Total DDT	Total PCB	Dieldrin	Total Identified Chlorinated Hydrocarbons
R1 Santa Clara River	22.7	0.15	0.22	0.016	0.39
R2 Ballona Creek	4.1	0.43	0.36	0.21	1.0
R3 Los Angeles River	9.7	0.88	2.5	0.13	3.5
R4 Santa Ana River	1.8	0.12	0.24	0.053	0.41

*Flow-weighted mean.
**Accumulated storm flow from which samples were obtained for chlorinated hydrocarbon analyses.

Trace Metals. The flow weighted mean concentrations of 11 trace metals in storm water samples from selected drainage basins are shown in Table 4-26. With the exception of lead, and possibly zinc and silver, samples from the Santa Clara River show significantly higher trace metal concentrations than those from the other rivers. This may be attributable to the relatively high suspended silt concentrations in Santa Clara River waters (see Table 4-21).

An example of the trace metal concentrations observed during the storm flow period of 22-23 December 1971 in the Los Angeles River is presented in Figure 4-6. The changes in trace metal concentrations appear to be similar to the changes in silt concentrations, suggesting that the metals may be associated with the particulate matter and that the bulk of silt and trace metals is transported during periods of peak flow. It was found that, with the exception of nickel and copper, more than 75 percent of the metals are retained with residues when the samples were filtered through 0.45-μ filters. This is consistent with the rough correlation observed between the total metal concentrations and the suspended silt concentrations in the storm water samples.

Based on the average trace metal concentrations shown in Table 4-26, and assuming that these data can be used to estimate concentrations in storm waters not studied and can be extrapolated to estimate concentrations in dry weather flows, the trace metals mass emission rates carried by surface runoff have been estimated and are reported in Table 4-27. These data indicate that, about 26,000 M tons iron, 180 M tons manganese, 100 M tons zinc, 90 M tons lead, 25 M tons chromium, 18 M tons copper and nickel, 5 M tons cobalt, and 1 M ton silver and cadmium were carried by surface runoff to the coastal water in 1971-72. For iron, manganese, lead, and cobalt, the mass emission rates from surface runoff are comparable to or higher than those from municipal wastewater discharges. For the other seven metals examined, the surface runoff contributes less than 10 percent of the annual mass emission rates from municipal wastewater discharges.

Table 4-25

CHLORINATED HYDROCARBON MASS EMISSION RATES (KG/YR) FROM SURFACE RUNOFF (STORM WATER PLUS DRY WEATHER FLOW), 1971-72

Area	Stream	Volume (10^6 cu m/yr)	Total DDT	Total PCB	Dieldrin	Total Chlorinated Hydrocarbons
I	Santa Barbara Group	3.7	0.6	0.8	0.06	1.5
II	Ventura River	14.7	2.2	3.2	0.24	5.6
	Santa Clara River	26	3.9	5.7	0.42	10.0
	Calleguas Creek	3.4	0.5	0.7	0.05	1.3
III	Malibu Creek	3.4	0.5	0.7	0.05	1.3
	Pico Drain	4.8	2.1	1.7	1.0	4.8
	Ballona Creek	42	18.1	15.1	8.8	42
V	Dominguez Channel	10.7	4.6	3.9	2.2	10.7
	Los Angeles River	68	60	170	8.8	239
	San Gabriel River	10.6	9.3	26	1.4	37
	Coyote Creek	31	13.3	11.2	6.5	31
	Santa Ana River	10.4	1.2	2.5	0.6	4.3
VI	San Diego River	10.5	1.3	2.5	0.6	4.4
	San Juan Creek	2.3	0.3	0.6	0.1	1.0
	TOTAL	242	119	246	31	396

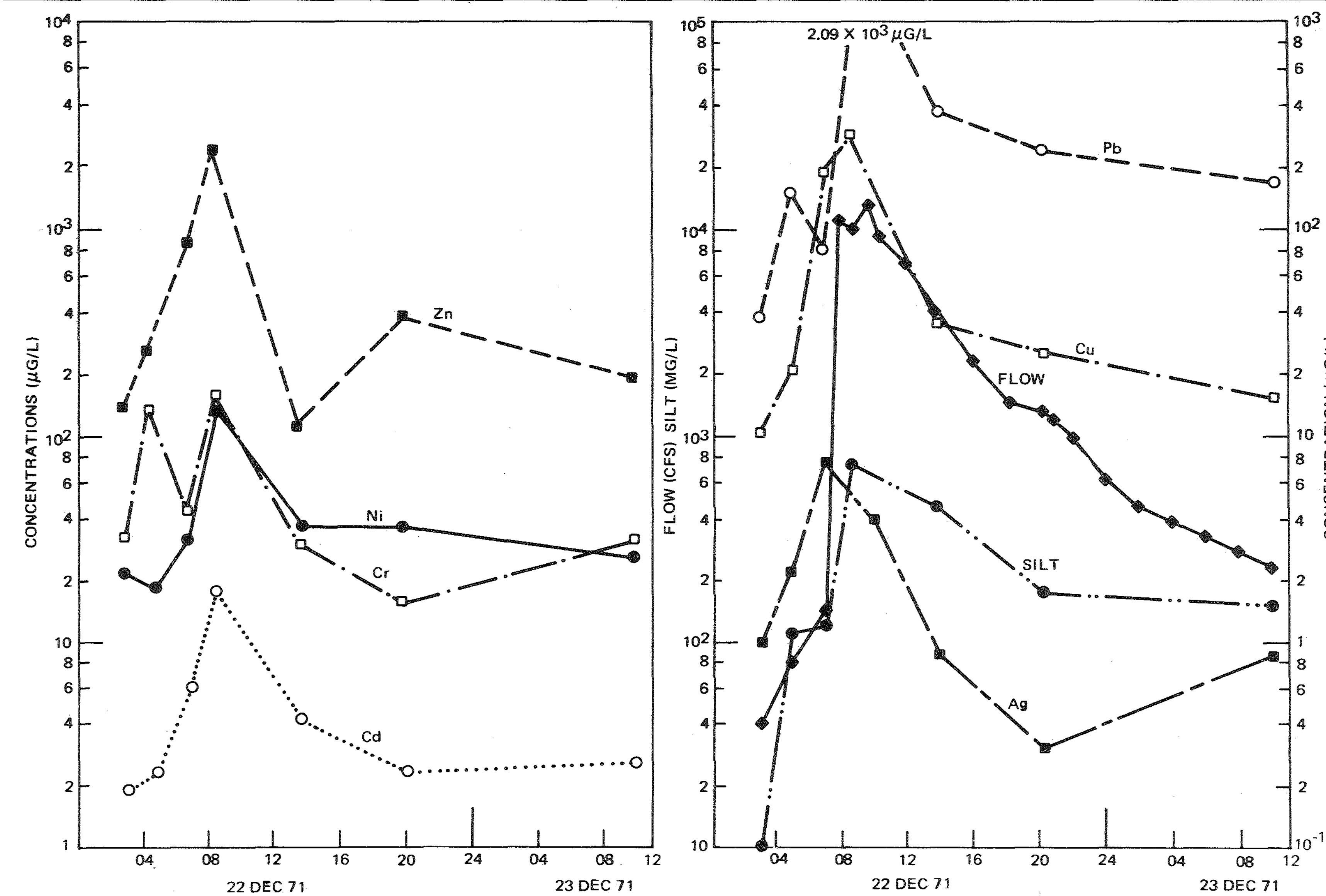

Figure 4-6. Concentrations of Trace Metals in Los Angeles River Stormwaters, 22-23 December 1971.

Table 4-26

AVERAGE CONCENTRATION OF TRACE METALS (μG/L) IN STORM WATERS, 1971-72

Stream	Flow* (10^6 cu m)	Silver	Cadmium	Cobalt	Chromium	Copper	Mercury	Nickel	Lead	Zinc	Iron	Manganese
R1 Santa Clara River	24.4	4.8	11.2	76	251	173	---	220	166	512	262,000	2,400
R2 Ballona Creek	24.9	8.3	2.4	2.9	92	42	---	27	464	410	6,300	140
R3 Los Angeles River	46.8	1.2	3.9	6.8	36	46	0.50	32	436	396	139,000	275
R4 Santa Ana River	1.8	1.7	4.2	26	62	64	0.81**	56	285	320	67,200	1,100

*Accumulated flow for which samples were taken for trace metal analysis.
**For mercury, the accumulated flow was 0.84 x 10^6 cu m.

Table 4-27

TRACE METAL MASS EMISSION RATES (M TONS/YR) IN SURFACE RUNOFF
(STORM WATER PLUS DRY WEATHER FLOW), 1971-72

Area	Stream	Volume (10^6 cu m/yr)	Silver	Cad-mium	Cobalt	Chro-mium	Copper	Mer-cury	Nickel	Lead	Zinc	Iron	Manga-nese
I	Santa Barbara Gp.	3.7	0.02	0.04	0.28	0.9	0.6	-	0.8	0.6	1.9	970	9.0
II	Ventura R.	14.7	0.07	0.16	1.1	3.7	2.5	-	3.2	2.4	7.5	3,900	35
	Santa Clara R.	26	0.13	0.29	2.0	6.5	4.5	-	5.7	4.3	13	6,800	62
	Calleguas Cr.	3.4	0.02	0.04	0.26	0.9	0.6	-	0.8	0.6	1.7	890	8.0
III	Malibu Cr.	3.4	0.02	0.04	0.26	0.9	0.6	-	0.8	0.6	1.7	890	8.0
	Pico Drain	4.8	0.04	0.01	0.01	0.4	0.2	-	0.1	2.2	2.0	30	1.0
	Ballona Cr.	42	0.35	0.10	0.12	3.9	1.8	-	1.1	20	17	270	6.0
V	Dominguez Ch.	10.7	0.09	0.03	0.03	1.0	0.4	-	0.3	5.0	4.4	67	2.0
	Los Angeles R.	68	0.08	0.27	0.46	2.4	3.1	0.034	2.2	30	27	9,400	19
	San Gabriel R.	10.6	0.01	0.04	0.07	0.4	0.5	0.005	0.3	4.6	4.2	1,470	3.0
	Coyote Cr.	31	0.26	0.07	0.09	2.9	1.3	-	0.8	14	13	200	4.0
	Santa Ana R.	10.4	0.02	0.04	0.27	0.6	0.7	0.008	0.6	3.0	3.3	700	11
VI	San Diego R.	10.5	0.02	0.04	0.27	0.7	0.7	0.009	0.6	3.0	3.4	710	12
	San Juan Cr.	2.3	0	0.01	0.06	0.1	0.2	0.002	0.1	0.7	0.7	150	3.0
	TOTAL	242	1.1	1.2	5.3	25.3	17.7	0.06	17.4	90	101	26,000	183

As indicated previously, the Santa Clara River water is high in the trace metals analyzed, except lead, zinc, and silver. The high mass emission rates for lead in rivers in the Los Angeles-San Gabriel River drainage basin probably reflects washout of airborne lead from the catchment basins. However, the high zinc mass emission rate from the Los Angeles-San Gabriel River basin may be a reflection of the relatively high volumetric flow rates in the Los Angeles-San Gabriel Rivers as compared to the other rivers during the year 1971-72.

4.2.4 Summary of Discrete Sources

Table 4-28 (Parts A and B) summarizes the estimated constituent mass emission rates from discrete sources along the southern California coast by area. This summary indicates that, at present, the significant constituent mass emission rates from all discrete sources to the southern California Bight are as follows:

Constituent	Mass Emission Rate (M tons/yr)
Total suspended solids	294,000
Volatile suspended solids	179,000
Total suspended silt	274,000
Chemical oxygen demand	782,000
Oil and grease	72,000
Total nitrogen	98,000
Ammonia nitrogen	69,000
Phosphate phosphorus	14,000
Phenols	2,000
Total DDT	19
Total PCB	10
Zinc	1,800
Chromium	670
Copper	590
Nickel	330
Lead	300
Cadmium	55
Mercury	3

Table 4-28
Part A

SUMMARY OF GENERAL CONSTITUENT MASS EMISSION RATES (M tons/yr)
FROM DISCRETE SOURCES, 1971-72

Area	Flow* (10^6cu m/yr)	Silt	Total Suspended Solids	Volatile Suspended Solids	5-day Biol. Oxy. Demand	Chemical Oxygen Demand	Oil and Grease	Dissolved Silica (SiO_2)	Nitrate Nitrogen	Ammonia Nitrogen	Organic Nitrogen	Total Nitrogen	Phosphate Phosphorus	Detergent (MBAS)	Cyanide (CN)	Phenols	Heat* (10^9 kwh/yr)
I. Muni. wastewaters	22		2,000	1,500	3,000	7,000	1,000	1,000	4	400	150	560	183	97	2	2	
Surface runoff	3.7	200				<1,000	<100	100	24	34	15	73	14	0.5	<0.1	<0.1	
Indust. waste	5.2		300			12,000	<100										
II. Muni. wastewaters	28		2,000	1,500	3,000	8,000	1,000	1,000	38	550	190	780	350	69	2	2	
Surface runoff	44	200,000				6,000	100	700	166	166	200	530	132	5	2	1	
Indust. waste	1.7		100			5,000	<100										17
III. Muni. wastewaters	470		61,000	37,000	59,000	154,000	14,000	12,000	290	8,100	6,400	14,800	3,200	2,200	117	46	
Surface runoff	50	12,000				8,000	1,400	800	210	102	260	570	64	17	5	3	
Indust. waste	100		2,800			18,000	1,300										23
IV. Muni. wastewaters	510		169,000	106,000	160,000	311,000	35,000	9,000	112	41,000	13,700	55,000	7,300	3,500	58	1,620	
V. Muni. wastewaters	196		28,000	21,000	36,000	113,000	7,400	5,500	48	5,900	2,600	8,600	1,180	970	16	39	
Surface runoff	131	45,000				14,000	2,400	900	400	100	560	1,070	165	40	4	265	
Indust. waste	144		12,800		6,000	43,000	800		9,500	9,500		10,000				43	38
VI. Muni. wastewaters	24		2,000	1,000	2,000	5,000	800	1,000	4	350	123	590	240	95	2	3	
Surface runoff	13	17,000				1,000	500	300	180	37	52	270	35	3	0.1	0.1	9
VII. Muni. wastewaters	132		14,000	11,000	28,000	77,000	5,800	3,500	33	3,100	1,700	5,100	810	690	13	16	7
All Area																	
Muni. wastewaters	1,380		278,000	179,000	291,000	675,000	65,000	33,000	530	59,400	24,800	84,500	13,300	7,600	210	1,730	
Surface runoff	242	274,000				29,000	4,400	2,800	980	440	1,090	2,510	410	66	11	269	
Indust. waste	251		16,000		6,000	78,000	2,200			9,500		10,000				43	94

*Cooling water flow not included in industrial waste flow rate.

Table 4-28
Part B

SUMMARY OF TRACE METAL AND CHLORINATED HYDROCARBON MASS EMISSION RATES (M tons/yr)
FROM DISCRETE SOURCES, 1971-72

			Trace Metals										Chlorinated Hydrocarbons			
Area	Flow (10^6 cu m/yr)	Silver	Cadmium	Cobalt	Chromium	Copper	Mercury	Nickel	Lead	Zinc	Iron	Manganese	Total DDT	Total PCB	Dieldrin	Total CHC
I. Muni. wastewaters	22															
Surface runoff	3.7	0.02	0.04	0.3	0.9	0.6		0.8	0.6	2	970	9	0.001	0.001	0.0001	0.002
II. Muni. wastewaters	28		0.3		1	1		1		4	8	2	0.002	0.003		0.005
Surface runoff	44	0.2	0.5	3.4	11	8		10	7	22	11,600	105	0.007	0.010	0.0007	0.018
III. Muni. wastewaters	470	1.1	25	3	148	190	2.1	147	31	330	660	16	0.088	0.57		0.86
Surface runoff	50	0.4	0.2	0.4	5	3		1	22	21	1,190	15	0.021	0.018	0.0098	0.049
IV. Muni. wastewaters	510	10.2	15.4		440	290	0.5	123	128	1,220	5,100	67	19	6		25
V. Muni. wastewaters	196	3.6	10.9		41	66	0.2	34	40	101	230	17	0.075	3		3.1
Surface runoff	131	0.5	0.4	0.9	7.3	6.0	0.05	4	57	52	11,900	39	0.088	0.214	0.02	0.322
VI. Muni. wastewaters	24															
Surface runoff	13	0.02	0.1	0.3	0.8	0.9	0.01	0.7	3	4	700	15	0.002	0.003	0.0007	0.006
VII. Muni. waste waters	132		2.5		19	20	0.1	8	12	22			0.022	0.11		0.14
TOTAL																
Muni. wastewaters	1,380	15	54	3.0	649	567	2.9	313	211	1,680	6,000	102	19.2	9.7		29
Surface runoff	242	1.1	1.2	5.3	25	18	0.06	17	90	101	26,000	183	0.119	0.246	0.031	0.396

Available data for discrete industrial wastes are too few to compare with those for municipal wastewater and surface runoff. Examination of Table 4-28 permits the following comparison between the municipal wastewater and surface runoff constituent mass emission rates.

A. Except for suspended solids, nitrate nitrogen, iron, manganese, lead, and cobalt, surface runoff associated constituent mass emission rates amount to less than 10 percent of those contributed from municipal wastewater discharges.

B. Approximately 278,000 M tons/yr of suspended solids are discharged from municipal wastewater discharges. This is approximately equivalent to the suspended silt mass emission rates of 274,000 M tons from surface runoff during the year 1971-72, although the natures of these two types of solids are considerably different.

C. Four parameters, namely, nitrate nitrogen, iron, manganese, and cobalt, are estimated to have higher mass emission rates in surface runoff than in municipal wastewaters. For iron, the mass emission rates are 26,000 M tons/yr from surface runoff and 6,000 M tons/yr from municipal wastewaters; for manganese, the values are 180 M tons/yr and 102 M tons/yr; and for cobalt, 5 and 3 M tons/yr, respectively. The high mass emission rates for these three metals from surface runoff may indicate that they originate from virgin soils. The nitrate nitrogen mass emission rate from surface runoff (980 M tons/yr) is markedly greater than that from the municipal wastewaters (530 M tons/yr); however, the total nitrogen mass emission rates are 85,400 M tons/yr from municipal wastewaters and 2,500 M tons/yr from surface runoff. Thus the significance of high nitrate mass emission rates from surface runoff should not be overemphasized.

D. The only other trace metal contributed significantly by surface runoff is lead. The mass emission rates of lead are 210 M tons/yr from municipal wastewaters and 90 M tons/yr from surface runoff. Of the latter, approximately 90 percent (or 80 M tons/yr) are contributed by surface runoff from rivers in the Los Angeles-San Gabriel and Santa Ana Basins. This may reflect the washing out of lead residue in automobile exhaust from the drainage basin.

E. The chlorinated hydrocarbon mass emission rates from surface runoff (0.12 M tons DDT/yr and 0.25 M tons PCB/yr) amount to about 1 to 3 percent of those from municipal wastewaters. These values are significantly lower than what would have been expected. This may be attributed to the low surface runoff for the year 1971-72. However, the exact reason can not be fully explained at this time.

4.3 DIFFUSE SOURCES

In addition to the discrete or point sources of constituents discussed in the previous section, there are a number of potentially significant materials entering the Bight from widely distributed sources, which are therefore, much more difficult to quantitate. Four such sources are vessel antifouling paint and fuel consumption, ocean dumping, airborne inputs, and

advective transport by the California Current. Although these source categories have not been investigated thoroughly by SCCWRP, preliminary analyses were conducted to provide a rough estimate of the possible importance of these sources and thereby to assist in establishing priorities for future studies. Thus, the data on inputs from diffused sources are order-of-magnitude estimates only and are presented here primarily to provide guidance for studies.

4.3.1 Vessel Body Protective Measures and Fuel Consumption

The Southern California Bight harbors a large number of recreational, commercial, and naval vessels. Losses of bottom antifouling paint and anticorrosion anodes and spent fuel residues may represent important sources of trace pollutants to the marine environment.

To investigate the magnitude of these potential sources of pollutants, a preliminary survey of recreational vessel activity was undertaken. The two major objectives of this investigation were to inventory the recreational craft in each of the 14 major marinas between Santa Barbara and San Diego, and to obtain preliminary information on the consumption (and presumed release to the Bight) of certain materials such as antifouling paint, sacrificial zinc anodes, and leaded fuel in one of the largest recreational vessel facilities, Marina del Rey in Los Angeles. Estimates of the quantities of trace constituents such as selected trace metals and PCB used in bottom paints and in spent fuel in Marina del Rey could be extrapolated to estimate annual marina-related input of trace constituents to the Bight. The major marinas and the number of craft presently harbored in each marina are shown in Table 3-8.

Antifouling Paints and Primers

The largest drydock in Marina del Rey, Windward Yacht and Repair, was studied to obtain an estimate of the use of antifouling paints. Of the 5,500 recreation craft in the marina, nearly 1,200 are hauled out and painted annually at this drydock. Fifty to sixty gallons of antifouling paint are applied weekly; the old paint is removed and washed through a storm drain into the marina. Thus, this drydock uses approximately 2,860 gallons of antifouling paint annually, which corresponds to about 2.4 gallons per boat. Based on this analysis, it is estimated that approximately 13,000 gallons of antifouling paint are applied annually to the recreational craft moored in Marina del Rey. Assuming that vessel activity in the marina is typical of recreation craft in the marinas of the Bight, and extrapolating this unit paint consumption, it is estimated that the annual antifouling paint requirement for the 34,850 recreation craft in the Bight area is approximately 84,000 gallons. A gallon of antifouling paint weighs about 8.6 kg, which results in an estimated total annual paint usage rate of approximately 720,000 kg for recreational craft.

In a recent study in San Diego Bay conducted by the San Diego Regional Water Quality Control Board, Barry (1972) estimated that the annual paint usage for commercial and naval vessels at the major shipbuilding and repair facilities in San Diego was approximately 30,000 gallons of antifouling paint (8.6 kg/gal), 23,000 gallons of red lead primer (5.2 kg/gal), and 10,000 gallons of zinc chromate primer (4.1 kg/gal). It is estimated that, at the most, about 10 percent of the paints or coatings removed by sand blasting of commercial and naval vessels is lost to the bay water. The bulk of the sand and coating

residues is disposed of in land fills. (This practice, however, is relatively recent, and harbor sediments may contain large reservoirs of antifouling paint residues.)

Comparable information for other major harbor facilities, such as the Los Angeles-Long Beach Harbor, is not available. If one assumes that San Diego Bay practices are representative of commercial and naval vessels generally, then the annual loss of antifouling paints and primers to the Bight is estimated to be as follows:

Antifouling paint	52,000 kg/yr
Red Lead Primer	24,000 kg/yr
Zinc Primer	8,200 kg/yr

Estimation of the concentrations of trace constituents in antifouling paints and primers is difficult; however, the results from the Marina del Rey survey indicate that antifouling paints typically contain between 35 to 78 percent cuprous oxide (31 to 69 percent as copper). Although the use of mercury compounds in marine paint was banned recently by the EPA, some paints containing about 7 percent mercury phenate and 3 percent yellow oxide of mercury, as well as unspecified concentrations of arsenic and PCB, have been employed in the past and are still being sold.

Based on Barry's report, it is estimated that antifouling paints contain (by weight) up to 67 percent cuprous oxide, 3.4 percent mercury phenate, 1.3 percent mercury oxide, and 1.7 percent phenarsazine chloride (zinc compound). In addition, primers (apparently used mostly on the larger commercial and naval vessels) may contain up to 45 percent zinc, 12 percent chromium (as zinc chromate), and 25 percent lead (red lead primer).

Based upon the limited information available, estimates have been made of the average trace constituent concentrations of antifouling paints and primers (Table 4-29). Using the foregoing estimated concentrations of trace constituents, the annual mass input of such materials from these sources has been estimated and is presented in Table 4-30.

Zinc Anodes

The use of sacrificial anodes to control galvanic corrosion provides another source of trace metals to the Bight. Investigations at Marina del Rey indicate that about 90 percent of the sail and power craft harbored there employ zinc anodes to control galvanic corrosion. It is estimated that each boat uses approximately 4 to 5 kg of zinc per year for this purpose. Thus it is estimated that some 160 M tons of zinc per year are contributed to the Bight from the use of zinc anodes, most of it entering marina harborage areas.

Data furnished by Bunker Hill, Inc. (a major supplier of anode material) indicates that approximately 0.1 M tons per year of cadmium enter the Bight from this source.

Table 4-29

TYPICAL TRACE CONSTITUENT COMPOSITION OF ANTIFOULING PAINTS AND PRIMERS

Type	Trace Constituent	Average Concentration (%)
Antifouling Paint 8.6 lbs/gal	Copper	50
	Mercury	0.5*
	Arsenic	0.2**
	PCB	0.5†
Zinc Chromate Primer 5.2 lbs/gal	Zinc	45
	Chromium	12
Red Lead Primer 4.1 lbs/gal	Lead	25

*Assuming that mercury content of mercury paints is 5% and that mercury paints comprise 10% of total paint usage.
**Assuming that arsenic content of arsenic paints is 2% and that arsenic paints comprise 10% of total paint usage.
†Assuming that PCB content of paints is 5% and that paints containing PCB comprise 10% of total paint usage.

It should be noted that the foregoing estimates do not consider the sacrificial anode contribution from commercial and naval vessels because of the lack of specific information on this source. Hence, the estimates appear to be quite conservative.

Leaded Fuel

Union Oil Company, which operates the only fuel dock at Marina del Rey, reports its annual fuel sales as about 440,000 gallons of low-lead gasoline (containing 0.5 gm Pb/gal) and 110,000 gallons of high octane gasoline (containing 3 gm Pb/gal). Thus, the consumption of these fuels results in the release of about 0.55 M tons of lead per year to the Bight from Marina del Rey fueled craft. If these fuel consumption-lead release data are applied to all recreational craft moored in the marinas of the Southern California Bight, an input of lead to the Bight of approximately 3.5 M tons/yr is obtained.

Trace Material Mass Emission Rates

Table 4-30 presents a summary of the annual mass emission rates for trace materials reaching the Bight from selected sources associated with recreational, commercial, and naval vessel activity. It is recognized that some of the estimated inputs are crude; however, they represent the best information available. Moreover, it should be noted that the estimated vessel-related mercury input of 4 M tons/yr is greater than the total input of mercury from treated municipal wastewater and surface runoff. The estimated vessel related input of PCB (4 M tons/yr) and copper (386 M tons/yr) is about half of the corresponding PCB and copper input to the Bight from municipal wastewater and surface runoff.

Table 4-30

TRACE CONSTITUENT MASS EMISSION RATES (M tons/yr) FROM RECREATIONAL, COMMERCIAL AND NAVAL VESSELS TO THE SOUTHERN CALIFORNIA BIGHT*

Source	Gross Tonnage	Arsenic	Cadmium	Chromium	Copper	Mercury	Lead	Zinc	PCB
Recreational Vessels									
Antifouling Paint	720	1.4	-	-	360	3.6	-	-	3.6
Zinc Anode	160	-	0.1	-	-	-	-	160	-
Fuel	-	-	-	-	-	-	3.5	-	-
Commercial and Naval Vessels**									
Antifouling Paint	52	0.1	-	-	26	0.3	-	-	0.3
Zinc Chromate Primer	8.2	-	-	1	-	-	-	4.1	0.1
Red Lead Primer	24	-	-	-	-	-	6	-	0.1
TOTAL		1.5	0.1	1	386	3.9	9.5	164	4.1

*Excludes ocean dumping contributions.
**No estimates for gross tonnage of zinc anodes and fuel used.

4.3.2 Ocean Dumping

In an investigation of past ocean dumping practices, data on eight major types of wastes dumped from vessels into the Bight were reviewed. These were: (1) refinery wastes, (2) chemical wastes, (3) filter cake, (4) oil drilling wastes, (5) refuse and garbage, (6) radioactive wastes, (7) military explosives, and (8) miscellaneous types of wastes.

Figure 4-7 shows the location within the southern California Bight of both active and inactive ocean dumping sites. Fourteen ocean dumping sites, which were approved either by the U.S. Corps of Engineers or by the California Regional Water Quality Control Boards, have been designated for waste dumping purposes since 1931. At present, dumping of various types of wastes at nine designated sites is prohibited by regulatory agencies, and disposal of military explosives at two other sites is still under a moratorium issued by the Department of Navy in 1971.

Tonnage Dumped

Table 4-31 lists the major dumping sites, the total tonnage dumped during various periods and the estimated present annual dumping rate for each type of waste.

Refinery Wastes. It is estimated that approximately 480,000 M tons of petroleum refining wastes were dumped between 1946 and 1971, corresponding to an average of about 18,000 M tons/yr. However, the reported annual dumping rate

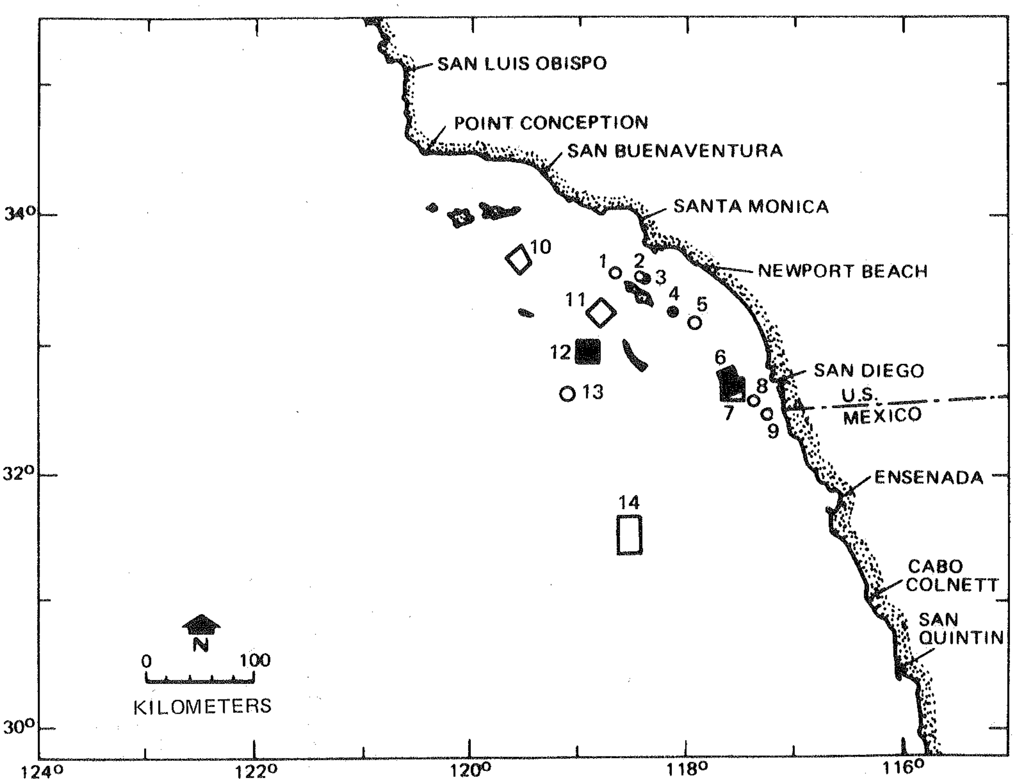

Figure 4-7. Designated Ocean Dumping Sites in the Southern California Bight (Shaded Sites are Active).

Table 4-31

SUMMARY OF WASTES DUMPED INTO THE SOUTHERN CALIFORNIA BIGHT, 1931-71

Type of Wastes	Major Dumping Sites*	Record Period	Estimated Total During Record Period (M tons)	Estimated Present Tonnage** (M tons/yr)
Refinery Wastes	3	1946-71	480,000	1,800
Chemical Wastes	2, 3	1965-71	2,800	470
	4	1947-71	5,700	210
	7	1960-67	140	-
Filter Cake	8	1969-70	320,000	-
Oil Drilling Wastes	2	1966-70	3,000,000	-
Refuse and Garbage	4	1931-71	47,000	1,200
	5	1944-70	7,400	-
	9	1947-68	90,000	-
Radioactive Wastes	10, 14	1946-68		-
Military Explosives	6, 11, 12	1945-70		-
Miscellaneous Wastes				250

*See Figure 4-7 for locations of dumping sites.
**Wastes for which no present tonnage estimate is given have been discontinued (military explosives by moratorium).

has dropped to about 1,800 M tons/yr since 1968. The principal dumping site for refinery waste is Site 3 (Figure 4-7) in the San Pedro Channel. Data on the specific composition of these refinery wastes are unavailable, however, they are believed to include spent caustic solutions, acid sludges, spent catalysts, petrochemical wastes, and chemical cleaning wastes. These materials surely must include phenols, trace metals, trace organics, and other potentially toxic substances, but quantitative information is not available.

Chemical Wastes. This type of industrial waste, which is dumped either in sealed containers or in bulk by tank barge, includes waste material from aerospace, heat-treating, plating, film processing, chemical processing, and electronic manufacturing firms and from industrial, medical, and academic laboratories, as well as from military and other sources. Most of the recorded bulk tonnage (210 M tons/yr since 1947) is discharged approximately 15 km east of Catalina Island (Site 4, Figure 4-7). Most of the containerized chemical wastes (470 M tons/yr since 1965) have been dumped at Sites 2 and 3 in San Pedro Channel. Between 1960 and 1967, approximately 140 M tons of chemical waste (sodium cyanide) were dumped in bulk 32 km west of Point Loma (Site 7). However, such dumping at Site 7 has been prohibited since 1967.

Filter Cake and Oil Drilling Wastes. Two types of relatively inert material, filter cake (70 percent fixed, 30 percent volatile solids) and oil drilling wastes (similar to dredging spoils) were dumped in the Bight in large amounts for a short period. Filter cake, consisting of about 50 percent perlite and 50 percent cellulose, is used in the extraction of algin from kelp, and approximately 320,000 tons were dumped about 15 km west of Point Loma (Site 8, Figure 4-7) during 1969 and 1970. More than 3 x 10^6 M tons of oil drilling mud and cuttings were dumped in the San Pedro Channel (Site 2) between 1966 and 1970. These two types of dumpings have been prohibited and discontinued since 1970.

Refuse and Garbage. Until recently, naval vessel refuse and garbage has been dumped into the Bight. Between 1947 and 1968, an estimated total of 90,000 M tons were dumped in the vicinity of the Coronado Islands (Site 9), and between 1944 and 1970 an estimated total of 7,400 M tons were dumped 40 km southeast of Catalina Island (Site 5). However, approximately 1,200M tons/yr of refuse and garbage from commercial vessels is still being dumped about 16 km east of Catalina Island (Site 4).

Other Types of Waste. Between 1945 and 1970, undetermined quantities of unspecified military explosives and toxic chemical ammunition have been dumped in several designated dumping sites in the Bight. Low-level radioactive wastes also have been dumped in the authorized locations between 1946 and 1968. Dumping of radioactive wastes has been terminated since its prohibition in 1968.

Based on information furnished by H-10 Water Taxi Company, Los Angeles, approximately 250 M tons/yr of undefined "miscellaneous wastes" are dumped in the Southern California Bight.

Trace Constituent Mass Emission Rates

Although there has been an attempt to quantify the distribution and amount of wastes in selected types dumped into the Bight, virtually nothing has been found in the public record regarding the concentration of specific pollutants

in the waste dumped. Thus, for pollutants such as trace metals and chlorinated hydrocarbons, estimation of mass emission rates from this source is very difficult. Nevertheless, order-of-magnitude estimates of the probable upper limits of such mass emission rates for selected trace metals and chlorinated hydrocarbons have been attempted. It appears that only refinery and chemical wastes and some undefined "miscellaneous" wastes constitute any significant source of trace pollutants to the Bight. As shown in Table 4-31, it is estimated that approximately 1,800 M tons/yr of refinery waste and 1,000 M tons/yr of chemical and miscellaneous wastes are being dumped into the Bight off Los Angeles and San Diego in 1971. It seems reasonable to assume that, on the average, these wastes would not contain more than 0.5 to 1 percent (by weight) of any one of the trace constituents being investigated by SCCWRP, with the exception of iron and zinc. It is likely that these wastes might contain more than 2 percent zinc and 10 percent iron. Owing to the value of mercury and silver, upper limits for their average concentrations are assumed to be an order-of-magnitude lower (0.05 percent). Based on these extremely rough assumptions, upper limit estimates of present annual trace constituent mass emission rates are presented in Table 4-32.

4.3.3 Aerial Fallout

Limited data are available on aerial fallout rates of trace constituents into the Bight. This source is difficult to quantitate for several reasons, including the high horizontal velocity compared to the vertical velocity of airborne particles, the diffuse nature of the source, the relatively high constituent gradients that may exist near the densely-populated areas, and the large area of the Bight.

Table 4-32
UPPER-LIMIT ESTIMATES OF TRACE CONSTITUENT MASS EMISSION RATES TO THE BIGHT FROM OCEAN DUMPING

Constituent	Maximum Concentration (% by Wt)	Est. Max. Mass Emission Rate* (M tons/yr)
Silver	0.05	1.5
Cadmium	0.5	14
Cobalt	0.5	14
Chromium	1	28
Copper	1	28
Mercury	0.05	1.5
Nickel	1	28
Lead	1	28
Zinc	2	56
Iron	10	280
Manganese	1	28
Total DDT	0.5	14
Total PCB	1	28

*Based on estimated 1971 dumping tonnage of 1,800 M tons/yr of refinery wastes and 1,000 M tons/yr of chemical and miscellaneous wastes.

Rainfall Washout

Several recent studies have provided some insight into this subject. Estimates of metal contributions from rain falling directly on the Bight, based on a study of Lazrus et al. (1970), conducted on Catalina Island from September 1966 to January 1967, are shown in Table 4-33. The median metal concentration values were used, and an average annual rainfall rate of 40 cm over a Bight area of 100,000 sq km was assumed. It should be noted that these data do not include the contribution of metals to the Bight from dry fallout.

The results of this rough estimate indicate that the mass emission rates of lead, mercury and manganese from direct rainfall washout on the Bight are significantly higher than those from the discrete sources to the Bight. The mass emission rates of iron and nickel from direct rainfall washout, on the contrary, are much lower than those from the discrete sources to the Bight. For both copper and zinc, approximately equal amounts are contributed from rainfall washout and from discrete sources.

Dry Fallout

It is possible that the contribution of particulate-borne materials to the Bight via dry fallout may exceed those due to direct rainfall washout. For example, Chow and Earl (1970) found that, at La Jolla, California, the fallout rate of lead on dust particles was 24 mg Pb/sq m/yr. Isotopic analysis confirmed that this lead was not of soil origin, but that essentially all of it origniated in the combustion of leaded gasoline. Extrapolation of the La Jolla fallout rates to the entire Bight yields annual lead input rates through dry and west fallout of approximately 2,400 and 1,000 M tons, respectively. It is interesting to note that the latter value is about the same as that obtained by extrapolating the Catalina Island rainfall data.

Chow and Earl reported that, in 1968, approximately 23,000 M tons of lead were burned in gasoline in California. It is probable that at least half of this consumption occurred in southern California. Thus, approximately 10,000 M tons of lead are released annually to the atmosphere in this area. As much as one-third of this amount may fall directly into the coastal waters, depending upon the degree to which fallout rates at La Jolla and Catalina Island are representative of fallout to the entire Bight.

Table 4-33
TRACE METAL MASS EMISSION RATES FROM DIRECT RAINFALL ON THE SOUTHERN CALIFORNIA BIGHT

Metal	Median Concentration in Rainwater (μg/ℓ)	Mass Emission Rate (M tons/yr)
Copper	10	400
Mercury	0.2	8
Nickel	1	40
Lead	25	1,000
Zinc	55	2,200
Iron	1	40
Manganese	12	480

Limited data on the relative rates of lead fallout in the southern California coastal region recently have become available. With the assistance of SCCWRP, Rabinowitz (1972) obtained samples of soil and vegetation from coastal and island stations in the Bight, as well as from numerous inland stations. Isotopic analysis of samples of wild oats and lettuce indicated that most of the lead on the water-washed leaves was of atmospheric origin. The distribution of the observed lead in the tops of the wild oats is shown in Figure 4-8. It may be noted from Figure 4-8 that coastal lead concentrations at stations between Oxnard and San Diego are similar to those at inland stations in the Los Angeles Basin. Although the island values are lower by an order of magnitude, these concentrations still are several times above the natural levels (2-3 ppm). These data indicate that there may be a significant input of atmospheric lead and other metals to the waters of the Bight from the densely populated urban regions of southern California. A research program to accurately determine current rates for wet and dry inputs of trace constituents appears to warrant high priority.

McClure[1] recently has obtained data on the aerial inputs of chlorinated hydrocarbons to the Bight. Using aluminum pans coated with mineral oil to catch falling particles, daily collections of dry fallout at La Jolla, California, were made during February 1972. Preliminary results indicate that the fallout rate of total chlorinated hydrocarbons there during this

1. Vance McClure, Institute of Geophysics, University of California at Los Angeles, personal communication.

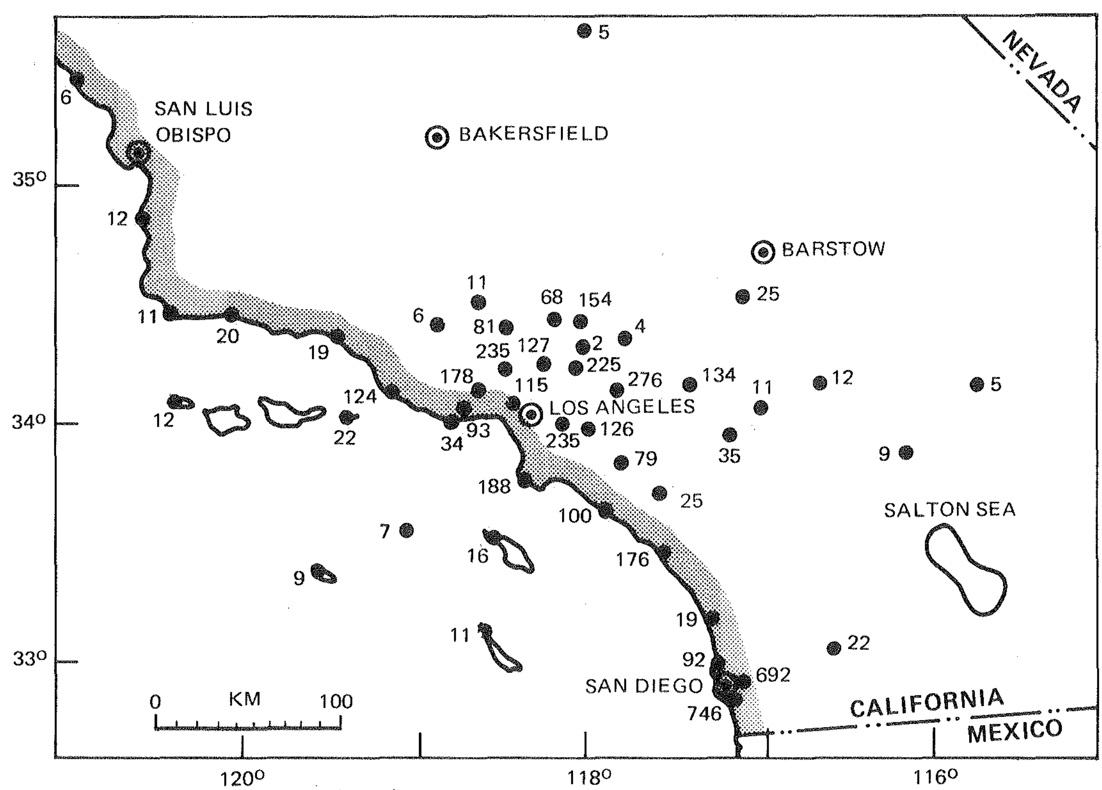

Figure 4-8. Distribution of Lead (ppm) in Wild Oats from Coastal and Island Stations of the Southern California Bight. From Rabinowitz 1972, Fig. 2.

period was the on order of 0.1 μg/sq m-day, with most of the material divided almost equally between DDT and PCB (principal components were p,p'-DDT and Arochlor 1254). Extrapolating these data to the entire Bight the annual dry fallout input of chlorinated hydrocarbons has been estimated to be in the order of 2 M tons of DDT and 2 M tons of PCB. These values are somewhat lower than the respective mass emission rates from municipal wastewaters.

4.3.4 Advective Transport

A potentially significant but largely unevaluated source of trace material transported into the Southern California Bight is the California Current. which carries seawater and associated constituents into the Bight. The complex flow pattern keeps the water in the Bight for some time, during which time various physical, chemical, and biological processes can occur. These processes may result in the retention of significant amount of some constituents from the Bight in the advective flow from the Bight.

Mass Emission Rates

The surface area of the Bight is about 1 X 10^{11} sq m. Assuming the mixed surface layer depth to be 50 m, the volume of the mixed layer of the Bight is 5 X 10^{12} cu m. It has been shown that the mean residence time of water in the mixed layer is on the order of 3 mo. Thus the advective flow rate of the California Current is estimated to be approximately 2 X 10^{13} cu m/yr.

Assuming that the trace material concentrations reported for ocean waters are representative of California Current waters, the mass transport rates of trace materials into the Bight by the California Current are estimated to be as shown in Table 4-34. Although the role of California Current as a source of trace material to the Bight may be different from that of other sources, the estimated mass transport rates of trace material by advective transport far outweigh the mass emission rates from other sources.

Table 4-34

ESTIMATED TRACE MATERIAL MASS TRANSPORT RATES TO THE SOUTHERN CALIFORNIA BIGHT BY THE CALIFORNIA CURRENT

Constituent	Concentration (μg/L)	Mass Transport Rates (M tons/yr)
Silver	0.3	6,000
Cadmium	0.1	2,000
Cobalt	0.4	8,000
Chromium	0.2	4,000
Copper	3	60,000
Mercury	0.03	600
Nickel	7	140,000
Lead	0.3	6,000
Zinc	10	200,000
Iron	3	60,000
Manganese	2	40,000
DDT	0.01	200
PCB	0.01	200

For example, the mass transport rate of mercury by the California Current is estimated to be about 600 M tons/yr, which is about 30 times the input of mercury from all other sources.

Concentration Differences in Inflow and Outflow of California Current

It is possible that the net advective transport of a constituent can be estimated accurately by direct measurement of the constituent concentrations (and thus the change in concentrations) in the inflow and outflow of the Bight with the California current system. To explore the possibility of such a direct determination, the detectable level of trace material in seawater by present analytical technique and the magnitude of concentration difference in inflow and outflow of the current system must be evaluated. For this purpose, the case of mercury will be discussed as an example.

Consider the steady-state mass balance of the upper mixed layer of the southern California Bight. The mercury budget may be written as:

$$[(\text{inflow}) + (\text{discrete source}) + (\text{diffused source})] - [(\text{outflow}) + (\text{sedimentation})] = 0$$

or

$$(\text{inflow}) - (\text{outflow}) = (\text{sedimentation}) - (\text{discrete source}) - (\text{diffused source})$$

The concentration difference between the inflow and outflow of the California Current may be calculated by:

$$\text{concentration difference} = \frac{(\text{inflow}) - (\text{outflow})}{\text{advective flow rate}}$$

Assuming the annual average sedimentation rate throughout the Bight to be approximately 5×10^{-4} m/yr; the average sediment density to be 2.2 M tons dry weight/cu m; and the concentration of mercury in bottom sediment, as reported by Klein and Goldberg (1970) to range from 0.02 to 1.3 ppm (or 2×10^{-8} to 1.3×10^{-6} M tons Hg/ton dry weight), the net rate at which mercury is removed from the mixed layer of the southern California Bight to the bottom sediment can be estimated to range from 2 to 140 M tons/yr.

Weiss (1971) reports that the annual influx of mercury from aerial fallout to the entire global surface is on the order of 25,000 to 440,000 M tons. The corresponding annual influx of mercury from aerial fallout to the southern California Bight thus may be estimated to range from about 5 to 88 M tons. Mercury mass emission rates from all other diffused sources to the Bight has been estimated to be 7 M tons/yr; the discrete source mercury mass emission rate has been estimated to be about 3 M tons/yr for 1971-72.

Based upon these estimates, it can be concluded that the mercury concentration of the California Current water will be essentially constant if the loss of mercury from the mixed layer of sedimentation is higher than the rate of

mercury input from aerial fallout to the Bight by about 10 M tons/yr. There are two conditions that may result in the maximum concentration differences for mercury between the inflow and outflow of the California current system.

a. At the highest estimated aerial fallout rate of 88 M tons Hg/yr and the lowest sedimentation rate of 2 M tons Hg/yr, a maximum increase of 0.0048 μg Hg/L might occur in the outflow of the California Current.

b. At the lowest estimated aerial fallout rate of 5 M tons Hg/yr and the highest sedimentation rate of 143 M tons/yr, a maximum decrease of 0.0064 μg Hg/L might occur in the outflow of the California current.

These calculations indicate that the estimated maximum difference between mercury concentrations in seawater flowing into and out of the Bight is in the order of 0.005 to 0.006 μg/L. This concentration difference, equivalent to approximately 20 percent of the background mercury concentration in ocean waters, is approximately the limit of detection level of present analytical technique for mercury. The problem is, of course, further complicated questions of the chemical state of the mercury and changes it may undergo between inflow and outflow. Thus a major effort would be required to determine the net advective transport of mercury by the California Current and to quantify the effect of advective transport on the mercury balance of the Bight. The same conclusion is true for the other trace materials studied.

4.4 SUMMARY OF TRACE CONSTITUENT MASS EMISSION RATES

Table 4-35 presents a summary of the trace constituent mass emission or transport rates from all sources to the Southern California Bight. Column 6 represents the total constituent mass emission rates from wastewater discharges, surface runoff, vessel protective coatings and spent fuel residues, ocean dumping, and direct rainfall washout to the Bight, whereas Column 7 represents the constituent mass transport rates into the Bight by advective flow of the California Current.

It is of interest to note that, for all trace metals listed, the contribution of advective transport is much larger than that from all other sources combined. In fact except for chromium, lead and iron, DDT and PCB, the contribution from all nonadvective sources is less than 4 percent (ranging from 0.3 percent for silver and nickel to 3.5 percent for cadmium) of the advective transport. However, the nonadvective contribution in terms of the advective transport rate was 54 percent for iron, 22 percent for lead, 18 percent for chromium, 22.5 percent for DDT, and 22 percent for PCB.

With reference to the relative contribution of wastewater discharges as compared to ther nonadvective sources, the contribution from wastewater discharges is the major source for all trace constituents except cobalt, mercury, iron, and possibly DDT and PCB. Surface runoff contributions of cobalt, iron, and manganese exceeded that of wastewater discharges.

The contribution of wastewater discharges in terms of the total of all discrete and diffuse sources (including advective transport) to the Bight

Table 4-35
ESTIMATED TRACE CONSTITUENT
MASS EMISSION RATES (M TONS/YR) FOR
ALL SOURCES TO THE SOUTHERN CALIFORNIA BIGHT, 1971

Constituent	1 Wastewater Discharge	2 Surface Runoff	3 Vessel Coating*	4 Ocean Dumping	5 Rainfall on Bight	6 Sum of Col. 1 through 5	7 Advective Transport**	8 Col. 6 / Col. 7 (%)	9 Total Sum of Col. 6 and 7	10 Col. 1 / Col. 9 (%)
Silver	15	1		1.5		18	6,000	0.3	6,020	0.3
Cadmium	54	1	0.1	14		69	2,000	3.5	2,070	2.6
Cobalt	3	5		14		22	8,000	0.3	8,020	0.04
Chromium	649	25	1	28		703	4,000	17.5	4,700	13.8
Copper	567	18	386	28	400	1,399	60,000	2.3	61,400	0.9
Mercury	3	0.1	4	1.5	8	17	600	2.8	617	0.5
Nickel	313	17		28	40	398	140,000	0.3	140,400	0.2
Lead	211	90	10	28	1000	1,339	6,000	22.4	7,340	2.9
Zinc	1680	101	164	56	2200	4,201	200,000	2.1	204,200	0.8
Iron	6000	26,000		280	40	32,320	60,000	53.8	92,300	6.5
Manganese	102	183		28	480	793	40,000	2.0	40,800	0.3
Total DDT	19	0.1		14	2†	45	200	22.5	245	7.8
Total PCB	10	0.2	4	28	2†	44	200	22.0	244	4.1

*Including vessel antifouling paints, primers, and spent fuel residues.
**Estimated mass transport rates of California current.
†Estimated influx of dry fallout.

was less than 1 percent for silver, cobalt, copper, mercury, nickel, zinc, and manganese. Of particular interest is the fact that wastewater discharges contribute about 14 percent of total copper, 6.5 percent of total iron, 2.9 percent of the total lead, and 2.6 percent of the total cadmium.

As shown in Table 4-35,wastewater discharges contribute 8 percent of the total DDT and 4 percent of the total PCB mass emission rates to the Bight. The data suggest ocean dumping to be another significant nonadvective source of DDT and PCB to the Bight.

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Chapter 5

PHYSICAL AND CHEMICAL CHARACTERISTICS AND PROCESSES

5.1 INTRODUCTION

All of the biological processes with which this project is most concerned occur within the context of the physical and chemical dynamic processes taking place within the southern California coastal waters. Although the physical, chemical, and biological realms are complexly interrelated, there is value in considering separately the general physical and chemical characteristics of the waters and sediments of the Bight, the major variations of these characteristics, and the nature of the currents that are a major route for the transport of both organisms and constituents.

The southern California coastal waters have been studied, over many years, by waste discharging agencies, consulting engineers, marine research laboratories, power companies, and others. Several sources have been used in the preparation of this chapter. The University of Southern California's Allan Hancock Foundation carried out two major studies on the mainland shelf. (The first Allan Hancock Foundation 1965a) was devoted to the oceanography of the shelf within the Bight; another (Allan Hancock Foundation 1965b) was concerned with the fate and effects of wastewater on the marine environment, particularly in San Pedro Bay. The oceanography of Santa Monica Bay has been described by Stevenson, Tibby, and Gorsline (1956). Emery's book (1960) on the sea off Southern California is concerned primarily with marine petroleum resources; however, it contains much data on the general marine characteristics, particularly those of the sediments.

5.2 WATER CHARACTERISTICS

The major water quality characteristics for which data are available throughout the study area are temperature, salinity, density, dissolved oxygen, selected nutrients, and transparency. These parameters do not provide, of course, a complete description of the waters. However, they do serve to describe and differentiate between different water environments that can be associated with identifiable biological regimes.

Because of the concern over the potential effects of trace metals on marine biota, data on the concentrations of metals in seawater in the southern California coastal waters and elsewhere have been reviewed. These data are also summarized in this section.

5.2.1 Temperature, Salinity, and Density

Salinity (a measure of the concentration of dissolved salts in seawater) is relatively constant throughout the open ocean. However, it can vary in coastal waters, primarily because of the inputs of freshwater from land or because of upwelling. Temperatures of the coastal waters also vary significantly more than those of the open ocean. This is due both to the relative shallowness of the water and, to some extent, the mixing of freshwaters from the land or again, because of upwelling. The density of the seawater is of importance in that it is a major factor in the stratification of the waters. The transition between two layers of varying density is often distinct; the upper layer, in which most wind-induced mixing takes place, extends to depths of 10 to 50 m in southern California waters. Another term often used in connection with the stratification or density structure of the coastal waters is "stability." Stability is related to the rate of change of density with depth.[1] Thus, waters in which the density is increasing rapidly with depth are more stable than those in which the density changes with depth are smaller. Work is required to move water vertically through a density gradient.

The water over the shelf reflects the influence of the Mediterranean climate of the area, which is characterized by dry, warm summers and mild, short winters with a modest amount of rainfall. A "cold season" in the water extends from November to May, followed by a warm season from May to November.

Over the mainland shelf, modification of incoming water occurs as the result of mixing, heating and cooling, dilution, evaporation, and biological activity, most of which are more intense and variable close to coastal boundaries.

The water over the mainland shelf is often isohaline below a depth of 15 m. Dilution and evaporation effects are detectable only in the upper 15 m. When the temperature-salinity relationship is variable, it can be presumed that there has been an introduction of one or more different water types into the area.

In its studies, the Allan Hancock Foundation divided the coastal shelf into 12 areas and subareas (Figure 5-1)[2]. Temperatures in each area for four seasons of the year at the surface and at 60 m are shown in Figure 5-2. During the winter months, there is a much smaller difference between temperatures at the surface and at 60 m than during the summer months; this is primarily a result of the relatively strong stratification during the summer, which permits the upper layers to become more heated than those near the bottom. Surface waters in the southern part of the Bight reach their maximum temperatures during the summer months, whereas in the northern portions of the Bight, the maximum temperatures are found during the fall months. Bottom temperatures are highest during the fall and winter.

The distribution of salinity at the surface and at 90 m of depth by season for each of the areas is shown in Figure 5-3; at most times and locations, the salinity was between 33.5 and 33.8 parts per thousand. During the first half of the year, the surface salinity is generally lower than that at 90 m.

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1. Stability, $E = (d\sigma_t/dz) \times 10^{-3}$.
2. These areas are not related to those defined in Chapter 4.

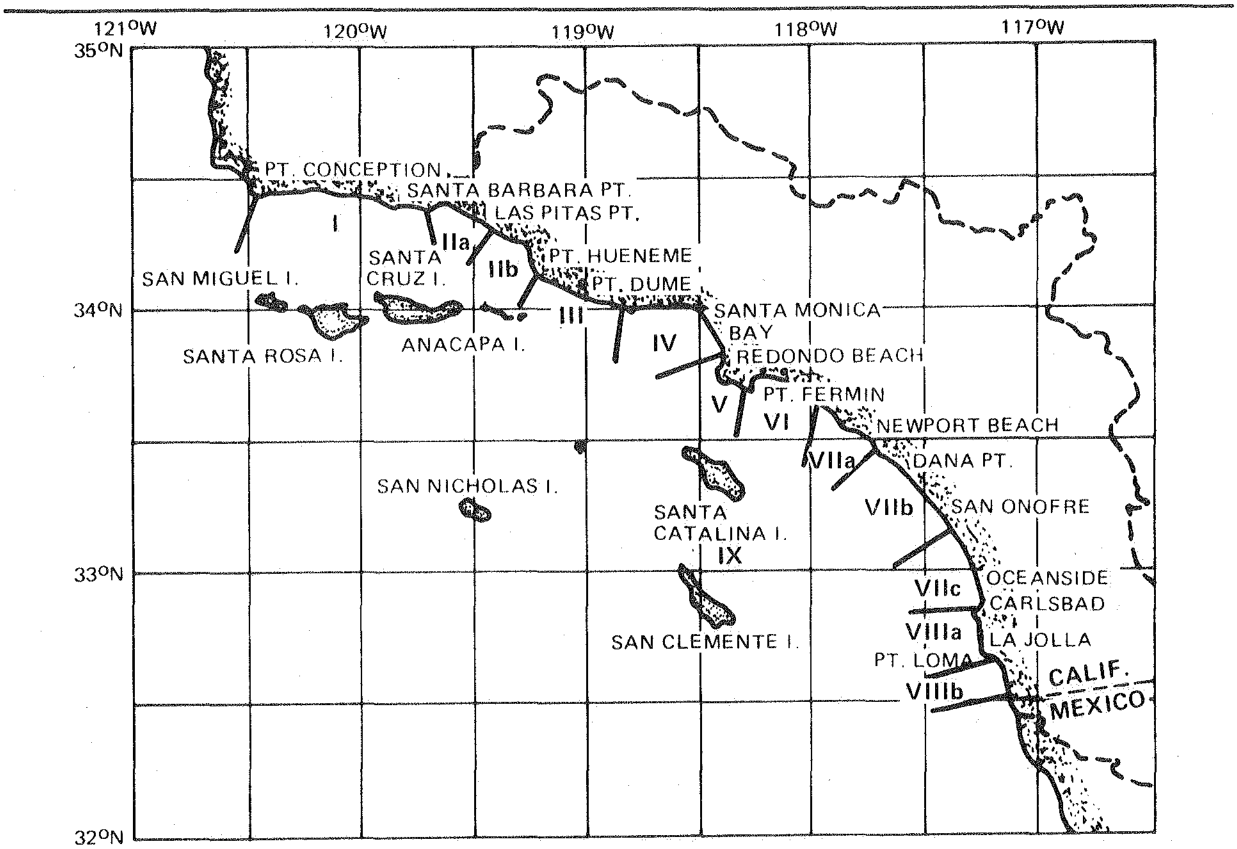

Figure 5-1. Water Quality Areas and Subareas Used in the Allan Hancock Foundation Survey of the Southern California Bight.

However, between July and December, the salinity variations between surface and depth are significantly less, and there is no consistent trend of minimum or maximum salinities at the surface.

In spite of the relatively small differences in salinity between surface and depth, the changes in temperature result in significant differences in density. The mean density variations in the shelf waters are shown in Figure 5-4. At all locations and in each of the four seasons, the density at 60 m depth was greater than that of the surface waters. The difference was greatest during the summer months.

The data above represent conditions found in the coastal waters between 1957 and 1960. In a SCCWRP technical report, Jones (1971) has discussed non-seasonal, 1- to 7-yr variations in temperature that have affected the waters of the Southern California Bight since 1950; other major year-to-year variations were mentioned in Chapter 2.

Long-term salinity variations have not been documented to the same extent as have temperature phenomena. In a 5-year study conducted by the U.S. Navy Undersea Research and Development Center at their tower off Mission Beach, California, more than 1,000 samples were analyzed for salinity. The mean salinity was 33.75 parts per thousand, and the standard deviation of these data was only 0.107 parts per thousand. Thus, about 90 percent of the observed values fell between 33.57 and 33.92 parts per thousand. These values are consistent with those shown in Figure 5-3.

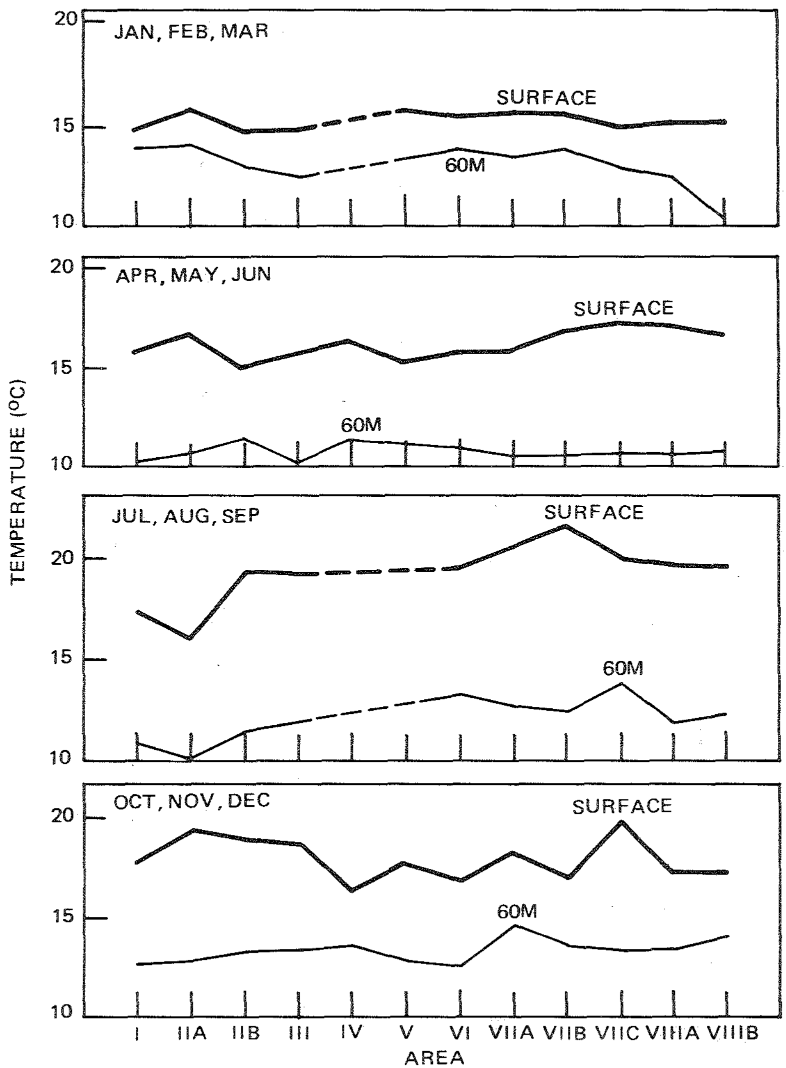

Figure 5-2. Distribution of Mean Temperature by Seasons. From Allan Hancock Foundation 1965a, Fig. 3.4.

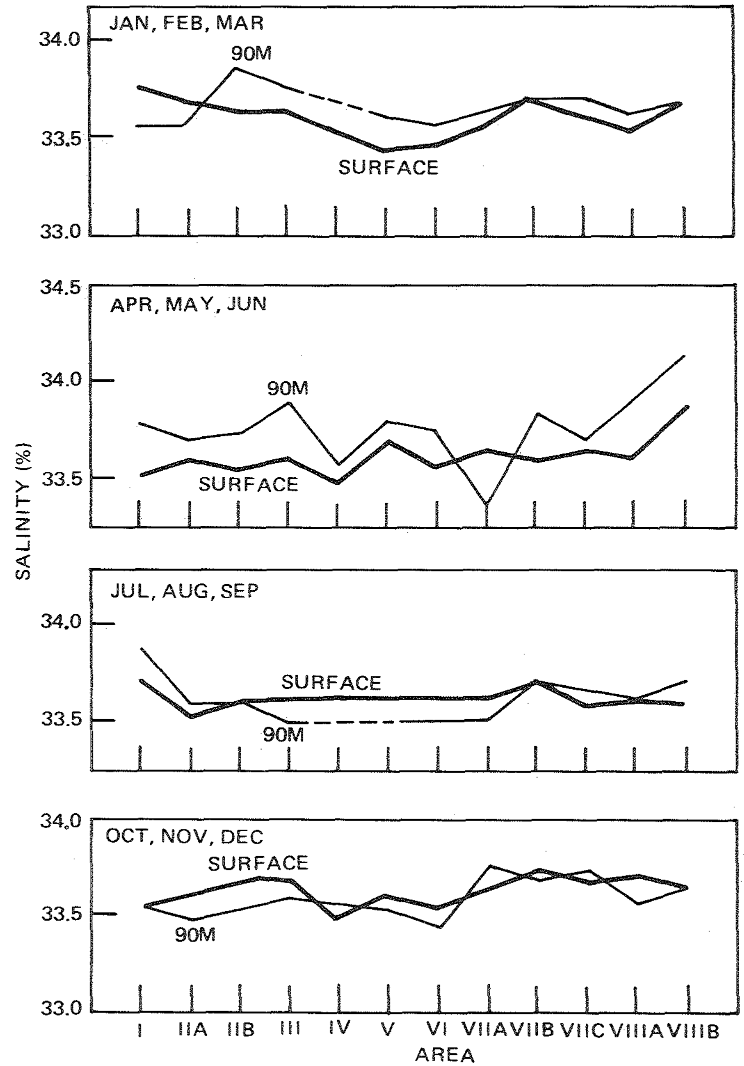

Figure 5-3. Distribution of Mean Salinity by Seasons. From Allan Hancock Foundation 1965a, Fig. 3.4.

Temperature, salinity, and density variations result from many phenomena, including incomplete mixing, cellular motion, turbulence and internal waves. Temperature variations ranging in duration from minutes to several decades have been described.

5.2.2 Dissolved Oxygen

Figure 5-5 summarizes the mean dissolved oxygen concentrations found in the waters of the mainland shelf. Surface concentrations during the spring and summer months were higher than those found during the fall and winter. At the surface, the water was nearly always saturated with dissolved oxygen. Saturation values at times reached 140 percent of saturation. A decrease of dissolved oxygen occurred with depth, but mean values near 60 m did not fall below 4 mg/L, which is about 50 percent of saturation and is adequate for the support of marine life.

The oxygen characteristics described above apply only to the mainland shelf waters. In deeper waters and, particularly, in several of the basins adjacent to the shelf, oxygen values are extremely low. Decomposable organic material is present in such high amounts in the waters and sediments of these nearshore basins that dissolved oxygen values below the sill depths are in the order of 0.3 to 0.4 mg/L, and may fall as low as 0.1 mg/L. The intrusion of this low-oxygen water into nearshore shelf areas and its impact on benthic marine life is discussed in Chapter 7.

5.2.3 Dissolved Inorganic Nitrogen

The common inorganic nitrogenous nutrients are nitrate, nitrite, and ammonia. In natural sea water, nitrate is the dominant of these three forms. Nitrite is usually an intermediate form appearing either as nitrate is reduced to ammonia or in the reverse process, as ammonia is oxidized to nitrate. Ammonia is normally present only in small concentrations in natural waters, although, in nitrogen-deficient waters, it may be the dominant form of the nitrogenous nutrients.

The Hancock Foundation surveys found nitrate concentrations in surface waters ranging from 0.01 to 0.16 mg/L over the study area. Surface concentrations in the spring months were somewhat higher than those found during the fall and winter months. Nitrate concentrations were significantly higher at 90 m depth, where the mean values ranged from approximately 0.2 to 0.4 mg/L.

Moberg and Fleming (1934) found ammonia to be irregularly distributed in concentrations ranging from 0.01 to 0 .04 mg/L. More recent work on ammonia concentrations in nearshore waters is described in Chapter 9, in connection with phytoplankton productivity studies.

Although not strictly an organic substance, urea is a naturally occurring source of nitrogen. It has seldom been included in measurements of nitrogen, but it appears to be important in regions of high biological productivity.

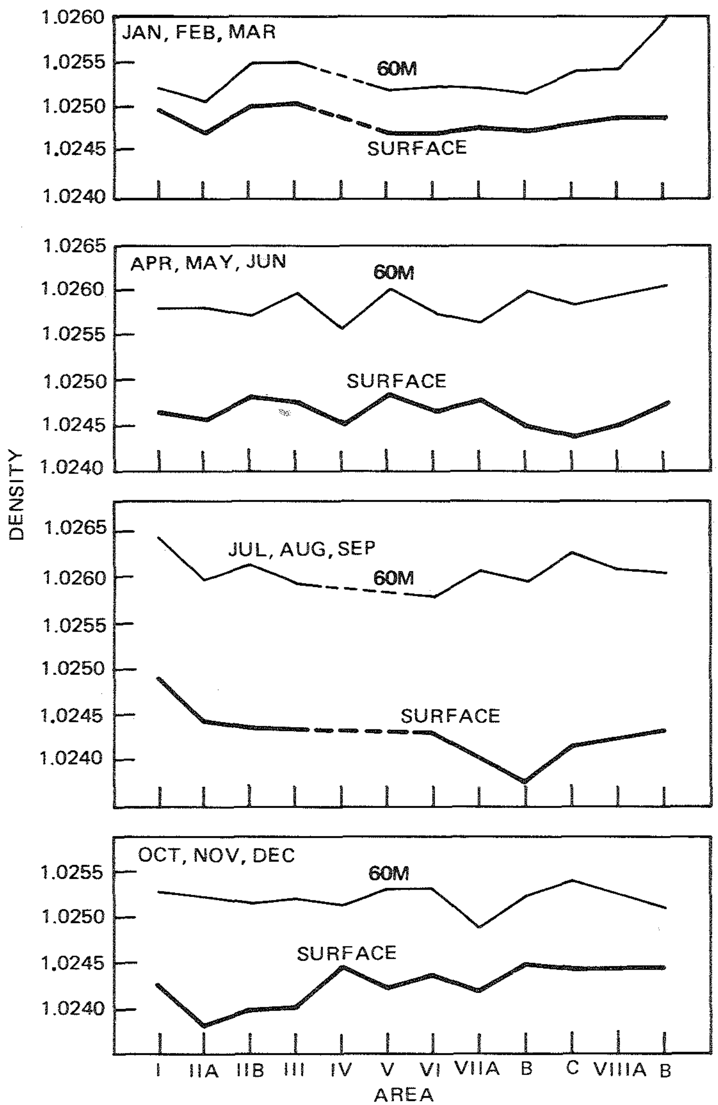

Figure 5-4. Distribution of Mean Density by Seasons. From Allan Hancock Foundation 1965a, Fig. 3.6.

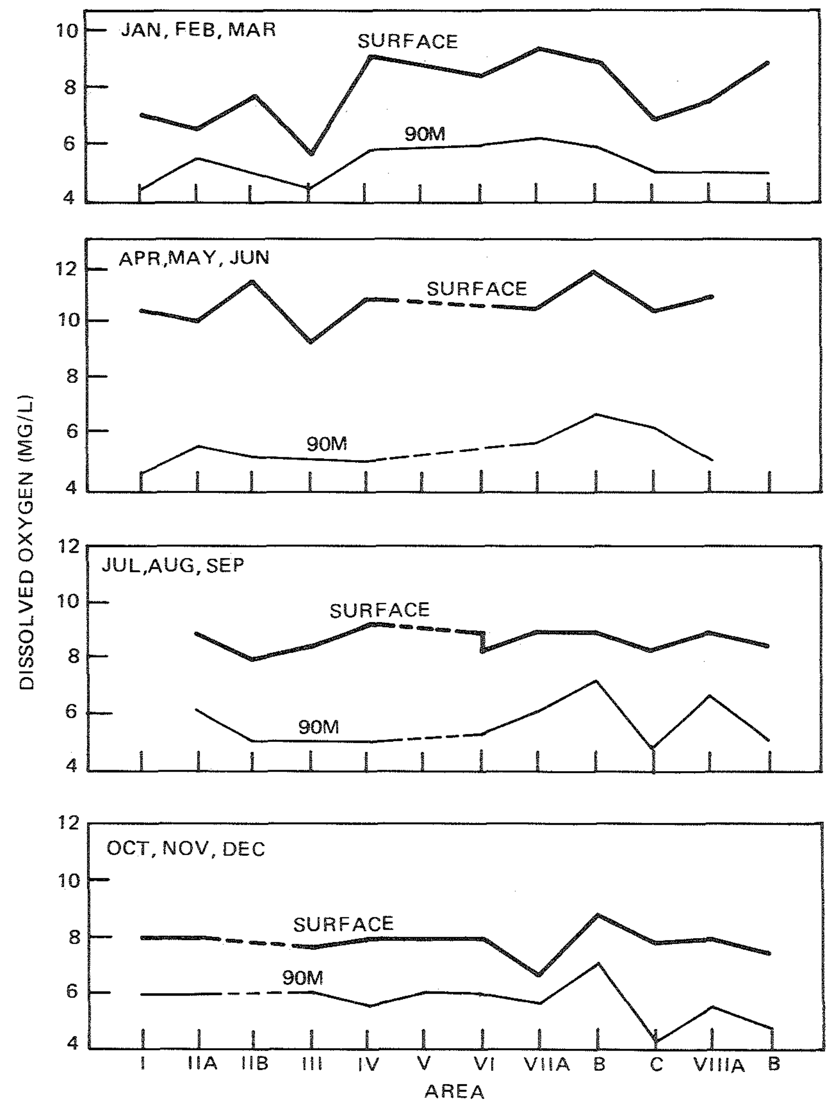

Figure 5-5. Distribution of Mean Dissolved Oxygen by Seasons. From Allan Hancock Foundation 1965a, Fig. 3.9.

5.2.4 Phosphate and Silica

In addition to nitrogen, phosphorous and dissolved silica are considered to be the primary macronutrients required for organic production. Silica is utilized almost exclusively by diatoms. In the open ocean, it has been commonly observed that total nitrogen and total phosphorous are found in a relatively constant ratio of about 15 atoms of nitrogen to 1 atom of phosphorous. This relationship is not nearly so constant in nearshore waters, which are affected by generally higher rates of organic production and subject to influences from land-based nutrient sources.

Mean phosphate and silica concentrations are shown in Figures 5-6 and 5-7. There is a fairly consistent pattern of increasing phosphate and silica concentration with depth. The differences in concentrations between surface waters and waters at 90 m of depth appear to be greatest during the spring months for both constituents.

5.2.5 Trace Metals

Although trace materials such as metals are difficult to measure and are therefore less well known, many are as essential to biological productivity as are the better known macronutrients such as phosphate, nitrate, and silica.[3] Yet these same trace elements, which are essential to a healthy physiological state, are toxic in certain concentrations to some organisms and may also be concentrated and/or transformed to a state toxic to organisms high in the food web. As trace metals are present in waste discharges, it is essential to learn the effects, if any, that they have on local and regional marine waters.

It is difficult to ascertain general concentration levels for trace metals in seawater. The difficulty arises from two sources. First, the seawater concentrations of these constituents are usually near the limit of detection by analytical techniques, and contamination of samples during collection and analysis is common. Secondly, there is usually uncertainty as to the physical/chemical state of the constituent, and analysis is difficult.

The variability resulting from these factors is superimposed on the natural variability of concentrations in the waters. Total concentrations and the state of trace materials in coastal waters can be expected to vary significantly from those in offshore waters. Similarly, concentrations in surface waters and in deep ocean water should differ significantly. Other factors, such as heavy rains, storm runoff in the coastal waters, upwelling of subsurface water, or extensive alterations in plankton population should produce additional differences.

Table 5-1 illustrates the range of values of seawater concentrations of 11 trace metals reported in the literature. As seen in this compilation, order-of-magnitude differences are common. The data presented in Table 5-1 cannot be used to make useful generalizations concerning the levels of trace metals in the southern California waters, except perhaps in the grossest terms. Metals exist in the waters in ionic forms, associated with particulates, organically

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3. Examples of physiologically essential metals are copper, cobalt, zinc, iron, manganese, boron, molybdenum, and selenium.

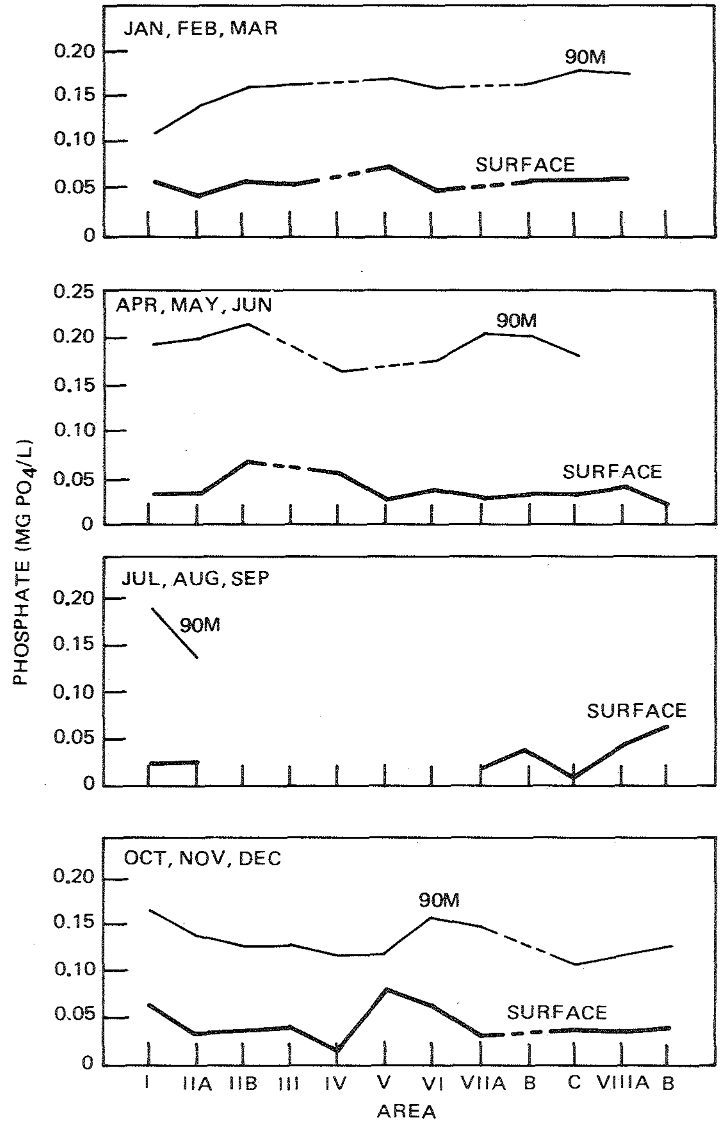


Figure 5-6. Distribution of Mean Phosphate by Seasons. From Allan Hancock Foundation 1965a, Fig. 3.14.

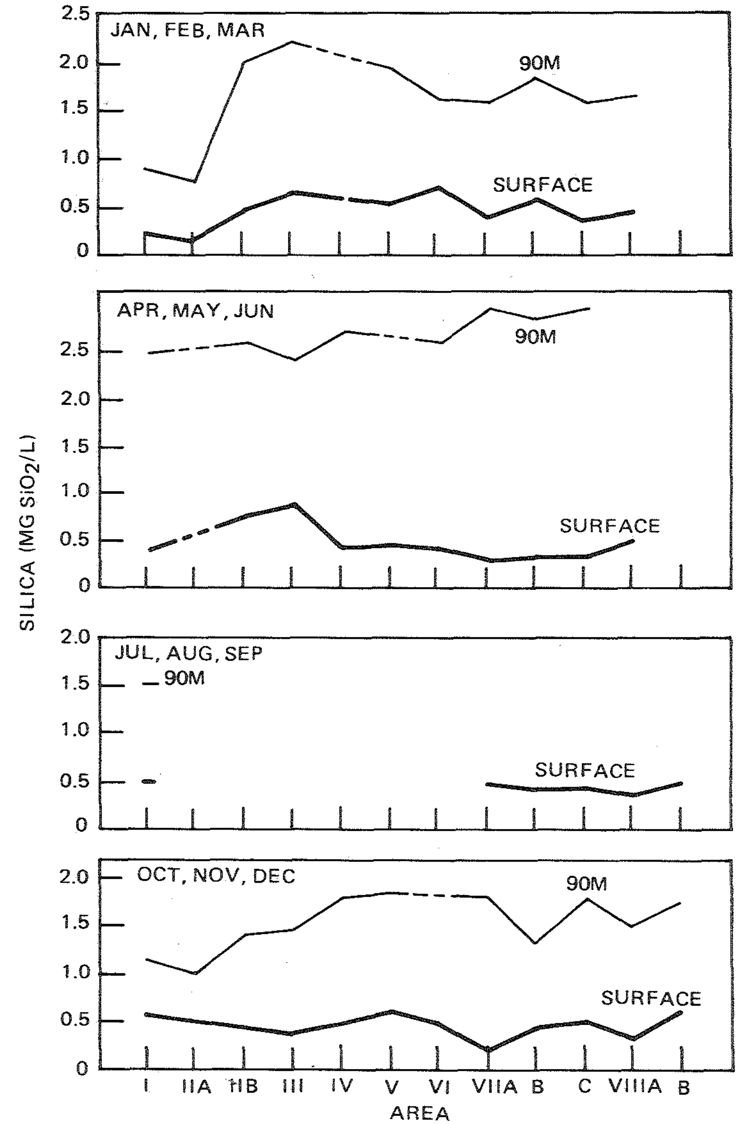


Figure 5-7. Distribution of Mean Silica by Seasons. From Allan Hancock Foundation 1965a, Fig. 3.15.

Table 5-1

TRACE METAL CONCENTRATIONS (RANGES AND MEDIANS,[a] μG/L) REPORTED FOR SURFACE SEAWATER (0-100 M)

Sea Region	Silver	Cadmium	Cobalt	Chromium	Copper	Iron	Mercury	Manganese	Nickel	Lead	Zinc	Source
World	0.3	0.1	0.4	0.5	3.0	3.0	0.2	2.0	7.0	0.03	10.0	Goldberg et al 1971[c]
	0.28	0.11	0.39	0.2	23.0	3.4	0.15	1.9	6.6	0.03	11.0	Turekian 1971[c]
	0.27 (0.06-0.96)	-	0.29 (0.04-4.1)	-	-	-	-	-	4.9 (0.84-30.5)	-	-	Schultz & Turekian 1965[a]
Southern California	-	-	0.2 (0.1-0.2)	-	4.3 (1.6-9.0)	8.3 (1.9-44.3)	-	-	1.0 (0.4-2.5)	4.7 (0.4-18.2)	8.0 (1.1-41.2)	Brooks et al. 1967
	-	-	-	-	1.33 (0.44-4.7)	-	-	-	-	-	-	Williams 1969
	-	-	-	-	-	-	-	-	-	0.35	-	Chow & Patterson 1966[c]
	-	-	-	-	-	-	0.03	-	-	-	-	SCCWRP data[c]
NE Pacific	-	-	0.04	-	-	-	-	-	-	-	-	Weiss & Reed 1960[c]
	-	-	-	-	-	-	-	-	-	-	1.8 (0.7-5.9)	Zirino & Healy 1971
NW Pacific	-	-	-	-	-	-	(0.10-0.27)	-	-	-	-	Hosohara 1961
SW Pacific	-	-	-	-	5.1 (3.5-6.5)	-	-	-	-	-	40.0 (29.0-50.0)	Brooks 1965[b]
Pacific Antarctic	0.02	-	0.03	-	-	-	-	-	1.6	-	-	Turekian et al. 1966[c]
Indian	-	-	0.03 (0.01-0.08)	-	1.2 (0.3-2.2)	4.5 (0.3-61.8)	-	0.8 (0.7-1.3)[b]	-	-	13.6 (7.3-48.4)	Topping 1969
	-	-	-	-	1.2 (0.5-3.1)	-	-	-	-	-	5.3 (3.0-8.5)	Torii & Murata 1966
So. Africa	-	-	-	-	(6.0-17.0)	(1.0-13.0)	-	(1.0-4.0)	-	-	-	Leisegang & Orren 1966
	-	-	-	-	8.6 (2.0-20.0)	-	-	-	-	-	-	Orren 1967
Mediterranean	-	-	-	0.38 (0.23-0.43)	-	-	-	-	-	-	-	Fukai 1967
	-	-	0.09	-	-	-	-	-	-	-	-	Fukai et. al 1966[c]
NE Atlantic	-	-	-	-	-	-	0.03	-	-	-	-	Stock & Cucuel 1934[c]
	-	-	0.04	0.05	-	2.3	-	-	-	-	1.3	Piper & Goles 1969[c]
	-	-	-	-	2.63 (2.39-3.99)	-	-	-	-	-	-	Foster & Morris 1971
	-	-	-	0.48	-	-	-	-	-	-	1	Chuecas & Riley 1966[c]
NW Atlantic	-	-	-	-	2.3 (0.1-14.6)	-	-	-	1.4 (0.4-2.7)	-	4.5 (0.8-52.6)	Spencer & Brewer 1969[a]
	-	-	-	-	-	-	-	-	-	0.04 (0.03-0.07)	-	Chow & Patterson 1966[b]
	-	-	-	-	10.0 (6.5-21.5)	10.0 (6.0-13.0)	-	-	0.9 (0.6-4.3)	-	-	Corcoran & Alexander 1964[b]
	-	-	-	-	1.3 (0.12-4.9)	-	-	1.6 (0.14-19.0)	-	-	3.9 (1.1-10.5)	Sloway & Hood 1971[a]

a. Mean value given if 30 or more values were reported

b. Values are for vertical profiles

c. Single value reported

bound, or as complexes. Chemical and biological processes can shift the equilibria between these states rapidly.

Concentrations of copper, cadmium, lead, and zinc were measured in 1971 in the waters around the Los Angeles County (JWPCP) and Los Angeles City (Hyperion) wastewater outfalls (Galloway 1972). Three sampling regions were delineated around each outfall; the first (termed "diffuser") includes samples taken from the area just above the bottom and close to the diffusers; the third (termed "control") includes those samples taken two or more kilometers from the discharge; the second (termed "intermediate") includes those samples taken from near-bottom and subthermocline levels at stations approximately half as far from the diffusers as the "control" stations.

The results of the study are summarized in Table 5-2. Included for comparison are Goldberg's (1971) world average values, modified by the addition of Chow and Patterson's (1966) value of 0.3 μg/L for lead off southern California (Table 5-1), Also listed are representative average concentrations for the four metals in JWPCP and Hyperion 5-mile effluent, divided by the factor 100. (This parameter was selected to illustrate the magnitude of metal concentrations that could be expected at a 100-to-1 seawater dilution of final effluent, assuming metal-free dilution water.)

The concentrations in samples taken near the JWPCP outfall diffuser are consistent with a first-stage dilution factor exceeding 100. Further, there is some suggestion of decreasing concentrations of all four metals at increasing distances from the outfalls. In general, the values at any station are consistent with "normal" levels ascertained from the literature. The only exception might be cadmium; but, as indicated in Table 5-1, there has been little study of the seawater distribution of this metal.

Over-interpretation of these gradients should not be made on the basis of the few measurements illustrated. No consistent pattern in metal concentrations away from the Hyperion 5-mile outfall is observed. However, the concentrations near the diffuser are consistent with a first-stage dilution factor of 100, and the levels observed at all stations are within reported ranges for seawater, again, with the possible exception of cadmium. Much more information is needed on ambient concentrations of trace metals in surface and subsurface inshore and offshore waters of the Bight.

5.2.6 Transparency and Light Extinction

Light is a major factor in the growth of phytoplankton and the growth and reproduction of attached marine plants. It also affects the daily vertical migration of zooplankton and benthic fishes. As a consequence, the transparency of the water, or the depth to which light will penetrate, is of concern in considering many biological processes.

Visual transparency is defined as the greatest distance to which a Secchi disc can be seen before it disappears against a background of scattered light. The transmission of light of a specific wavelength is usually expressed as a numerical coefficient (k), which relates the ratio of the light remaining at a depth (I) to the incident light (I_o) and the depth; i.e., $k = -1/d \cdot \log_e (I/I_o)$.

Table 5-2

CONCENTRATIONS OF FOUR TRACE METALS (μG/L) IN RECEIVING WATERS AROUND TWO LOS ANGELES WASTEWATER OUTFALL SYSTEMS

	JWPCP 90-in. Outfall				Hyperion 5-mi. Outfall				
	April '71 Effl.[1] (x 10^{-2})	Diff.	Interm.	Control	1971 Effl.[2] (x 10^{-2})	Diff.	Interm.	Control	Ranges of values from Table 5-1
Cadmium	0.3	0.56	0.23	0.20	0.5	0.33	0.26	0.74	0.1*
Copper	5.2	1.5	1.2	0.74	2.3	1.6	0.83	1.9	0.1 -23
Lead	1.6	<0.16	<0.16	<0.12	0.6	0.73	0.80	<0.16	0.03- 0.3
Zinc	24.0	9.0	8.8	6.8	4.6	5.3	8.0	18.0	0.7 -52.5

[1]Average of 4 weekly composites during April 1971

[2]Average of 12 monthly composites during 1971.

*Single value only.

For southern California shelf waters, the ratio between remaining and incident light (I/I_o) and the Secchi disc depth in feet (D) is expressed approximately as $I/I_o = 0.17e^{-0.009D}$, and the mean relationship between the extinction coefficient (averaged over the visible light spectrum) and the Secchi disc depth in meters as: $k = 1.4/d$. The depth to which light is available for photosynthesis is generally considered to be about 2.5 times the Secchi disc depth, although recent findings indicate that net photosynthesis may take place at lower light levels.

The mean visual transparency of the coastal waters for all seasons varies from less than 6 to more than 15 m, with the lowest values occurring close to shore. Great variations occur over the southern California shelf.

Extinction coefficients are usually higher and transparencies lower during the spring than during the fall, especially off the alluvial land plains of Ventura, in Santa Monica Bay, and off the coast to the south of San Pedro. This difference is probably associated with increased runoff of freshwater and detritus from the land during the spring season.

The coast as a whole is nearly always marked by a band of low transparency water within a mile or so of the beach. Within about one mile of the beach, transparencies of less than 6 m are common opposite alluvial land plains, with transparencies between 6 and 12 m typical of rocky shores. Extinction coefficients are in the range of 0.08 to 0.40 per meter.

5.3 GENERAL CHARACTERISTICS OF SEDIMENTS

Marine sediments provide clues to the nature of the environment from which their constituent materials were derived, the transportation processes by which they arrived at the final site of deposition, and the physico-chemical and biological characteristics of the depositional environment. The Southern California Bight is quite different in character from more northerly reaches, with much greater areas of soft sediments and less of the rocky types of the north; this has a profound influence on the character of the benthos and is discussed further in Chapter 8.

Table 5-3 summarizes characteristics of several thousand samples of sediments from various environments, both terrestrial and marine, within the southern California area. The coarsest sediments are found on island shelves and bank tops, and the finest on basin floors and the deep-sea floor. The most uniform sediments in terms of grain size are the coarse sediments found in the shelves, and the least uniform are the finer sediments of the continental slope--all environments of relatively slow nonminerogenic deposition. Organic matter ranges from essentially zero in sands, through low concentrations in the sediments of the shelves and bank tops to an average high value of 7 percent in the sediments of the basin floors.

5.3.1 Mainland and Island Shelves

Most mainland shelf sediments are sand or sand-silt combinations, with median diameters between 62 to 125μ. The average Trask sorting coefficient (a measure of the uniformity in particle size) is about 1.30. Geologically recent detrital sediments cover the largest area on the mainland shelf. They are low in calcium carbonate and consist principally of grains of sand and silt

Table 5-3

CHARACTERISTICS OF SEDIMENTS FROM VARIOUS ENVIRONMENTS IN SOUTHERN CALIFORNIA

(From Emery 1960, tab. 12)

Environment	Median Diameter (μ)	Trask Sorting Coefficient*	$CaCO_3$** (%)	Organic Matter† (%)
Coastal soils	80	3.1	0.4	1.5
Santa Ana dust	34	1.2	4.2	4.5
Dunes, El Segundo	330	1.3	1.1	0
Stream beds	610	2.0	1.0	0
Stream suspended load	31	2.6	8.6	2.4
Marshes	32	4.2	1.2	18
Gravel beaches	60,000	1.3	0	0
Mainland sand beaches	240	1.2	6.3	0.05
Island sand beaches	290	1.2	12	0
Suspended sediment in waves	160	1.3	0	0
Mainland shelves	130	1.6	9.2	0.9
Island shelves	260	1.7	27	0.6
Bank tops	270	2.3	56	0.8
Basin slopes	43	2.7	19	2.8
Submarine canyons	59	2.3	11	3.0
Basin floors††	5.3	3.9	20	7.0
Pliocene of Los Angeles Basin	14	3.9	4.9	2.6
Continental slope	8.0	4.4	44	4.1
Deep-sea floor	1.8	2.7	3.8	2.1
Totals				

*The Trask sorting coefficient, S_o, is equal to $\sqrt{Q_1/Q_3}$, where Q_1 and Q_3 are the diameters corresponding to the 25th and 75th percentiles, respectively, of a cumulative grain size distribution curve.
**Organic matter = nitrogen X 17, or organic carbon X 1.7.
†$CaCO_3$ from acid loss and from gasometric CO_3 = determinations.
††Values for basin floors weighted according to relative areas of basins.

recently derived from adjacent beaches on the shoreline. The mineral composition of these detrital sediments is similar to the sands of nearby beaches.

Shelf sediments also resemble beaches in mobility. Movement of material and the resulting changes occur over times that range from tidal periods to thousands of years. Changes are most pronounced at depths near 10 m. While changes in depth average only 8 cm, they locally can amount to as much as a meter. During high waves, turbulence and longshore transport may move shelf sediments into large canyons such as La Jolla and Redondo, where they are lost permanently from the shelf.

One of the most dramatic examples of recent change in the sediments is the comparison of grain sizes in two Santa Monica Bay collections taken almost 20 yr apart. Within an area almost entirely at water depths greater than 20 m, a definite decrease of grain size has occurred between surveys. The change, which is greater than could be expected from differences in field collection and laboratory analytical techniques, is attributed principally to the diversion of the mouth of the Los Angeles River from Santa Monica Bay to San Pedro Bay and to reduction of sand sediment contribution caused by water control projects. This change may be related to the present abundance and diversity of benthic organisms and fish in Santa Monica Bay (see Chapter 7).

Other types of sediments found in shelf areas include (1) relict sediments deposited during late Pleistocene or Early Recent times consisting principally of red sands, (2) well-graded, coarse-grained organic sediments containing shell material and foraminifera tests, and (3) biochemically precipitated authigenic sediments consisting principally of glauconite and phosphorite.

The results of a study of the Santa Catalina Island shelf are shown in Figure 5-8. Organic sediments predominate over other types, with calcium carbonate and foraminifera being the significant constituents of the sediments on the island shelf. These increase in the seaward direction as the supply of detrital material decreases.

5.3.2 Basin and Trough Slopes

Slope sediments generally have been poorly sampled and have received relatively little study. The occurrence of rock is not unusual, especially on the upper slope on the seaward side of the basins. Sediment is commonly mud, i.e., either silty-clay or clayey-silt. This mud is often found on moderately steep slopes of 9 to 18°. Water contents 15 percent higher than the Atterberg limits classify the mud in place as a liquid. In some mud, shear strength produced by thixotropy (a gel-like stiffening) of the sediment at rest was high enough to resist movement. Shaking by earthquakes or local slides may reduce this shear strength to the point where mass movement occurs. Evidence of such phenomena is often seen on a small scale in bottom photographs.

5.3.3 Submarine Canyons

Submarine canyons off southern California cut through materials that range from recent unconsolidated surface sediments, such as mud and sand, to

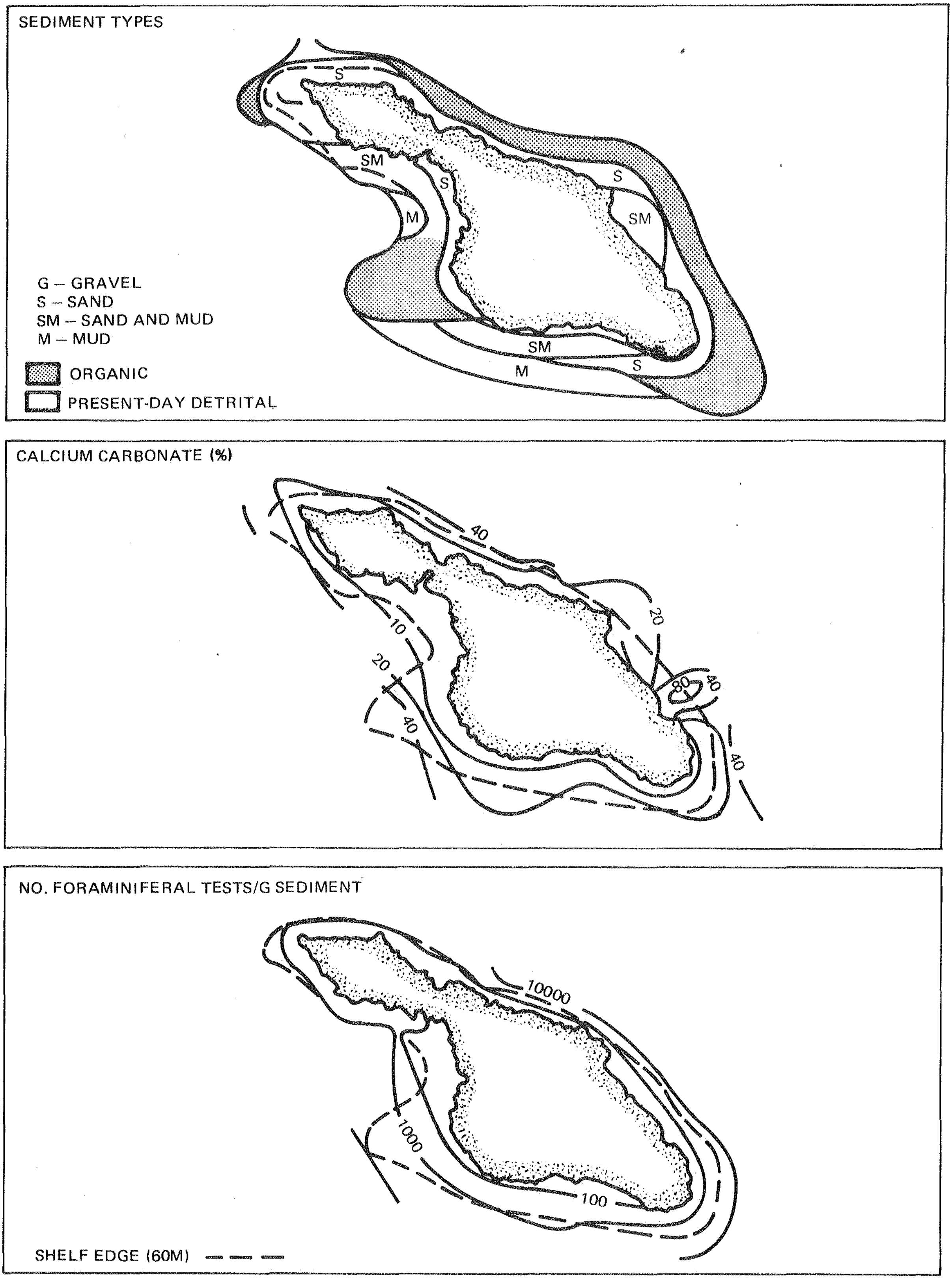


Figure 5-8. Sediments of the Shelf Around Santa Catalina Island (Based on 137 Samples). From Emery 1960, Fig. 181.

Cretaceous shales and sandstones. It is believed that, to a present depth of about 120 m, submarine canyons were cut by surface streams at the time of a lowered sea level. Submarine erosion by submarine slides, mudflows, and turbidity currents has maintained erosion, as the sea level rose, as in the lower portion of the canyons that did not emerge during Pleistocene sea levels. Deposition has occurred where submarine turbidity currents discharge into the nearby flat offshore basins and troughs, but these sediments are also cut into from time-to-time by strong currents of the same type.

Submarine canyons occupy less than 1 percent of the sea floor in the Southern California Bight, but they are important sediment pathways from shelves and banks into the basins. Erosion is the dominant process in the heads and in the sections leading to the points at which the canyons open onto adjacent basin floors. Here, alluvial fans are evidence of deposition, but the occasional incision by fan-valleys demonstrates some erosion. Thus, any sediments deposited from the active upper and middle parts must be regarded as temporary and ephemeral.

At the heads of canyons, sediments resemble nearby shelf and beach sediments, but some notable differences occur where the canyon head is in water shallow enough to affect and to be affected by wave currents. Thus, the shelf sand near the heads of Scripps Canyon is predominantly quartz with some mica. In the canyon heads, the sediment is a silty sand in which the dominant minerals are micas mixed with considerable debris derived from marine plants such as kelp and eel-grass. Mica, having a plate structure, remains in suspension after disturbed sand has settled; thus it is transported readily into the canyon heads, where it is redeposited. The heads of canyons farther from shore--Santa Monica, San Pedro, San Gabriel--are usually floored by sandy green silty muds. At depths of 100 to 200 m in canyons with heads close to shore, a sediment composed of a mixture of sand with an organic mat of decomposing kelp and surf-grass often has been observed. This type of organic material of undisputed nearshore origin has been seen in sediments within the canyons and extending into the fan-valleys. Again, such processes have obvious significance regarding marine dispersal of land-based pollutants.

Canyons are sites of local upwelling and downwelling, often associated with nearby phytoplankton blooms. They are important avenues for migratory fish and invertebrates. They strongly influence wave refraction, upwelling and the offshore transport of sediment. Consequently, the benthic distributions of particulate waste materials introduced into such areas are subject to significant and unpredictable changes as sediment is transported down-canyon and onto the basin floors.

5.3.4 Basins and Troughs

The bulk of the sediments deposited on the continental borderland have been eroded and transported to the area from the adjacent land areas. The primary sources for sediments are believed to be the higher Transverse Ranges-- the San Bernardino and San Gabriel Mountains; the Santa Monica, Santa Ynez, and Santa Ana Ranges are secondary sources. The filling of the emergent basins has been accomplished in the basins closest to the primary sources; the Santa Barbara, San Pedro, and Santa Monica Basins probably owe their smaller size and shallower depths to this process.

The volume of sediment in the Bight is estimated to be 125,000 cu km, most of it in the basins. This compares to 208,000 cu km of seawater and about 10,000 cu km for the volume of the Transverse Ranges (Santa Ynez, San Gabriel, San Bernardino, and Santa Monica Mountains).

Most of the filling has been through transport and deposition of detrital or clastic particles of minerals and rocks. One process is the diffusion and advection of these sediments outward from shore in seawater (sometimes diluted with runoff) to the ultimate sites of deposition. Another process is transport and deposition by turbidity currents, which--laden with sediment--move close to the sea floor in areas where bottom slopes are responsible for redistribution of sediment beyond the shelf and in submarine canyons, where they may dramatically alter benthic distributions of materials. Only the nearshore basins receive significant amounts of sediment through this process; deposition of detrital rock particles and chemical and organic sedimentation prevails in the outer basins, which are only slowly filling.

Cores from the basins commonly contain sand layers (even occasional fine gravel layers) separated by green mud. Such cores have been taken in all except Santa Barbara Basin, in which the gray silt substitutes for the sand. The sand or silt layers usually have a lower content of water and organic matter than the intervening fine-grained mud. In the nearshore basins, the sands are similar mineralogically and dimensionally to those on the mainland and island shelves; the sandy layers in the outer basins contain shallow-water foraminifera and grains of authigenic minerals, such as glauconite, from the adjacent bank tops and island shelves. These layers occur most often in the fans at the mouths of submarine canyons and in the channels that incise these fans and extend out into the basins, again indicating the importance of aperiodic transport of material down the canyons and into the adjacent basins.

Sediment cores from the basins can provide a record of conditions over a long historical period. A study of trace constituents in such cores is described in Chapter 6.

5.3.5 Continental Slope

Study of the sediments on the continental slope has been limited. Large areas of the bottom consist of bare rock, especially on the upper slope. Based on the small number of cores taken, the sediments of the continental slope appear to be silty muds, coarser than the sediments of the basins and somewhat finer-grained than those of basin slopes. Calcium carbonate is high (averaging 44 percent) and reflects the deposition of foraminiferal tests.

5.3.6 Natural Trace Metal Concentrations in Sediments

Although distinct enrichment of trace metal levels above natural coastal sediment concentrations occurs close to the major sewage outfalls in the Bight (see Chapter 6), it is important to realize that comparable levels may occur naturally elsewhere on the ocean bottom. Table 5-4 summarizes such data from the literature. The first data column lists average values for 11 trace metals in coastal surface sediments of the Bight; the last column lists the single largest surface value observed for each metal off the Los Angeles County (JWPCP) wastewater outfall system where the highest sediment concentrations of metals have been observed. The other four columns list literature values

Table 5-4

NATURAL TRACE METAL CONCENTRATIONS (MG/DRY KG)
AS REPORTED FOR SURFACE SEDIMENTS FROM
SEVERAL PARTS OF THE WORLD OCEAN

Metal	So. Calif.[a]	Other Nearshore	Organic Rich Cont. Shelf[b]	Pacific Basins[c]	Manganese Nodules[d]	Outfall Max.[e]
Silver	1.0					21
Cadmium	0.4	2[f]				79
Cobalt	7	5[g]		4-195	3,000	11
Chromium	46	30[g]		4-93		1,000
Copper	16	7[h], 48[i]	18-129	82-686	5,000	670
Iron	2.5%	1-5%[j]		0.4-5.5%	14%	3.7%
Mercury	0.06	0.04[k]		0.09-0.86		4
Manganese	320	580[f]		42-1,075	19%	380
Nickel	14	15[h], 55[i]	35-455		4,000	45
Lead	8	15[h], 20[i]	3-32		1,000	490
Zinc	63	95[i]	18-337		400	2,400

a. Averages of natural values at the five major sewage outfalls in the Bight. However, mercury value is estimated natural subsurface concentration in Santa Barbara Basin.

b. Organic-rich diatomaceous muds, S.W. Africa shelf. Calvert and Price, 1970.

c. Sample No. 21-29, Pacific Ocean Basins. Robertson et al. 1972.

d. Average composition of ferromanganese minerals from the Pacific Ocean. Goldberg, 1963.

e. Maximum surface sediment concentration measured off Palos Verdes Peninsula sewage outfalls.

f. Caribbean sediment, Station 50. Forster et al. 1972.

g. Japanese Island sediments, Ishibashi, et al. 1964.

h. Gulf of Paria, Caribbean sediments. Hirst, 1962a.

i. Atlantic nearshore sediments. Wedepohl, 1960.

j. Gulf of Paria, Caribbean sediments. Hirst, 1962b.

k. Washington Shelf, N.E. Pacific. Carpenter, 1972.

for four classes of natural ocean bottom material: (1) various coastal sediments, (2) organic-rich shelf sediments, (3) deep Pacific Basin sediments, and (4) the widely-distributed ferromanganese nodules.

As the table shows, it is not uncommon to find relatively high trace metal concentrations on the ocean bottom. Diatomaceous clays of the Gulf of California and the Saanich Inlet, British Columbia, are reported to have trace metal ranges similar to those listed for the organic-rich shelf sediments of Southwest Africa (Calvert and Price 1970). Even higher values have been reported for some metals in the Pacific Basins. In the case of copper, three of the five basin values (325, 469, and 686 mg/dry kg) recently found southwest of the North American continent (Robertson et al. 1972) are comparable to the highest surface sediment concentration (670 mg/dry kg) found in the sewage field off Palos Verdes Peninsula (Los Angeles County). Levels in the ferromanganese nodules are one order of magnitude higher; for some of the other metals, the differences are even greater. As surface concentrations in the sewage fields fall off rapidly from peak values (often approaching local background levels within a few kilometers of the outfall), the naturally occurring high sediment values discussed above lend important perspective in evaluating anthropogenic enrichments of trace metal concentrations. High sediment values alone do not necessarily imply ecological damage; it remains to be shown that such sewage field sediment metals are available to the biota in sufficient concentration to be detrimental. Localized and regional studies performed to date by SCCWRP (on the benthic dover sole from outfall areas and intertidal mussels from throughout the Bight) have not revealed any uptake of metals related to elevated metal levels near wastewater outfalls (see Chapter 7).

5.4 NEARSHORE CIRCULATION

5.4.1 Introduction

The major ocean currents off the coasts of California and Mexico were described briefly in Chapter 3. This current system is part of the overall circulation system of the Pacific Ocean. The major surface oceanic currents are driven by a variety of forces, including gravity, friction, and forces due to pressure gradients and the earth's rotation (Coriolis acceleration). In the deeper waters, minor perturbations in the overall circulation patterns also result from winds and tidal forces.

The situation is quite different, however, in the nearshore waters overlying the continental shelf. Here, because of the shallowness of the water and the proximity of the shore, currents are affected more directly and in relatively greater degree by wind and tidal forces, internal waves, and irregularities in the ocean bottom. In many cases, the effects of winds, tides, and even runoff from major coastal rivers may so distort the nearshore currents that it is difficult to perceive the effects of the major geostrophic circulations.

Nearshore currents often are so complex in their changes, both with location and with time, that it seems almost impossible to draw general conclusions or to make predictions as to their behavior. As will be shown, however, there are general patterns that emerge from the consideration of the local currents in the Southern California Bight.

Wind-drift currents are caused directly by the stress of the wind on the water's surface. Where the fetch of the wind is sufficiently long, these surface currents may achieve a velocity of 2 to 3 percent of the wind speed. In deeper waters, the direction of the current in the northern hemisphere is about 45 degrees to the right, or clockwise, of the wind. The current speed decreases with depth. As wind-induced currents approach the shore, they may either turn and flow parallel to the shoreline, or, in some cases, may induce a countercurrent along the bottom. Tidal currents along the coast of California are affected primarily by the diurnal and semidiurnal components of the tides. Tidal currents tend to have greatest velocity more or less parallel to the shore in southern California coastal waters, although the current velocity vector at a given point tends to describe an ellipse approximately every 12-1/2 to 25 hr, depending upon the relative strength of the main tidal components. Tidal currents are strongly influenced by the topography of the bottom.

In addition to these types of currents, there are local water movements that should be identified. These include upwelling, currents in submarine canyons, currents in the surf zone, internal waves, and turbidity currents.

5.4.2 Shelf Currents

There has been very little investigation of the currents on the mainland shelf, perhaps because of the complexity of the factors and forces that affect and shape these currents. Of the investigations that have been made, most have been conducted in conjunction with studies for the siting and design of marine wastewater outfalls. As a consequence, the data have been collected in localized areas and, for the most part, over a short period of time--1 to 2 yr at the most. In a few areas, current measurements have been made in the vicinities of outfalls over longer periods. Figure 5-9 shows the areas in which current studies that are reviewed in this section have been made.

Most of the current study work conducted over the last 15 to 20 yr has been done with drogues or drift cards, although a number of studies have supplemented these data with measurements using current meters. It should be recognized that drogues, drift cards, and current meters produce different types of data. A current drogue presumably follows (ignoring the problems of wind drag or friction) a particular mass of water as it moves under the various current-inducing forces. Drift cards provide an indication of the strength and general direction of onshore surface currents. To provide useful data, of course, the drift cards must reach the shore and be found. Current meters provide information on the strength and direction of the current at a given point over some period of time. All three types of information may be useful, but their differences should be recognized, and the investigator must be reconciled to the fact that the data resulting from the use of these different techniques are not always comparable.

Santa Barbara Channel

Surface currents in the Santa Barbara Channel were investigated in 1969 and 1970 using surface drift cards (Kolpack, 1971). It was concluded that currents entering the Channel from either end converge and interact in the area between Santa Barbara and Santa Cruz Island. These currents resulted in a complex pattern of eddies superimposed on a relatively stable counterclockwise cir-

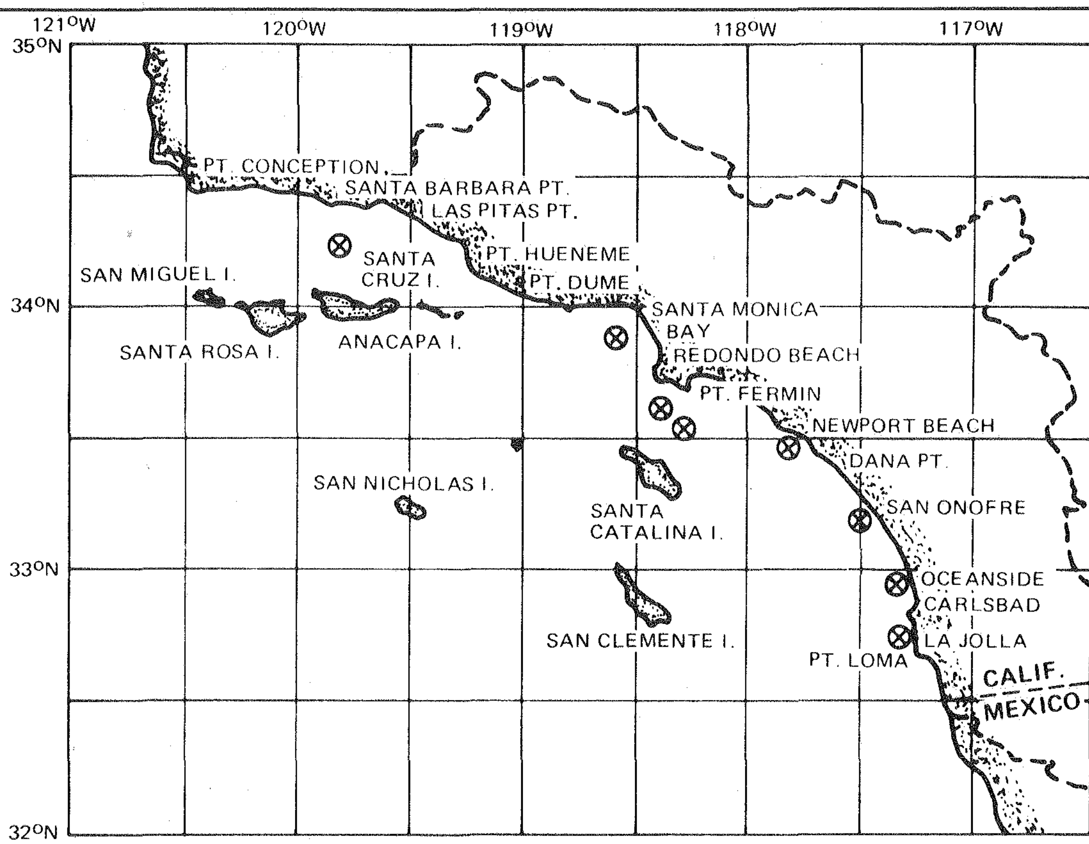


Figure 5-9. Locations of Recent Nearshore Current Surveys in the Southern California Bight

culation cell in the western half of the Channel and a northwesterly flowing current in the eastern part of the Channel.

Santa Monica Bay

Investigations were conducted in 1955 and 1956, using drift cards, drogues, and current meters (Stevenson, Tibby, and Gorsline 1956). Santa Monica Bay is open to the west and faces the prevailing wind from that direction. There is general south-setting coastal current, which induces a slow counterclockwise eddy within the Bay. During periods when coastal currents are relatively weak, the onshore winds tend to push water into the Bay, and it flows out both to the north and south. Measurements made with current meters during the 2-yr period showed that current speeds ranged from approximately 0 to 20 cm/sec. Most of the speeds, however, were less than 10 cm/sec. It was not possible to relate current velocity to the tides, and the currents were extremely variable.

Palos Verdes

The Los Angeles County Sanitation Districts provided SCCWRP with all of the current measurement data taken between 1960 and 1964 in the JWPCP (Whites Point) outfall area off the Palos Verdes Peninsula. Results of the analysis of the data taken between June 1960 and December 1961 were published by Parkhurst, Garrison, and Whitt in 1964.

The data collected over the 4-yr period showed that the currents at all depths during each season of the year tended to flow in either a northwest or east-southeast direction. Exceptions to this general pattern occurred during the winter, when the prevailing winds were from the southwest and currents below

50 m tended to travel between the northwest and west-southwest. During the summer, with winds blowing from the west-northwest, the surface currents tended to travel towards the northeast to south-southeast. Current speeds were generally in the range of 5 to 25 cm/sec. Weakest currents were found during the spring; the strongest currents occurred in the summer. In general, it was noted that a decrease in current speed with depth occurred during all seasons, although the differences in current speed between surface and bottom were relatively small in all seasons except for summer. This characteristic is probably related to stratification, which is greatest at this location during the summer.

An analysis of the 1960 to 1964 data is presented in Appendix B.

In 1972, SCCWRP and the Los Angeles County Sanitation Districts have cooperated in a continuing program of more refined current measurements that can provide more detailed information on the short-term variations in currents. These techniques have been incorporated into the Districts' monthly monitoring program.

San Pedro Channel

In 1935, currents in the San Pedro Channel were observed between June and October from a relief lightship anchored approximately 11 kilometers south of the Los Angeles Harbor. These observations indicated that the currents in this vicinity were influenced strongly by both the tides and the diurnal wind characteristics. Both the tidal current and the wind current were rotary, i.e., they changed direction progressively in a clockwise movement during the day. The monthly values for the net resultant current varied from 17 cm/sec southeastward to 11 cm/sec northwestward.

Orange County

Drogue studies were conducted in October 1964 and between August 1966 and February 1967 in connection with the design of a new wastewater outfall. The studies were made for the Orange County Sanitation Districts by John Carollo Engineers (1967).

The predominant current direction was to the east-southeast (nearly one-third of the measurements), but one-quarter of the measurements showed a current flowing in the north-northwest direction. These currents parallel the coastline, and the data strongly suggest that tidal currents dominate the subsurface circulation. The fact that the current flows to the east-southeast more than in the opposite direction is explained by the prevailing winds from the west. The average current speed in either direction was about 11 cm/sec. Current speeds were higher at the deepwater stations than at locations near shore. As was noted at Palos Verdes, the surface currents had a higher speed than those near the bottom. These conclusions are consistent with the results of benthic fish studies (see Chapter 7).

San Onofre

A 1-year study (May 1964 to April 1965) was conducted in connection with the siting of the San Onofre power plant thermal discharge by Marine Advisers (1965a, 1965b). In the relatively shallow waters at this site (less than

15 m depth), the currents appeared to be strongly influenced by both winds and tides. The currents were generally parallel to the coast; however, in September 1965, strong currents (up to 34 cm/sec) were recorded during a period of calm winds and minimum tidal range. This was believed to be due to an inshore extension of the California current system. Over the study period, subsurface currents rarely exceeded a speed of 15 cm/sec and were usually less than 10 cm/sec.

Oceanside

Current measurements were taken during April and September 1971 in connection with the design of the La Savina outfall near Oceanside. The study was conducted by Neste, Brudin, and Stone, Engineers. The results of this limited study indicated that the predominant current direction was towards the east-southeast, with some currents in the opposite direction.

Point Loma

Current surveys were conducted between March 1956 and 1957 in connection with the design of a wastewater outfall for San Diego. The results of these studies were reported by the San Diego Marine Consultants (1959) and by Gaul and Stewart (1960).

Surface and subsurface drogues were used to measure currents in the two areas. In the area off Point Loma, the predominant currents rotated in a clockwise direction; in the shallower area off Imperial Beach, the current velocities were less than half those off Point Loma, and the rotating subsurface circulation was counterclockwise. In the surface waters in both areas, the currents were strongly influenced by wind, and the current speed was about 2 percent of the wind speed, with the direction to the right of the wind at an angle of less than 25 degrees.

Additional current data were taken by SCCWRP in January and May 1972. These measurements were made with surface and subsurface drogues and a Savonius current meter. During the survey, when light winds were observed, the subsurface currents showed a persistent movement toward the northwest, parallel to the shoreline. Rotating tidal currents (clockwise) were superimposed on this general current. During the May cruise, winds were generally from the west, and both surface and subsurface currents were predominantly to the south.

Conclusions

Although the data obtained from individual current measuring surveys often appear to be inconsistent and difficult to understand, the total data from Point Dume to San Diego present a surprisingly consistent picture of the mean currents in the area. These data have been taken using drift cards, drift poles, and various types of drogues and current meters with a wide assortment of techniques; yet, there is consistency in the general picture they present.

Surface currents tend to follow the wind when it is blowing; otherwise, they appear to be dominated by the general patterns generated by mean winds and the offshore geostrophic circulation. Subsurface currents showed a close relationship with the tides, except possibly when strong winds were blowing for more than a few hours and stability was low. It should be noted that much

of the data that have been collected have, for obvious reasons, been taken during periods of relatively light winds. Consequently, many of the reported data are necessarily biased towards conditions of low wind velocity. During times of weak winds or weak tidal currents, residual currents apparently related to the offshore circulation system may dominate the flow at all depths on the shelf. In general, the strongest and most persistent currents are parallel to the coast. The greater prevalence of currents towards the east-southeast appears wherever more than a few measurements have been made. However, flow to the north-northwest is only 10 to 15 percent less persistent usually than currents in the east-southeast direction. It should also be noted that this flow reversal occurs quite frequently and is usually related to the diurnal or semidiurnal tide. Although the net advective transport along and across the shelf may consequently be quite small, the large variations of the current speed and direction in time and space act to greatly increase the rate of dispersion of materials over that which would result from ordinary turbulent diffusion in a steady mean flow. This shear-induced dispersion effectively acts to transport materials along and across the shelf.

In general, the surface currents have a greater velocity than those below, say, 15 to 20 m. The differences between surface and subsurface currents are most pronounced during summer, when the stability is the highest and stratification is most pronounced.

5.4.3 Upwelling

Upwelling, which is the phenomenon whereby bottom waters are brought to the surface generally in rather localized areas, is conspicuous along the eastern boundaries of the oceans where prevailing currents result in flow of surface water away from the coast. Upwelling is of importance because the characteristics of the bottom waters in a coastal water system differ markedly from those of the surface waters. The bottom waters are generally colder and have a higher nutrient concentration, and such waters are easily observed in the surface layers.

Upwelling is markedly seasonal in the California current system. The northwesterly winds that blow more or less parallel to the coast are strongest off Baja California and southern California in the spring and drive surface waters offshore. Since upwelling is a result of these winds, the most intense upwelling in the Bight usually occurs during April, May, and June. Factors other than wind may result in upwelling; consequently, there are occurrences during other times of the year.

No direct measurements of the vertical velocities associated with upwelling on this coast are available. Various theoretical analyses have yielded values of the vertical velocity during an upwelling episode on the order of 0.001 cm/sec. This velocity is in qualitative agreement with estimates inferred from the displacement of isoconcentrations of physical properties in the southern California coastal waters. Sverdrup and Fleming (1941) have shown changes in density that occurred during an upwelling period during April 1937 off Port San Luis (Figure 5-10).

Upwelling may also be induced by tidal currents in an area having an irregular sea floor. Leipper (1955) describes such an effect off La Jolla, and its presence on the San Pedro shelf was verified and reported by Stevenson and

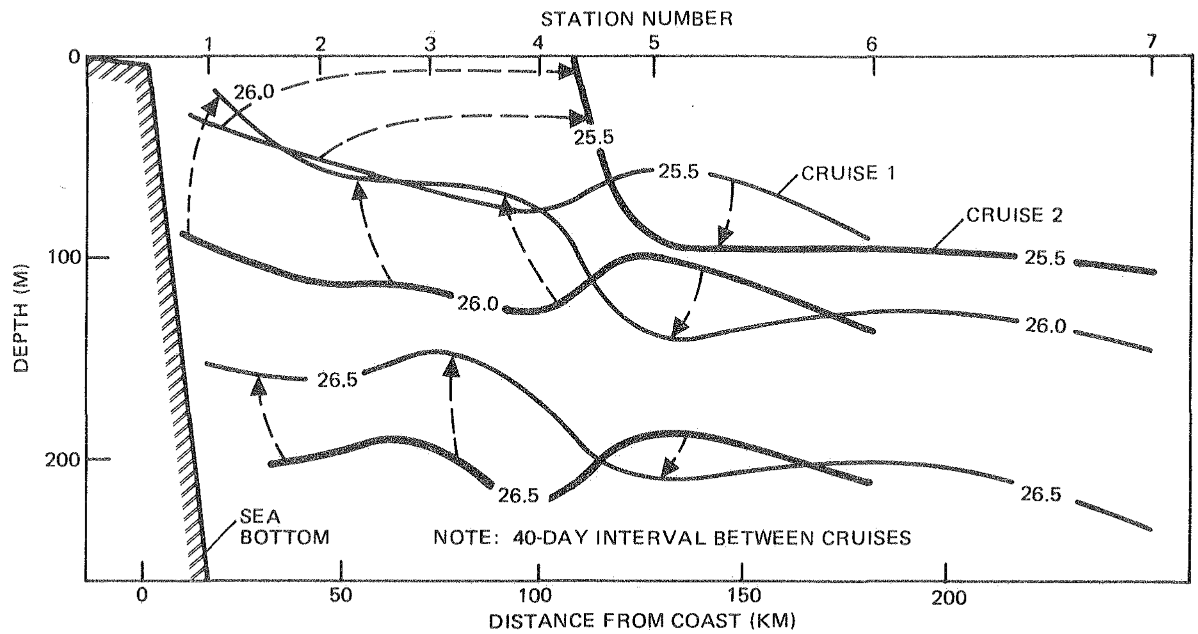


Figure 5-10. Density Distribution of Water Above a Depth of 250 m in a Selected Area of the Southern California Bight. From Sverdrup and Fleming 1941, Fig. 51.

Gorsline in 1956. An instrusion of cold water surfaced near the Los Angeles breakwater in July 1954 in the absence of wind; the cold water also seems to have caused the formation of intense local fog. Measurements taken at the time indicated that the mean rate of ascension of this bottom water was about 3 m/day (0.003 cm/sec). The event occurred during a period of increasing tidal range, weak winds, and warm weather. The water was well stratified and stability was high. These are not classical cases of upwelling but "cold domes" produced by eddies. Local upwelling has been observed in Santa Monica Bay and on the San Pedro shelf in every month of the year. Thus, local upwelling may occur in various areas even when the wind conditions which normally induce upwelling are not present.

Coastal upwelling has a major influence on biological productivity. Upwelling is often intense enough to alter significantly the surface concentration of nutrients; indeed, upwelled waters are the primary source of nutrients in eastern boundary currents.

5.4.4 Littoral Currents

Littoral currents are those found in the portion of the coastal waters immediately adjacent to the shore. They are most strongly influenced by the waves breaking on the shore and by the backwater from those waves, as well as by the topography in that restricted zone. Littoral currents are the most important factor in the transportation and deposition of nearshore sediments, beach erosion, and related processes.

When waves break so that there is an angle between the crest of the breaking wave and the beach, the momentum of the breaking wave has a component along the beach in the direction of wave propagation. This results in the generation of long-shore currents that flow parallel to the beach inside of the breaker zone. After flowing parallel to the beach as long-shore currents, the water is returned seaward in relatively narrow zones by rip currents. The net onshore transport of water by wave action in the breaker zone, the lateral transport inside of the breaker zone by long-shore currents, the seaward return of the flow through the surf zone by rip currents, and the long-shore movement in the expanding head of the rip current, constitute the nearshore circulation system.

The nearshore circulation system produces a continuous interchange between the waters of the surf and offshore zones. Offshore water is transported into the surf zone by breaking waves, carrying with it floatables, grease, oil and other materials. Long-shore currents with velocities in excess of 250 cm/sec and rip currents with velocities greater than 150 cm/sec have been measured. The littoral zone is easily penetrated by offshore surface waters, and any materials that have reached the surface offshore have a high probability of penetrating to the shoreline area. There they may be spread widely, escaping to the waters outside the breaker zone only through rip currents, or they may be deposited on the beach along the uprush where the water sinks into the beach material.

5.4.5 Currents in Submarine Canyons

Submarine canyons represent a potential "short-cut" between the nearshore waters and the deeper waters off shore. Upwelling has often been associated with submarine canyons, which provide a means of more rapid dispersal of waters, constituents, and marine organisms. However, there has been surprisingly little study of currents in these canyons.

Currents in La Jolla Canyon were measured during spring tides in July and October 1939 by Revelle and Shepard (1943). Speeds ranged from 2.2 to 20.4 cm/sec. In most cases, the current direction was either up canyon or down canyon. The periodicity of these flows was irregular.

In 1969, Shepard and Marshall reported on systematic measurements of currents in and near the La Jolla Canyon. They concluded that, during the period of investigation, the net transport was down canyon. Most current speeds were less than 20 cm/sec. Although there was a clear relationship with the tides, the reversals appeared to occur at periods of about 4 hr. Shepard and Marshall have also conducted studies in Scripps, Newport, and Redondo Canyons. In all but 4 of the 45 sets of observations recorded, they found the net transport to be down canyon. In general, higher velocities and longer durations of flow were found down canyon as compared to up canyon. In spite of this fairly common pattern of predominant flow in the down-canyon direction, this pattern is by no means consistent. For example, during one set of observations in Redondo Canyon, almost 74 percent of the flow was up canyon. Newport Canyon provided an example of very weak currents. The mean velocities were only 0.92 cm/sec on one occasion and only 0.16 cm/sec on another.

Table 5-5 presents statistics on canyon currents gathered by Shepard and Marshall (1972). These data show the general pattern of the predominantly down-canyon flow in these particular canyons.

Table 5-5

CANYON CURRENT STATISTICS
From Shepard and Marshall 1972

Canyon	Sta.	Depth (m)	Number Successful Lowerings	Mean Velocity (cm/sec)	Highest Velocity (cm/sec)	% Time > 18 cm/sec		Net Transport (m/hr)	
						Up	Down	Up	Down
La Jolla	1	46	2	1.07	26	0.003	0	33.7	0
	6	78	2	0.60	17	0	0	26.5	0
	5	167	8	1.12	29	0.017%	1.24%	0	37.1
	3	206	14	2.51	29	0.066%	3.23%	0	63.6
	10	375	2	2.08	22	1.29%	0.64%	0	15.8
Scripps	9	125	2	0.85	34	0.65%	1.58%	0	13.9
San Lucas*	14	137	3	0.86	17	0	0	0	29.4
	13	216	1	0.44	9.5	0	0	0	13.6
	15	328	2	3.70	33	0	6.20	0	123.1
Newport	20	101	2	0.92	17	0	0	0	34.1
	21	252	1	0.16	11.5	0	0	0	0
Redondo	18	92	2	1.97	27.0	0.006	0.011	0	34.2
	19	283	1	3.19	19.0	0.002	0	119.4	0
Carmel**	11	156	1	3.36	20.0	0	0.28%	0	113.9
				TOTALS		2.01	13.18	179.6	468.7
				AVERAGES		0.14	0.94	59.8	66.9

*Off Cabo San Lucas, Baja California

**Off Carmel, California

5.4.6 Transport in Turbid Layers

Turbid layers formed by the suspension of dense sediments may act like denser water and move quite differently from the original parent water in which they were entrained. Indeed, "turbidity currents" are clearly involved in the transport of coarse sediments from submarine canyon heads to the abyssal plain. Extremely violent turbidity currents carrying away undersea tables for hundreds of miles have occurred in the North Atlantic, and even more violent ones have been observed in the Congo canyon system. The turbidity currents in southern California appear to be relatively simple and confined to submarine canyons, although there is evidence of wide-scale and perhaps violent turbidity currents following the earthquake of 1812 and a similar event about 1100 AD in this region.

Turbidity associated with wastewater plumes tends to form in submerged layers. As the particles entrained are not much denser than seawater, the layers have already reached approximate hydrostatic equilibrium (from dilution of the effluent). It is unlikely that the density of the particles influences the motion of these layers in any substantial way. Turbidity currents associated with wastewater particles are probably restricted to density flows of settled particles on sloping bottoms.

The physical influence of wastewater-derived turbid layers is probably restricted to their influence on light penetration. In this way, they may somewhat reduce the otherwise potential level of phytoplankton productivity and have been implicated in reducing or preventing growth of young kelp plants. Both of these effects are clearly minor for deeply submerged plumes. The diminution of light below such plumes may selectively influence the normal day-night migration habits of some groups of organisms, however. Nearshore and offshore migration of many benthic fish, as well as the vertical migration of zooplankton, may be reduced. Both of these effects would result in an increased density of the affected organisms under and above the submerged plume.

5.4.7 Internal Waves

The implications of internal waves to the conditions and processes in the Southern California Bight have not yet been evaluated. Internal waves, as the name suggests, are gravity waves moving through the internal density structure of the ocean. They have many of the characteristics of surface waves--approximately elliptical orbital motion, complex frequency spectra, ubiquity, etc.

They differ from surface waves, however, in that they progress very slowly--a few knots at most, their dominant components usually correspond to tidal periods, and their height usually exceeds that of surface waves. Internal waves may break when entering shallow water, and, when encountering upwelling areas, they may produce submerged bores and trains of higher frequency waves.

As already pointed out, density changes in California waters are principally the result of temperature gradients. Thus, the major physical manifestation of internal waves in this region is the continuous fluctuation in temperatures at any given depth below the mixed layer. These fluctuations are, of course, more conspicuous where the vertical temperature gradient is the greatest.

The effects of internal waves on the problems investigated by SCCWRP need to be evaluated in the future, but their principal effect is to produce small-scale random and unpredictable variations in a great number of local conditions. Currents, temperature, depth of stable layers (and of submerged sewage fields), midwater and freeswimming bottom organisms, all are subject to the complex small-scale displacements on the order of tens of meters vertically and hundreds of meters horizontally.

Internal waves are associated with short-period fluctuations in current speed and direction, particularly in regions of high bathymetric relief. They have been shown to produce currents of alternately warm and cold water on the nearshore bottom and to assemble surface-active materials into series of slicks; they undoubtedly are involved in surges of upwelling and hence, possibly in aperiodic surfacing of sewage plumes. However, their principal

immediate importance to the studies of SCCWRP is to introduce a random element into the great majority of field measurements.

5.5 THE BROAD-SCALE DISPERSION MODEL

One objective of attempting to measure, understand, and predict currents in the Bight is to achieve the ability to predict the dispersion and transport of materials introduced into the Bight. As was emphasized in the preceding section, the current phenomena (especially in the nearshore waters) are complex and subject to influence by many factors. In spite of these complexities, a model of these phenomena, simplified as it must be, is a useful tool in understanding the possible effects of dispersion and transport processes in the Bight. To this end, a simple two-dimensional model incorporating the general features of the ocean currents off the coast of southern California has been developed.

The model calculations, which have been used to estimate the flushing rates for wastewaters discharged into the Bight, indicate typical residence times of 3 to 4 mo. for the region from Point Conception to the Mexican border, and from the shoreline to approximately 110 to 130 km offshore. Comparison of the residence times for various current velocity assumptions indicates that the combined processes of advection and eddy diffusion are about five times as efficient in diluting waste inputs as a purely eddy diffusional process.

The high dilutions predicted by the model (on the order of 10^4 to 1) indicate the difficulties that might be expected in experimentally testing the model. In spite of these difficulties, a qualitative comparison of the predicted distributions of DDE, lead, and cadmium in the Bight with the values observed in intertidal mussels (Chapter 8) has been made. The model gives some indication of a correlation of DDE in mussels with inputs from the Los Angeles County JWPCP outfall and of a correlation of lead content of mussels with a spatially continuous source of lead along the coastline. No correlation between observed cadmium distributions and the predicted distributions for inputs from outfalls, surface runoff, or a spatially continuous source could be discerned.

The model consists of a single layer of cells as shown in Figure 5-11. The distribution of a substance among these cells is assumed to be the result of advection, lateral diffusion, and simple sources or sinks internal to each cell.

A detailed description of the formulation of the model is contained in Appendix C. In brief, currents are estimated from a geostrophic flow approximation, using monthly data from the CalCOFI program and the continuity relationship. The velocities of currents near shore, where the geostrophic approximation breaks down, are estimated and supplied as input data to the model. Lateral diffusion is calculated using a "diffusion velocity" representation. The calculation represents a "quasi-steady-state" solution because current strengths and directions and input rates are allowed to vary during the course of a year, but are cyclical with a period of 1 year. Computation is performed using a time increment of 3 days; the computation is repeated over several years until the concentrations exhibit a reproducible cyclical pattern.

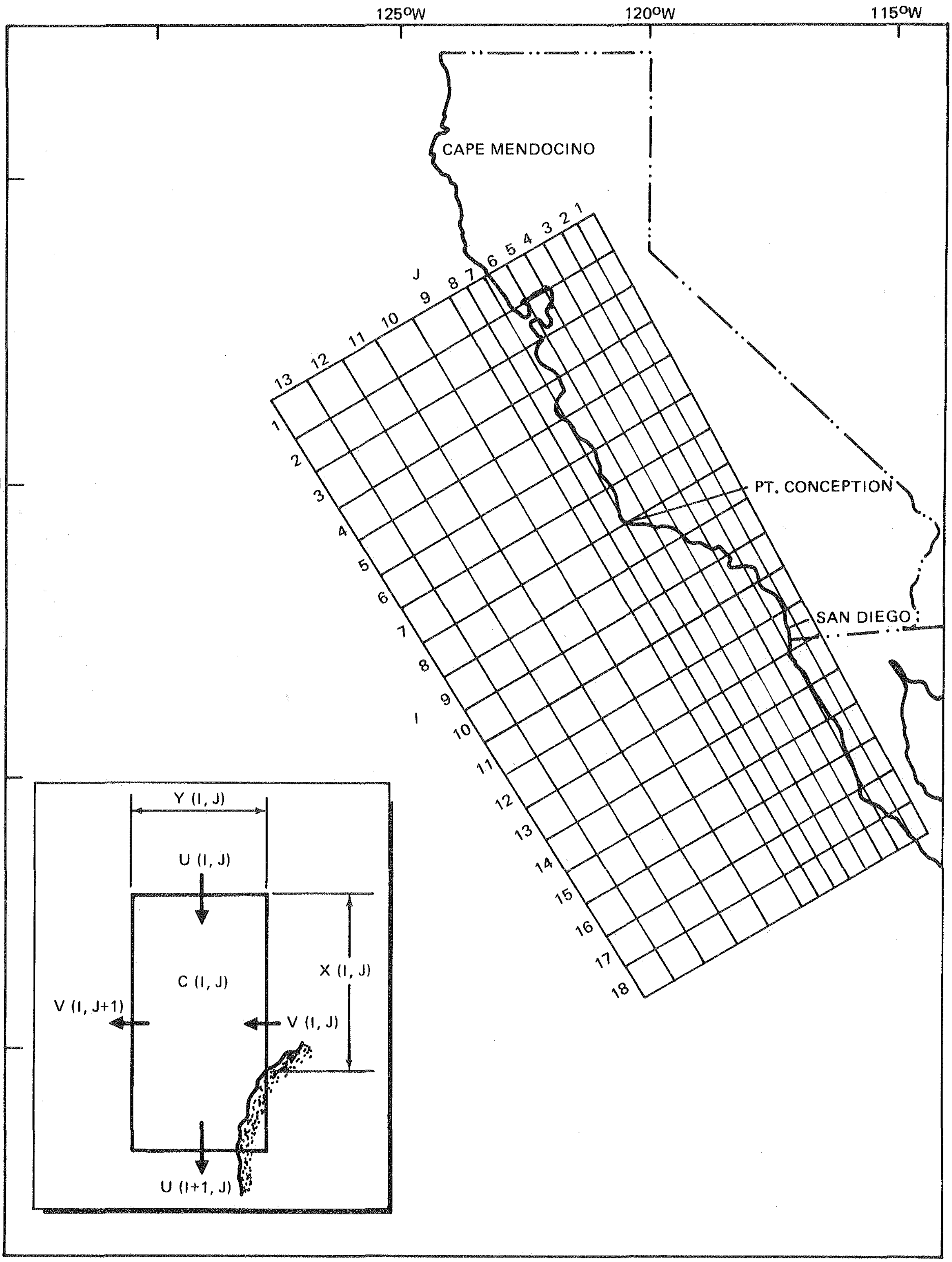


Figure 5-11. Definition and Location of Cells in Broad-Scale Dispersion Model

Figure 5-12A shows a typical dilution distribution for the combined wastewater discharges from the five major outfalls into the Bight, averaged over a period of 1 year. The units are expressed in terms of the quantity,

$$D_{10} = \log_{10} (\text{volume of effluent contained in a unit volume of ocean water})^{-1}$$

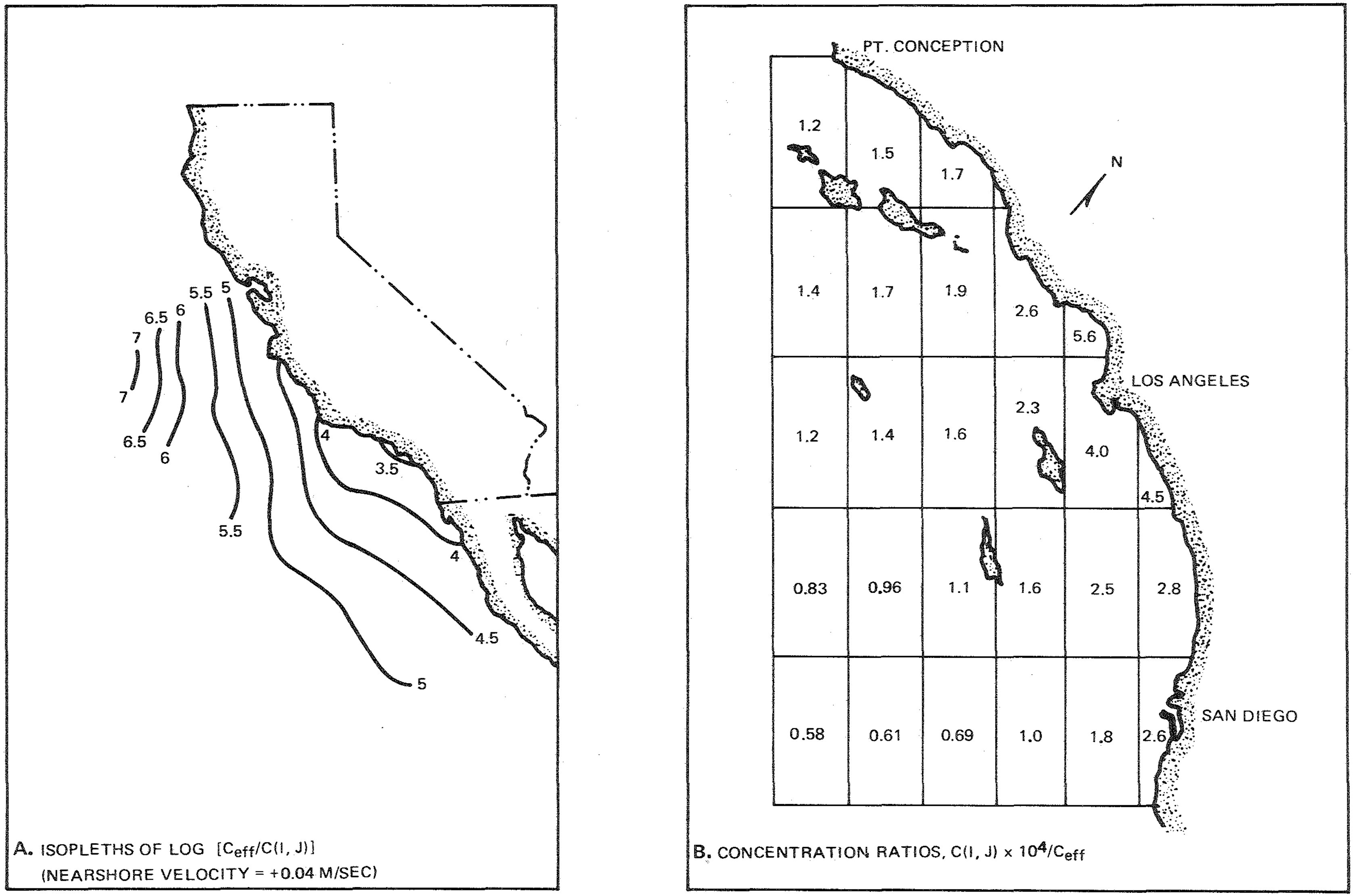
so that, for example, $D_{10} = 4$ corresponds to a dilution of 10^4 to 1. An expanded illustration of the effluent concentration distribution in the region from Point Conception to the Mexican border (including the Channel Islands) is shown in Figure 5-12B. It should be noted that the somewhat lower concentration in the cell containing the Whites Point outfall, compared with the cells containing the Hyperion and Orange County outfalls, is an artifact of the differing cell sizes. The model essentially assumes a uniform concentration within a cell, when, in reality, concentration gradients are present.

The illustrated distribution was obtained assuming a nearshore mean transport velocity (at the depth of the wastefield) of 4 cm/sec, flowing northwesterly for one-half of the year and southeasterly for one-half of the year. Similar distributions can be obtained for other nearshore current assumptions and for inputs from the surface runoff, aerial inputs, or discharges upstream from the Bight (see Appendix C).

The calculated concentration distributions have been used to estimate the flushing rates for the Bight with a variety of assumptions for the nearshore currents. The results are summarized in Table 5-6.

Considerable difficulty has been encountered in attempting to experimentally test the model. This is due, in part, to the choice of a "conservative" substance as a tracer, and to the necessity to sample at the wastefield depth for a rigorous comparison. The concentrations of DDE, lead, and cadmium in the digestive glands of intertidal mussels (discussed in Chapter 8) were used to test the model, although they are hardly ideal monitors since they sample the surface waters. and the observed concentrations are complicated by unaccounted for biological processes. In each case, the observed distributions were compared with the model predictions for wastewater inputs from outfalls, seasonally dependent surface runoff, and a spatially distributed source chosen to simulate aerial inputs. Some evidence of a correlation of DDE distribution with the Los Angeles County JWPCP outfall and of lead distribution with presumed aerial inputs was observed, although some anomalies were apparent in the case of DDE. These anomalies could be related to the possible absorption of DDE onto floatables or its incorporation into phytoplankton.

One value of this very preliminary version of a broad-scale dispersion model lies in the fact that it forces consideration of the many factors affecting observed phenomena in the Bight. As the model is improved and is made able to incorporate more complex processes, it will aid in establishing priorities for study of the multiple facets of the ecology of the Bight.



A. ISOPLETHS OF LOG $[C_{eff}/C(I, J)]$
(NEARSHORE VELOCITY = +0.04 M/SEC)

B. CONCENTRATION RATIOS, $C(I, J) \times 10^4/C_{eff}$

Figure 5-12. Dilution Isopleths for Combined Outfall Discharges

Table 5-6

RESIDENCE TIMES

Nearshore Current* Velocity (m/sec)	Residence Time (mo.)
± 0.04**	4.5
± 0.08**	3.0
+ 0.04	4.1
- 0.04	4.0
0.00	6.7
All Currents = 0† (Pure Diffusion)	20.3

*Nearshore currents are those in the cells adjacent to the coast. Other currents are calculated from geostrophy and continuity.

**Currents are along a southerly trending direction from April to September and along a northerly trending direction from October to March.

†Refers to removal by eddy diffusion in all cells, assuming no net advection in the entire area.

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Chapter 6

TRACE CONSTITUENTS IN SEDIMENT

6.1 INTRODUCTION

In recent years, much concern has been expressed over the fates and effects of metals and pesticides in municipal wastewaters discharged to the marine environment. Mercury and DDT have received the greatest public attention; however, there are a number of other metals and persistent organic compounds in wastewaters that are toxic to aquatic biota or humans. Although many studies have shown that concentrations of trace materials in fish may be several orders of magnitude greater than the concentrations in their immediate environment, there is very little information on the distribution of these constituents in nearshore waters and sediments. Even less is known about the mechanisms by which the biota take up these materials from the environment. As a first step in studying these problems, SCCWRP conducted special studies between 1970 and 1972 to determine the distribution of trace metals and organics in the sediments around several major wastewater outfalls.

6.2 SAMPLING AND ANALYSIS

Two types of coring devices were used to obtain sediment samples for the SCCWRP program. Most of the collections from the Palos Verdes, Santa Monica Bay and Point Loma areas were obtained with stainless steel Phleger corers with plastic liners. Because the average length of the cores obtained with this sampler is only 14 cm, and because vertical profiles from Phleger core samples are often distorted, metal box corers were used to take additional samples from off the Palos Verdes Peninsula and from Santa Monica Canyon areas. Box core samples were also taken from the Orange County and Oxnard areas. The box cores generally exceed 30 cm in length.

Upon collection, the Phleger corer barrels were plugged and returned to the laboratory for freezing and subsequent sampling. The box core collections were subsampled on board ship and frozen in polyethylene or glass containers. Following overnight drying at 110°C, analyses for metals (by atomic absorption spectrometry) were made on 1-gram, acid-digested samples. Samples for mercury analysis were processed and measured separately by refluxing with hot acid prior to analysis with a flameless atomic absorption technique. Analyses for chlorinated hydrocarbons were made using gas-liquid chromatography with electron capture detection.

6.3 TRACE METALS IN SEDIMENT

6.3.1 Distributions Around Major Outfall Systems

Whites Point Outfall Area

Sediment samples for trace metal analyses were collected from 26 locations (Figure 6-1) around the County Sanitation Districts of Los Angeles County wastewater outfall system off Whites Point on the Palos Verdes Peninsula. The samples, collected in May 1970 and July 1971, were analyzed for 10 metals:

Silver	Nickel
Cadmium	Lead
Chromium	Zinc
Cobalt	Iron
Copper	Manganese

The concentrations of these metals in the top 1-cm layer of both Phleger and box cores are listed in Table D-1 of Appendix D.

Most of the metals (with the principal exceptions of iron and manganese) showed strongly increased concentration in an area centered just to the northwest of the northernmost outfall. As an example, Figure 6-2 shows copper contours and concentration values obtained from Phleger core data. The maximum concentration (550 mg/dry kg) was found in the samples from Station B_1. This concentration is

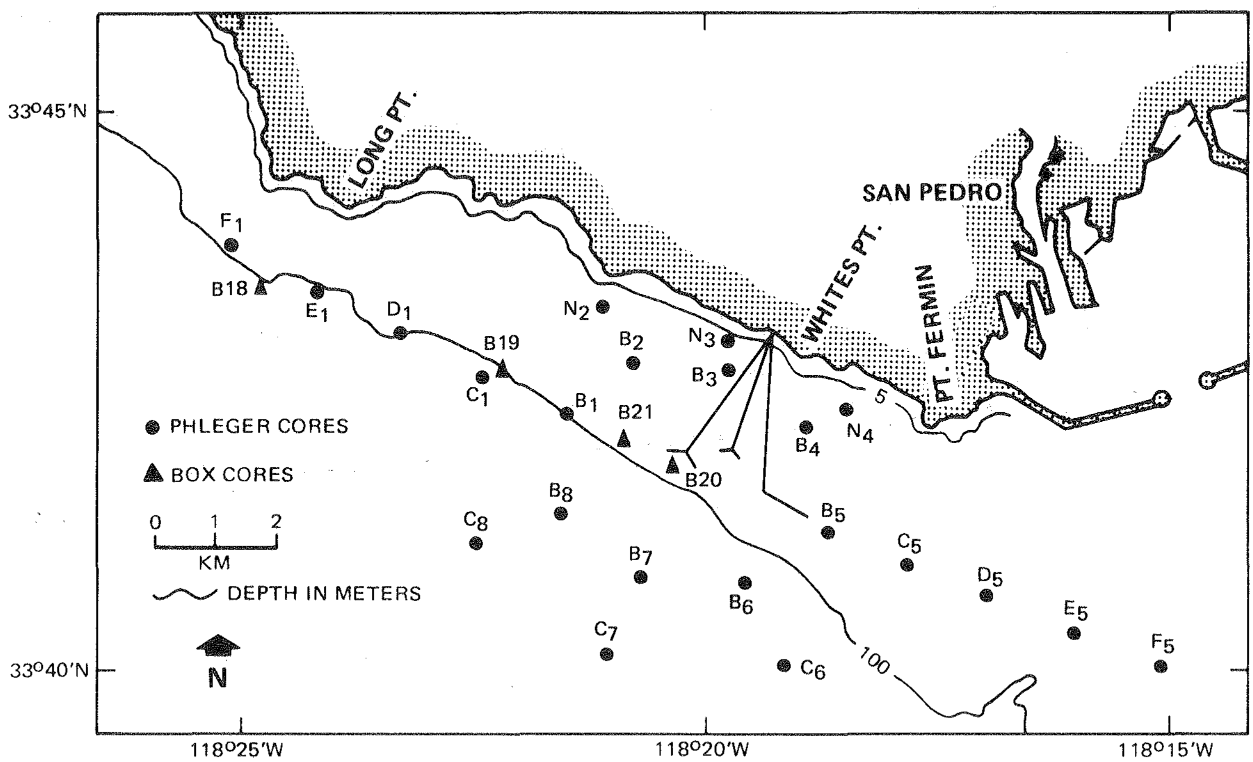


Figure 6-1. Sediment Core Collection Locations Around the Whites Point Outfall System.

about an order of magnitude higher than those observed near the shore or 6 to 10 km southeast of the outfall. A similar pattern was observed for lead (Figure 6-3): The maximum concentration (350 mg/dry kg) was observed at Station B_1.

Box core sampling stations were different, but the data collected with this sampler suggest the same pattern: Maximum concentrations of copper (670 mg/dry kg) and lead (490 mg/dry kg) were noted in samples from Station B21, located just northwest of the northernmost outfall.[1]

Maximum Phleger core concentrations of cadmium, chromium, nickel, and zinc occurred at either Station B_1 or, in the case of cadmium, at Station C_1. Highest concentrations of these metals in the box core camples occurred at Stations B20 and B21. The distribution of iron and manganese did not show a pattern of higher concentration in the vicinity of the outfall. Concentrations of these metals were relatively uniform: Iron values ranged from 11,000 to 37,000 mg/dry kg; manganese, from 120 to 410 mg/dry kg.

Mercury concentrations in the surface sediments were determined from Phleger core samples collected in June 1972 at the locations shown in Figure 6-4, which also shows the observed concentrations. For mercury (and for most of the other metals studied), the concentrations appear to be related strongly to both proximity to the outfalls and to water depth. That is, maximum surface sediment concentrations were observed between 40 and 100 meters depth, even at some distance to the northwest of the outfall. Concentrations to the southeast of the outfall fell off rapidly with distance.

Box core samples for vertical profiles were taken in July 1971 at the four box corer stations shown in Figure 6-1. These samples were sectioned every 2 cm, and separate analyses were made for each section. The results of analyses for copper, lead, manganese, and mercury are shown in Figure 6-5, and the complete set of analytical results is given in Table D-2 of Appendix D. The vertical distributions of copper, lead, and mercury showed remarkably similar patterns. Maximum concentrations in surface sediments were observed in samples from the three stations nearest the outfall; surface sediment values were significantly lower at Station B18, which is approximately 8 km northwest of the outfall. The distribution of manganese was significantly different in that concentrations were lowest in surface sediments and increased with depth; there appeared to be no significant difference between the manganese concentrations at the four stations. Concentrations of all four metals remained almost constant below a depth of 20 cm.

These data show that, for most of the metals analyzed, higher concentrations in the surface sediments are associated with the area of wastewater discharge.

Santa Monica Bay

In June 1970, Phleger core samples were collected from 26 stations (Figure 6-6) around the City of Los Angeles Hyperion outfall system in Santa Monica Bay. Box

1. The metal concentrations obtained from the Phleger cores were somewhat lower than those obtained from box cores taken at similar depths. This may be due to the fact that the Phleger corer "blasts away" the surface sediment layers before beginning to sample. The Phleger corer also significantly compacts the core.

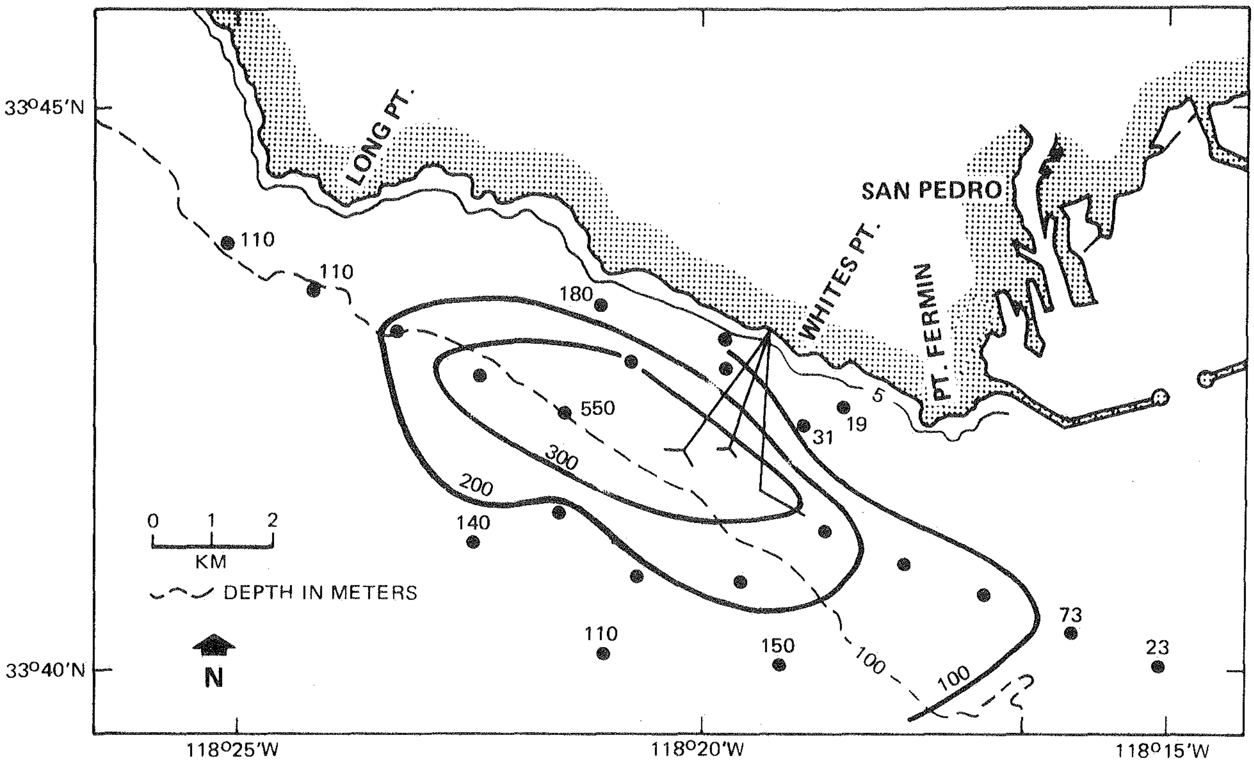


Figure 6-2. Copper Concentrations (mg/dry kg) in Surface Sediments Around the Whites Point Outfall System (Phleger Cores, May 1970).

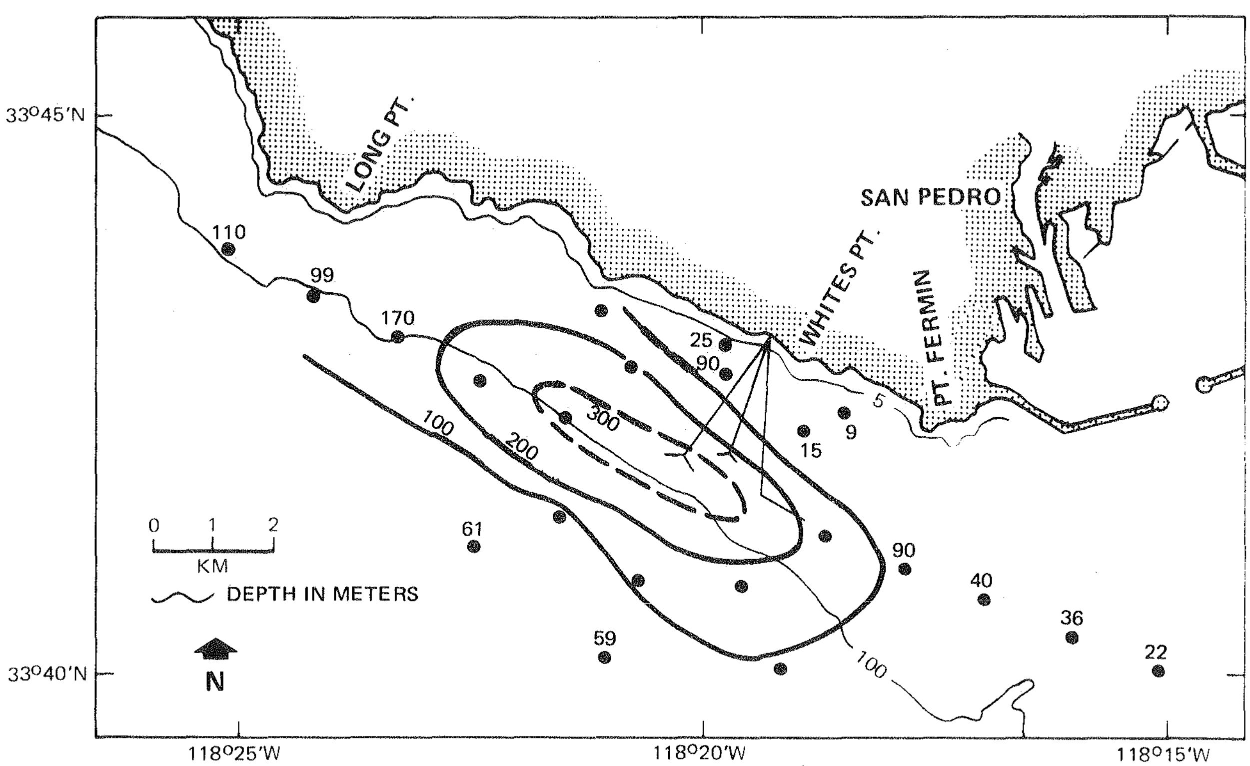


Figure 6-3. Lead Concentrations (mg/dry kg) in Surface Sediments Around the Whites Point Outfall System (Phleger Cores, May 1970).

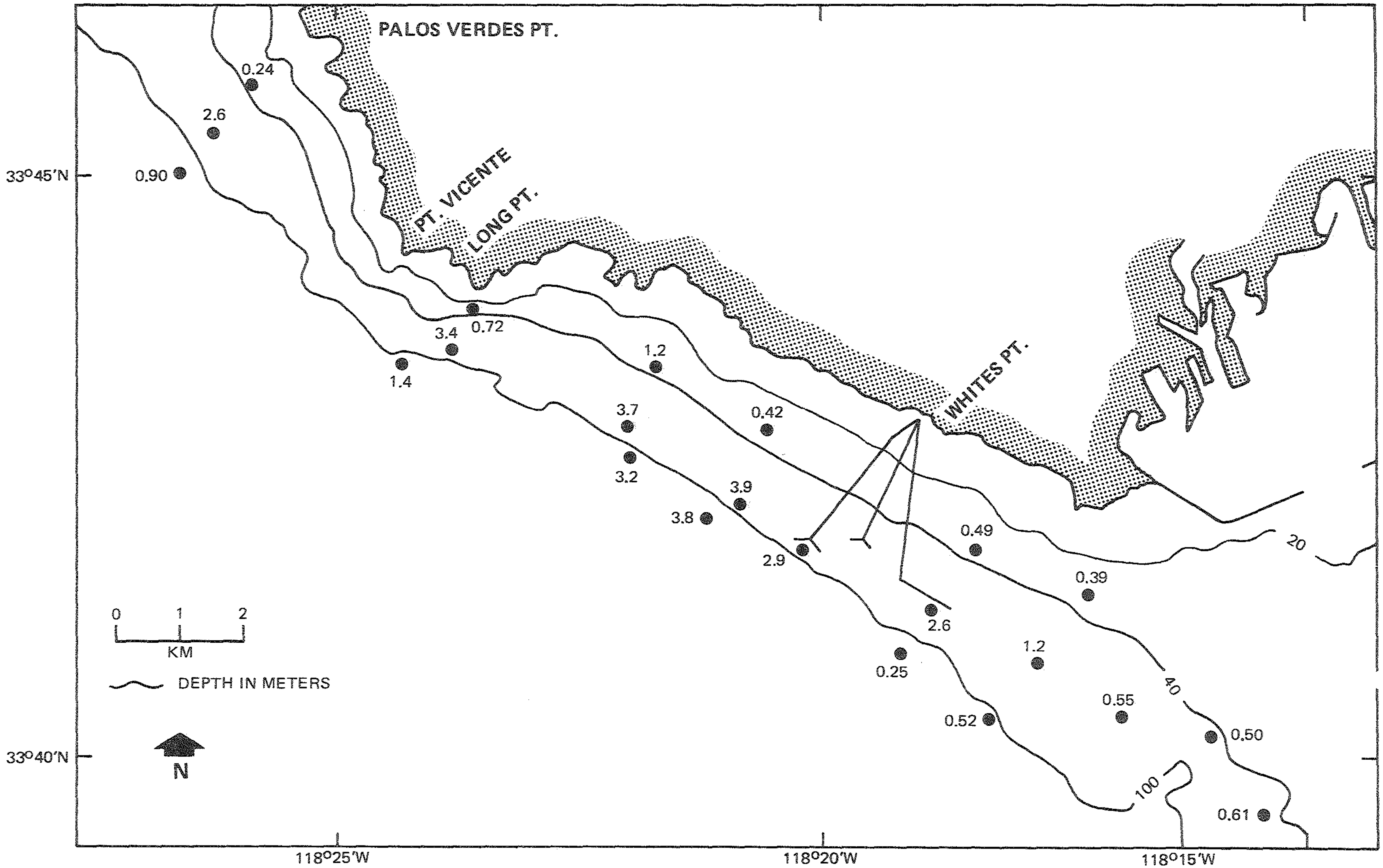


Figure 6-4. Mercury Concentrations (mg/dry kg) in Surface Sediments Around the Whites Point Outfall System (Phleger Cores, June 1972).

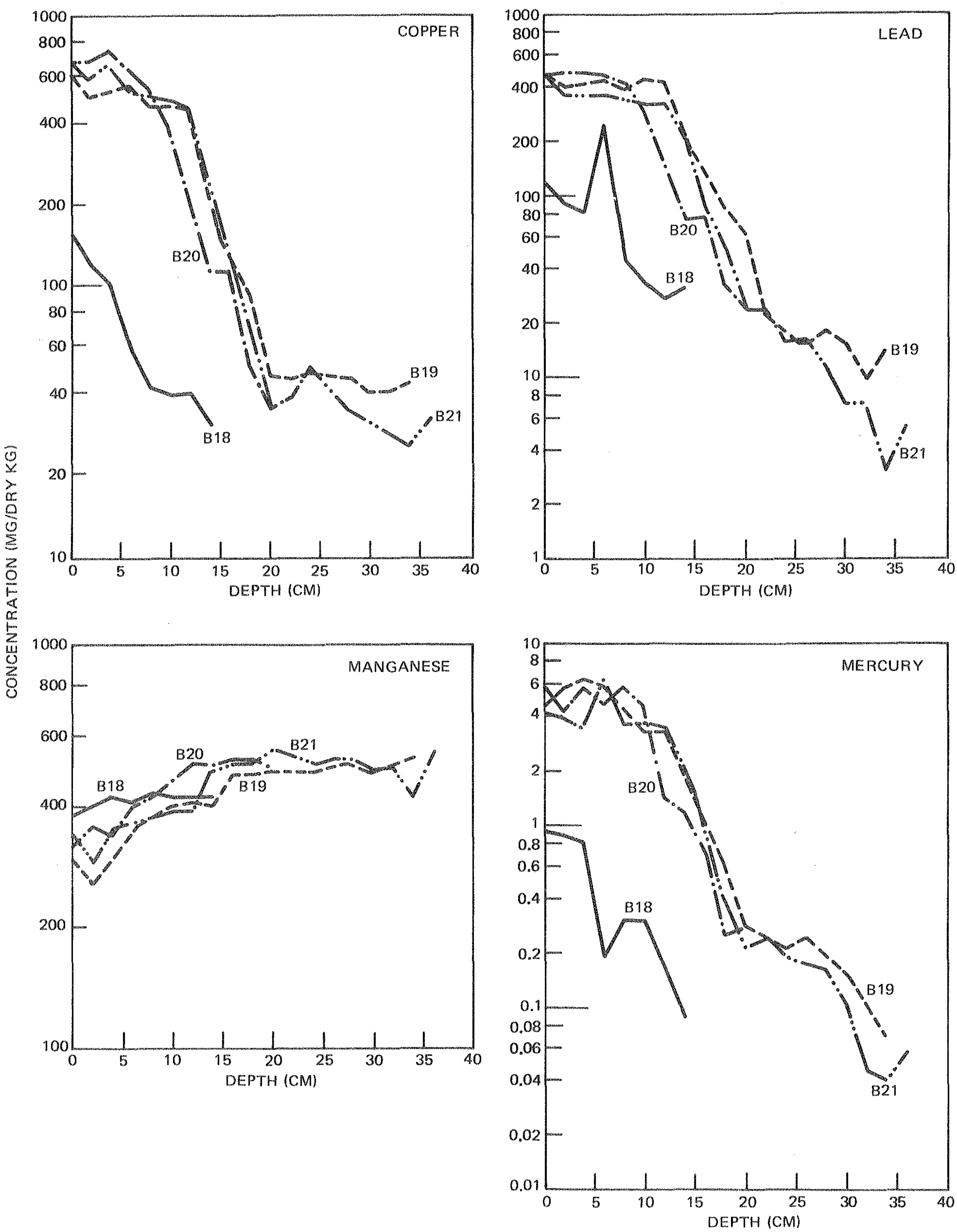


Figure 6-5. Vertical Profiles of Metal Concentrations in Sediments Collected Northwest of the Whites Point Outfall System (Box Cores, July 1971). Station Locations Shown in Figure 6-1.

core samples were collected from stations in Santa Monica Canyon (Figure 6-7) in July 1971. The upper 1 cm of each sample was analyzed for the same metals listed in the preceding section.

The distribution of surface concentrations of copper and lead are shown in Figures 6-8 and 6-9, respectively. The maximum copper concentration (500 mg/dry kg) was found in the box core sample from the station immediately west of the end of the sludge outfall at the head of Santa Monica Canyon. Although the concentrations obtained from box and Phleger cores differed, they show a fairly consistent pattern--highest concentrations were found near the ends of the outfalls. The distribution of lead concentrations in the surface sediments was generally similar to that for copper. The maximum concentration of lead, 250 mg/dry kg (box core), was observed at the station where the maximum copper concentration was found. The concentrations of lead generally decreased with distance from the ends of the outfall. However, relatively high lead concentrations (in the range of 30 to 60 mg/dry kg) were observed at the stations nearest the shore both north and south of the outfalls, suggesting the possibility of other significant inputs of lead to Santa Monica Bay.

Figure 6-10 shows the distribution of mercury in the surface sediments of Phleger cores collected in 1969 by Klein and Goldberg (1970) and Phleger cores taken in 1970 by personnel of the Hyperion Sewage Treatment Plant. Values shown are averages of these two collections. Again, the concentration contours show generally higher values around the termini of the outfalls. Samples were not collected from the eight stations immediately surrounding the end of the shorter (effluent) outfall, so the peak concentrations in this area are not known.

In July 1971, deeper box core samples were taken from the 17 stations shown in Figure 6-7. These stations are concentrated in and near Santa Monica Canyon. Concentration profiles of copper, lead, manganese, and mercury at four stations (B3, B6, B8, and SMC) are shown in Figure 6-11. The concentrations of copper, lead, and mercury at Station B3 (approximately 0.5 km from the end of the longer (sludge) outfall) tended to increase with depth in the sediment, although the subsurface concentrations are quite variable. In samples from Stations B6 and B8, which are about 1 and 2 km from the end of the outfall, concentrations of these three metals were highest at or near the surface and tended to decrease with depth, becoming relatively constant by a depth of about 20 cm. Concentrations of copper and lead at Station SMC (mercury was not measured at this station) were significantly lower than at the other three stations, and there was little variation with depth.

As was the case off Whites Point, the distribution of manganese differed greatly from that of most of the other metals. Manganese concentrations tended to increase with distance from the end of the sludge outfall. Concentrations at Station SMC were almost twice as great as those at Station B3. At all three stations, the changes of concentration with depth were quite small.

The analytical results for all of the metals tested in Santa Monica Bay are presented in Tables D-3 and D-4 of Appendix D.

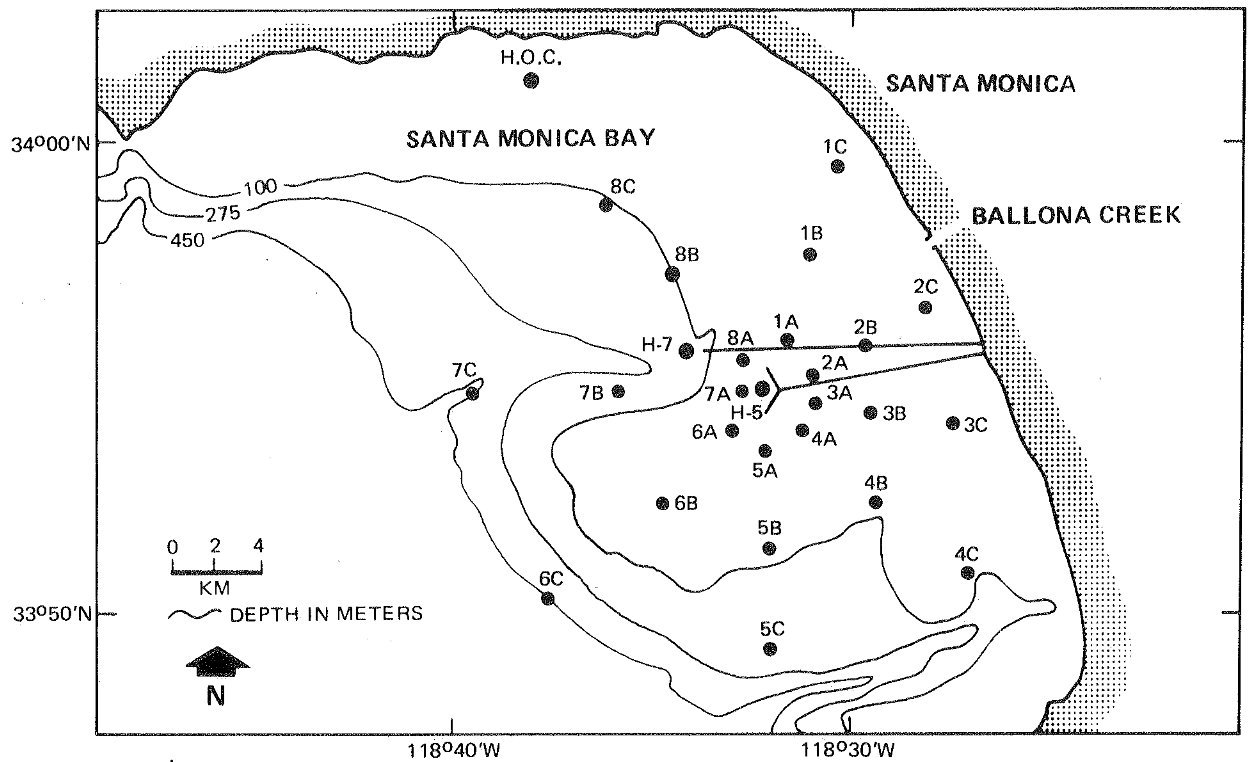


Figure 6-6. Phleger Core Collection Locations Around the Hyperion Outfall System, June 1970.

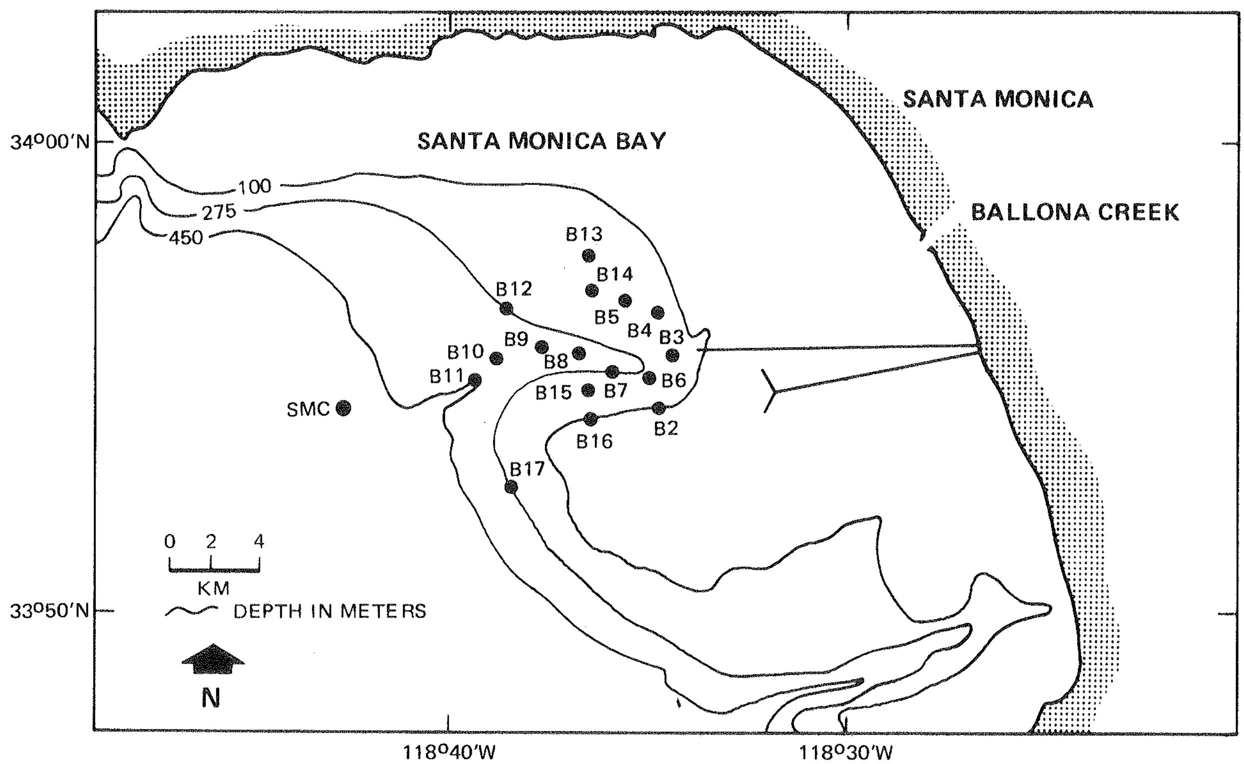


Figure 6-7. Box Core Collection Locations Around the Hyperion Outfall System, July 1971.

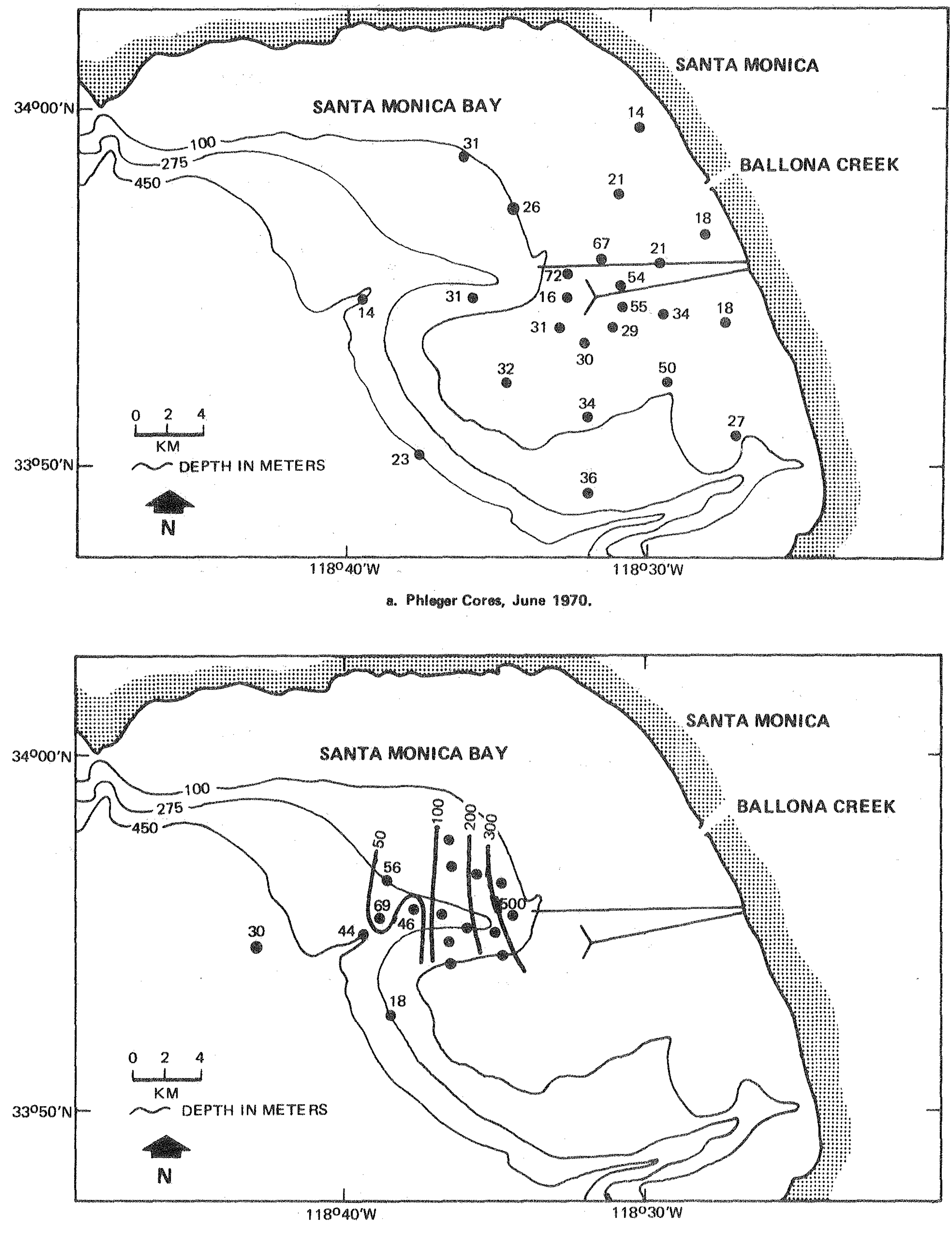
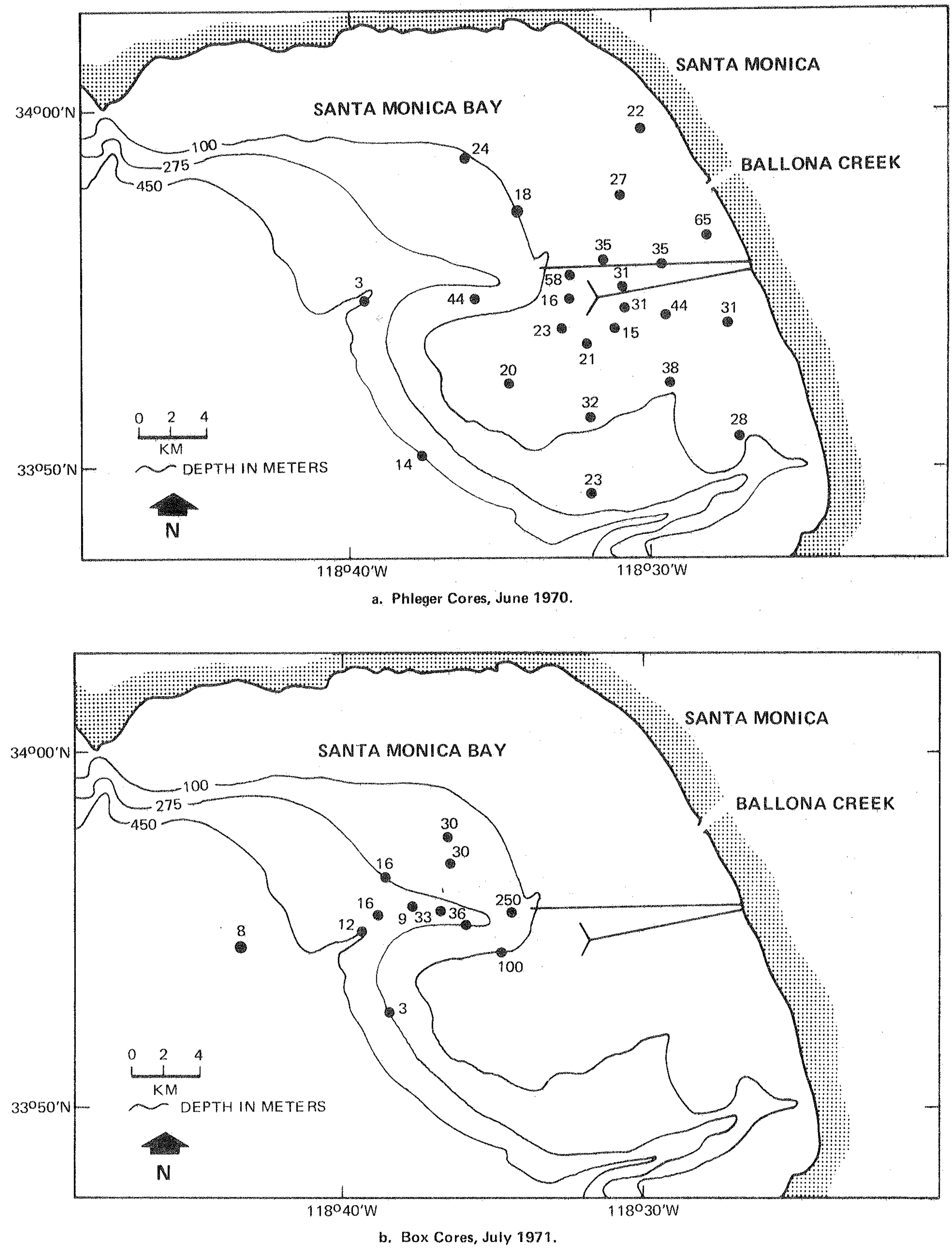


Figure 6-8. Copper Concentrations (mg/dry kg) in Surface Sediments Around the Hyperion Outfall System.



a. Phleger Cores, June 1970.

b. Box Cores, July 1971.

Figure 6-9. Lead Concentrations (mg/dry kg) in Surface Sediments Around the Hyperion Outfall System.

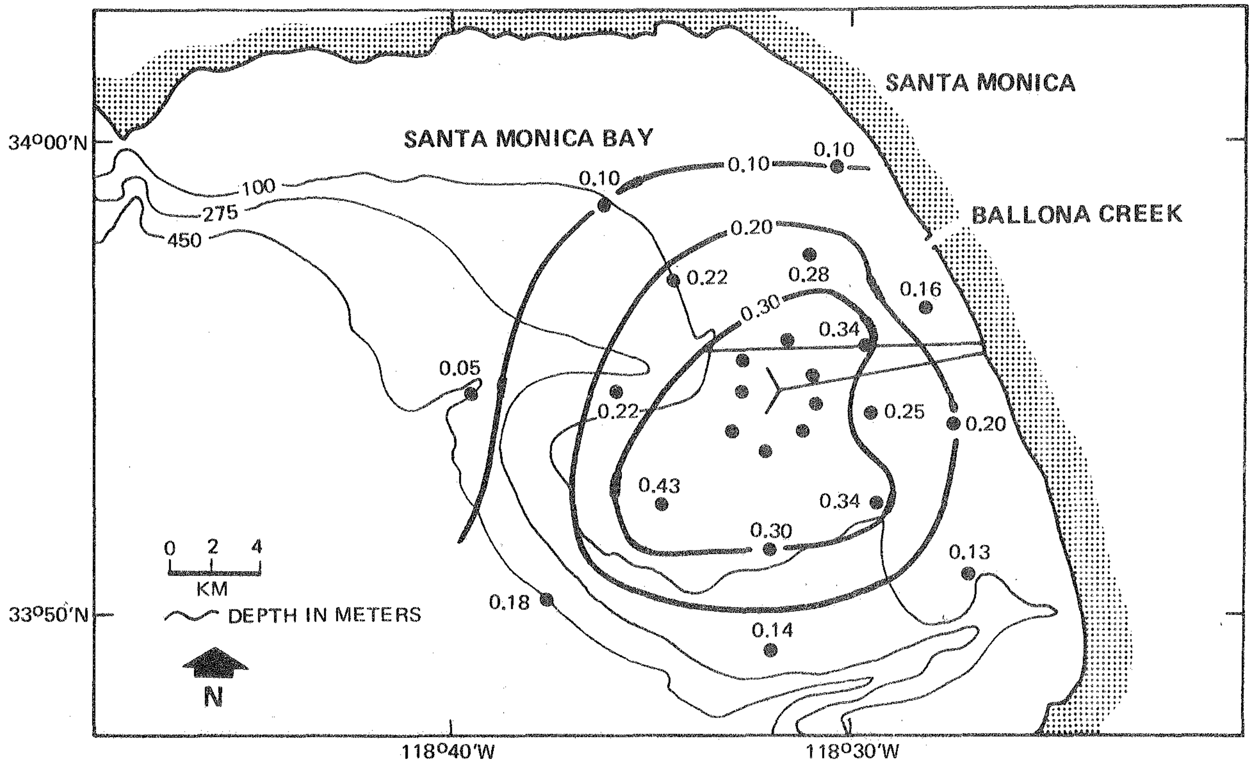


Figure 6-10. Mercury Concentrations (mg/dry kg) in Surface Sediments Around the Hyperion Outfall System (Phleger Cores, 1969 and 1970).

Orange County Outfall Area

In April 1971, the Orange County Sanitation Districts began operation of a new 6-km outfall and terminated wastewater discharge through the older 1.6-km outfall. Sediment core samples were taken from 22 stations surrounding these two outfalls in 1970 and 1971. The locations of these sampling stations are shown in Figure 6-12. Nine of the stations are located north and south of the outfalls along the 20-meter depth contour (the depth at which the old outfall discharged). Samples from these stations were collected in March and May of 1971 (before and after the outfall changeover) by divers using hand corers. Box core samples were collected from the other stations in October 1970 and September 1971. These samples were analyzed for silver, cadmium, chromium, copper, manganese, nickel, lead, and zinc. Mercury was analyzed in the box core samples collected in September 1971. The results of these analyses are presented in Table D-5 in Appendix D.

The copper concentrations in the surface sediments before and after the change in outfall are shown in Figure 6-13. Over the total area, the concentration varied from 12 to 55 mg/dry kg. In the period before the changeover (October 1970 and March 1971), the mean concentration to the southeast of the outfall in use at that time was 36.3 mg/dry kg, and the mean concentration of copper at the nine stations near the end of the new outfall was 20.4 mg/dry kg. In May 1971, approximately 1 month after abandonment of the old outfall, the concentration at

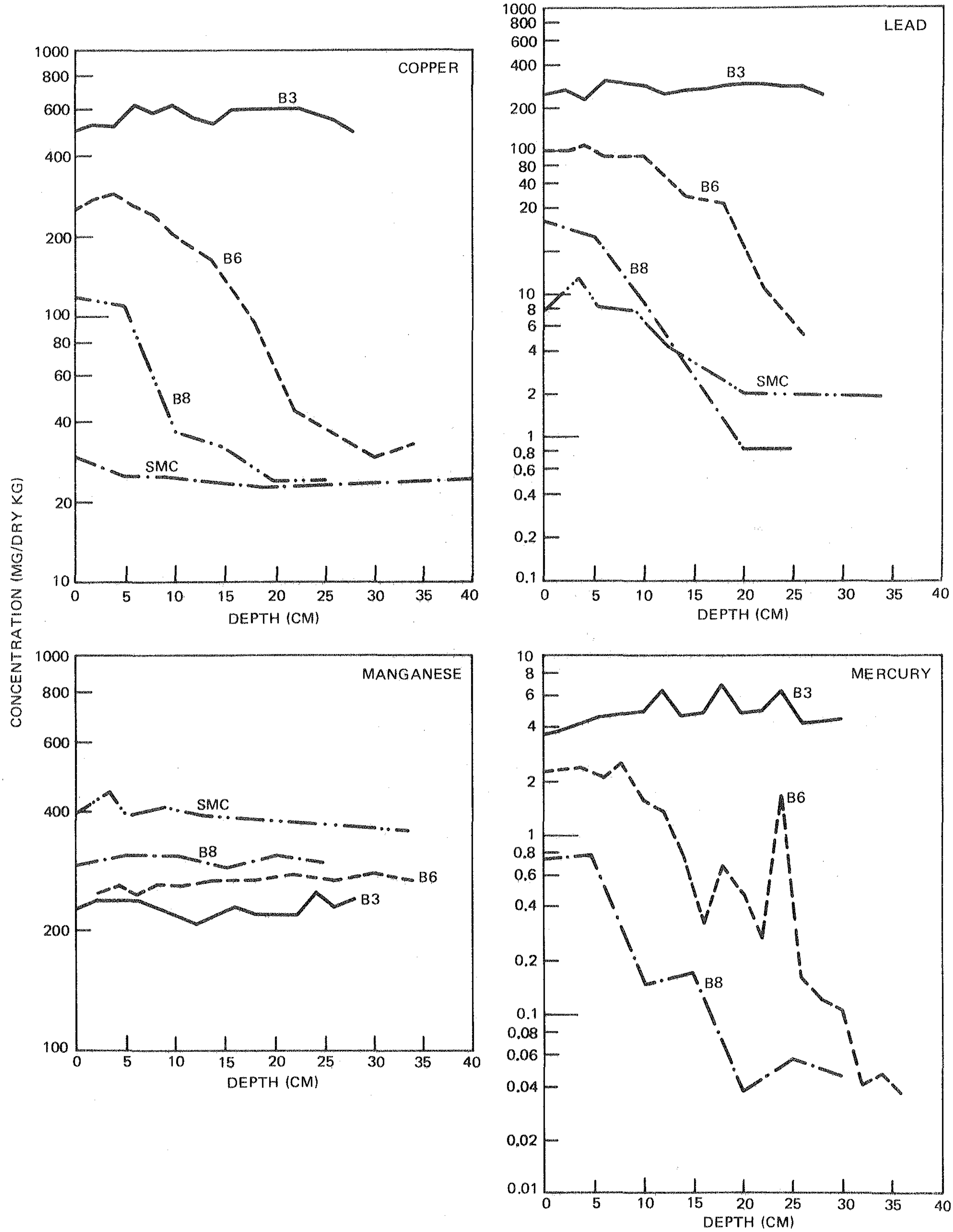


Figure 6-11. Vertical Profiles of Metal Concentrations in Sediments Collected in Santa Monica Canyon off the Hyperion Sludge Outfall (Box Cores, July 1971). Station Locations Shown in Figure 6-7.

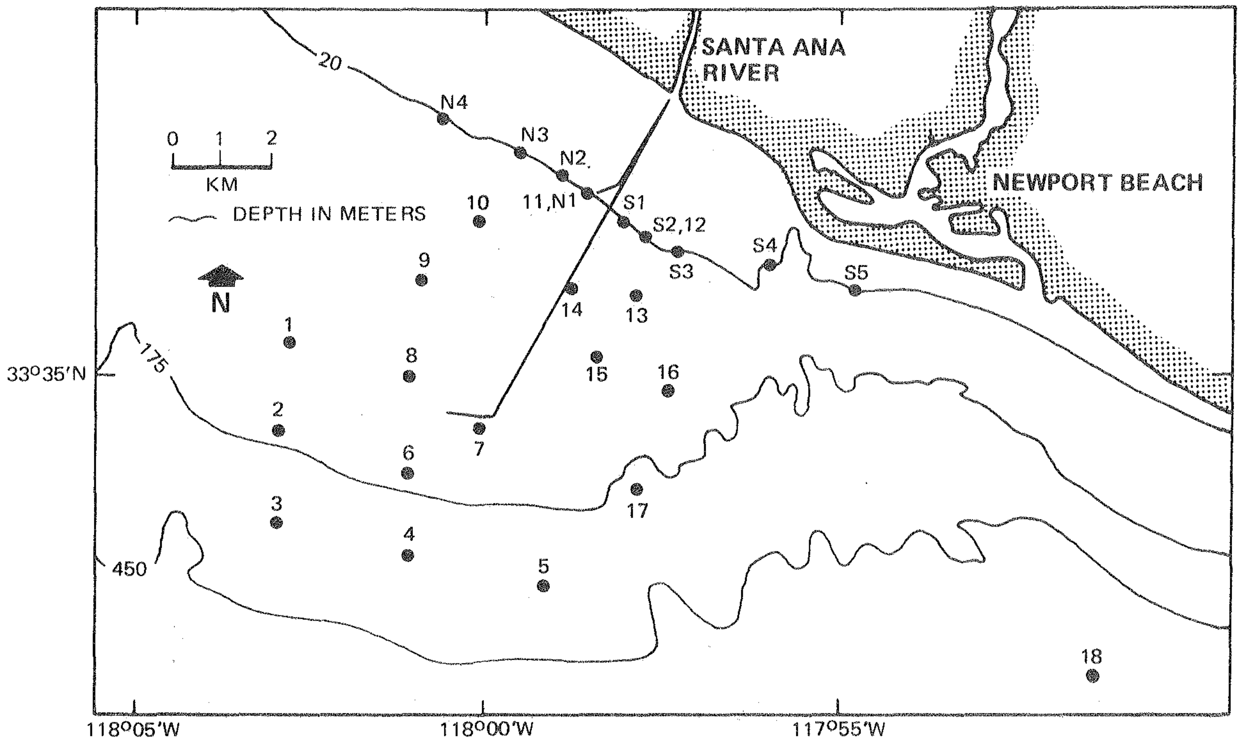


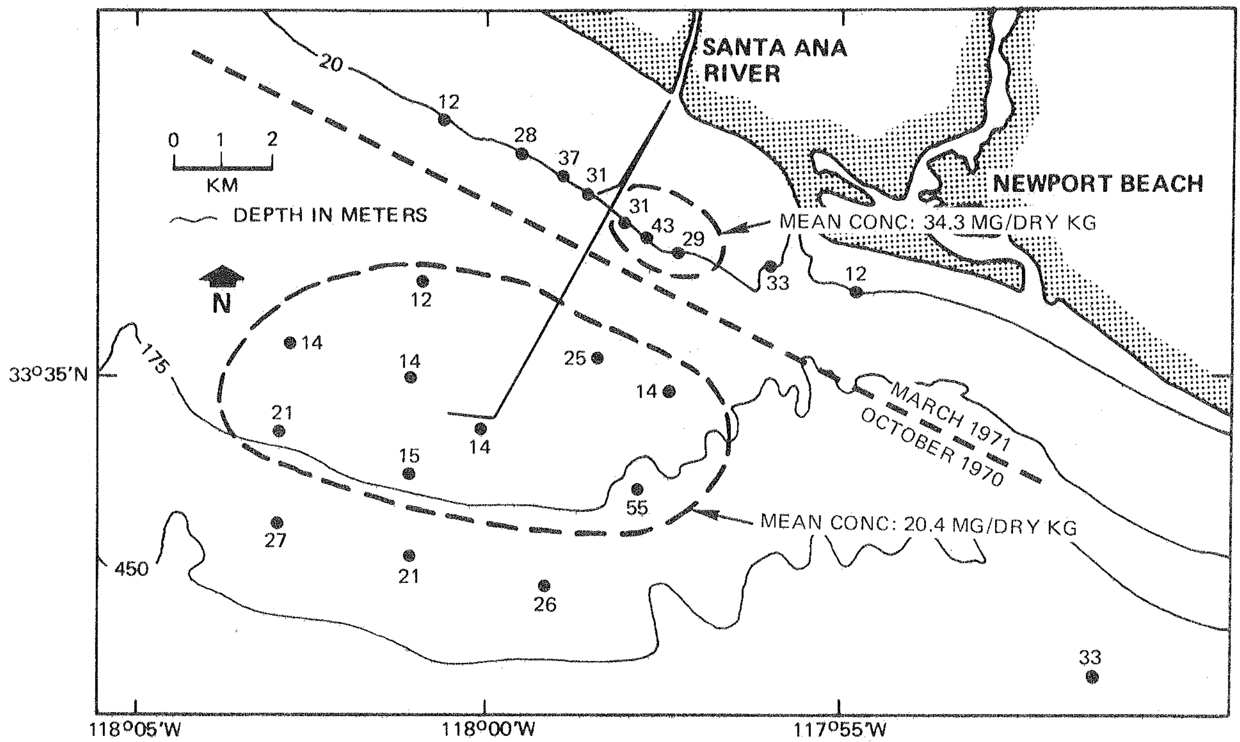
Figure 6-12. Sediment Collection Locations Around the Orange County Outfall System. Cores Along the 20-m Contour Collected by Divers; Others by Box Corer.

the same three stations southeast of the outfall had dropped to 23.3 mg/dry kg. Measurements near the new outfall in September 1971, 5 months after use of the new outfall began, showed an insignificant increase ($p > 0.3$) to a mean concentration of 20.7 mg/dry kg for the nine stations.

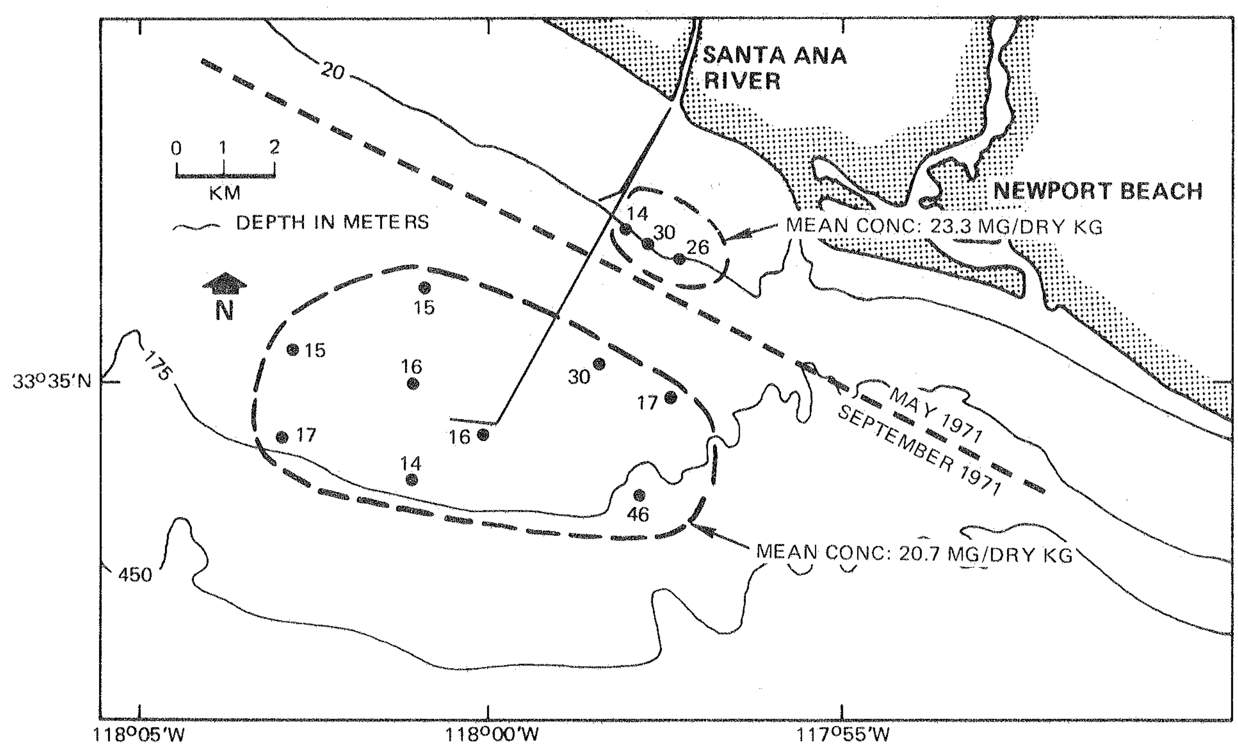
Results of a similar analysis for lead in surface sediments are shown in Figure 6-14. Lead concentrations over the entire area ranged from 6 to 62 mg/dry kg in the surface sediments. Before the change in outfalls, the mean concentration at the three stations southeast of the old outfall was 52 mg/dry kg. In the month following termination of this discharge, the mean concentration at these three stations had dropped to 34.7 mg/dry kg. In the area surrounding the new outfall, the mean lead concentration in October 1970 was 14.6 mg/dry kg. Five months after the initiation of the discharge, the mean concentration had increased to 16.6 mg/dry kg. This apparent increase is not statistically significant ($p > 0.3$).

Mercury concentrations in the sediments were not measured before the change in outfalls. In September 1971 (Figure 6-15), the concentrations of mercury ranged from 0.04 to 0.18 mg/dry kg. There was no particular pattern of concentration around either of the outfall termini.

It is clear from these data that the concentrations of at least some metals are responsive to changes in wastewater discharge and that, upon termination of a

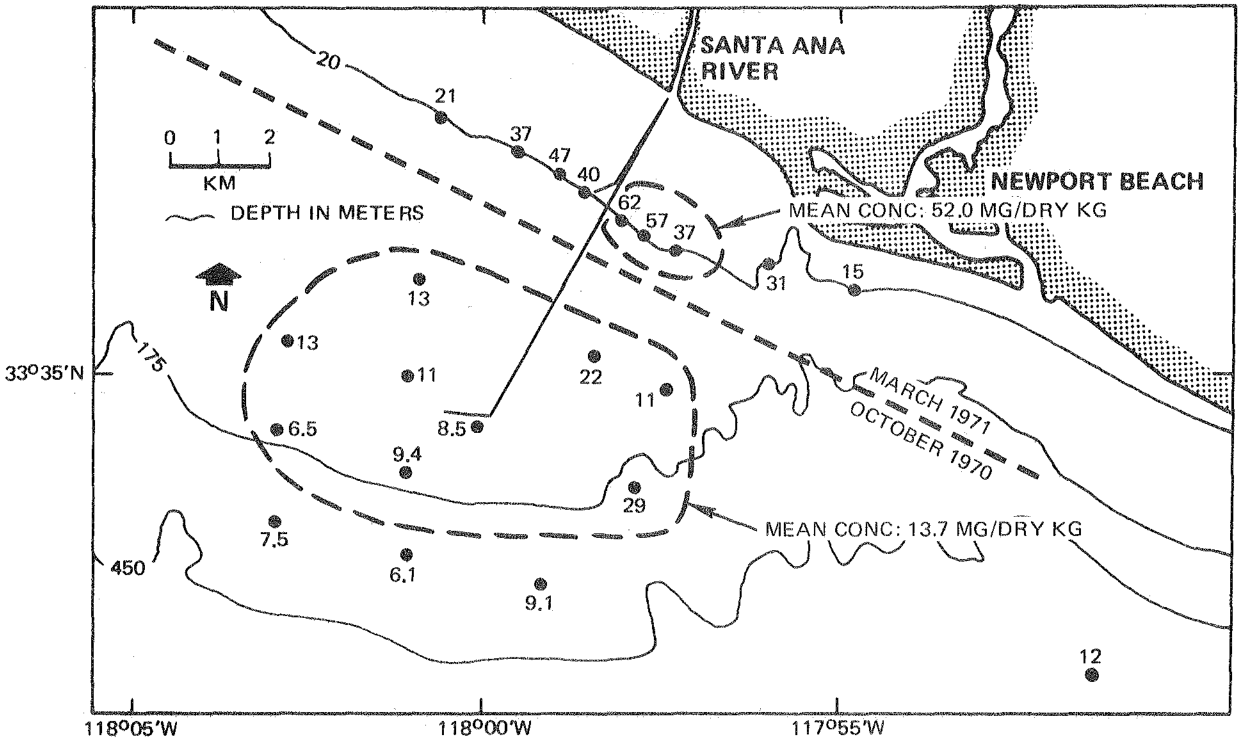


a. Cores Collected October 1970 and March 1971.

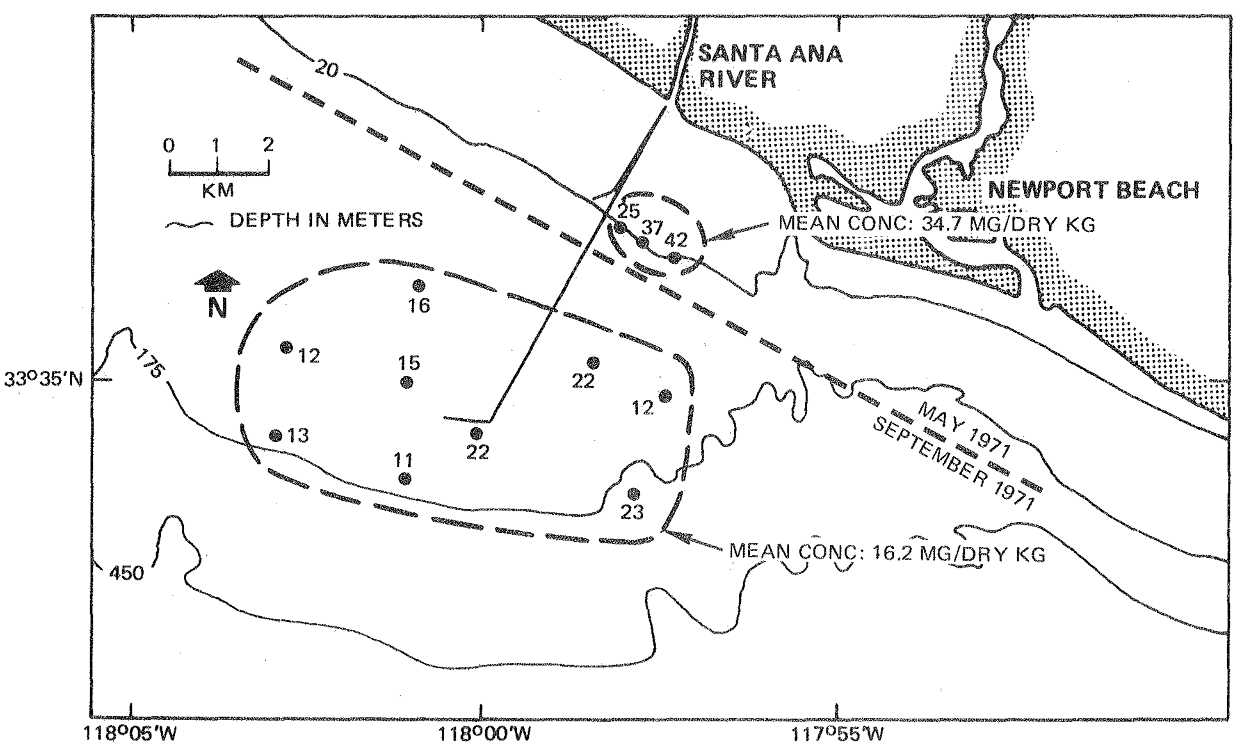


b. Cores Collected May and September 1971.

Figure 6-13. Copper Concentrations (mg/dry kg) in Surface Sediments Around the Orange County Outfall System.



a. Cores Collected October 1970 and March 1971.



b. Cores Collected May and September 1971.

Figure 6-14. Lead Concentrations (mg/dry kg) in Surface Sediments Around the Orange County Outfall System.

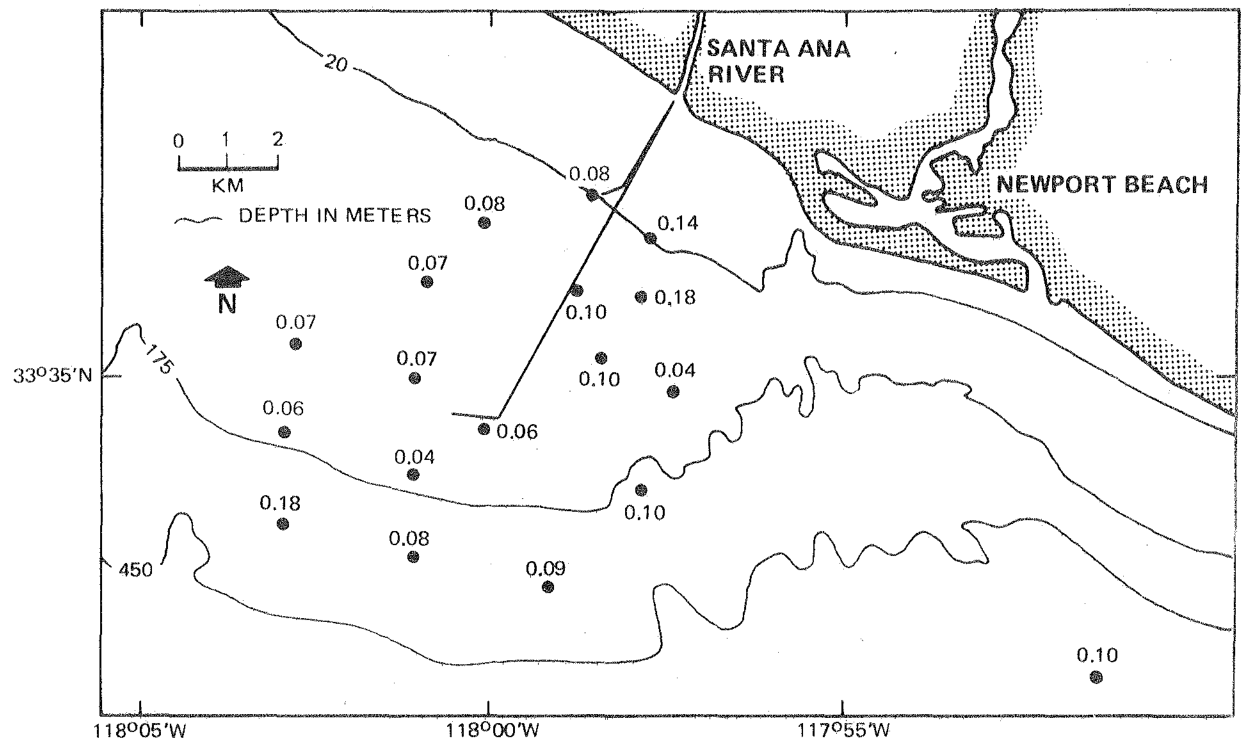


Figure 6-15. Mercury Concentrations (mg/dry kg) in Surface Sediments Around the Orange County Outfall System (Box Cores, September 1971).

discharge, there can be a fairly rapid decrease in sediment levels. This would imply a relatively rapid rate of exchange between the sediments and the waters overlying them.

Point Loma Outfall Area

The City of San Diego wastewater outfall extends out from Point Loma. In November and December of 1970, Phleger core samples from six stations around the outfall (Figure 6-16) were collected and analyzed for silver, cadmium, chromium, copper, iron, manganese, lead, and zinc. Maximum concentrations of cadmium, copper, and zinc were observed at station Y1B, centered in the wye of the outfall diffuser. One of the six stations was located in the harbor, and maximum concentrations of silver, chromium, and lead were found at this station. The results of all of these analyses are presented in Table D-6 of Appendix D.

Phleger cores for mercury analysis were obtained in August and September 1971, and Figure 6-17 shows the results of the analysis. Maximum concentrations (0.14 to 0.16 mg/dry kg) were found at three of the four stations directly north of the outfall. Lower concentrations (0.02 and 0.05 mg/dry kg) were observed at the two stations about 9 km south and north of the outfall, respectively.

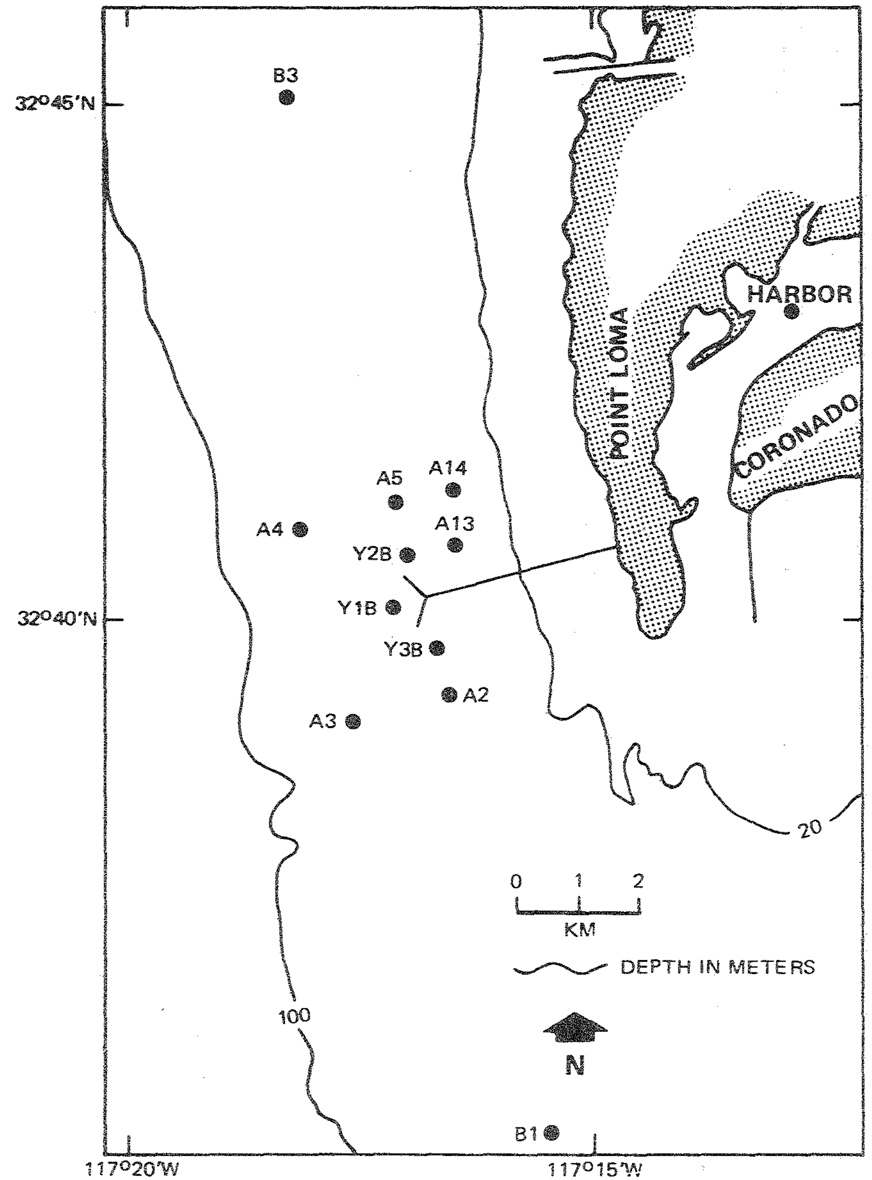


Figure 6-16. Phleger Core Collection Locations Around the Point Loma Outfall.

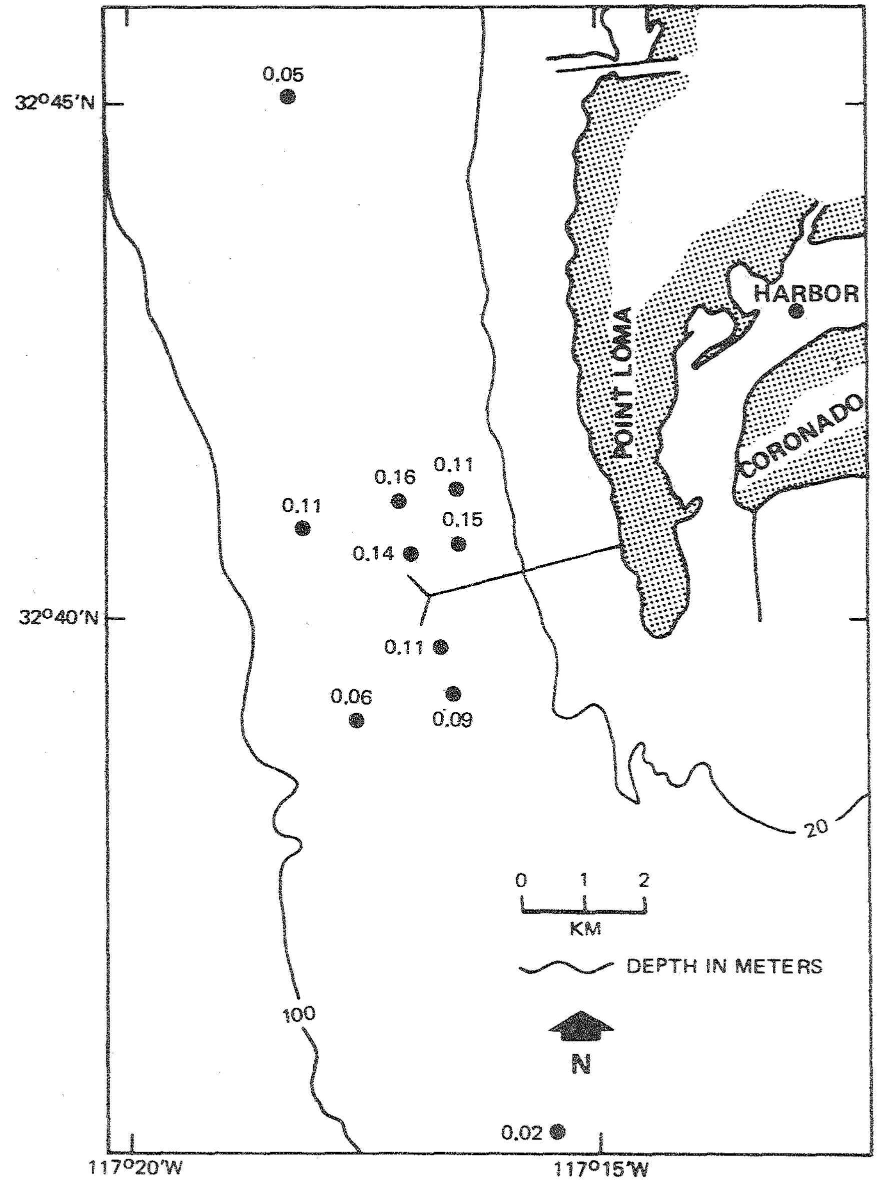


Figure 6-17. Mercury Concentrations (mg/dry kg) in Surface Sediments Around the Point Loma Outfall (Phleger Cores, Nov-Dec 1970).

Oxnard Outfall Area

Figure 6-18 shows the locations of 17 sampling stations in the vicinity of the City of Oxnard outfall. Six metals (silver, cadmium, chromium, copper, lead, and zinc) were measured at four of the stations (Stations 58, 59, 66, and 70). These data are presented in Table D-7 of Appendix D. The distribution of mercury concentrations in the surface sediments at 13 stations is shown in Figure 6-19. The concentrations in the 13 samples ranged from 0.02 to 0.10 mg/dry kg. There appeared to be no pattern to the concentrations except for the higher values to occur outside the 100-meter depth contour and to the southeast of the outfall.

6.3.2 Natural Sediment Metal Concentrations

The previous sections have described the distributions of various metals around five of the outfalls in the Southern California Bight. In some areas and for some metals, there appears to be an obvious "enrichment" in the sediments at the point of discharge. To provide a basis for estimating the degree of such enrichment, an estimate of the natural or background metal concentrations in these areas should be made. The vertical concentration profiles in Figures 6-5 and 6-11 suggest a method for determining such background concentrations. In these profiles (and in those for most other metals analyzed), concentrations were highest in the surface layers, presumably reflecting the effects of wastewater discharge. In the deeper layers of the cores, concentrations were generally lower and nearly constant.

As a consequence, the metal concentrations in the bottom layers of the cores--at sufficient depth presumably to be free of the influence of wastewater discharge--were assumed to be indicative of natural background levels. Table 6-1 gives an estimation of the background levels of 10 metals in each of the five outfall areas. These estimates are the means of metal concentrations in the bottom layers of cores from each of the areas.

Because of the differences in concentrations obtained from Phleger and box cores (and because of the limited number of box core samples), only Phleger core data were used for the estimates of background metal concentrations off Whites Point and in Santa Monica Bay. In the area off Whites Point, concentrations at depths of 20 cm or greater in the cores were used. In Santa Monica Bay, where the cores were somewhat shorter and the metal concentrations less, the minimum depth selected for inclusion in the estimates was 15 cm.

The values in Table 6-1 for any given metal in each of the five areas are similar. For silver, cadmium, and mercury, the ratio of highest to lowest value was 2.5; the high and low values for each of the other metals differed by less than a factor of 2. The mean estimated background concentration for each metal in nearshore sediments is also shown in Table 6-1; these values are the average over the five outfall areas.

6.3.3 Surface Sediment Enrichment Around Outfalls

The degree of enrichment around each of the outfalls was estimated by averaging the surface metal concentration at stations within a radius of approximately 1.5 km from the wastewater outfalls and dividing this average by the estimated natural background level from Table 6-1. These "enrichment ratios" are presented in Table 6-2. The highest ratio obtained was 70 for mercury in the area off

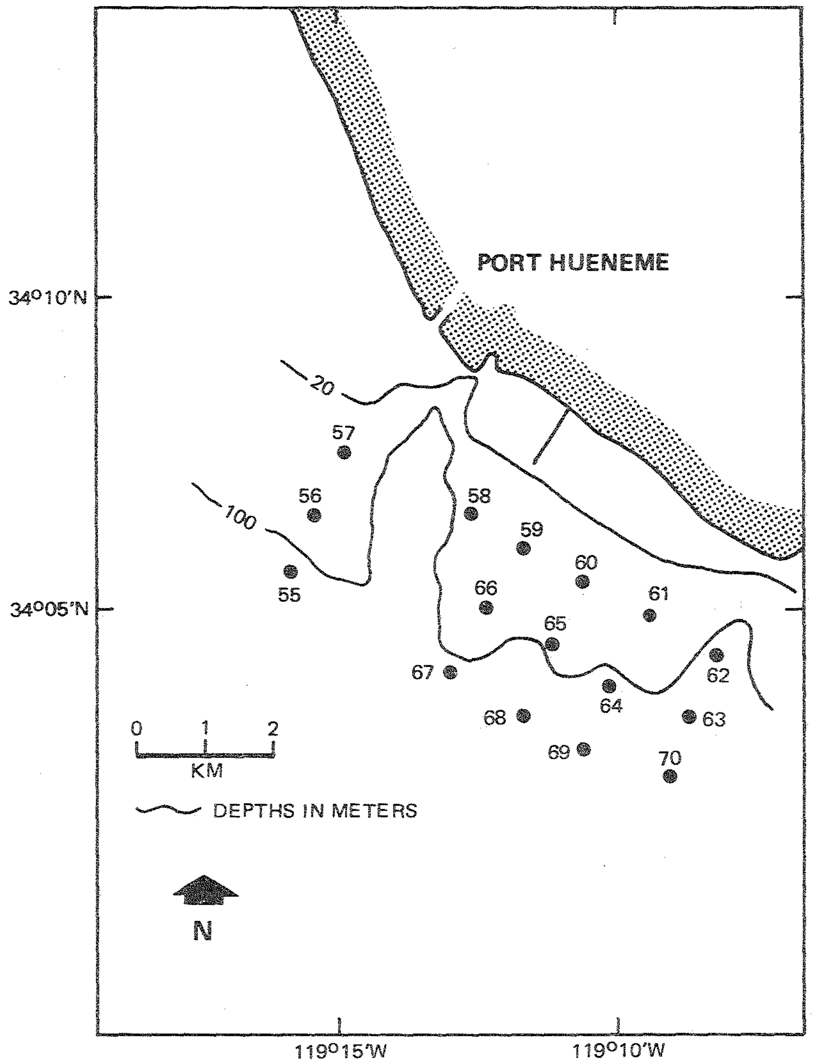


Figure 6-18. Box Core Locations Around the Oxnard Outfall.

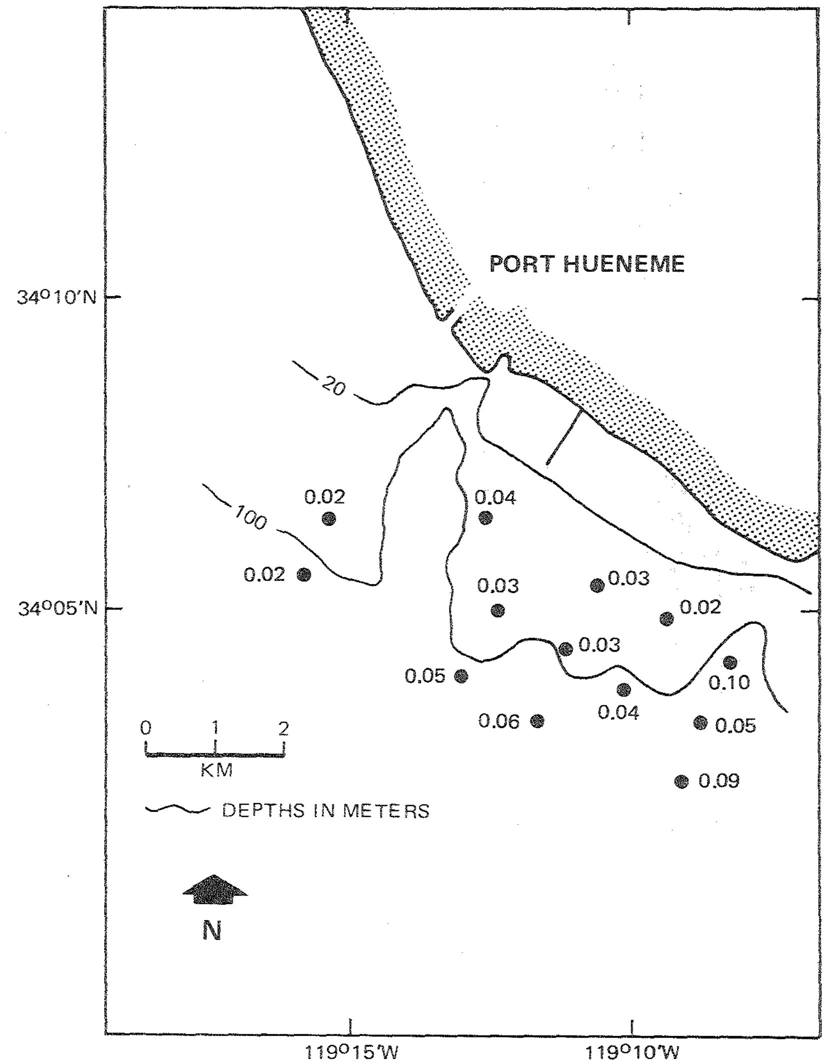


Figure 6-19. Mercury Concentrations (mg/dry kg) in Surface Sediments Around the Oxnard Outfall (Box Cores, August 1971).

Table 6-1
ESTIMATED BACKGROUND CONCENTRATIONS (MG/DRY KG) OF
TRACE METALS IN THE SEDIMENT AROUND MAJOR OUTFALL SYSTEMS

Metal	Whites Point	Santa Monica Bay	Orange County	Point Loma	Oxnard	Five-Area Mean (Nearshore Sediment Background Concentration)
Silver						
Mean	0.61	0.71	1.5	0.88	1.5	1.0
Std. Error	0.05	0.08	0.08	0.34	0.09	0.19
No. of Samples	9	11	30	4	3	5
Cadmium						
Mean	0.42	0.22	0.53	0.48	0.20	0.37
Std. Error	0.04	0.03	0.08	0.09	0.07	0.07
No. of Samples	9	11	19	4	3	5
Cobalt*						
Mean	9.3	5.0	---	---	---	7.2
Std. Error	1.0	0.27	---	---	---	2.2
No. of Samples	10	12	---	---	---	2
Chromium						
Mean	53	62	34	39	41	46
Std. Error	5.6	5.4	2.3	2.5	5.6	5.1
No. of Samples	10	11	30	5	5	5
Copper						
Mean	21	13	14	14**	18	16
Std. Error	2.3	1.0	1.5	---	2.9	1.5
No. of Samples	10	11	30	---	5	5
Iron						
Mean	27,000	20,000	---	29,000	---	25,000
Std. Error	1,500	1,600	---	810	---	2,700
No. of Samples	10	12	---	5	---	3
Mercury						
Mean	0.043	0.043	0.019	0.046	0.035	0.037
Std. Error	0.007	0.003	0.003	0.012	0.006	0.005
No. of Samples	5	9	5	6	5	5
Manganese						
Mean	390	230	390	280	---	320
Std. Error	11	22	15	9.0	---	40
No. of Samples	10	12	21	5	---	4
Nickel†						
Mean	17	15	9.4	---	---	14
Std. Error	1.2	1.1	0.71	---	---	2.0
No. of Samples	10	10	30	---	---	9
Lead						
Mean	6.2	6.9	10	7.5	12	8.5
Std. Error	1.0	0.60	1.2	1.8	1.5	1.1
No. of Samples	8	12	30	5	5	5
Zinc						
Mean	75	57	67	54**	61	63
Std. Error	4.0	4.6	3.7	---	4.4	3.7
No. of Samples	10	11	30	---	5	5

*These values are approximations ±50%
**Summary value; see Galloway (1972)
†These values are approximations ±30%

Table 6-2
AVERAGE ENRICHMENT RATIOS* FOR TRACE METALS IN SURFACE SEDIMENTS (0-1 CM) AT A RADIUS OF 1.5 KM FROM MAJOR WASTEWATER DISCHARGES

Metal	Whites Point	Hyperion**	Orange County†	San Diego	Oxnard
Silver	4.8	5.4	1.7	1.8	0.93
Cadmium	64	13	4.9	0.79	1.3
Cobalt	0.85	1.2	-	-	-
Chromium	6.8	1.8	1.4	1.0	0.83
Copper	11	3.4	2.0	1.3	0.78
Iron	1.0	0.90	-	0.97	-
Mercury	70	5.1	5.3	2.6	1.1
Manganese	0.85	1.1	1.0	0.93	-
Nickel	1.6	1.3	1.0	-	-
Lead	24	4.2	3.9	1.3	1.3
Zinc	8.8	1.9	1.3	1.0	0.72

*Relative to the natural concentration of the metal in the sediment for each outfall region (Table 6-1).
**"Five-mile" effluent outfall.
†Old Orange Country outfall.

Whites Point, although the ratio for cadmium, 64, was nearly as high. Mercury and cadmium were among the three metals having the highest observed ratios in each of the five areas. Lead was also among the top three in four of the five areas. Both iron and manganese showed a ratio of about 1 or less, indicating no substantial enrichment from the wastewater outfalls. Although cobalt was measured in only two areas (off Whites Point and in Santa Monica Bay), the ratios obtained--0.85 and 1.2, respectively--would suggest that the outfalls were not a significant source of this metal. There is also an obvious general relationship between the enrichment ratios for most of the metals and the size of the wastewater discharge: The highest enrichment ratios observed were for the Whites Point and Hyperion areas; the smallest were for the Oxnard outfall area. Part of the explanation for this, of course, may be in the selection of stations 1.5 km from the outfalls. If data were available from locations closer to the outfalls and a shorter distance were used for the Oxnard estimates, for example, the ratios might have been more comparable.

During the summer of 1971, composite wastewater samples were collected over a period of 1 week. These samples were filtered through a 0.45-μ millipore filter, and the concentrations of metals in the filter residues were measured. The results of these analyses, as well as the estimated natural or background concentrations of the metals in the sediments, are presented in Table 6-3. For most of the metals, the concentrations associated with the wastewater solids are from 20 to 320 times as high as the estimated background levels in the sediments. The concentrations of iron and manganese in the wastewater solids are less than one-half the estimated background levels; the cobalt concentrations in the wastewater solids and the natural levels in the sediments are similar.

Table 6-3
CONCENTRATIONS (MG/DRY KG) OF TRACE METALS IN WASTEWATER PARTICULATES

Metal	Whites Point	Hyperion Effluent	Hyperion Sludge	Orange County	Point Loma	Oxnard	Mean*	Nearshore Sediment Background Concentration**
Silver	32	130	265	40	105	30	67	1.0
Cadmium	65	108	180	245	65	115	120	0.37
Cobalt	8	4	23	-	8	15	9	7.2
Chromium	1,700	1,440	3,430	1,330	1,000	350	1,160	46
Copper	1,120	1,500	2,500	1,850	1,600	1,000	1,410	16
Iron	20,000	5,400	13,000	7,000	10,000	9,000	10,300	25,000
Manganese	150	108	156	120	200	140	144	320
Nickel	220	520	670	220	310	145	283	14
Lead	570	320	1,000	920	545	300	531	8.5
Zinc	4,100	2,300	4,820	2,330	3,000	1,500	2,650	63

*Excluding Hyperion sludge data.
**From Table 6-1.

In Table 6-4, the Whites Point average enrichment ratio (Table 6-2) is compared with the ratio of the metal concentrations in wastewater particulates to the natural background level. The metals in Table 6-4 are ranked according to the enrichment ratio; the correlation between this ranking and the ranking based on wastewater particulate concentrations is extremely high.

6.3.4 Historical Record of Sediment Metal Concentrations in the Santa Barbara Basin

As described in Chapter 3, there are a number of deep basins within the Southern California Bight. These basins generally are removed from the direct influence of discharged wastewaters or surface runoff. As a consequence, the concentrations of metals in the basin sediments may be useful in providing another estimate of natural or background metal concentrations.

Two of the basins are anoxic and therefore do not support benthic fauna that might disturb the sediments. Box core samples were obtained from one of these basins, the Santa Barbara Basin. Because of the lack of disturbing influences, it was possible to identify the annual depositions of sediments in a manner analogous to enumerating growth rings in a tree section. Dated sediment layers from the box core samples were analyzed for several metals.

Figure 6-20 shows copper and lead concentrations in the dated sediment layers of one core taken in the Santa Barbara Basin. The results of analyses for silver, cadmium, cobalt, chromium, manganese, nickel, and zinc are presented in Table 6-5.

The copper profile in Figure 6-20 is reasonably typical of most of the metals studied, except lead and mercury (and possibly silver and zinc); the constant

Table 6-4
COMPARISON OF SEDIMENT ENRICHMENT RATIOS AND WASTEWATER-TO-BACKGROUND RATIOS FOR TRACE METALS AROUND THE WHITES POINT OUTFALLS

Metal	Enrichment Ratio*	Wastewater-to-Background Ratio**
Mercury	70	-†
Cadmium	64	176
Lead	24	67
Copper	11	70
Zinc	8.8	65
Chromium	6.8	37
Silver	4.8	32
Nickel	1.6	16
Iron	1.0	0.80
Manganese	0.85	0.47
Cobalt	0.85	1.1

*From Table 6-2.
**Ratio of metal concentration in wastewater solids (Table 6-3) to background metal concentration (Table 6-1).
†Not measured in wastewater solids.

Table 6-5

CONCENTRATIONS (MG/DRY KG) OF TRACE METALS IN DATED VARVED SEDIMENTS OF THE SANTA BARBARA BASIN

Date	Silver	Cadmium	Cobalt*	Chromium	Copper	Manganese	Nickel**	Lead	Zinc
1962	5.0	2.7	4.6	81	31	310	13	39	230
1957	2.9	3.3	6.4	79	30	240	13	25	100
1952	2.5	2.9	5.5	68	30	200	13	9.3	92
1947	2.6	2.0	6.5	75	30	210	14	9.1	93
1942	2.5	2.2	6.9	74	31	210	15	7.5	99
1936	2.4	2.6	6.5	74	30	210	14	8.7	97
1931	2.2	2.7	4.2	68	27	210	12	7.4	85
1925	2.5	1.9	6.7	74	30	210	16	6.0	80
1920	2.3	2.0	5.7	74	29	210	13	9.0	85
1915	2.4	2.9	5.4	66	27	210	13	5.9	87
1910	2.4	2.0	5.1	61	27	200	12	7.0	85
1905	2.4	1.9	7.0	68	29	210	15	10	92
1900	2.4	2.6	5.0	56	23	160	13	4.2	66
1895	2.2	1.9	5.8	68	29	200	14	3.2	84
1890	2.3	3.4	4.9	69	28	210	13	7.3	90
1885	2.5	1.7	6.8	65	29	210	15	5.9	87
1880	2.0	1.5	5.4	65	27	190	14	4.6	82
1875	2.3	2.0	4.7	61	27	180	14	4.4	88
1870	2.4	1.6	6.1	66	27	210	15	3.5	91
1865	2.3	2.0	6.6	68	30	200	14	4.9	85
1858	2.1	4.3	5.7	63	29	200	12	5.7	89
1851	2.2	7.4	6.7	66	30	230	15	4.6	100
1846	2.2	2.0	5.6	60	26	210	11	7.1	93
1840	2.5	1.6	6.6	66	30	220	14	6.9	95
1835	2.4	2.2	5.0	62	32	230	13	7.3	93

*These values are approximations ±50%.
**These values are approximations ±30%.

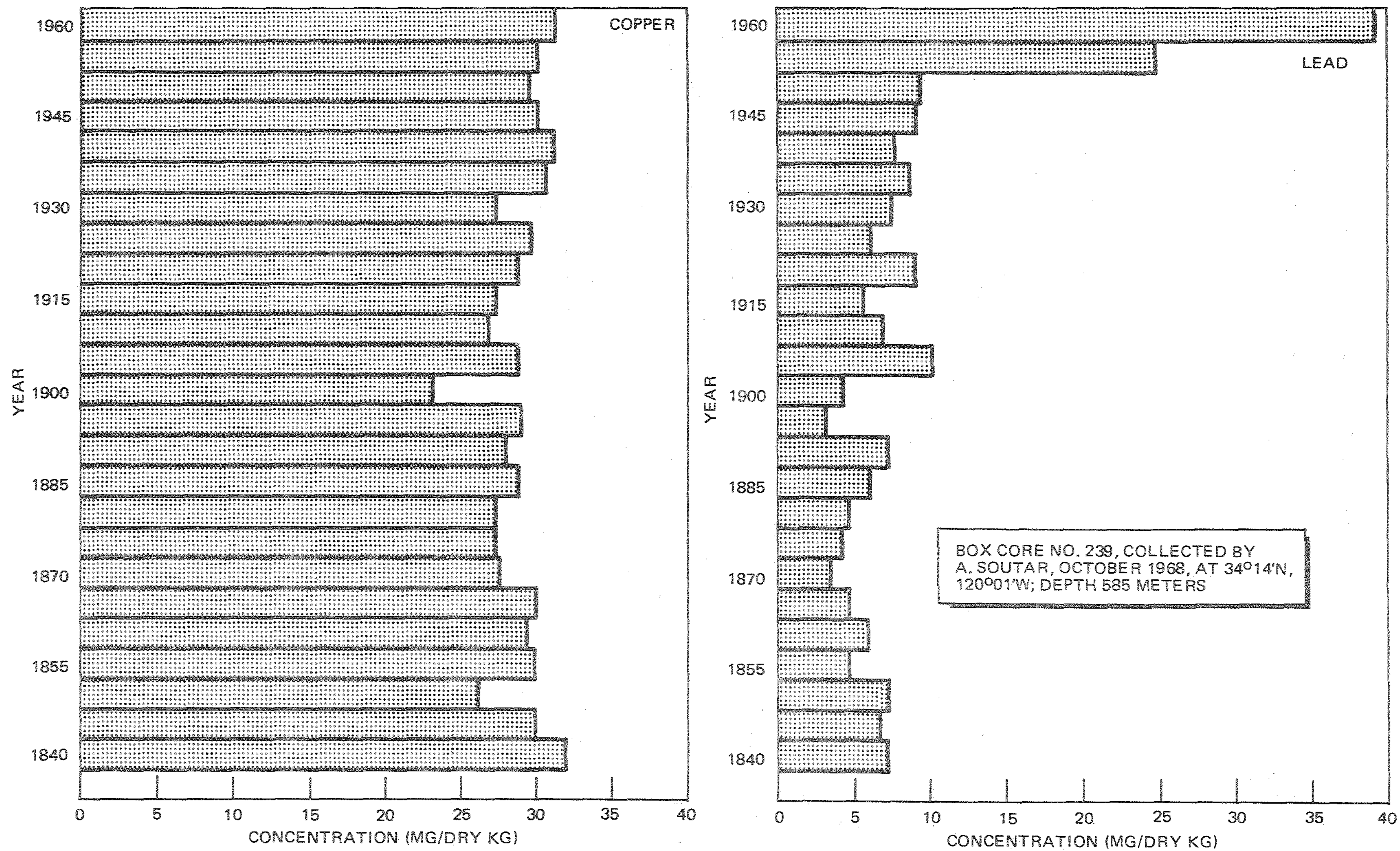


Figure 6-20. Concentrations of Copper and Lead in Dated Varved Sediments from the Santa Barbara Basin.

profiles suggest that there have not been any large-scale anomalous inputs of these metals to the Santa Barbara Basin during the last century. For example, there is no indication that recent inputs from specific point sources such as wastewater or industrial waste discharges have significantly influenced the sediments of the Basin: The copper concentration in the sediment is essentially the same now as it was more than 100 years ago, in the range of 25 to 35 mg/dry kg (compare this value with the "background" value for copper of 16 mg/dry kg given in Table 6-1).

The profile for lead shows a relatively constant concentration (7 to 8 mg/dry kg) in the layers from 1840 through about 1950. However, between 1950-60, the concentrations increased to nearly 40 mg/dry kg. The timing of this rise in lead concentrations is coincident with the rapid increase in the use of high compression automobiles and leaded gasoline in the Los Angeles area following World War II, suggesting that the increased lead concentrations may be due to aerial fallout. The estimated background concentration of lead around the wastewater outfalls of 8.5 mg/dry kg (Table 6-3) is consistent with the concentrations found in the deeper layers of the core from the basin.

Figure 6-21 shows the profile of mercury concentrations from the dated sediment layers in the Santa Barbara Basin. In addition to the regular box core samples, samples were obtained using a "bootstrap" corer, which provided samples dating back 1,400 and 1,500 years. The concentrations of mercury have tended to increase fairly steadily in the last 150 years; sediment mercury concentrations are now approximately twice as great as they were in the 1820's. This observation is consistent with that of Weiss et al. (1971), who found approximate doubling of mercury concentration in dated glacial layers laid down in the Arctic in the last few decades. These authors have attributed this effect to an increased degassing of mercury from the earth's surface, possibly brought about by man's activities. Although the higher concentrations of lead in the recent sediments appear to be due to increased use of leaded gasoline in southern California, the source of mercury that has caused the recent concentration increases may be much more global in nature.

It should be noted that this discussion assumes that the increased concentration of metals in the surface layers of the sediment is due to deposition rather than to upward migration of the metals from deeper layers. This latter explanation for the observed concentration patterns is a possibility that must be investigated.

6.4 CHLORINATED HYDROCARBONS IN SEDIMENT

Most of the Phleger and box core samples described in Section 6.3 were also analyzed for chlorinated hydrocarbons (total DDT and total PCB).

6.4.1 Whites Point Outfall Area

Measurements of total DDT and total PCB were made at the stations shown in Figure 6-22. Maximum concentrations of total DDT (Figure 6-22) were observed at the stations immediately adjacent to the outfalls and to the northwest. In general, concentrations declined both to the north and to the south of the outfall system, although the decline was more rapid to the south. DDT and PCB concentrations, like those of the metals studied, appeared to be highest in surface sediments taken between the 40- and 100-meter water depth contours.

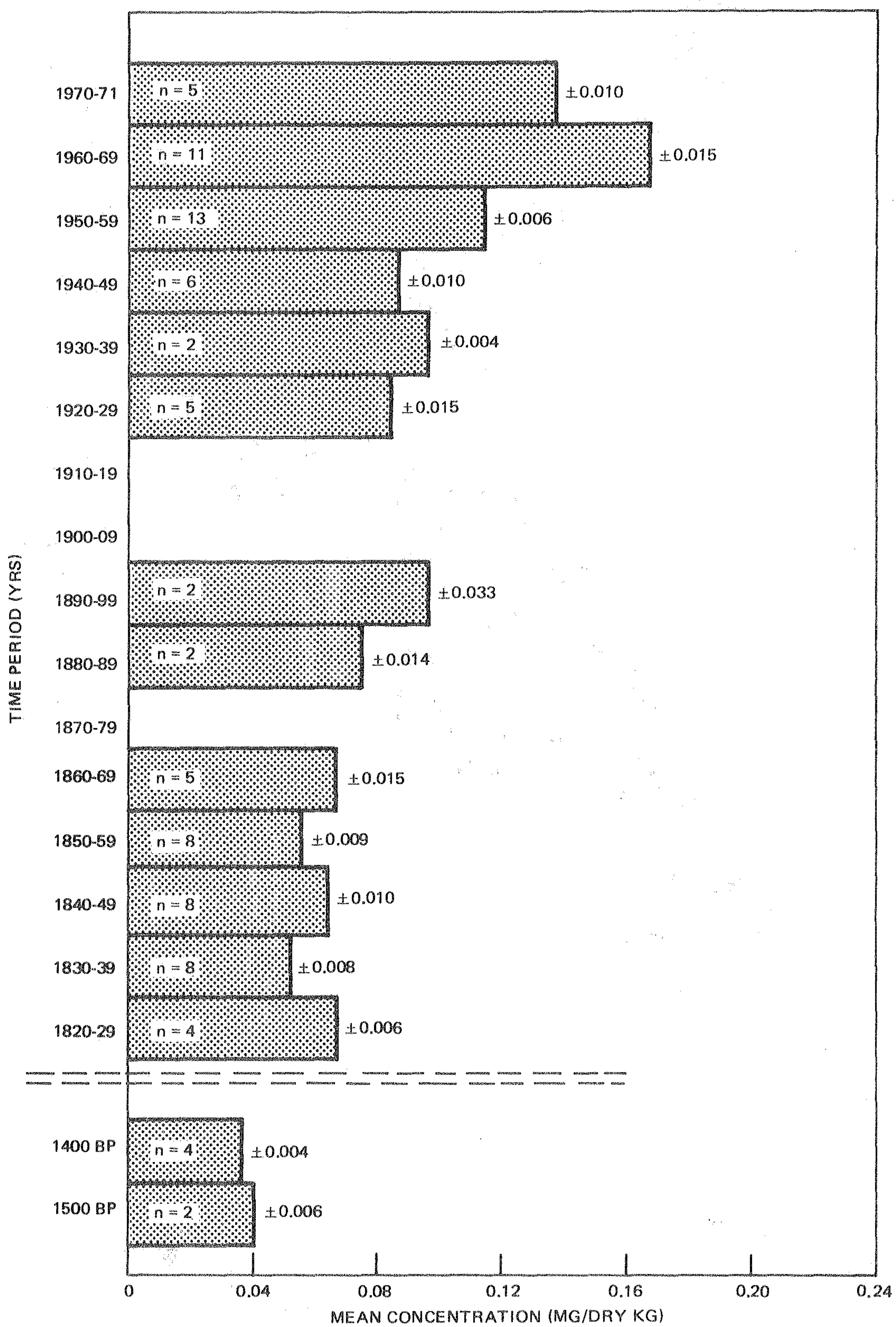


Figure 6-21. Mean Concentrations of Mercury in Dated Varved Sediments from the Santa Barbara Basin (Box and Bootstrap Cores, 1966-71). Number to Right of Bar is Standard Error; BP: Before Present.

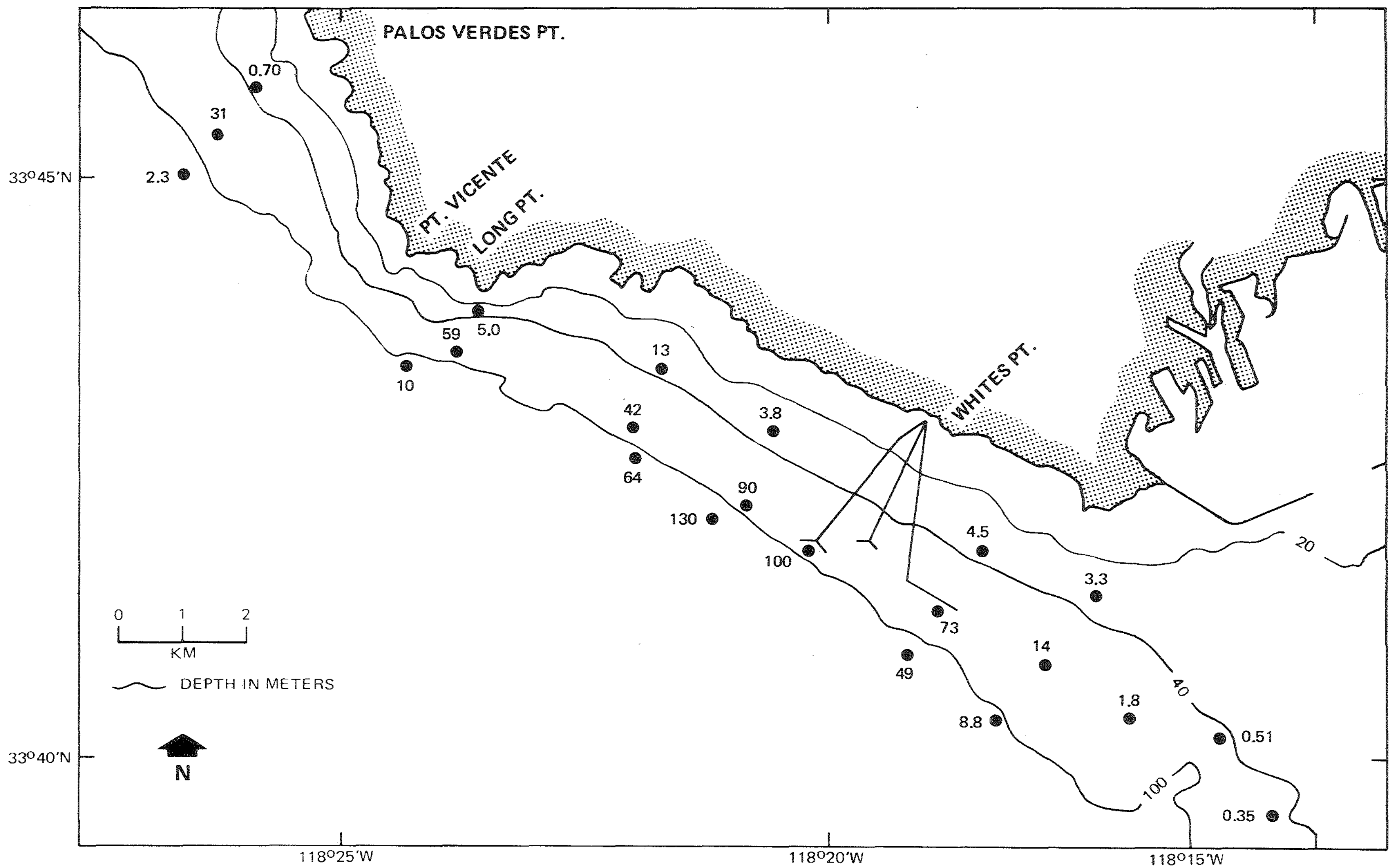


Figure 6-22. Total DDT Concentrations (mg/dry kg) in Surface Sediments Around the Whites Point Outfall System (Phleger Cores, June 1972).

The pattern for total PCB (Figure 6-23) was very similar to that for DDT. Maximum concentrations of 5 to 10 mg/dry kg were found at the stations at the ends of the outfalls and at several just to the northwest.

Figure 6-24 shows the results of analyses for DDT and PCB in separate layers of box cores. The results show a pattern similar to that found for the metals in that the concentrations in the surface layers were much higher than those in the deeper layers. Insufficient analyses were made to determine if the concentrations in the deeper layers become constant with increasing depth.

6.4.2 Santa Monica Bay

Total DDT in the surface sediments of Phleger cores from stations around the Hyperion outfall was measured. These concentrations (Figure 6-25) varied from 0.03 to 0.3 mg/dry kg; there appeared to be little pattern or consistency in the observed concentrations. Total DDT was also measured in box core samples taken at stations in and around Santa Monica Canyon. These concentrations (Figure 6-26) varied between 0.1 and 0.9 mg/dry kg, although a concentration of 2.4 mg/dry kg was observed at the station just west of the end of the 7-mile sludge outfall. Again, there was no pattern in the measured concentrations.

Figures 6-27 and 6-28 show the concentrations of PCB measured at the two sets of Santa Monica Bay stations. The PCB concentrations from Phleger cores (Figure 6-27) varied between 0.006 and 0.4 mg/dry kg. The total PCB values shown in Figure 6-28 for the Santa Monica Canyon stations (Figure 6-7) were obtained from box cores; these values ranged from 0.03 to 0.71 mg/dry kg, with a single value of 12 mg/dry kg at the station near the end of the sludge outfall.

Figure 6-29 shows the vertical profiles for DDT and PCB at three box core stations near the 7-mile sludge outfall. The concentrations of both constituents were highest in samples from the core taken at Station B3 (nearest the end of the outfall): DDT concentrations at Station B3 were highest at a core depth of 12 cm; PCB concentrations were highest in the surface layer. Relatively few measurements were made in the cores from Stations B5 and B7. Concentrations of both DDT and PCB were quite low at Station B5, which is to the north of the Santa Monica Canyon. However, there was some tendency for concentrations to be highest in the surface layer and to decrease with depth. Only two measurements were taken in the core from Station B7, which is in the canyon, approximately 2 km from the end of the sludge outfall. Total DDT concentration was about 0.4 mg/dry kg in the surface layer at Station B7 and decreased to almost 0 at a depth of 24 cm. Total PCB concentration at this station was lower in the surface sediment, but there was some decrease with depth.

6.4.3 Orange County Outfall Area

In September 1971, box core samples collected from stations off the new and old Orange County outfalls were analyzed for total DDT and total PCB. The distributions of these two materials are shown in Figures 6-30 and 6-31. All but one of the 12 DDT measurements fell within the range of 0.01 to 0.06 mg/dry kg. One measurement from a station south of the outfall system was 0.12 mg/dry kg. The observed PCB concentrations were in the range of 0.01 to 0.06 mg/dry kg; the highest concentration noted was in a core from the station at the end of the new outfall, which had been in service 5 months at the time the samples were taken.

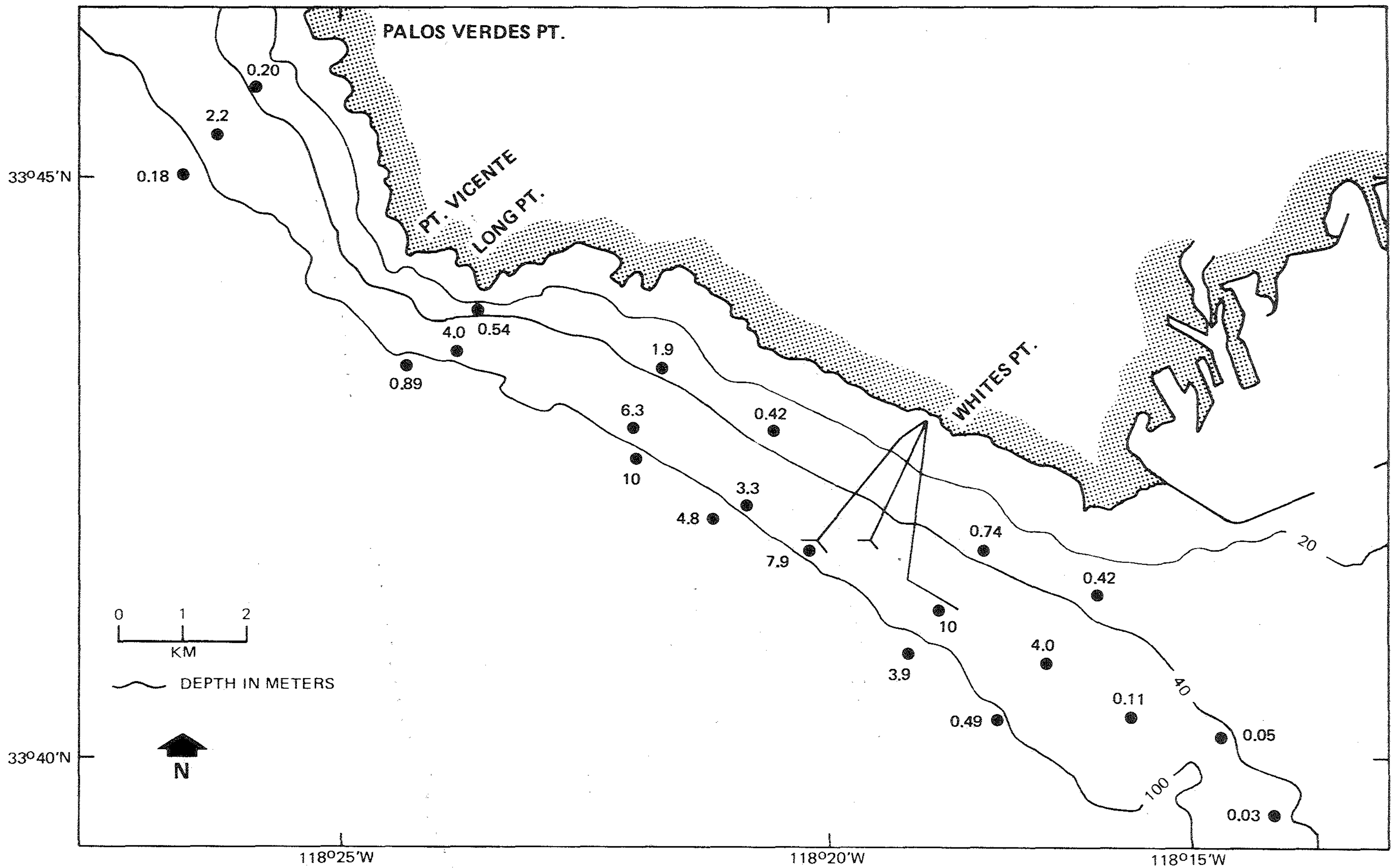


Figure 6-23. Total PCB Concentrations (mg/dry kg) in Surface Sediments Around the Whites Point Outfall System (Phleger Cores, June 1972).

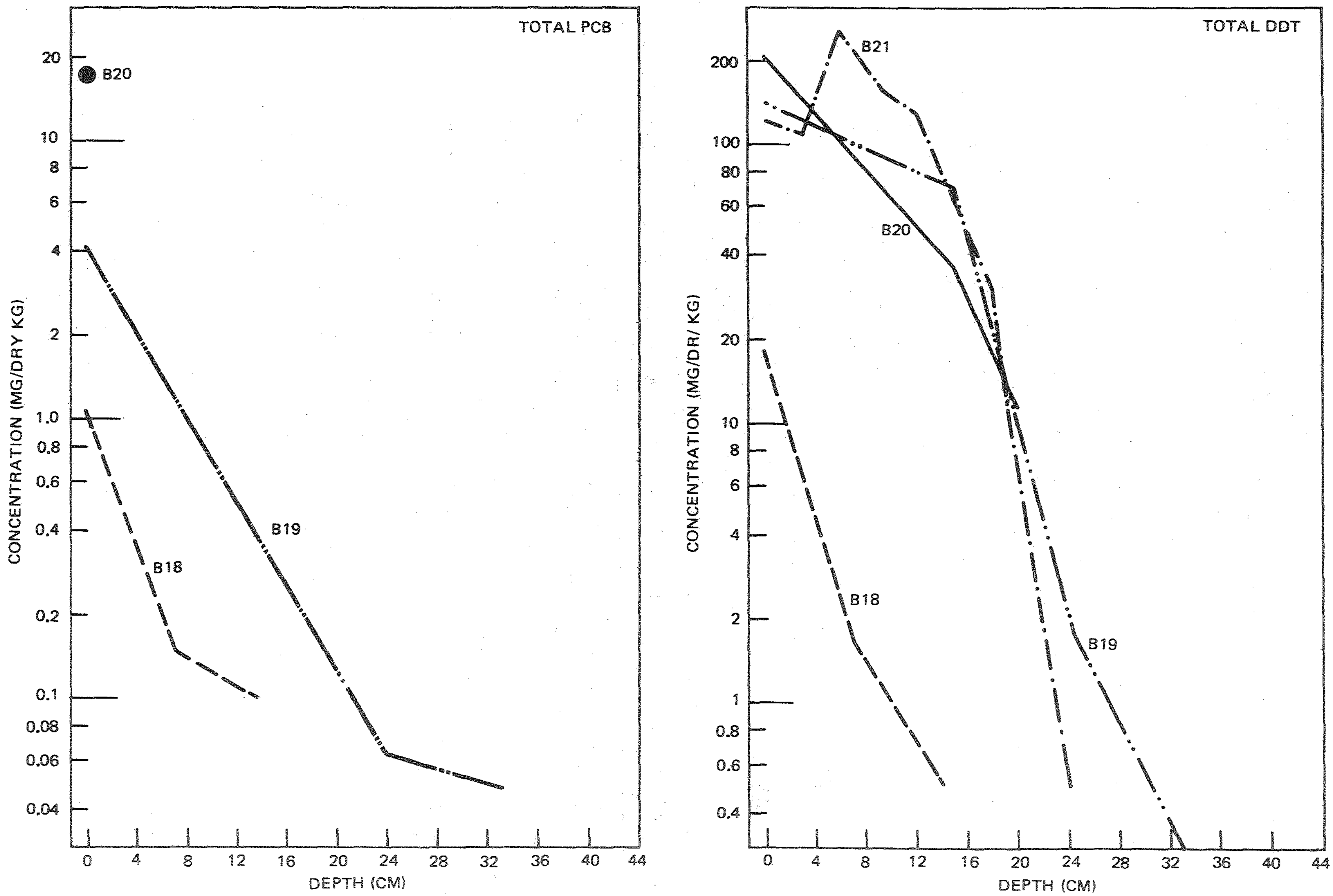


Figure 6-24. Vertical Profiles of Concentrations of Total DDT and Total PCB in Sediments Collected Northwest of the Whites Point Outfall System (Box Cores, July 1971). Station Locations Shown in Figure 6-1.

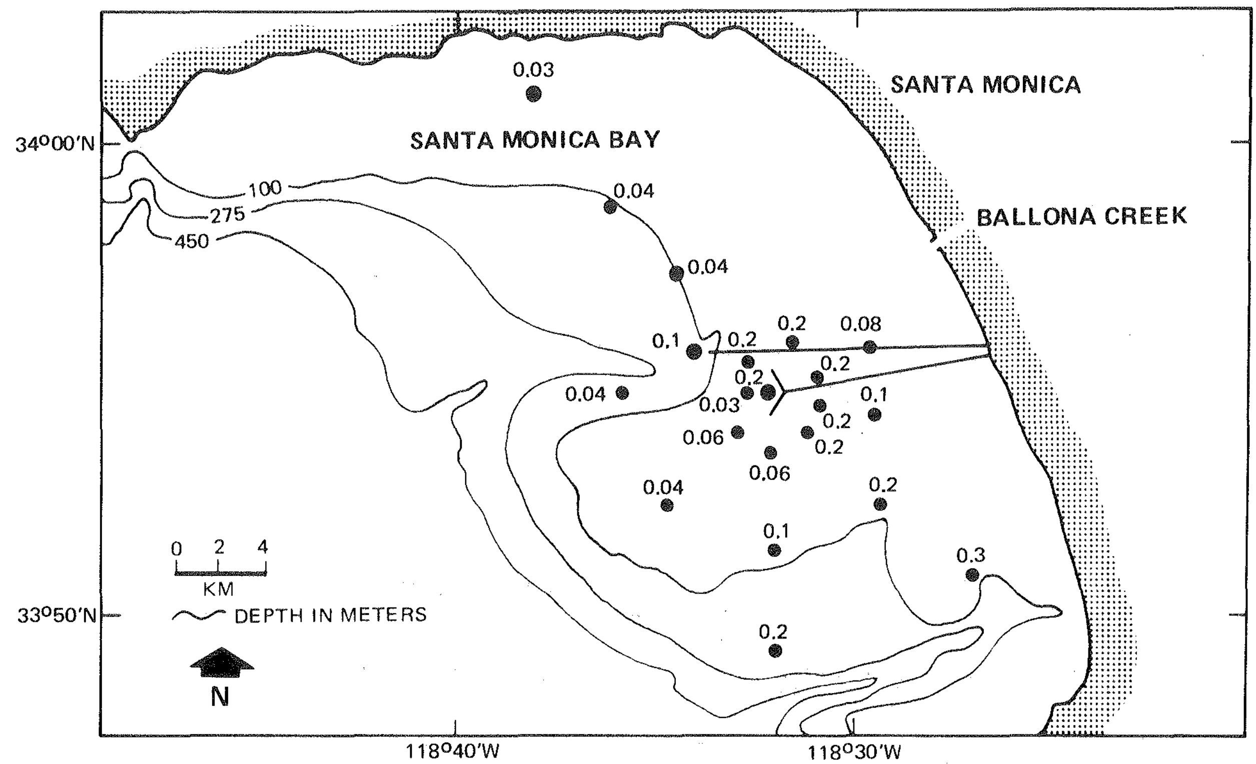


Figure 6-25. Total DDT Concentrations (mg/dry kg) in Surface Sediments Around the Hyperion Outfall System (Phleger Cores, July 1972).

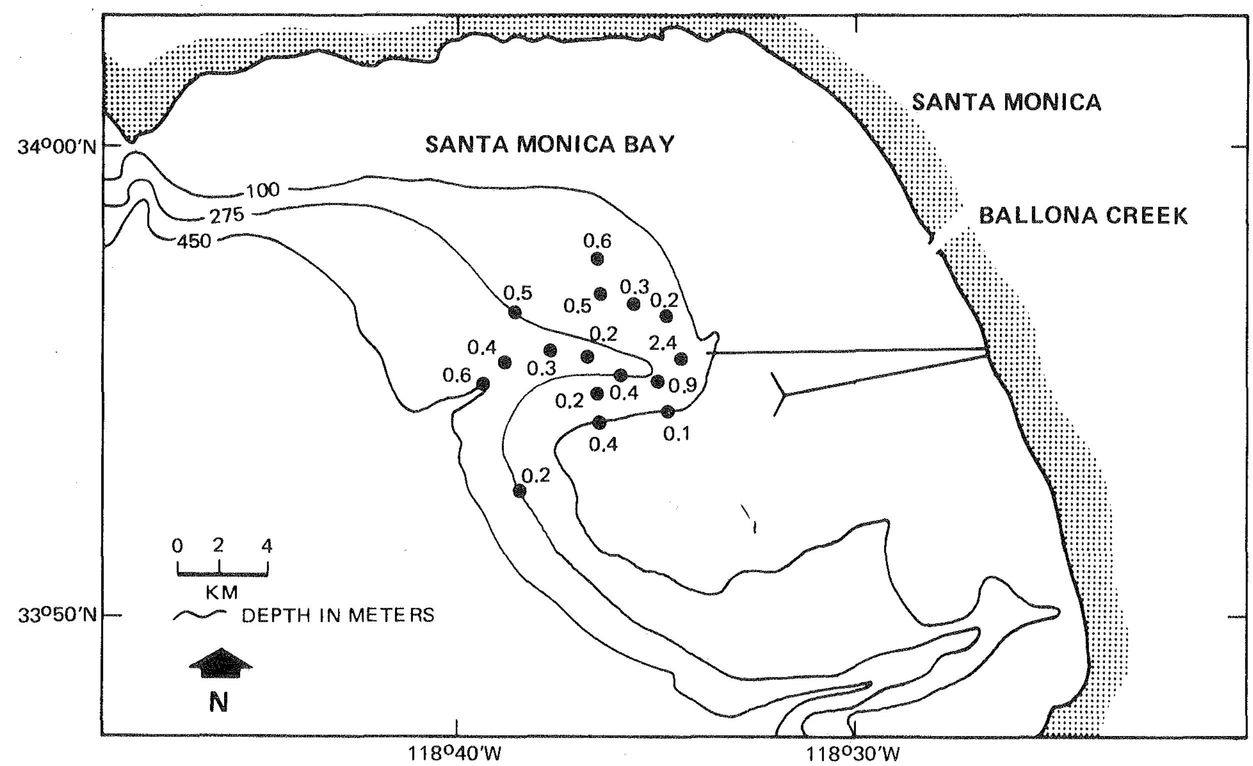


Figure 6-26. Total DDT Concentrations (mg/dry kg) in Surface Sediments Around the Hyperion Outfall System (Box Cores, July 1971).

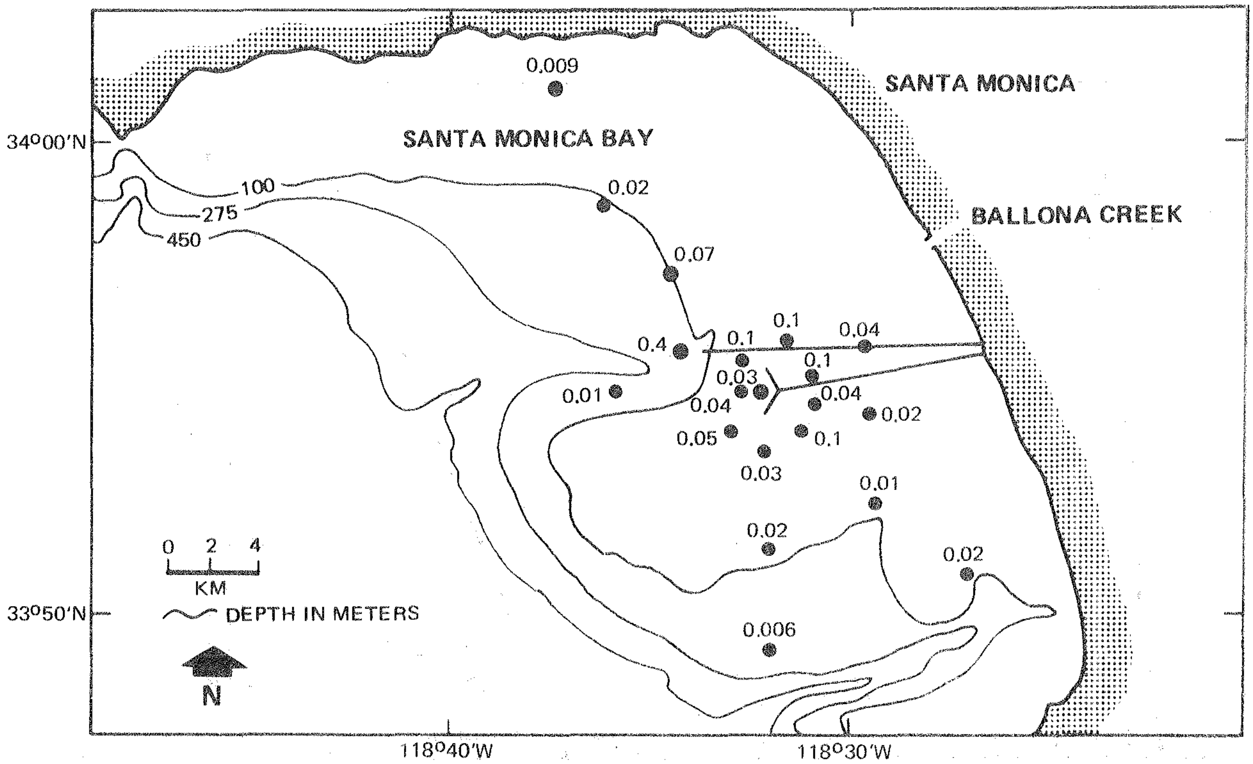


Figure 6-27. Total PCB Concentrations (mg/dry kg) in Surface Sediments Around the Hyperion Outfall System (Phleger Cores, July 1972).

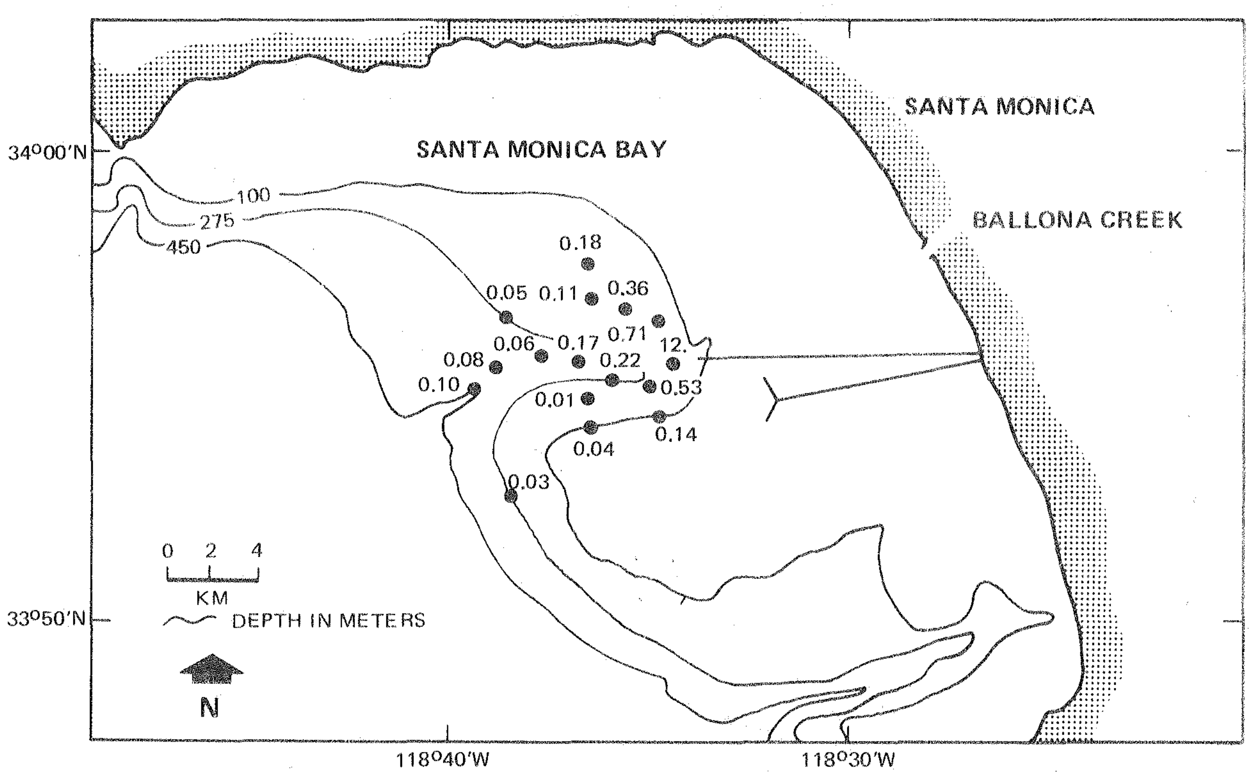


Figure 6-28. Total PCB Concentrations (mg/dry kg) in Surface Sediments Around Hyperion Outfall System (Box Cores, July 1971).

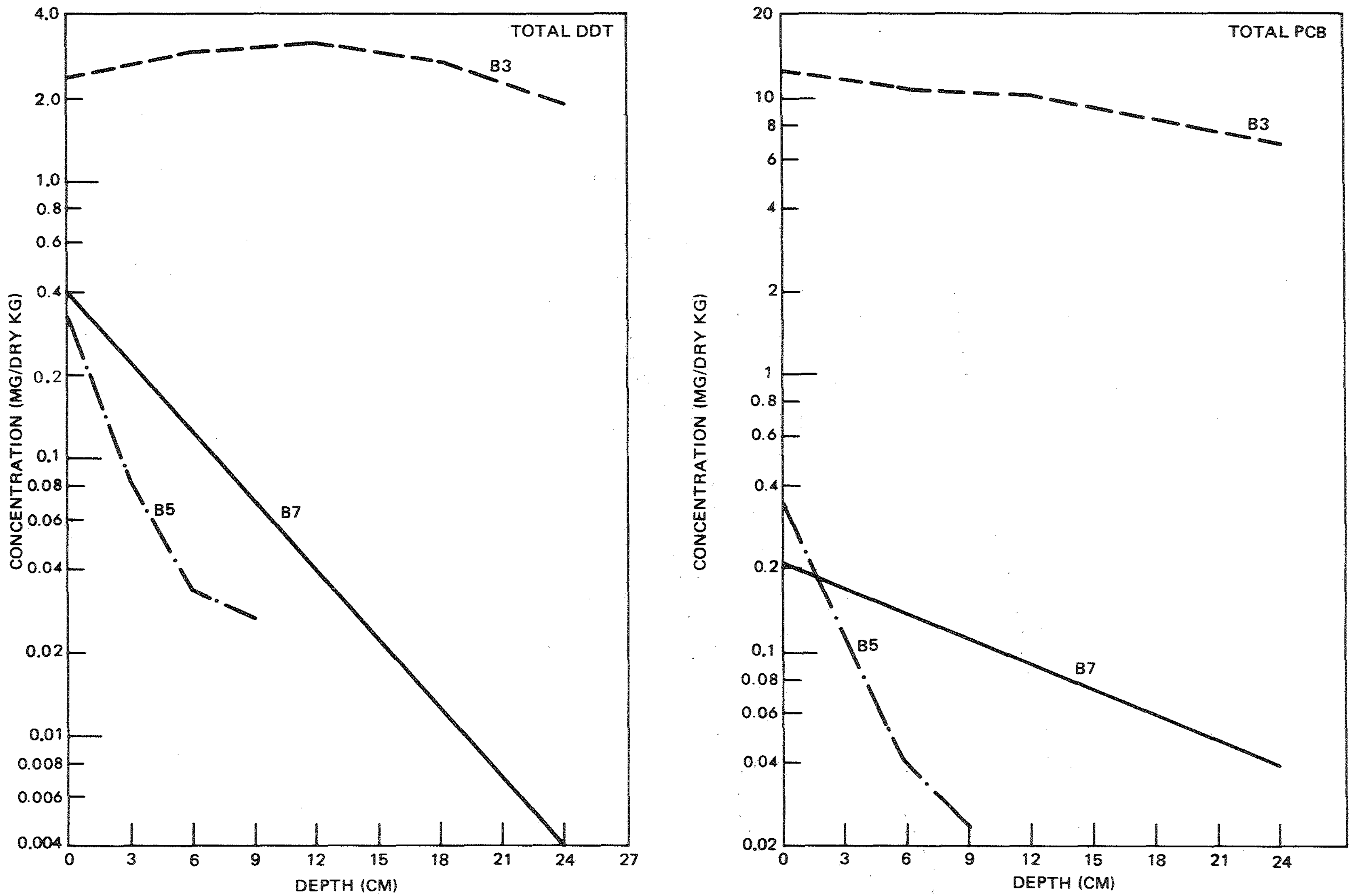


Figure 6-29. Vertical Profiles of Concentrations of Total DDT and Total PCB in Sediments Collected in Santa Monica Canyon off the Hyperion Sludge Outfall (Box Cores, July 1971). Station Locations Shown in Figure 6-7.

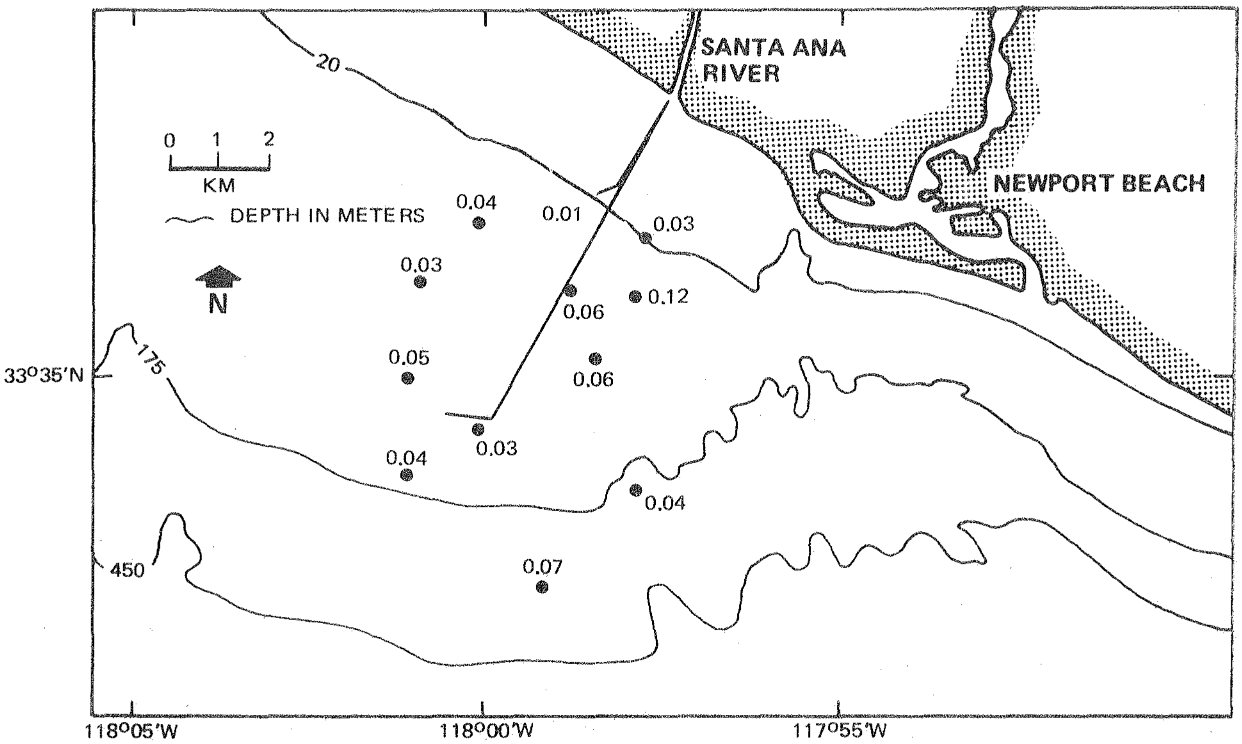


Figure 6-30. Total DDT Concentrations (mg/dry kg) in Surface Sediments Around the Orange County Outfall System (Box Cores, September 1971).

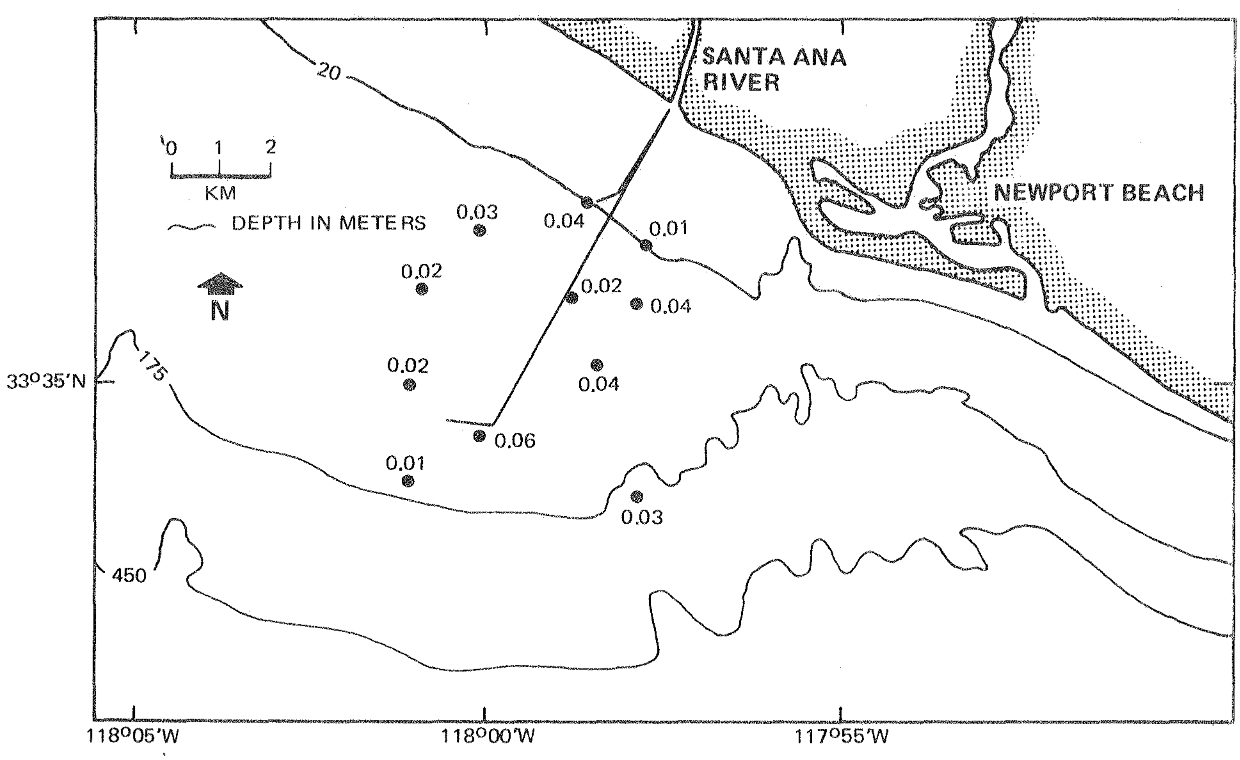


Figure 6-31. Total PCB Concentrations (mg/dry kg) in Surface Sediments Around the Orange County Outfall System (Box Cores, September 1971).

6.4.4 Oxnard Outfall Area

Figures 6-32 and 6-33 show the distributions of total DDT and PCB in the vicinity of the Oxnard outfall. DDT concentrations ranged from 0.02 to 0.06 mg/dry kg; PCB concentrations were in the range of 0.003 to 0.03 mg/dry kg.

6.4.5 Point Loma Outfall Area

Measurements of the distributions of DDT and PCB compounds in Phleger cores obtained off Point Loma in August and September 1971 are currently (December 1972) in progress. Values to date range from 0.002 to 0.022 mg/dry kg for total DDT and from 0.032 to 0.092 mg/dry kg for total PCB.

6.5 SUMMARY

The measurements of metals and chlorinated hydrocarbons in sediments presented in this chapter indicate clearly that the discharge of these materials in municipal wastewaters has been reflected in increased concentrations in the sediments around the wastewater outfalls. This relationship is particularly evident in the Palos Verdes and Santa Monica Bay areas, the sites of the major discharges from the County Sanitation Districts of Los Angeles County and the City of Los Angeles. There is also some evidence that trace metals are not "locked" in the sediments, but that a dynamic interchange occurs between the sediments and the overlying waters. The studies made around the two Orange County outfalls before and after the change of discharge location showed a decrease in concentrations of many metals around the old outfall, and an increase around the new outfall, following the change.

Measurements of metals and chlorinated hydrocarbons in undisturbed layers of core samples from the Santa Barbara Basin indicated that concentrations of most metals in these sediments were relatively constant over the last 100 or more years. Lead concentrations had increased substantially in the last 20 years, an increase coincident with a major increase in the use of high-compression automobile engines using leaded gasoline. In the last 150 years, sediment concentrations of mercury have increased from about 0.06 to 0.15 mg/dry kg at a relatively constant rate.

6.6 REFERENCES

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Klein, D.H. and E.D. Goldberg. 1970. Mercury in the marine environment. Environ. Sci. and Tech. 4:765-8.

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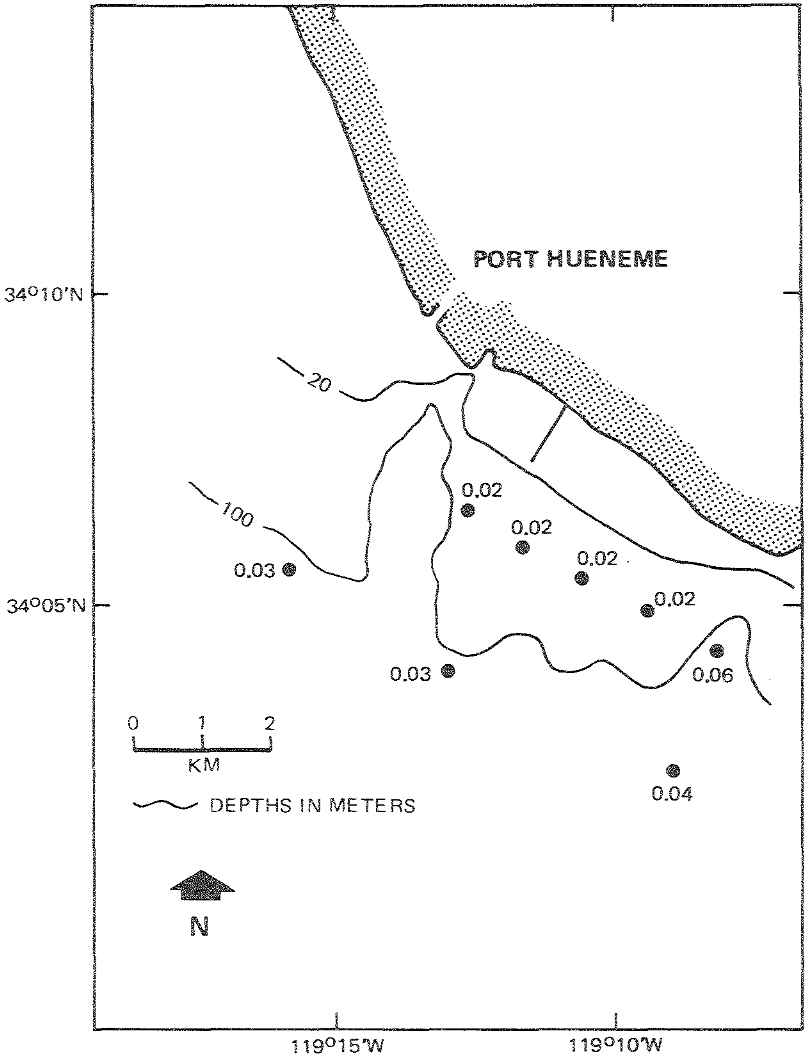

Figure 6-32. Total DDT Concentrations (mg/dry kg) in Surface Sediments Around the Oxnard Outfall (Box Cores, September 1971).

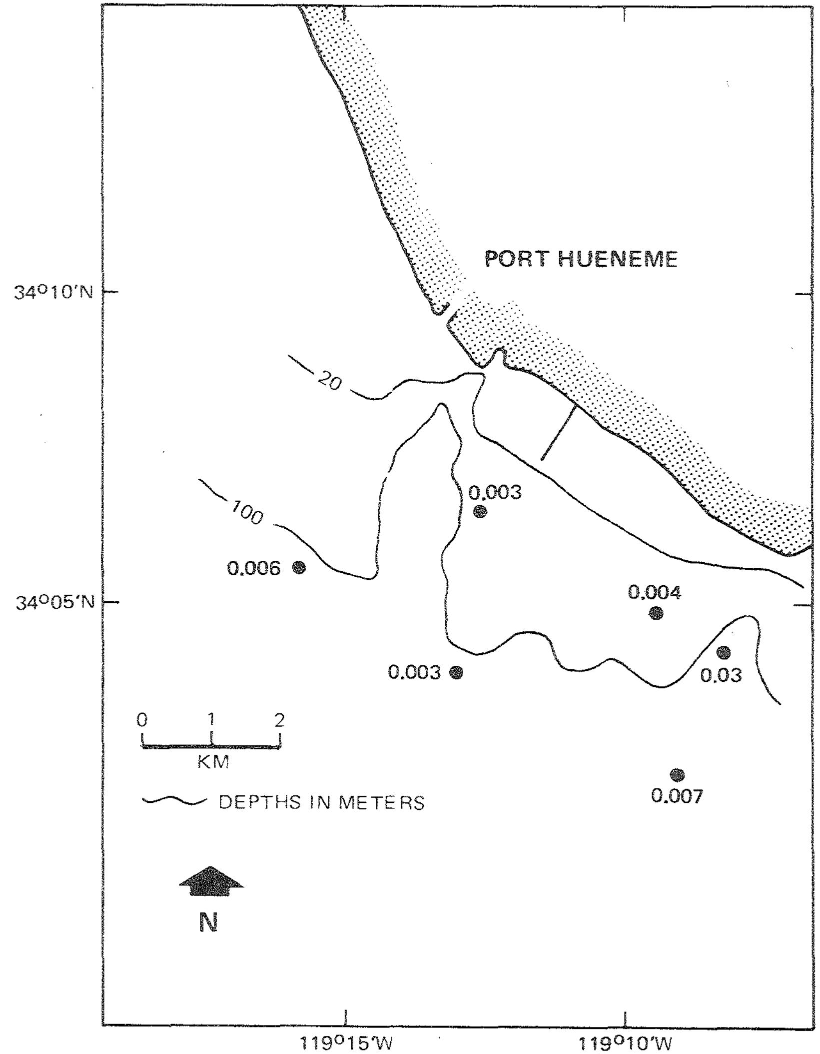

Figure 6-33. Total PCB Concentrations (mg/dry kg) in Surface Sediments Around the Oxnard Outfall (Box Cores, September 1971).

Chapter 7

COASTAL FISH POPULATIONS

7.1 INTRODUCTION

The protection of marine fish populations is an important objective in environmental quality programs. Not only are these recreational and commercial resources vulnerable to pollutants, but they also can act as agents by which undesirable chemical substances are transported to man, via his consumption of seafood.

The fish communities of southern California coastal waters are as varied and dynamic as those of many land-based animals, including man. They are subject to individual and group interactions as well as to both small- and large-scale natural environmental changes. Species within a community respond to these internal and external stresses in complex and diverse ways.

Observation of fish responses to environmental changes is difficult; quantification of a response often seems impossible, especially in a short-term or small-scale investigative program. Specimens are often sparsely distributed through a broad and deep ocean, or irregularly and variably schooled, and the many environmental conditions that may be associated with the behavior of a particular species fluctuate widely and often are only partially understood. Research on coastal species is further complicated by the wide variety of species present, each with its own developmental stages, and by the fact that many species inhabit these waters during only a portion of their life cycles. Nevertheless, even limited research programs can provide significant insights into fish responses, as well as information useful in protecting and enhancing fish resources. Recent major fluctuations in marine fish populations--the decline of the Pacific sardine and the spectacular rise of the Northern anchovy, for example--underscore the need for this type of information.

Although a number of local fish species and groups of species have been studied intensively in recent years, there has been only modest scientific interest in the inshore demersal (bottom-dwelling) species. These communities, which have the most direct contact with man's coastal effects, have been the object of the SCCWRP fisheries studies.

Fish species presently being monitored in southern California coastal waters are generally not unique to the area. Aside from the large, migratory fishes, such as tuna and albacore, the fish fauna of the Pacific Coast of North America can be categorized into three major groups, according to region--cold water (Alaskan-Vancouveran), temperate (Californian), and tropical (Panamic). The approximate boundaries of these groups are illustrated in Figure 7-1. The southern California Bight lies in the central portion of the Californian fish faunal region. This region contains subregions (also shown in Figure 7-1); all of the major coastal inputs to the Bight (e.g., municipal wastewater discharges) occur within the San Diegan subregion.

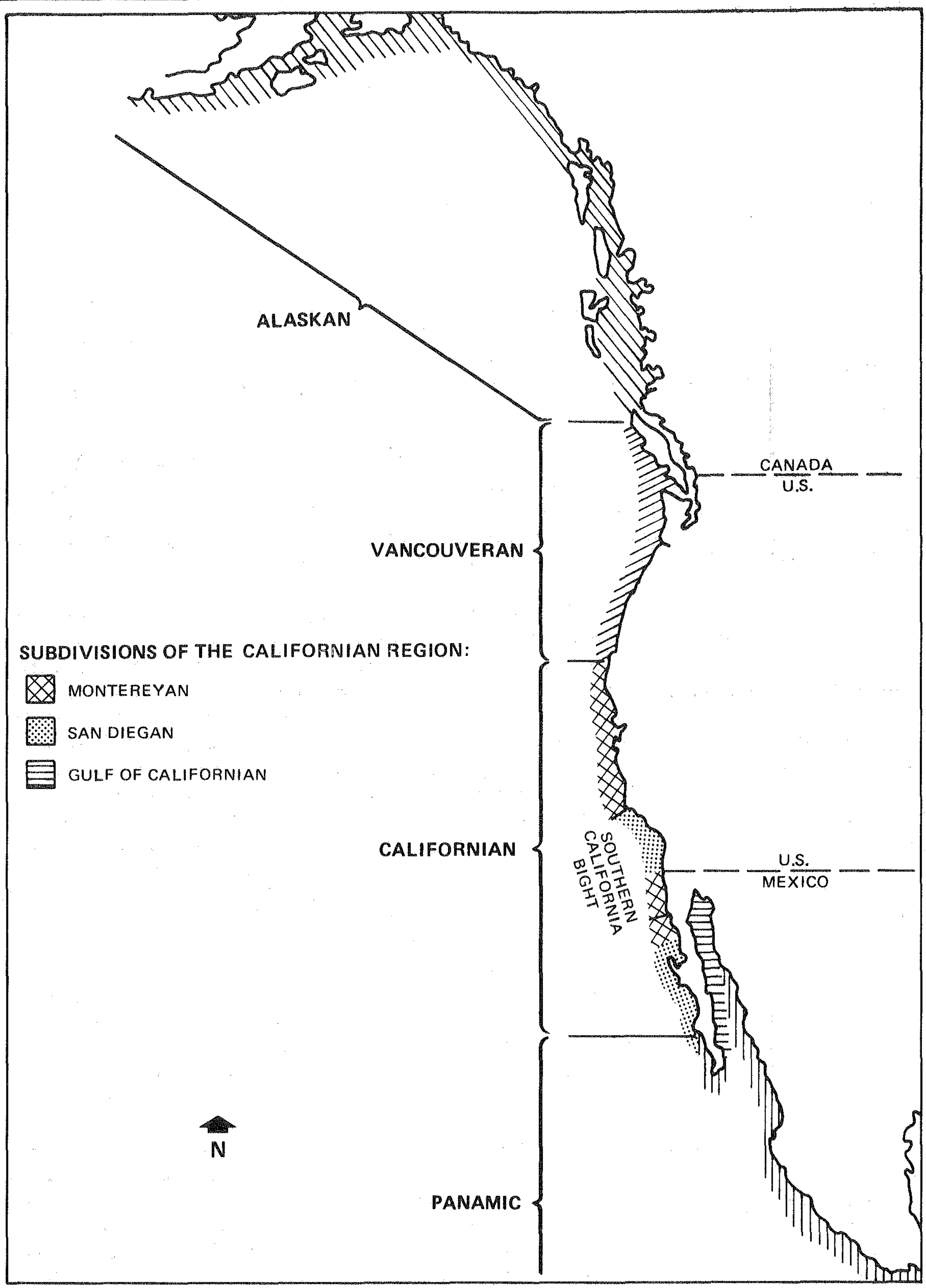

Figure 7-1. Fish Faunal Regions of Western North America.

To date, the SCCWRP studies have been based primarily on data collected by several agencies in trawls of the coastal waters off Ventura, Los Angeles, and Orange Counties between fall 1969 and spring 1972. The project's literature survey has provided additional information on demersal fishes within the Bight and in other areas of the world. SCCWRP has used these data in a three-part fisheries program.

A. A tabulation of the species of demersal fishes present in southern California coastal waters, and a study of the apparent associations of various species into communities. Periodic (seasonal and daily) movements of fishes in and offshore were studied, and comparisons of the abundance and diversity of fish populations in the Bight were made.

B. An analysis of the concentrations of trace metals and chlorinated hydrocarbons in several demersal fish populations.

C. A study of the characteristics of diseases observed in several of the local fish populations.

7.2 DEMERSAL FISH POPULATIONS AND ASSEMBLAGES

Between August 1969 and March 1972, six agencies conducted individual trawling surveys in southern California coastal waters. The surveys covered a total of 119 stations off the coast of Ventura, Los Angeles, and Orange Counties (station locations are shown in Figure 7-2). Each agency worked only in certain areas of the Bight; although all collected samples with otter trawls, there were differences in the vessels, nets, and procedures used, as well as in the depths trawled and the seasons of the year during which the surveys were conducted (these differences are discussed in Section 7.2.3).

The data from the 303 trawl samples taken in the 1969-72 surveys show that at least 121 species, representing 41 families of cartilaginous and bony fishes, were present on or near the bottom of the coastal shelf at depths of 10 to 360 meters. The major types of fish present in the samples are listed in Table 7-1; Table 7-2 gives all species and common names. It is estimated that the species collected account for one-quarter to one-third the total fish species in the Southern California Bight and approximately one-half the local coastal zone species. Rockfishes, sharks and rays, and flounders were best represented in the samples, in terms of numbers of species collected.

Review of the literature on fish collections along the Pacific Coast of North America shows that many of the nearshore demersal fishes found in the Bight are ubiquitous and are found along the entire coast as far north as British Columbia. The deeper water species, such as the slender sole (*Lyopsetta exilis*) and rex sole (*Glyptocephalus zachirus*), are essentially cool-water, temperate fishes, with centers of distribution lying to the north of the Bight. Thus, a distinct San Diegan fauna does not occur below the thermocline or in the deeper waters of the coastal shelf.

Only a few of the species commonly captured in the 1969-72 otter trawl surveys are of direct importance in the southern California sport or commercial fishing

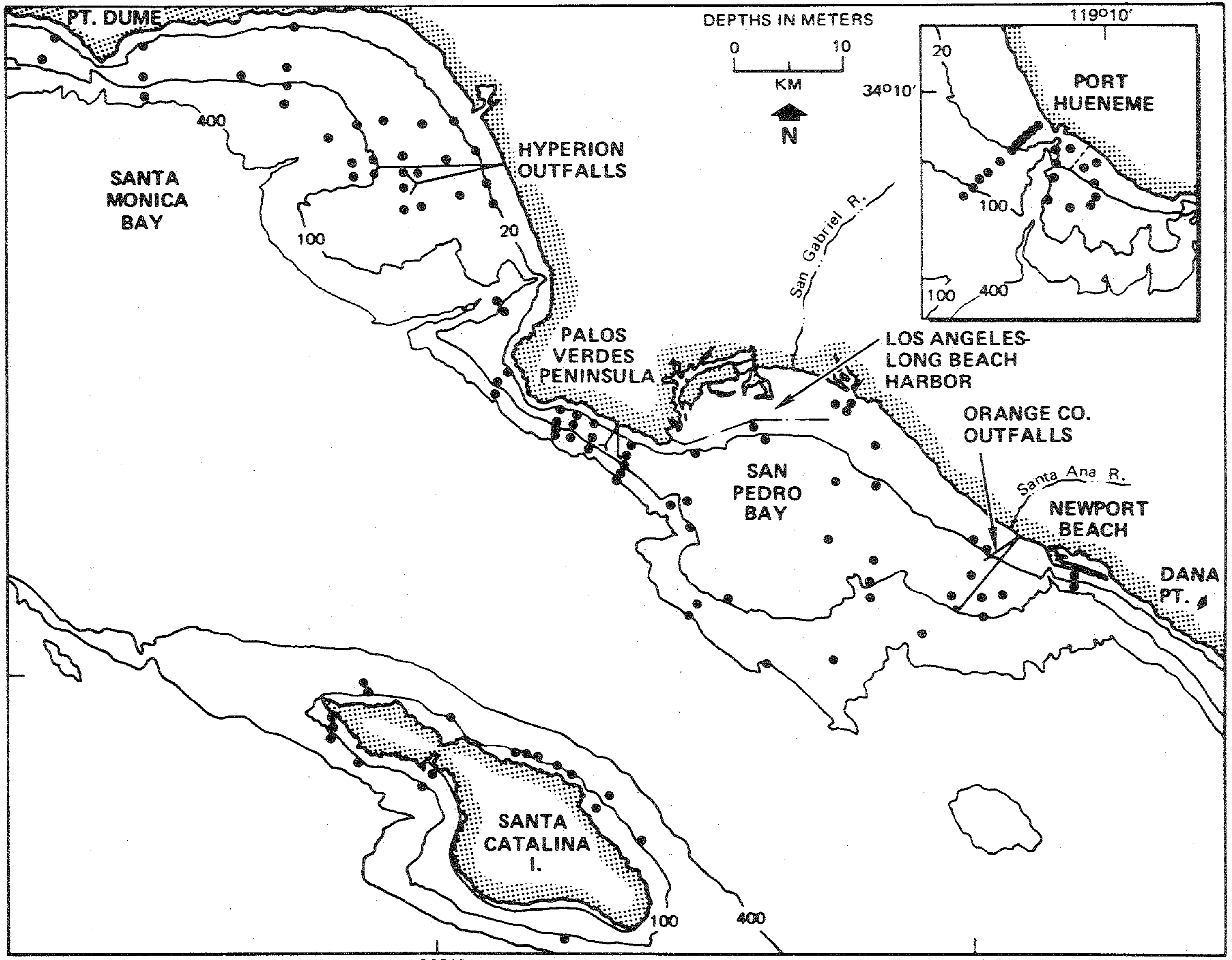

Figure 7-2. Station Locations for the 1969-72 Trawling Surveys of Southern Californ.ia Nearshore Demersal Fishes.

Table 7-1
MAJOR TYPES OF FISH FOUND IN THE 1969-72 TRAWLING SURVEYS OF SOUTHERN CALIFORNIA COASTAL WATERS

Group	Number of Species
Hagfishes	1
Sharks and rays	13
Ratfishes	1
Bony fishes	
Rockfishes	28
Right-eyed flounders	11
Perches	9
Sculpins	7
Left-eyed flounders	6
Poachers	5
Clinids	4
Anchovies	3
Eelpouts	3
Basses	3
Croakers	3
Combfishes and greenlings	3
Miscellaneous	21
TOTAL	121

industries. These include the Pacific sanddab (*Citharichthys sordidus*), the petrale sole (*Eposetta jordani*), the northern anchovy (*Engraulis mordax*), and some species of rockfish. White croaker, queenfish (*Seriphus politus*), and several perch species caught in the trawls are taken frequently at local piers and jetties, but the more desirable sport fishes (bass or halibut, for example) were neither common nor abundant in the trawl surveys. However, a number of the flatfishes and rockfishes common in the southern California trawl catches are commercially fished north of Ventura County by longline and trawl and do constitute important resources; also, many of the trawl-caught species are potential food for the larger sport and commercial species.

7.2.1 Species Commonness and Abundance

The 20 most commonly encountered species, ranked by frequency of occurrence in the 303 trawls, are listed in Table 7-3. This table also shows the frequencies of occurrence of these 20 species in the five general areas of the Bight in which surveys were conducted. Dover sole (*Microstomus pacificus*) was the most frequently encountered species; in fact, four of the five most frequently found species were flatfishes. Of particular interest is the relatively frequent occurrence of dover sole off Palos Verdes and in the Orange County coastal area, and the infrequent occurrence of yellowchin sculpin (*Icelinus quadriseriatus*) and California tonguefish (*Symphurus atricauda*) off Palos Verdes. The speckled sanddab (*Citharichthys stigmaeus*) and the plainfin midshipman (*Porichthys notatus*) were the most common species in Santa Monica Bay. Thus, it appears that each of the five areas might be characterized by the relative

Table 7-2
SPECIES TAKEN IN THE 1969-72 TRAWLING SURVEYS OF SOUTHERN CALIFORNIA COASTAL WATERS.[a]

Species	Common Name
MYXINIDAE	
Eptatretus stouti	Pacific hagfish
HETERODONTIDAE	
Heterodontus francisci	Horn shark
SCYLLIORHINIDAE	
Cephaloscyllium ventriosum	Swell shark
CARCHARHINIDAE	
Mustelus californicus	Gray smoothhound
Mustelus henlei	Brown smoothhound
SQUALIDAE	
Squalus acanthias	Spiny dogfish
SQUATINIDAE	
Squatina californica	Pacific angel shark
RHINOBATIDAE	
Platyrhinoidis triseriata	Thornback
Rhinobatos productus	Shovelnose guitarfish
TORPEDINIDAE	
Torpedo californica	Pacific electric ray
RAJIDAE	
Raja kincaidi	Sandpaper skate[b]
Raja stellulata	Starry skate
DASYATIDAE	
Urolophus halleri	Round stingray
MYLIOBATIDAE	
Myliobatis californica	Bat ray
CHIMAERIDAE	
Hydrolagus colliei	Ratfish
CONGRIDAE	
Gnathophis catalinensis	Catalina conger
ENGRAULIDAE	
Anchoa compressa	Deepbody anchovy
Anchoa delicatissima	Slough anchovy
Engraulis mordax	Northern anchovy
ARGENTINIDAE	
Argentina sialis	Pacific argentine
SYNODONTIDAE	
Synodus lucioceps	California lizardfish
BATRACHOIDIDAE	
Porichthys myriaster	Specklefin midshipman
Porichthys notatus	Plainfin midshipman
MORIDAE	
Physiculus rastrelliger	Hundred-fathom codling[b]
GADIDAE	
Merluccius productus	Pacific hake
OPHIDIIDAE	
Chilara taylori[c]	Spotted cusk-eel
Otophidium scrippsae	Basketweave cusk-eel
ZOARCIDAE	
Aprodon cortezianus	Bigfin eelpout
Lycodopsis pacifica	Blackbelly eelpout
Lyconema barbatum	Bearded eelpout
MACROURIDAE	
Nezumia stelgidolepis	California rattail
SYNGNATHIDAE	
Syngnathus californiensis[d]	Kelp pipefish
SERRANIDAE	
Paralabrax clathratus	Kelp bass
Paralabrax maculatofasciatus	Spotted sand bass
Paralabrax nebulifer	Barred sand bass
BRANCHIOSTEGIDAE	
Caulolatilus princeps	Ocean whitefish
SCIAENIDAE	
Genyonemus lineatus	White croaker
Menticirrhus undulatus	California corbina
Seriphus politus	Queenfish
EMBIOTOCIDAE	
Amphistichus argenteus	Barred surfperch
Cymatogaster aggregata	Shiner perch
Embiotoca jacksoni	Black perch
Hyperprosopon anale	Spotfin surfperch
Hyperprosopon argenteum	Walleye surfperch
Phanerodon furcatus	White seaperch
Rhacochilus toxotes	Rubberlip seaperch
Rhacochilus vacca	Pile perch
Zalembius rosaceus	Pink seaperch
BATHYMASTERIDAE	
Rathbunella sp.	-
Rathbunella hypoplecta	Smooth ronquil
URANOSCOPIDAE	
Kathetostoma averruncus	Smooth stargazer
CLINIDAE	
Alloclinus holderi	Island kelpfish
Heterostichus rostratus	Giant kelpfish
Neoclinus blanchardi	Sarcastic fringehead
Neoclinus uninotatus	Onespot fringehead
STICHAEIDAE	
Plectobranchus evides	Bluebarred prickleback
GOBIIDAE	
Coryphopterus nicholsi	Blackeye goby
Lepidogobius lepidus	Bay goby
STROMATEIDAE	
Peprilus simillimus	Pacific pompano
SCORPAENIDAE	
Scorpaena guttata	California scorpionfish
Sebastes chlorostictus	Greenspotted rockfish
Sebastes crameri	Darkblotched rockfish
Sebastes dalli	Calico rockfish
Sebastes diploproa	Splitnose rockfish
Sebastes elongatus	Greenstriped rockfish
Sebastes eos	Pink rockfish
Sebastes flavidus	Yellowtail rockfish
Sebastes goodei	Chilipepper
Sebastes hopkinsi	Squarespot rockfish
Sebastes jordani	Shortbelly rockfish
Sebastes lentiginosus	Freckled rockfish[b]
Sebastes levis[e]	Cow rockfish
Sebastes macdonaldi	Mexican rockfish
Sebastes melanostomus	Blackgill rockfish
Sebastes miniatus[f]	Vermilion rockfish
Sebastes mystinus	Blue rockfish
Sebastes paucispinis	Bocaccio
Sebastes rosaceus	Rosy rockfish
Sebastes rosenblatti	Greenblotched rockfish[b]
Sebastes rubrivinctus	Flag rockfish
Sebastes saxicola	Stripetail rockfish
Sebastes semicinctus	Halfbanded rockfish
Sebastes serranoides	Olive rockfish
Sebastes serriceps	Treefish
Sebastes umbrosus	Honeycomb rockfish
Sebastes vexillaris	Whitebelly rockfish
Sebastolobus alascanus	Shortspine thornyhead
ANOPLOPOMATIDAE	
Anoplopoma fimbria	Sablefish
HEXAGRAMMIDAE	
Oxylebius pictus	Painted greenling
Zaniolepis frenata	Shortspine combfish
Zaniolepis latipinnis	Longspine combfish
COTTIDAE	
Chitonotus pugetensis	Roughback sculpin
Icelinus filamentosus	Threadfin sculpin
Icelinus quadriseriatus	Yellowchin sculpin
Icelinus tenuis	Spotfin sculpin
Leptocottus armatus	Pacific staghorn sculpin
Radulinus asprellus	Slim sculpin
Rhamphocottus richardsoni	Grunt sculpin
AGONIDAE	
Agonopsis sterletus	So. spearnose poacher
Asterotheca pentacanthus	Bigeye poacher
Odontopyxis trispinosa	Pygmy poacher
Xeneretmus latifrons	Blacktip poacher
Xeneretmus triacanthus	Bluespotted poacher
BOTHIDAE	
Citharichthys sordidus	Pacific sanddab
Citharichthys stigmaeus	Speckled sanddab
Citharichthys xanthostigma	Longfin sanddab
Hippoglossina stomata	Bigmouth sole
Paralichthys californicus	California halibut
Xystreurys liolepis[g]	Fantail sole
PLEURONECTIDAE	
Eopsetta jordani	Petrale sole
Glyptocephalus zachirus	Rex sole
Hypsopsetta guttulata	Diamond turbot
Lepidopsetta bilineata	Rock sole
Lyopsetta exilis[h]	Slender sole
Microstomus pacificus	Dover sole
Parophrys vetulus	English sole
Pleuronichthys coenosus	C-O sole
Pleuronichthys decurrens	Curlfin sole
Pleuronichthys ritteri	Spotted turbot
Pleuronichthys verticalis	Hornyhead turbot
CYNOGLOSSIDAE	
Symphurus atricauda	California tonguefish

a. Common and scientific names given here (except those covered by Note b) are from American Fisheries Society (1970).
b. Common name from Miller and Lea (in press).
c. *Chilara* is used here instead of *Otophidium* for reasons given by Follette (1970). Included here is a specimen presumably misidentified as *Anarrichthys ocellatus* (wolf-eel).
d. Included here are specimens identified as an undescribed species of *Syngnathus*.
e. Included here are specimens presumably misidentified as *Sebastes nigrocinctus* (tiger rockfish).
f. Included here are specimens presumably misidentified as *Sebastes ruberrimus* (yelloweye rockfish).
g. Included here are specimens presumably misidentified as *Isopsetta isolepis* (butter sole).
h. Included here are specimens presumably misidentified as *Atheresthes stomias* (arrowtooth flounder).

Table 7-3
FREQUENCY OF OCCURRENCE (PERCENT) OF THE 20 SPECIES MOST COMMON IN SAMPLES FROM THE 1969-72 TRAWLING SURVEYS OF SOUTHERN CALIFORNIA COASTAL WATERS

Rank	Species	All Areas	Port Hueneme	Santa Monica Bay	Palos Verdes	San Pedro Bay	Santa Catalina Island
1	Dover sole	66	16	55	84	73	52
2	Pacific sanddab	57	72	31	68	53	91
3	Speckled sanddab	55	80	74	45	55	10
4	Plainfin midshipman	49	20	74	34	52	57
5	English sole	48	68	33	46	56	0
6	California tonguefish	48	64	57	13	64	5
7	Hornyhead turbot	46	84	45	22	61	19
8	Pink seaperch	42	32	35	30	48	76
9	Stripetail rockfish	36	8	39	36	36	43
10	Yellowchin sculpin	32	24	53	3	41	81
11	Shortspine combfish	31	16	14	16	41	81
12	Longspine combfish	30	64	33	16	31	19
13	Curlfin sole	29	72	25	50	12	24
14	Rex sole	29	8	14	28	41	33
15	Bigmouth sole	26	28	12	18	35	48
16	Slender sole	25	8	23	12	38	33
17	Shiner perch	24	12	8	33	33	0
18	Halfbanded rockfish	23	0	8	22	33	24
19	White croaker	22	20	12	22	30	0
20	California scorpionfish	20	0	10	28	23	19
	Number of Hauls	303	25	49	76	132	21

occurrence of certain fish species. However, this conclusion does not consider variations in the data that might result from differences in collecting vessels and gear.

Although there is a relationship between frequency of occurrence and abundance, the most frequently captured species are not necessarily the most abundant. As shown in Table 7-4, the speckled sanddab was the most abundant, followed by the Pacific sanddab, the dover sole and the stripetail rockfish (*Sebastes saxicola*). Together, these four species accounted for nearly 50 percent of all the coastal fishes captured during the surveys. The 20 most abundant species accounted for slightly over 90 percent of the fishes captured. Comparison of Tables 7-3 and 7-4 shows that 16 species ranked high in both frequency of occurrence and abundance. The white croaker (*Genyonemus lineatus*), which is fifth ranking in abundance, ranks 19th in frequency of occurrence. Such a difference in ranking (higher in abundance than in frequency of occurrence) indicates that the fish is not uniformly distributed over the coastal shelf, but rather occurs in distinct concentrations or schools. In constrast, the English sole (*Parophrys vetulus*), which ranked fifth in frequency of occurrence, does not appear among the 20 most abundant species; this suggests that the fish is widely but sparsely distributed throughout the waters trawled.

7.2.2 Species Associations

Studies of communities of animals ordinarily yield better indices of environmental conditions than studies of individual species. To provide a picture of the present coastal shelf bottom fish communities, the 303 trawl samples were analyzed to identify recurrent groups (commonly associated species) of fishes.[1] The analysis showed that about one-fifth of the 121 nearshore demersal species found in the 1969-72 trawling surveys appeared in statistically significant associations. Five major groups and six associate species were defined in this analysis. The groups are listed in Figure 7-3; the first species named in each group list is the dominant member of the group.

The distribution of each of the five groups is shown in Figure 7-4. The distributions of Groups 1, 2, and 4, which are composed primarily of bottom flatfish, were depth-dependent to some extent. The speckled sanddab group usually occurred in shallow areas, the slender sole/rex sole association appeared primarily in deeper areas, and the Pacific sanddab/dover sole group was usually found at intermediate depth (the distribution of this third group overlapped the other two at the edges of its depth range). There was some interassociation among these three groups, as well as with Group 5, the yellowchin sculpin group, which was found in shallow to mid-depth waters. The analysis also identified an independent group (Group 3) of freeswimming fishes that was dominated by the white croaker.

As this recurrent group analysis was based on data collected by a single method (otter trawl), the groups described here may or may not represent complete fish communities; additional data, collected with a variety of sampling devices, is needed to ensure a complete description of the communities as they exist in nature. At a minimum, the analysis identifies species that are very frequently found together in nature and that therefore select similar environmental

1. Recurrent group analysis is discussed in Chapter 8; details of the method used can be found in papers by Fager (1957, 1963) and Fager and Longhurst (1968).

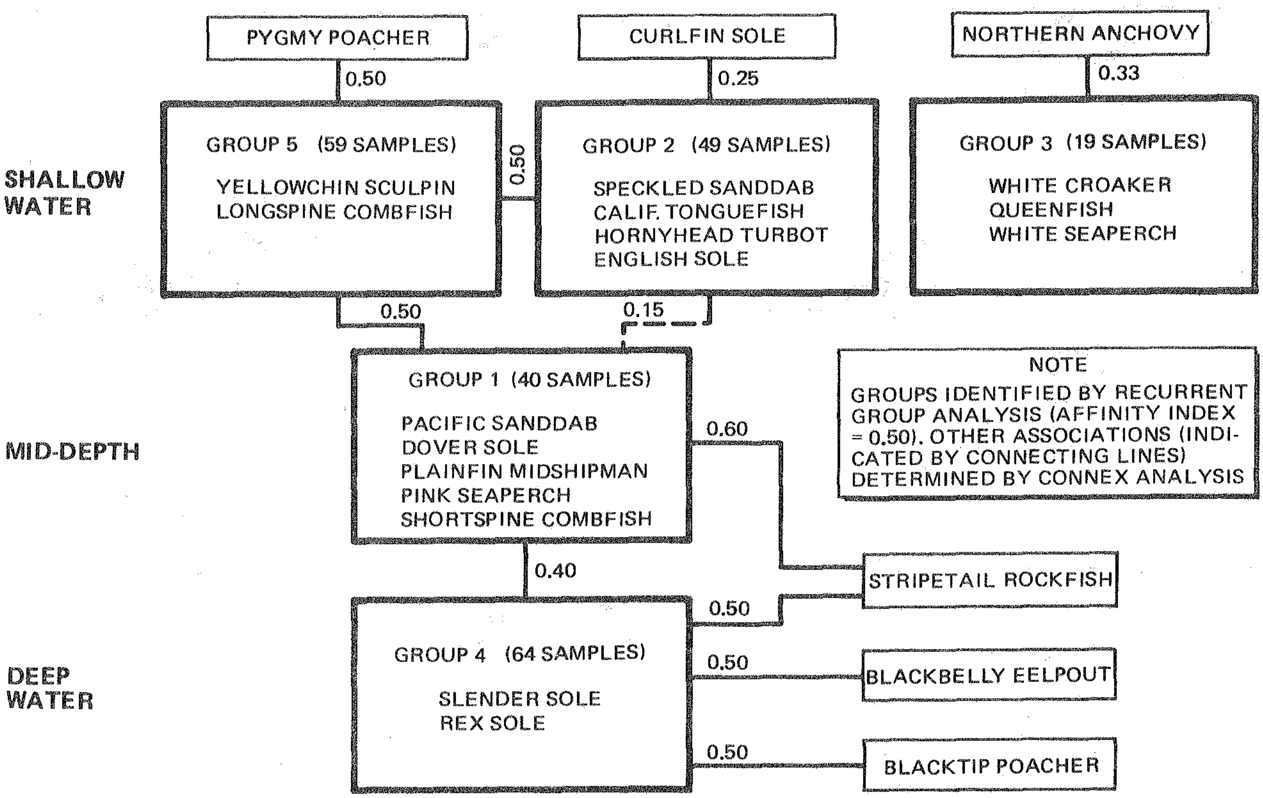

Figure 7-3. Species Associations of Southern California Nearshore Demersal Fishes, 1969-72.

conditions. The groups can thus be regarded as operational communities. Major discontinuities in the distribution of a group -- a reflection of the absence of one or more of the component species -- merit further investigation, as they mark an area or time period that is unusual in some respect. Several such discontinuities have been found, and studies are now underway to examine them in more detail. Thus, with recurrent group analysis, species to be monitored in ecological studies can be selected objectively, from among those with similar environmental requirements as well as those that have recreational or commercial value, that are known to have anomalies, or that are notable for other reasons.

Most of the specimens of the fish species caught during the 1969-72 trawling surveys were small relative to those taken in the sport and commercial fisheries. About 95 percent of the approximately 18,000 fish captured off Orange County in 1970-71 surveys ranged in size from 25 to 300 mm, standard length (S.L.); the average sizes of many of the common species ranged from 60 to 160 mm. In contrast, rockfishes, croakers, basses, and flatfishes taken by hook and line in the local party boat fishery generally exceed 250 or 300 mm in length. The implication is that large fishes either are rare in the areas trawled and possibly restricted to habitats unsuitable for trawling (rocky areas, kelp beds, etc.) or are capable of avoiding or escaping the slow-moving trawl net. The latter hypothesis is supported by the fact that limited fish trapping and night trawling showed that large fish (such as sablefish, hake, and adult rockfishes) were present in areas where they were rarely captured in daytime trawl hauls.

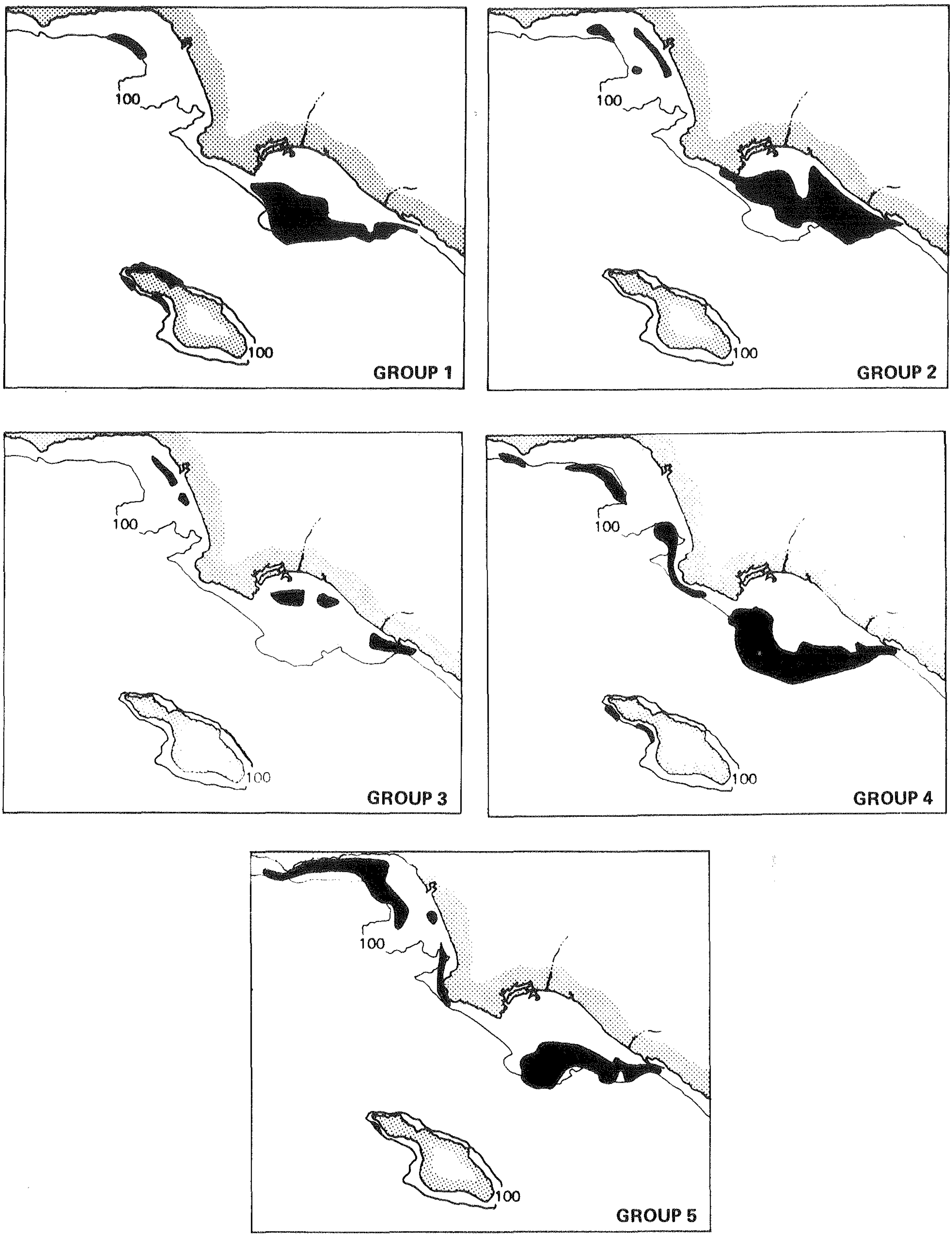

Figure 7-4 Distribution of Recurrent Groups of Southern California Nearshore Demersal Fishes, 1969-72 (Depth Line is 100 Meters).

Table 7-4
TOTAL NUMBER OF SPECIMENS OF EACH OF THE 20 SPECIES MOST ABUNDANT IN SAMPLES FROM THE 1969-72 TRAWLING SURVEYS OF SOUTHERN CALIFORNIA COASTAL WATERS

Rank	Species	Number of Specimens
1	Speckled sanddab	17,626
2	Pacific sanddab	10,312
3	Dover sole	9,375
4	Stripetail rockfish	5,535
5	White croaker	4,155
6	Plainfin midshipman	3,943
7	Slender sole	3,893
8	California tonguefish	3,590
9	Halfbanded rockfish	3,310
10	Yellowchin sculpin	2,836
11	Shiner perch	2,008
12	Pink seaperch	1,975
13	Northern anchovy	1,952
14	Rex sole	1,865
15	Queenfish	1,864
16	Longspine combfish	1,402
17	Splitnose rockfish	1,186
18	Curlfin sole	1,063
19	Blackbelly eelpout	849
20	Shortspine combfish	815
	TOTAL	79,554
	TOTAL (ALL SPECIES)	87,418

The apparent selectivity of the otter trawl for smaller and less mobile species indicates that some important population and community interactions may not be evident from recurrent group associations or from other analyses of population and community dynamics based solely on daytime trawling data. For example, the trawl data alone are insufficient for determining predator-prey relationships, which are important in the understanding of fish diseases. To provide complete and representative data, the daytime otter trawl data eventually must be supplemented by data collected during both day and night by additional methods such as longline fishing, purse seining, fish trapping, and in situ photography.

The otter trawl does have several advantages over other collection methods. It may be used over a large portion of the total coastal shelf environment and is effective in collecting a variety of species. Although specimens are small on the average, approximately half of these small fish are juveniles, which are not easily captured by other means. Thus, the trawl permits observation of various species at an important (and, often, critical) stage in their life cycles.

7.2.3 Relative Species Diversity

Table 7-5 summarizes a number of characteristics of the 303 trawl samples taken between August 1969 and March 1972 in the Bight. Overall, each 10-minute haul yielded an average of 12 species and a median of 193 fish. Abundance, as represented by the median catch per haul in each sampling period, varied about 15-fold, from a minimum of 22 at Port Hueneme to nearly 900 in San Pedro Bay. The average number of species per haul in each sampling period varied to a lesser degree, from 7 to about 20. As might be expected, there was a positive correlation between the number of species found and the median catch per haul.

The Shannon-Weaver (S-W) diversity index[2] was calculated for each of the 303 trawls, and the results of this analysis are summarized in Table 7-5. Excluding surveys of less than 10 hauls and those covering one season only (i.e., Port Hueneme), mean diversity indices ranged from 1.3 off Palos Verdes to 1.7 off the Santa Ana River in Orange County.

Mean values of diversity per haul in several areas of the Bight are as follows:[3]

Area	Mean S-W Diversity
Port Hueneme	1.15
Santa Monica Bay	1.34
Off Palos Verdes	1.30
San Pedro Bay	1.47
Off Orange County	1.68
Off Laguna Beach	2.10
Santa Catalina Island	1.48

These means do include values from the small samples and from areas where sampling was done during only a limited portion of the year. The table also shows the diversity of a recent collection off Laguna Beach, which is not described in Table 7-5.

There appears to be a marked decrease in diversity with increasing latitude: The diversities per haul at the northern end of the Bight, around Point Hueneme, are significantly smaller than those off Orange County. However, the data for each area were collected at different seasons with different combinations of vessels and trawling gear, and the effects of these differences must be further evaluated before firm conclusions on interareal variations in species diversity can be drawn from these data.

2. Diversity index = $-\sum_{i=1}^{s} (n_i/N)\log_e(n_i/N)$, where n_i = number of individuals in species i and N = total number of individuals (Σn_i) in the sample. (See also Chapter 8).

3. These diversity values are the means of several samples and are not based on pooled or combined samples. Thus, the values presented may underestimate the "true" diversity in each area.

Table 7-5
CHARACTERISTICS OF THE TRAWL CATCHES OF EACH AGENCY INVOLVED IN THE 1969-72 TRAWLING SURVEYS OF THE SOUTHERN CALIFORNIA COASTAL WATERS

Agency and Vessel	Sampling Location	Sampling Period	Depth Range (m)	No. of Hauls	Total No. of Species	Total Catch	Median Catch/Haul	Species/Haul Mean	Species/Haul S.E.	Shannon-Weaver Diversity/Haul Mean	Shannon-Weaver Diversity/Haul S.E.
CITY OF LOS ANGELES* Marine Surveyor	Santa Monica Bay	2/71	18-183	15	40	3,005	169	9.4	0.5	1.35	0.08
		5-6/71	18-183	6	25	962	108	8.3	0.8	1.03	0.17
		9/71	18-183	28	54	4,389	132	10.4	0.7	1.39	0.10
			Total	49	72	8,356	135	9.9	0.5	1.34	0.07
L.A. COUNTY SAN. DIST. Sea-S-Dee	Palos Verdes	5-6/70	23-61	13	38	1,786	107	8.8	1.3	1.19	0.18
		2-4/71	23-183	24	43	4,957	164	8.9	0.7	1.10	0.09
		10/71	23-137	28	50	3,931	82	10.0	0.8	1.38*	0.09
		11/71-2/72	61	11	43	2,272	102	12.5	2.2	1.69	0.13
			Subtotal	76	72	12,946	117	9.8	0.5	1.30	0.06
	San Gabriel R. Area	12/71	5-9	3	13	341	79	8.0	1.5	1.10	0.37
	S. Catalina I.	5/71	61-137	4	22	2,453	620	14.5	1.9	1.56	0.16
		10/71	23-137	4	27	756	184	11.5	1.0	1.31	0.28
		11/71	91-116	5	24	603	77	10.4	2.0	1.56	0.18
			Subtotal	13	41	3,812	217	12.0	1.0	1.48	0.12
			Total	92	81	17,099	129	10.1	0.5	1.32	0.05
ORANGE CO. SAN. DIST.** Fury II	Santa Ana R. Area	8/69	11-55	6	33	3,728	197	12.2	2.2	1.66	0.14
		11/69	11-141	8	37	2,119	220	12.5	1.5	1.70	0.22
		2/70	11-141	8	38	2,072	228	13.5	1.4	1.62	0.17
		5/70	11-141	8	36	2,281	262	14.2	0.8	1.88	0.15
			Subtotal	30	58	10,200	244	13.2	0.7	1.72	0.09
Van Tuna	Santa Ana R. Area	8/70	11-141	8	37	3,816	409	14.2	1.8	1.66	0.19
		11-12/70	11-141	8	50	4,102	418	17.0	1.5	1.51	0.24
		2/71	11-141	8	50	4,271	373	15.9	1.4	1.58	0.24
		5/71	11-141	8	50	6,227	880	17.4	1.3	1.64	0.13
		8/71	11-141	8	57	6,201	598	20.2	1.6	1.76	0.19
		12/71	11-141	8	47	3,472	454	17.4	1.3	1.96	0.15
			Subtotal	48	86	28,089	474	17.3	0.6	1.68	0.08
			Total	78	90	38,289	395	15.7	0.5	1.70	0.06
LOS ANGELES CO. MUSEUM OF NAT. HIST. Searcher	S. Catalina I.	10/71	81-110	6	19	360	63	8.3	1.5	1.56	0.06
ALLAN HANCOCK FOUND. Van Tuna 25-ft otter trawl	Port Hueneme	12/71	9-55	11	38	5,215	447	13.0	1.1	1.12	0.14
		2/72	11-183	7	28	1,093	129	9.1	1.2	1.17	0.19
			Subtotal	18	48	6,308	314	11.5	0.9	1.14	0.11
16-ft otter trawl	Port Hueneme	2/72	11-26	7	19	205	22	7.1	1.1	1.75	0.12
			Total	25	51	6,513	141	10.3	0.8	1.29	0.10
OCCIDENTAL COLLEGE Van Tuna	San Pedro Bay	1/71	22-274	3	30	1,028	314	12.3	1.4	1.38	0.36
		2-4/71	22-366	15	47	3,604	154	10.1	0.6	1.40	0.09
		5-7/71	20-22	3	30	935	309	11.7	3.3	1.44	0.58
		8-10/71	9-366	12	47	5,200	296	11.1	1.7	1.31	0.16
		11/71-1/72	9-274	10	60	2,630	220	14.8	0.9	1.60	0.20
		2-3/72	11-110	8	46	2,939	332	15.2	1.3	1.67	0.23
			Subtotal	51	88	16,336	224	12.3	0.6	1.46	0.08
	S. Catalina I.	3-4/71	60-137	2	19	465	232	11.5	3.5	1.39	0.20
			Total	53	91	16,801	228	12.2	0.6	1.46	0.07
			TOTAL	303	121	87,418	193	11.8	0.283	1.46	0.03

*Survey conducted by Hyperion Sewage Treatment Plant.
**Survey conducted by Marine Biological Consultants for the Orange County Sanitation Districts.

The few studies to date on the diversity of demersal fish indicate that values less than 0.2 or 0.3 or greater than 2.6 or 2.7 are extremely rare. Mean values of about 2.0 have been found in one estuarine area (Salo 1969). In this context, the overall mean diversity of 1.46 found in the 1969-72 surveys in the Bight is low; however, lower values may be normal for open coastal areas. Analysis of samples from other coastal areas is required to properly assess the significance of the local values.

Although small otter trawls (16- to 40-ft headropes) are the common collecting devices in demersal fish surveys, there has been little or no standardization of the design or use of the trawls in surveys of the Bight and other areas. As gear and trawling techniques could substantially affect the number of fish caught, comparison of the catches made in various surveys is extremely difficult. Table 7-6 presents a number of statistics on the gear and trawl procedures used by the six agencies involved in the 1969-72 surveys; the table also gives the median numbers of fish and species per haul found by each agency in each area surveyed. Net size (headrope length), trawl speed, and time, distance and bottom surface area trawled varied between agencies; however, most of these parameters were not directly related to fish abundance. There was an inverse relationship between fish catch and the size of the mesh in the cod end of the net; thus, net mesh size may account for some of the differences noted in the several areas sampled.

The obvious assumption to explain the relationship between cod-end mesh size and abundance is that many of the fish were small enough to escape through the larger mesh, but were retained on the smaller mesh. Table 7-7 shows the distribution by length of speckled sanddab caught in six trawls made in each of two areas, off Palos Verdes and in Santa Monica Bay. The Palos Verdes trawls were made with a net having a 1-3/8-in. cod-end mesh; a net with a 1-in. cod-end mesh was used in the trawls in Santa Monica Bay. The modal length of fish caught with the larger mesh was between 80 and 89 mm; the modal length using the small mesh was between 60 and 69 mm. Although the sizes of fish captured in the two nets were different, the fact that the trawls were made in different areas leaves open the possibility that the size distributions of the populations sampled might have been different in the two areas. The only positive methods to resolve this problem are, of course, (1) to conduct trawls in the same areas at the same time using nets with differing characteristics, or (2) to sample all areas with the same vessel/gear combination. To date, this has not been done.

7.2.4 Fish Distribution

The movements and migrations of fish, both with depth and with location, are often complex and sometimes seemingly random. Factors known to affect these movements include light, temperature, currents, the availability of food and the presence or absence of predators. Changes in these factors can be a function of natural periodic or aperiodic fluctuations; they also may be affected by man-related activities, such as wastewater and thermal discharges and fishing pressure. The distribution of fish is also, of course, determined by the natural life cycles of the various species. The distribution and movements of commercially important fish are relatively well known, and this knowledge has been successfully applied to the prediction and management of the commercial fisheries. However, there have been few studies of the short- or long-term fluctuations in the distribution of nearshore fish populations, which may be more directly influenced by human activities.

Table 7-6
SELECTED GEAR, VESSEL, AND FISH CATCH STATISTICS FOR THE SIX MAJOR AREAS COVERED IN THE 1969-72 TRAWLING SURVEYS OF SOUTHERN CALIFORNIA COASTAL WATERS

Survey Parameter	Port Hueneme (Allan Hancock Found.)	Santa Monica Bay (City of Los Angeles)	Palos Verdes (Los Angeles Co. San. Dist.)	San Pedro Bay (Occidental College)	Santa Ana R. Area (Orange Co. San. Dist.)	S. Catalina I. (Los Angeles Cc Museum of Nat. Hist.)
Net						
Headrope length (ft)	25	25	40	16	25	15
Bag mesh, stretched (in.)	1-1/2	1-1/4	1-7/8	1-1/2	1-1/2	1-1/2
Cod-end mesh, stretched (in.)	1/2	1	1-3/8	1/2	1/2	1
Trawl speed (kt)	2.5	1.5	2.7	2.5	2.5	3.0
Average trawl time (min.)	10	10	10	20	10	10
Estimated trawl distance (m)	772	463	834	1,544	774	927
Surface area trawled (sq m)	5,880	3,530	10,160	7,540	5,880	4,230
Number of samples	18	49	76	51	78	6
Median number of fish per haul	314	135	117	224	475	63
Mean number of species per haul	12	9.9	9.8	12	17	8.3

Day/Night Variations

Comparison of data collected in daytime and nighttime trawls at four stations off the Palos Verdes Peninsula showed significant differences in the species composition and abundance of day and night samples. Between March and November 1971, a total of 19 hauls (15 during the day and 4 at night) were made at a depth of 60 meters. A summary of the catch statistics for these 19 trawls is presented in Table 7-8. More than twice as many species per haul were found at night as during the day, and the median catch per haul was more than six times greater at night than during the day. The presence of a few large predatory fishes in the night hauls accounted for some of the differences. These species included the spiny dogfish (*Squalus acanthias*), sablefish (*Anoplopoma fimbria*), and Pacific hake (*Merluccius productus*). Night samples contained four to eight times as many spiny dogfish and five to twenty times as many sablefish as day samples. The Pacific hake was never caught during the day, yet one to six of these fishes were found in each nighttime trawl. A smaller, euphausid-eating fish, the shortbelly rockfish (*Sebastes jordani*), was also abundant at night, although rarely found during the day.

These observations on the differences in species composition and abundance of day and night samples emphasize the importance of considering the limitations inherent in the use of any single sampling methodology. Obviously, the data obtained by daytime trawls with one type of gear do not provide a complete picture of the fish communities.

In general, the diel (day-to-night) variations in flatfish species composition and abundance were not significant. This may indicate that most flatfishes found at 60 meters depth do not migrate on a daily basis, or that they do not depend on vision to avoid or escape the trawl net. Larger and more mobile fishes, such as perch, roundfish, and large rockfish, are either able to avoid the net by day or are present in the areas trawled only at night. These species are basically deep-water demersal fishes, and their occurrence in shallower waters at night may be indicative of a major migration into the shallow waters to feed. The trawls showing the greatest diel variability of all parameters were those from a station located within several hundred meters of the "L" diffuser off Whites Point.

Seasonal Variations

The seasonal migration patterns exhibited by almost all marine fish populations on the open coast are largely determined by water temperature. Measurements of marine temperature discontinuities have been used for the past 50 years to predict the location and relative abundance of commercially important fish populations in the Pacific Ocean. However, this information has not been used in developing or conducting field data collection programs directed toward characterizing the nearshore demersal fish populations. Studies of the responses of these populations to water temperature changes have focused primarily on the effects of upwelling.

During 1958-63, the California Department of Fish and Game conducted a study of demersal fish populations and bottom water characteristics in Santa Monica Bay

LENGTH-FREQUENCIES OF SPECKLED SANDDAB CAUGHT WITH 1-3/8-IN. AND 1-IN. COD-END STRETCH MESH NETS

Standard Length (mm)	No. of Fish Caught*: 1-3/8-in. Mesh (Palos Verdes, Jun 72)	1-in. Mesh (Santa Monica, May 72)	Total
20-29	0	4	4
30-39	0	25	25
40-49	0	51	51
50-59	0	27	27
60-69	6	103	109
70-79	41	87	128
80-89	107	40	147
90-99	78	4	82
100-109	27	1	28
110-119	3	0	3
120-129	1	0	1

*Six trawls in each area

Table 7-8
CATCH STATISTICS FROM DAY AND NIGHT TRAWL HAULS AT FOUR STATIONS (60 m DEPTH) OFF PALOS VERDES, 1970-72

	Day	Night	Total
Number of hauls	15	4	19
Number of fish	1,991	1,785	3,776
Median catch per haul	70	459	80
Number of species	32	34	42
Mean number of species per haul (S.E.)	9.1(1.1)	20(2.6)	12(1.4)
Mean diversity per haul (S.E.)	1.2(0.10)	2.1(0.15)	1.4(0.12)
Average catch per haul (No. fish)			
Elasmobranchs	0.40	7.0	1.8
Large roundfish*	2.9	82	20
Intermediate roundfish**	33	207	70
Small bottomfish†	13	34	17
Flatfish	80	120	88

*Includes meandering piscivores, such as sablefish, large rockfish, hake, and California scorpionfish, which may attain a length of 1 meter at maturity.
**Includes schooling invertebrate- and plankton-eaters, such as white croaker, anchovy, and perch.
†Includes sculpins, poachers, combfish, and small rockfish that feed on micro-invertebrates and larvae.

(summarized in Carlisle 1969). A recent SCCWRP analysis of portions of the data from this study revealed significant changes in the distribution of demersal fish that were apparently related to mass inshore movements of basin waters.

The data examined by SCCWRP were collected in the winter and summer of 1960. Figure 7-5 shows the location of the five areas trawled in the two surveys; Table 7-9 is a summary of the bottom water and fish catch characteristics.

In the winter (January and February), dissolved oxygen decreased from 7.6 mg/L in the inshore areas to a little less than 6 mg/L in the deeper offshore areas. The temperatures in the five areas varied from a high of 14.3°C in Area 2 to a minimum of 10.8°C in the Redondo Canyon area. There were no major differences in the chlorinity of the bottom waters in the five areas. In summer (June), dissolved oxygen concentrations in each area were between 2 and 3 mg/L less than the values observed during the winter. Temperatures of the bottom waters during the summer were also between 2 and 5°C less than temperatures observed in January and February. The chlorinity concentrations in the two nearshore areas were slightly lower in summer than in winter, but the summer value for the Redondo Canyon area (18.725 parts per thousand) was the highest observed in any of the areas during the two surveys. The pattern of bottom water characteristics observed in the five areas in summer indicates that upwelling occurred during or shortly before the summer survey.

Fish catches in each area in the two sampling periods varied. In winter, the highest median catch (171 fish) was in the Redondo Canyon area; in the other four areas, the winter catches varied from 24 to 64 fish per haul. In all five

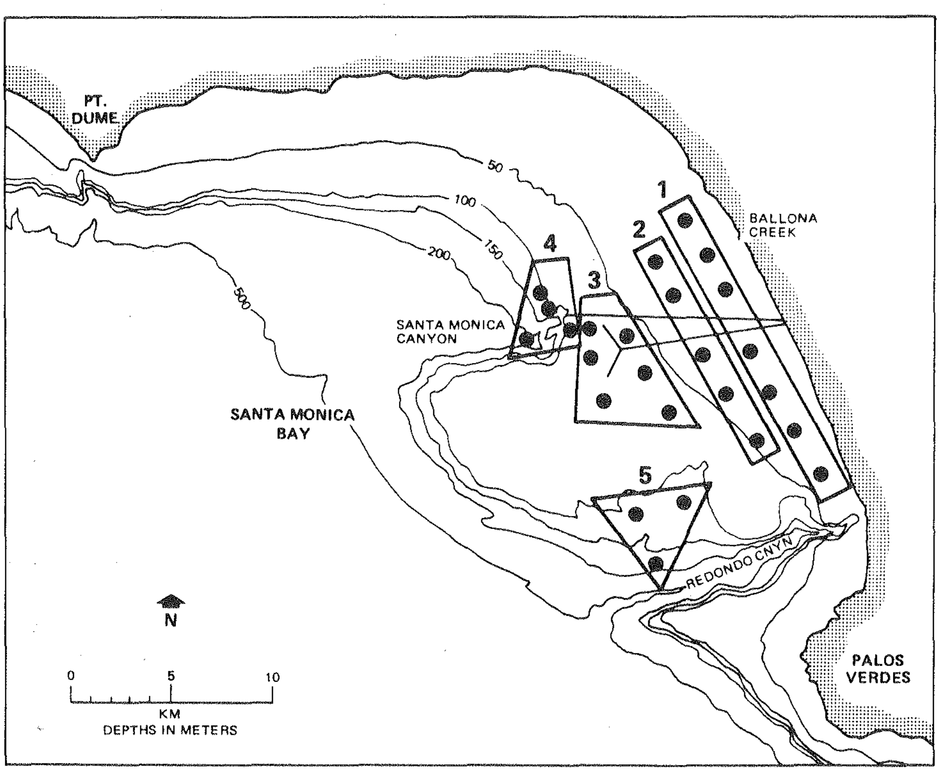

Figure 7-5. 1958-63 Trawling Stations in Santa Monica Bay, Grouped by Depth. After Carlisle 1969, fig. 1.

Table 7-9
BOTTOM WATER AND FISH CATCH CHARACTERISTICS IN SANTA MONICA BAY, WINTER AND SUMMER 1960

Characteristic	Area 1, Inshore (18 m)	Area 2, Offshore (37 m)	Area 3, Offshore (55-73 m)	Area 4, Santa Monica Canyon (92-137 m)	Area 5, Redondo Canyon (92-152 m)
BOTTOM WATER					
Winter (Jan-Feb)					
Dissolved oxygen (mg/L)	7.6 ±0.03(7)*	7.2 ±0.16(4)	7.1 ±0.05(5)	5.8 ±0.21(3)	5.9 ±0.75(2)
Temperature (°C)	13.8 ±0.29(7)	14.3 ±0.23(4)	13.7 ±0.11(5)	11.5 ±0.18(3)	10.8 ±0.25(2)
Chlorinity (°/oo)	18.525 ±0.023(7)	18.568 ±0.061(4)	18.510 ±0.15(5)	18.525 ±0.014(3)	18.562 ±0.012(2)
Summer (Jun)					
Dissolved oxygen (mg/L)	5.3 ±0.24(5)	5.5 ±0.15(5)	4.7 ±0.16(4)	3.8 ±0.15(2)	3.8 ±0.20(2)
Temperature (°C)	10.6 ±0.08(7)	9.8 ±0.12(5)	9.1 ±0.06(6)	8.4 ±0.17(3)	8.2 ±0.15(2)
Chlorinity (°/oo)	18.470 ±0.012(5)	18.330 ±0.207(5)	18.575 ±0.017(4)	18.575 ±0.024(2)	18.725 ±0.000
FISH CATCH					
Winter (Jan-Feb)					
Median catch/haul	29(7)	64(4)	42(6)	24(4)	171(1)
Number of species/haul	5 ±0.8(7)	7 ±1(4)	9 ±0.7(6)	9 ±2(4)	6(1)
Diversity/haul**	0.851 ±0.168(7)	1.27 ±0.07(4)	1.33 ±0.18(6)	1.80 ±0.16(4)	1.13(1)
Summer (Jun)					
Median catch/haul	48(6)	352(5)	29(5)	66(4)	110(2)
Number of species/haul	6 ±1(6)	11 ±0.7(5)	6 ±1(5)	8 ±3(4)	8 ±0(2)
Diversity/haul**	1.06 ±0.09(6)	1.37 ±0.07(5)	1.35 ±0.15(5)	1.42 ±0.26(4)	0.879 ±0.014(2)

*Mean ± std. error (number of samples).
**Shannon-Weaver diversity.

areas, the mean number of species per haul was between five and nine. During the summer, both catch per haul and species per haul in the nearshore Areas 1 and 2 increased; the five-fold increase in catch in Area 2 was a result of higher abundance of the yellowchin sculpin, speckled sanddab, English sole, and California tonguefish in this area. At the same time, catchès in the deeper areas contained fewer yellowchin sculpin and speckled sanddab. These differences indicate that some demersal fish populations in Santa Monica Bay respond to changes in bottom water characteristics that occur in early summer by accumulating in relatively high densities in inshore waters.

These data are consistent with the conclusions of Laevastu and Hela (1970), whose diagram of the general influence of coastal upwelling on the nearshore distribution of pelagic and demersal fish is interpreted in Figure 7-6. When upwelling occurs, many shelf fish generally avoid the intruding offshore waters by moving either inshore (demersal fish) or to the surface and offshore (pelagic fish). The actual factors that affect the demersal fish are most likely decreasing temperature or decreasing dissolved oxygen. In the 1960 observations in Santa Monica Bay, dissolved oxygen in the areas farthest offshore did not appear to reach limiting levels for fish (all values were above 3.0 mg/L). Although some species might tend to avoid such waters, the bottom temperature changes associated with upwelling are sufficient to cause major changes in the distribution of affected fish populations.

Considering these observations, it seems reasonable to presume that demersal fish will also avoid other kinds of water mass changes, such as those associated with strong storm runoff.

Natural and Man-Related Aperiodic Variations

The abundance and community structure of coastal zone fishes vary with the life cycle patterns of the individual species as well as with changes in environmental conditions. Abundance of southern California coastal zone species changes with the annual influx and mortality of young fish and the out-migration of more mature fish. If measurements are taken frequently, an annual cycle of size or age composition and abundance changes for every species should be observable. Natural or man-related environmental changes altering a portion or all of these life cycles can occur.

Effects of Wastewater Discharge

Between August 1969 and May 1972, quarterly trawls were made off Orange County in the vicinity of the two municipal wastewater outfalls of the Orange County Sanitation Districts (Figure 7-7). At the beginning of the study period, wastewaters were being discharged through the shorter outfall. On 1 April 1971, use of this outfall was terminated, and discharge of wastewaters through the longer, deeper outfall was initiated.

Table 7-10 shows the white croaker catch at five trawling stations over the 3-year period. Catches at Station T-0 (near the old outfall) ranged from 100 to 1,000 fish per haul prior to April 1971. In this period, no white croaker were found at the control station (T-OC) or at Station T-3 near the new outfall, although a few fish were caught at Station T-2. Following the outfall changeover in April 1971, very few white croaker were found at Station T-0 or at any

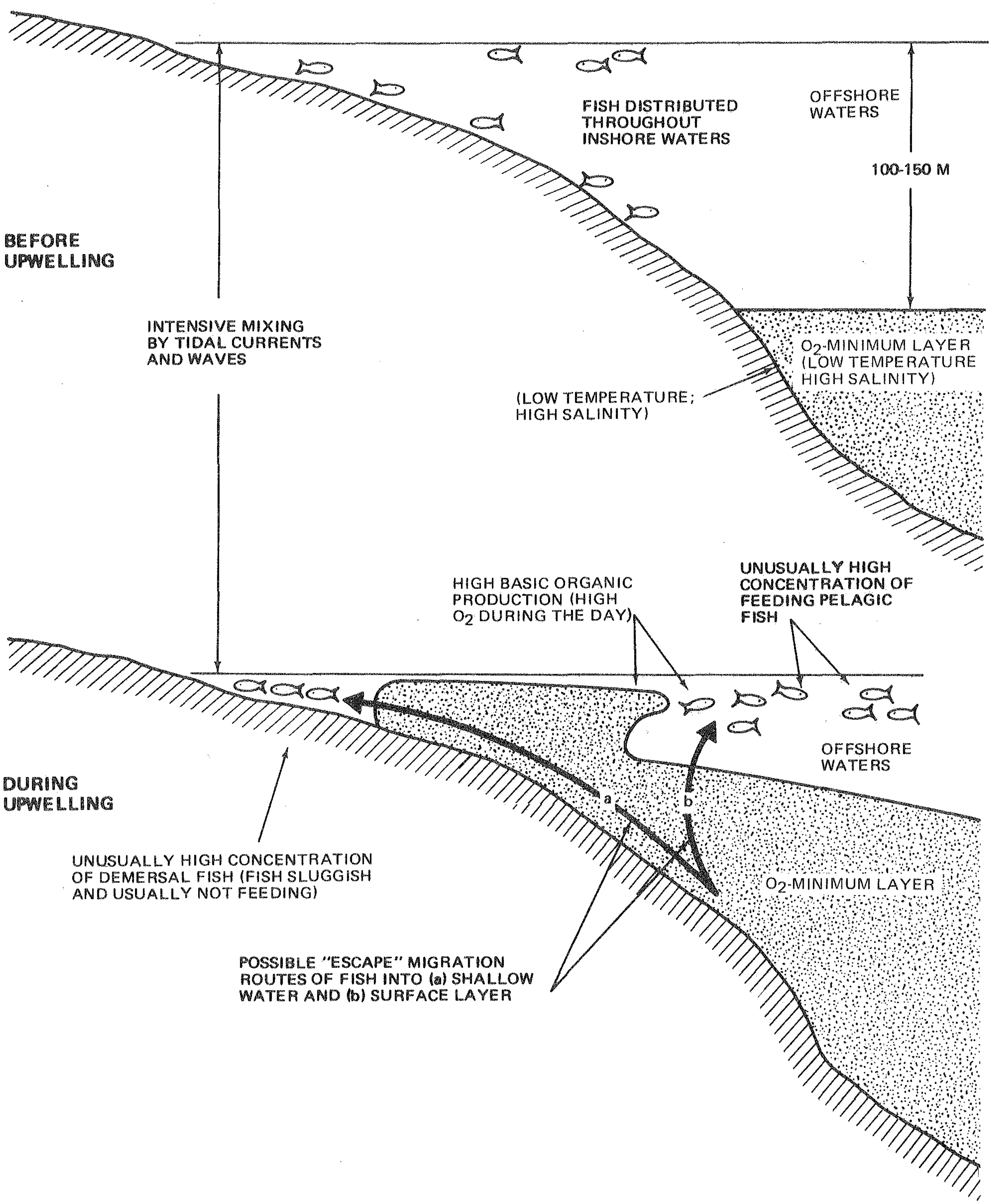

Figure 7-6. Diagram of the Influence of Coastal Upwelling on the Distribution of Nearshore Demersal and Pelagic Fishes.

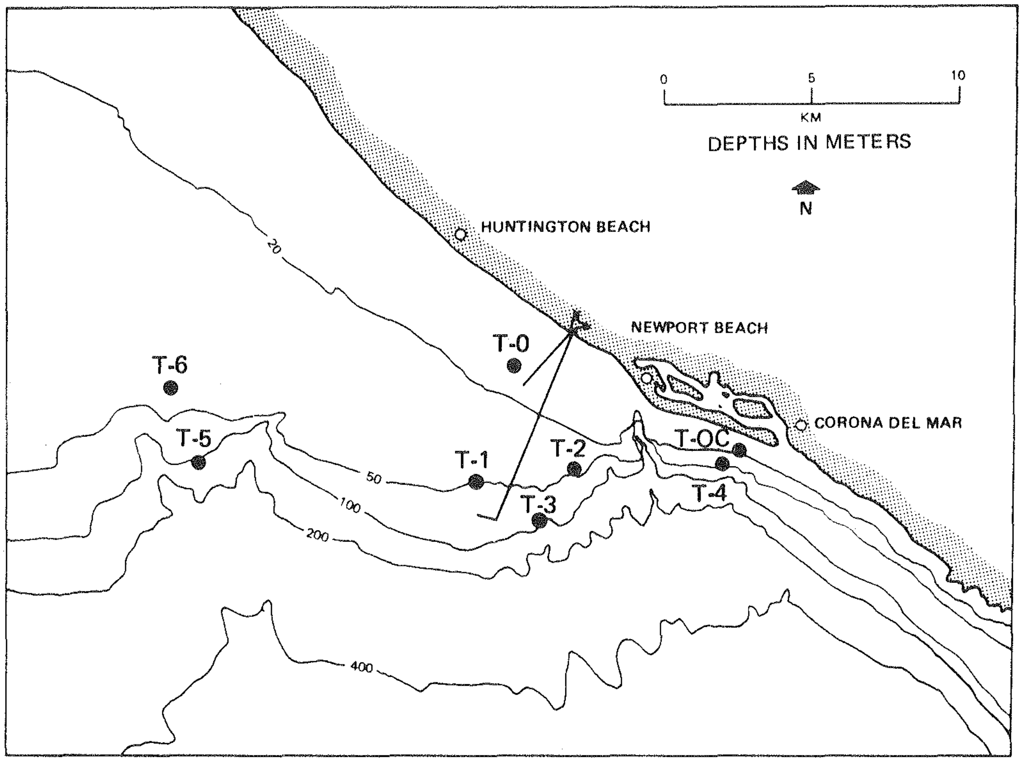

Figure 7-7. Station Locations for the 1969-72 Quarterly Trawls off Orange County.

Table 7-10
CATCHES OF WHITE CROAKER FROM QUARTERLY TRAWLS AT FIVE STATIONS OFF ORANGE COUNTY, 1969-72

Sample Date		Old Outfall (T-0)	Control (T-OC)	New Outfall (T-1)	(T-2)	(T-3)
1969						
	Aug	1,024	-	1	4	0
	Nov-Dec	160	0	1	3	0
1970						
	Feb	293	0	0	39	0
	May	455	0	0	3	0
	Aug	578	0	2	14	0
	Nov	254	0	0	0	0
1971						
	Feb	100	0	0	0	0
	May*	6	0	0	0	0
	Aug	11	2	0	1	1
	Dec	0	0	0	0	0
1972						
	Feb**	32	0	0	0	0
	May	0	0	0	0	0

*Outfall changeover, April 1971
**Old outfall flushed with 1 mgd, February 1972

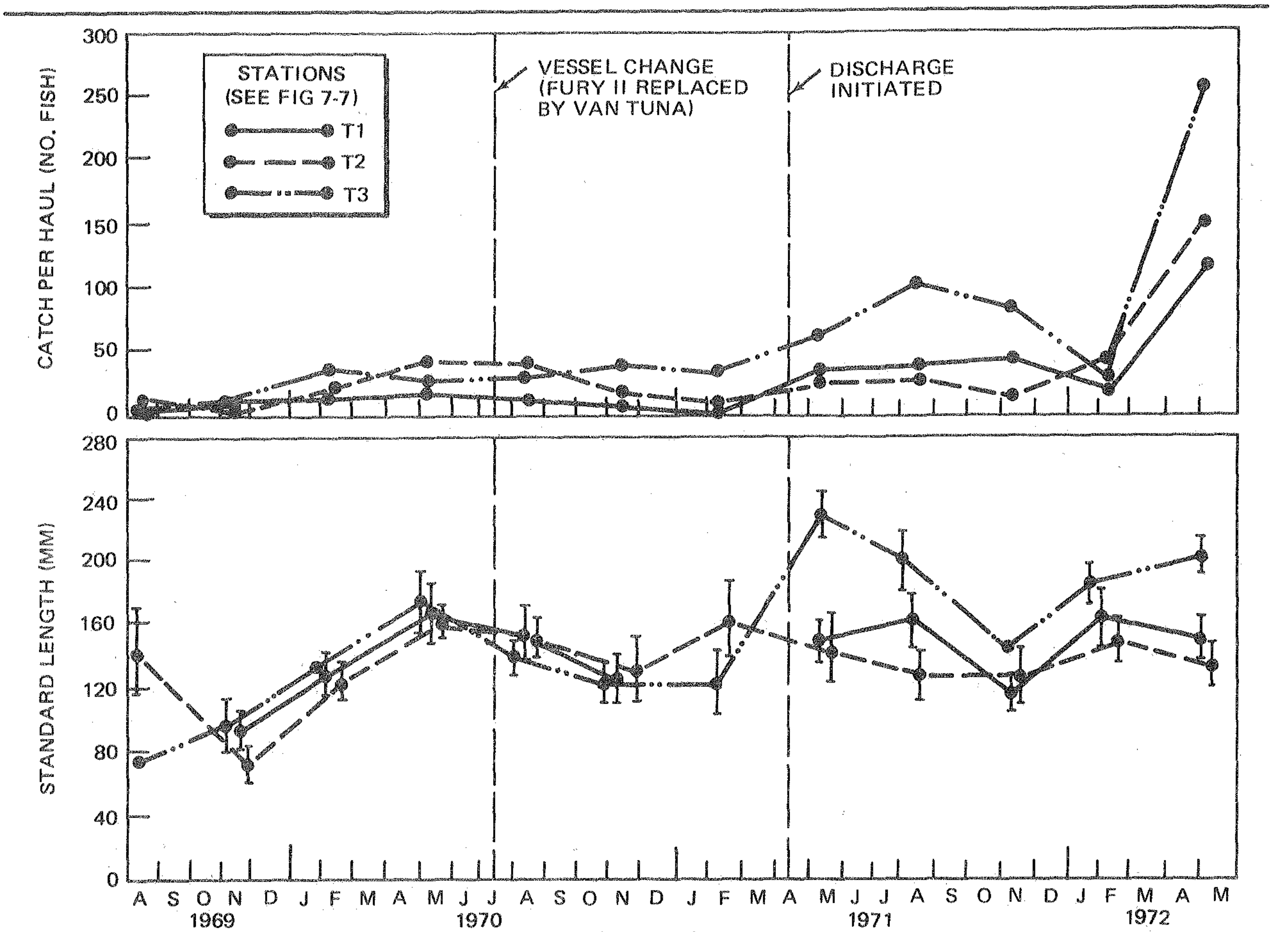

Figure 7-8. Catch per Haul and Mean Standard Length (± 2 S.E.) of Dover Sole from Three Stations Near the New Orange County Outfall, 1969-72.

of the other trawling stations, suggesting that the white croaker were avoiding or at least were no longer attracted to these locations. The variability of the data is such that it is not certain whether the decrease in abundance at the old outfall began before or after the discharge was terminated.

During the survey period, there were also changes in abundance and size composition of the dover sole catch at the three stations (T-1, T-2 and T-3) closest to the new outfall. Figure 7-8 shows the catch per haul and the mean standard length of dover sole from the three trawling stations between August 1969 and May 1972. Before the change in wastewater discharge location, the catch per haul at all three stations was fairly constant and always less than 50 fish per haul. There appears to have been a slight increase in abundance at Station T-2 during the summer of 1970, paralleling an increase and a subsequent decrease in length of the captured fish at all three stations. Following initiation of the new discharge in April 1971, the abundance of dover sole appeared to increase, particularly at Station T-3 which is downstream from the new discharge. Before April 1971, the average length of the fish caught at the three stations was similar. After the new discharge was initiated, larger fish were found at Station T-3. Thus, changes in the structure of the dover sole population off

the new outfall coincided with the initiation of wastewater discharge through this outfall. These observations of white croaker and dover sole indicate that both natural and wastewater-related changes in environmental conditions cause changes in the abundance and size composition of fish populations that can be detected and distinguished with present gear at sampling intervals as great as every 3 months.

Effects of Fishing Pressure

Changes in the abundance of certain fish species are of major concern to both the commercial and sports fishing groups. Various hypotheses have been offered to explain certain observed fluctuations; too often, however, the explanations are based on incomplete and biased information and do not reflect the fact that overfishing, and even the lack of fishing, can have major effects on the relative abundance of all fish populations.

The results of overfishing that are most obvious to the fisherman are a reduction in the catch of a species per unit effort, a reduction in the average size of fish landed (a possible sign of a change in the age composition of the population), and, perhaps, the proliferation of the target species' competitors. Any of these changes in catch in an area may necessitate an economically undesirable movement of the fishing effort to waters farther from port.

Other changes in a fish community that are associated with fishing pressure may not be reflected in commercial or sport catches. For example, when fishing effort in an area is intensive and aimed solely at large predators, the predator-prey ratio in the area may become unbalanced, permitting the survival of genetically unfit or diseased individuals in prey species.

A reduction in catch does not always indicate a decrease in the abundance of the target species. For example, intensive fishing with one type of gear may result in decreased catches in that individuals may learn to avoid the gear or the population as a whole may become adapted toward successful avoidance of the gear.

The currently available data on many of the major sport and commercial fisheries are insufficient to determine the causes of major changes in abundance of important fish stocks. A recent report by the California Department of Fish and Game (Frey, 1971) concluded:

> At the present time, when landings of a particular species decline, it may be impossible to determine if this decline is due to a decrease in the size of the resource, a reduction in the amount of fishing effort, or a shift of fishing effort to another species.

This problem is illustrated in the record of overall southern California party boat catch since 1947 (Figure 7-9). Party boat landings in the waters between Point Dume and the Coronados Islands have increased at the rate of about 80,000 to 100,000 fish per year since 1947. However, the catches of individual sport fish species have fluctuated greatly, with no apparent relationship to either the overall effort or the overall landings. No information is available on the

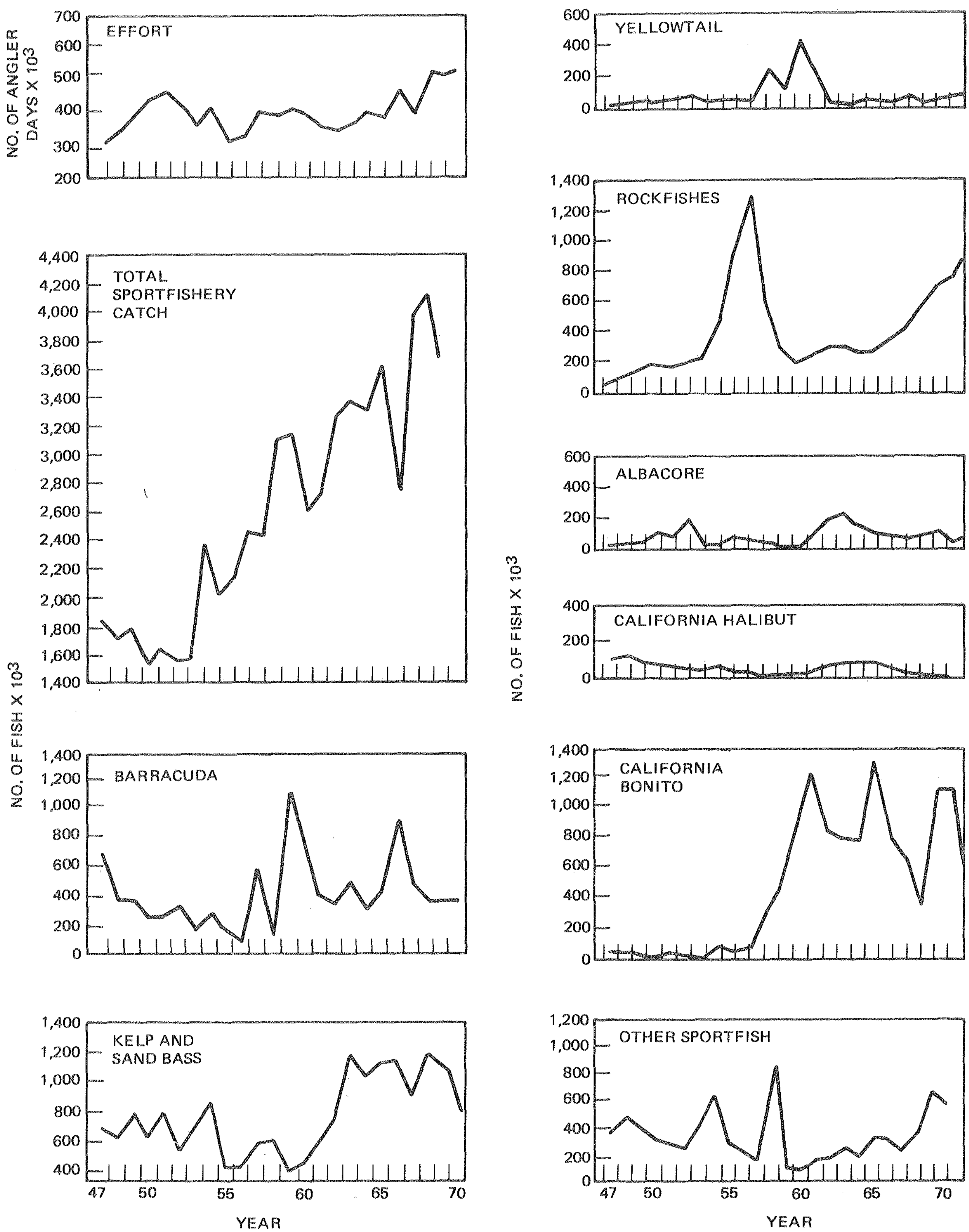

Figure 7-9. Party Boat Catches from Southern California Waters (Point Dume to the U.S./Mexico Border), 1947-70. Based on Calif. Dept. of Fish and Game, Fish Bull. 145.

effort vested in catching the individual species listed in Figure 7-9, and it is difficult to judge whether major catch increases or declines were due to changes in the populations of a particular species or to changes in the demand for the species.

Landings in local commercial fisheries have also fluctuated greatly, as shown in Figure 7-10, and the total catch during the last two decades has been substantially less than the catch during the 1940's. Landings in the Los Angeles region alone have decreased from 225 to 325 million kg/yr in the 1940's to 45 to 90 million kg/yr since 1952. The major decline in total catch between 1950 and 1952 was primarily a reflection of a well-documented reduction in the abundance of sardines. Figure 7-11 shows the total commercial catch in the Los Angeles and San Diego regions since 1943. When the variable sardine and anchovy landings are removed from the data, the landings of the remaining commercial fishes showed a fairly uniform total catch between about 25 and 70 million kg/yr.

Almost all of the sport and commercial fish landed in southern California are either pelagic fishes, taken by a variety of methods, or inshore predatory fishes, such as halibut and rockfishes, caught by selective hook-and-line fishing. Bottom fish caught by commercial trawling represent an insignificant fraction of the total catch. This situation is in direct contrast to the effort distribution in central and northern California, where trawling and longline fishing of bottom fish communities accounts for much of the fish landed. These differences in fishing modes should result in major differences in the abundance, health, and diversity of the bottom and nearshore fish communities of the two areas.

Within the Southern California Bight, there is a difference between the fishing effort distribution and selectivity in coastal and offshore areas. For example, commercial trawling within the Bight has been restricted primarily to the shelf areas of the Santa Barbara Basin (as regulated by law), with little or no trawling of benthic fishes to the south. In contrast, sport hook-and-line fishing (especially party boat fishing) for the larger, more pelagic and strongly predaceous fishes has been intense along the coasts of Los Angeles, Orange and San Diego Counties and off Santa Catalina and, more recently, Santa Cruz Islands. Variations in fishing effort selectivity and intensity must be recognized as factors affecting the health, abundance, and ecological stability of fish populations.

Other Factors Related to Distribution

A number of the fish species found in the nearshore waters spawn in bays and estuaries or in offshore waters. Consequently, the abundance of these fishes in nearshore waters may be more the result of variations in the conditions in the spawning areas than in the immediate nearshore water. Analysis of data on the age and length composition of the nearshore fish populations would aid substantially in evaluating the spawning success and juvenile mortality of these populations.

There have been long-term changes in the sediment characteristics of the Southern California Bight. As demersal fish are, by definition, dominantly bottom feeders, such changes might play an important part in the distribution of these species. For example, as discussed in more detail in Chapter 5, there has been a major shift in the relative proportions of sand and silt in the Santa Monica Bay

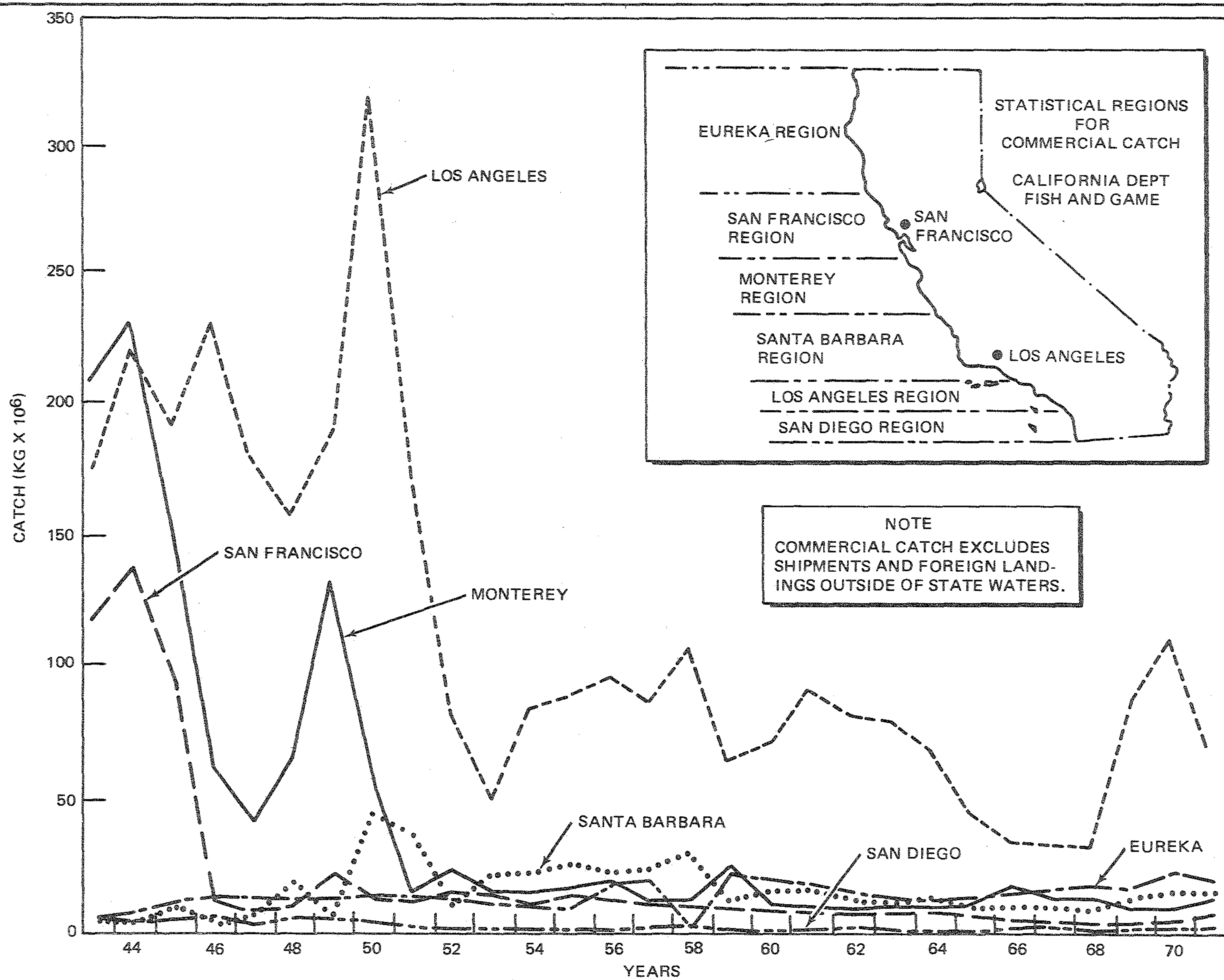

Figure 7-10. California Commercial Fish and Shellfish Landings, 1943-71.

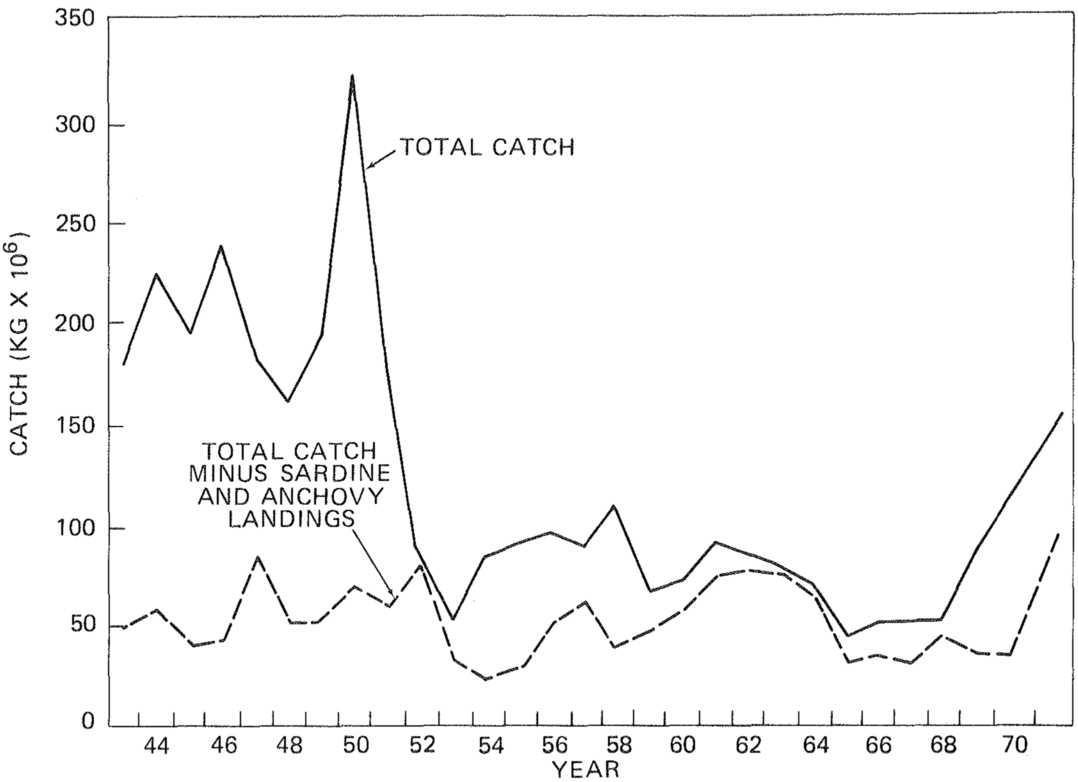

Figure 7-11. Commercial Fish and Shellfish Landings Into the Los Angeles and San Diego Regions from California Waters, 1943-71.

sediments over the last 50 years. Fifty years ago, the Pacific sanddab was found in more than 50 percent of the trawls in this area. In the last 15 years, the Pacific sanddab has been found less frequently; it was found in less than 20 percent of the most recent samples from the bay. Conversely, the dover sole and speckled sanddab, which were found relatively infrequently in the earliest collections, have moved steadily upward in relative frequency; since 1969, they have dominated local trawl catches. At present, there is insufficient data to demonstrate a causal connection between these changes and the changing sediment composition in Santa Monica Bay.

7.3 TRACE CONSTITUENTS IN DEMERSAL FISHES

To complement the SCCWRP analysis of concentrations of chlorinated hydrocarbons and trace metals in the sediments around southern California municipal wastewater outfalls, the project has measured the concentrations of these trace substances in the tissues of fish from various areas of the Bight. The SCCWRP program supplemented an ongoing study of pesticide concentrations in fish and other organisms from southern California coastal waters conducted by the San Jose Creek Pesticide Laboratory of the County Sanitation Districts of Los Angeles County.

Two laboratories were involved in the chlorinated hydrocarbon measurements, and it was necessary to determine the comparability of their results. Specimens of the intertidal mussel, *Mytilus californianus*, were collected from the Royal Palms State Beach near the base of the Whites Point outfall system at Palos Verdes. Multiple composite samples of whole soft tissue were sent to the San Jose Creek Laboratory and the University of California at Bodega Bay Institute of Pollution Ecology for analysis of p,p'-DDE and Arochlor-1254 (the two major components of the DDT and PCB series found in organisms of the Southern California Bight). Table 7-11 presents the results of these replicate analyses. In general, the agreement between the two laboratories was very good, particularly for Arochlor-1254. There is some evidence that one component of the DDT series, DDMU, was present in the samples and was not reported by the San Jose Creek Laboratory.

Analyses of trace metals were made on composite samples of dover sole liver tissue (the fish liver plays an important role in detoxification and is known to concentrate metals). Neutron activation analysis was used in the study because of the small size of the samples, the small amounts of metals involved, and the need to detect small variations from natural background levels. The method was standardized by measuring trace-metal-certified samples from the National Bureau of Standards. The differences between the measured and certified values of the standard samples were generally less than 10 percent.

7.3.1 Chlorinated Hydrocarbon Concentrations

Figures 7-12 and 7-13 show the results of analyses of 92 composite samples of muscle tissue from dover sole for DDT and PCB. The highest DDT values found were in specimens collected near the Whites Point, Hyperion, and Orange County outfalls. These values were significantly higher than those found at Santa Catalina Island and in areas to the northwest towards Point Hueneme. As described in Chapter 4, the Whites Point outfall system has been a significant point source of chlorinated hydrocarbons in the past, and concentrations of DDT in the sediments near these outfalls reflect the magnitude of the input (Chapter 6). PCB values showed a similar pattern (Figure 7-13).

These concentrations of DDT and PCB in Palos Verdes dover sole were within the range of values found by the Los Angeles County Sanitation Districts in black perch, *Embiotoca jacksoni*, (DDT: 0.61 to 64 mg/wet kg and PCB: 0.35 to 43 mg/wet kg) and kelp bass, *Paralabrax clathratus* (DDT: 0.77 to 47.0 mg/wet kg, and PCB: 0.1 to 6.0 mg/wet kg) caught off the Palos Verdes Peninsula during 1971 and 1972.

About 60 percent of the composite samples of muscle tissue from dover sole captured during 1971 and 1972 in trawls between Redondo Canyon and the western entrance of the Los Angeles Harbor exceeded the maximum total DDT concentrations (5 mg/wet kg) permitted by the U. S. Food and Drug Administration in fish to be offered for sale. Similar excess of DDT have been noted in white croaker taken from the Los Angeles Harbor breakwater area (Castle and Woods 1972). The close correspondence between DDT and PCB levels in fish and those in the sediments of the areas in which the fish were caught strongly suggests that the fish were indigenous to the areas in which they were collected or that they remained in these areas long enough to be affected by the local environmental levels of DDT and PCB.

Table 7-11
CONCENTRATIONS OF p,p'-DDE AND AROCHLOR-1254 IN WHOLE SOFT TISSUES OF *MYTILUS CALIFORNIANUS* FROM THE PALOS VERDES AREA

Laboratory	Aliquot Number	Concentrations (mg/wet kg) p,p'-DDE	Arochlor-1254
San Jose Creek (County Sanitation Districts of Los Angeles County)	1	0.95	0.21
	2	0.81	0.21
	3	0.68	0.21
	4	0.81	0.22
	Mean	0.81	0.21
	Standard Error	0.06	0.002
Bodega Bay (University of California)	1	0.94	0.22
	2	1.17	0.22
	3	1.13	0.19
	4	1.06	0.20
	5	1.08	0.29
	6	1.18	-
	Mean	1.09	0.22
	Standard Error	0.04	0.02

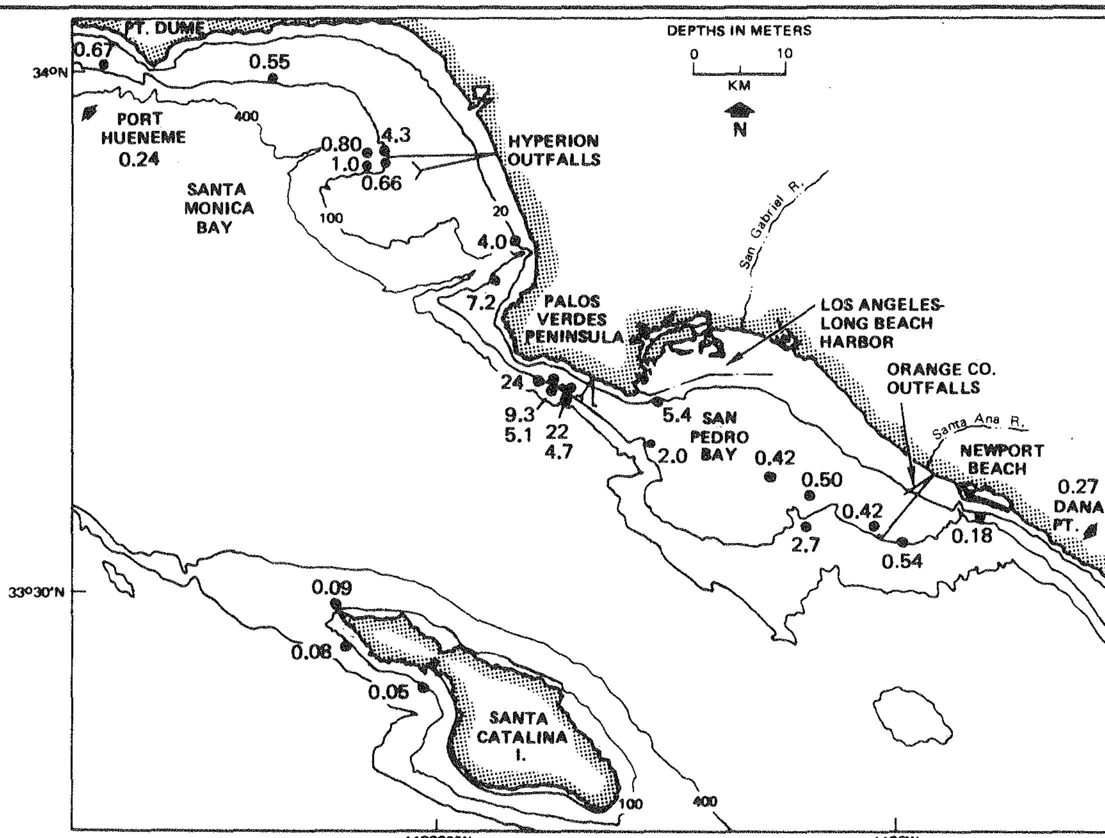

Figure 7-12. Concentrations (mg/wet kg) of Total DDT in Muscle Tissue of Dover Sole from Southern California Coastal Waters, 1971-72.

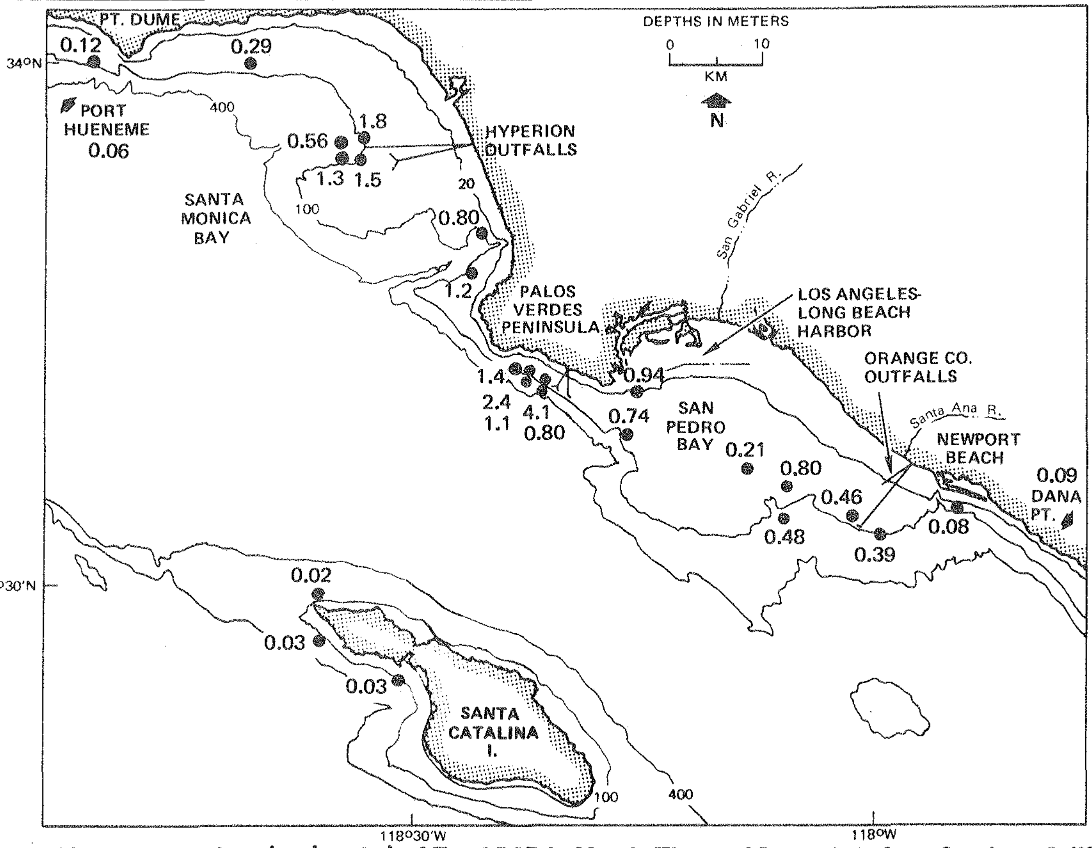

Figure 7-13. Concentrations (mg/wet kg) of Total PCB in Muscle Tissue of Dover Sole from Southern California Coastal Waters, 1971-72

7.3.2 Trace Metal Concentrations

Table 7-12 summarizes the results of analyses of 39 composite samples of dover sole liver tissue for 11 metals. The locations from which the dover sole were collected were grouped into four categories, according to the degree of sediment metal contamination (Chapter 6):

A. Natural -- The Santa Catalina Island area, assumed to have natural trace metal concentrations in surface sediments.

B. Intermediate -- Coastal areas near wastewater discharges that have slightly elevated trace metal concentrations in the surface sediments.

C. High -- Three areas (directly off the Hyperion 7-mile outfall and off the northern and southern tips of the Palos Verdes Peninsula) that have significant enrichment of trace metals in surface sediments.

D. Very High -- The area centered approximately 5 km northwest of the Whites Point outfall system that has highest surface sediment concentrations of metals.

The concentrations of all metals except iron in the livers of specimens from the "very high" area were less than or equal to those in specimens from the Santa Catalina Island control stations. In fact, for six of the metals, the highest liver concentrations were found in the "natural" area. In most cases,

Table 7-12

METAL CONCENTRATIONS IN SAMPLES OF DOVER SOLE LIVER TISSUE (MG/WET KG) AND SURFACE SEDIMENTS (MG/DRY KG) COLLECTED IN SOUTHERN CALIFORNIA COASTAL WATERS

Metal	Collection Site (Grouped According to Degree of Sediment Metal Concentration)				Probability (p) of Differences in Means for "Natural" and "Very High" Areas Occurring by Chance
	Natural	Intermediate	High	Very High	
SILVER					
Fish liver conc.					
Mean	3.0	2.4	7.1	2.1	$p > 0.30$
Std. error	1.2	0.30	1.2	0.31	
No. of samples	2	6	9	6	
Sediment conc. (est. avg.)	1.0	-	-	3.0	
Ratio, liver to sediment	3	-	-	0.7	
ARSENIC					
Fish liver conc.					
Mean	3.1	1.3	1.5	1.3	$p < 0.001$
Std. error	0.32	0.07	0.13	0.09	
No. of samples	6	9	12	11	
Sediment conc. (est. avg.)	-	-	-	-	
Ratio, liver to sediment	-	-	-	-	
CADMIUM					
Fish liver conc.					
Mean	0.58	0.29	0.33	0.19	$0.001 < p < 0.01$
Std. error	0.14	0.03	0.08	0.03	
No. of samples	6	9	12	11	
Sediment conc. (est. avg.)	0.37	-	-	59	
Ratio, liver to sediment	2	-	-	0.003	
COBALT					
Fish liver conc.					
Mean	0.06	0.04	0.04	0.04	$0.001 < p < 0.01$
Std. error	0.009	0.003	0.006	0.004	
No. of samples	6	9	12	12	
Sediment conc. (est. avg.)	7.2	-	-	7.6	
Ratio, liver to sediment	0.008	-	-	0.003	
COPPER					
Fish liver conc.					
Mean	2.2	2.5	3.4	2.0	$p > 0.30$
Std. error	0.25	0.49	0.61	0.20	
No. of samples	6	9	12	12	
Sediment conc. (est. avg.)	16	-	-	360	
Ratio, liver to sediment	0.1	-	-	0.006	
IRON					
Fish liver conc.					
Mean	180	190	180	210	$p > 0.30$
Std. error	29	13	17	13	
No. of samples	6	9	12	12	
Sediment conc. (est. avg.)	25,000	-	-	30,000	
Ratio, liver to sediment	0.007	-	-	0.007	
MERCURY					
Fish liver conc.					
Mean	0.11	0.14	0.19	0.11	$p > 0.30$
Std. error	0.02	0.01	0.03	0.007	
No. of samples	6	9	12	12	
Sediment conc. (est. avg.)	0.05	-	-	3.4	
Ratio, liver to sediment	3	-	-	0.03	
MOLYBDENUM					
Fish liver conc.					
Mean	0.13	0.09	0.08	0.08	$0.01 < p < 0.02$
Std. error	0.02	0.009	0.005	0.009	
No. of samples	6	9	12	12	
Sediment conc. (est. avg.)	-	-	-	-	
Ratio, liver to sediment	-	-	-	-	
ANTIMONY					
Fish liver conc.					
Mean	0.0034	0.0026	0.0021	0.0029	$p > 0.30$
Std. error	0.0007	0.0004	0.0002	0.0004	
No. of samples	5	8	12	12	
Sediment conc. (est. avg.)	-	-	-	-	
Ratio, liver to sediment	-	-	-	-	
SELENIUM					
Fish liver conc.					
Mean	1.2	0.66	0.97	0.64	$0.001 < p < 0.01$
Std. error	0.14	0.09	0.12	0.07	
No. of samples	6	9	12	12	
Sediment conc. (est. avg.)	-	-	-	-	
Ratio, liver to sediment	-	-	-	-	
ZINC					
Fish liver conc.					
Mean	27	29	25	26	$p > 0.30$
Std. error	1.6	2.3	1.6	1.4	
No. of samples	6	9	12	12	
Sediment conc. (est. avg.)	63	-	-	1,100	
Ratio, liver to sediment	0.4	-	-	0.02	

however, the differences between areas were small. Figure 7-14 shows the distribution of copper concentrations in fish livers from the various stations sampled. Highest concentrations (6.8 and 6.0 mg/wet kg) were found south of the Los Angeles Harbor and northwest of the Orange County outfalls.

Chromium (not shown in Table 7-12) was found in concentrations of about 0.1 mg/wet kg in approximately 25 percent of the fish liver samples. There were no significant differences in chromium concentrations in the four types of collection sites, and the best estimate for the level of chromium in dover sole livers is about 0.05 mg/wet kg.

The overall average concentrations of metals in southern California dover sole liver tissues are within the general ranges of concentrations reported for other Pacific and Atlantic Ocean fishes (Table 7-13). Concentrations of selenium in albacore liver, however, exceed those in dover sole by an order of magnitude, and the levels of antimony in salmon livers are lower than those observed in dover sole (typical concentrations are so low (0.001 mg/wet kg) that the significance of the discrepancy is questionable). Concentrations of silver in dover sole livers appear to be higher than the values reported for other fishes.

These data indicate the quite remarkable fact that concentrations of 12 metals in livers of dover sole (known by their DDT and PCB levels to have been associated with sediments with high metal concentrations) do not increase as a result of exposure to and feeding in the contaminated sediments.

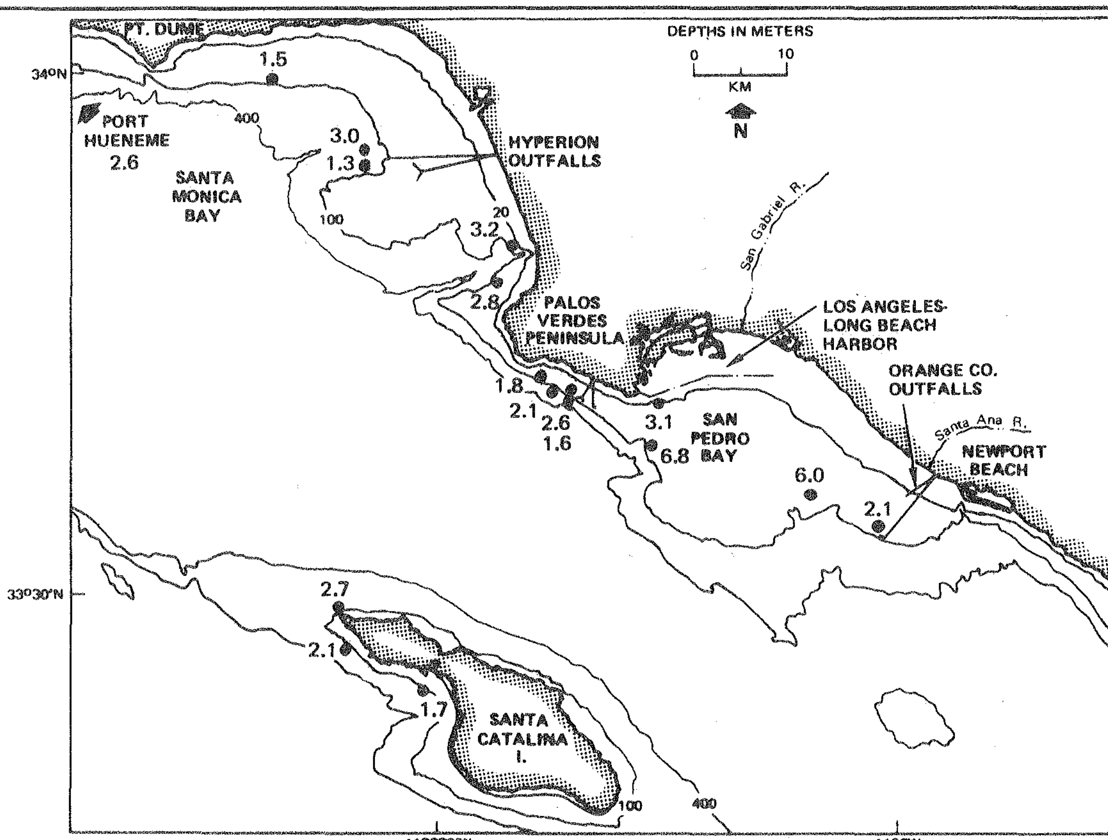

Figure 7-14. Copper Concentrations (mg/dry kg) in Liver Tissue of Dover Sole from Southern California Coastal Waters, 1970-71.

Table 7-13
TRACE METAL CONCENTRATIONS IN LIVER TISSUES OF ATLANTIC AND PACIFIC OCEAN FINFISH AND SOUTHERN CALIFORNIA DOVER SOLE

Finfish	Concentrations (mg/wet kg)											
	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mo	Sb	Se	Zn
False albacore*		0.9	0.6			0.9		0.3				50
Spanish mackerel*		0.7	0.1			0.8		0.1				8
Unidentified grouper*		0.5	0.8			9		1.1				25
Salmon**												
Chum	1.0			0.02	<0.005-0.14		150	0.1		<0.0003	5	25
Coho	0.06			0.04	<0.005		110	0.1		0.0004	1	25
King	0.08			0.01	<0.005-0.12		100	0.1		0.0004	1	30
Pink	0.25			0.01	<0.005-0.01		100	0.1		0.006	1	40
Sockeye	1.5			0.01	<0.005-0.12		80	0.1		0.006	10	25
Skipjack tuna†								0.2				
Sea bass†								0.7			3	60
Albacore†								0.2-0.9			8-19	33-52
Calico bass††	0.005		6	0.5	0.38	1.5	180		0.1			30
Dover sole (Bight avg.)	4.2	1.6	0.32	0.04	(~0.05)	2.6	190	0.14	0.09	0.0026	0.83	27

*From Windom (1972). Wet-weight values obtained from original dry-weight values assuming a wet/dry ratio of 4.0.

**From Robertson et al. (1972). Wet-weight values obtained from original dry-weight values using the wet/dry ratio of 4.2 listed by the authors for chum salmon liver.

†From Kishore and Guinn (1972).

††From Stapleton (1968). Wet-weight values obtained from original dry-weight values assuming a wet/dry ratio of 4.0.

7.4 DISEASES IN NEARSHORE DEMERSAL FISHES

Although there is a great deal of information on diseased and abnormal fishes, little is known about diseases in marine fish populations. Most reports are based either on case history descriptions of single anomalous specimens or on data from research in controlled (aquarium) or partially controlled (hatchery) conditions.

Soviet high-seas fisheries investigators have reported high incidences of disease in wild, unfished stocks in remote areas. Other reports of diseased or abnormal wild fish populations include those of Wellings et al. (1964), Miller (1969), Nigrelli et al. (1965), Cooper and Keller (1969), and Kelly (1971) on the distribution of tumor-bearing flatfishes of the Pacific Coast and Olsen and Merriman (1946) on muscle parasites in Atlantic eelpout populations. In these studies, the diseased populations were well sampled and biologically described, and the affected tissues were critically examined; the report on parasites in eelpouts by Olsen and Merriman included a discussion of the economic factors attending a disease in commercially important populations. In all cases, the diseases appeared to be natural in origin rather than related to pollution of the environment.

Two aspects of a disease must be considered--its initiation and its maintenance in the population--and both are subject to natural variability and to the effects of man-related activities. Factors regulating maintenance of a disease in a population include mortality, migration, predation pressure, and competition. Initiation of a disease may be a function of the species life cycle and may depend on environmental stress and population density as well as on an etiological agent.

In recent years much concern has been expressed over the relationship of diseased and anomalous fishes to areas of wastewater discharge and uptake of trace pollutants. Of particular significance to the discussion of wastewater effects in southern California are the observations of Young (1964). He reported observing "cancerous" lesions on dover sole from Santa Monica Bay and papillomas on white croaker, California tonguefish (*Symphurus atricauda*), basketweave cusk-eel (*Otophidium scrippsae*), and Pacific sanddab from Santa Monica Bay and the Los Angeles-Long Beach Harbor. The papillomas on the white croaker were found to be nonmalignant (Russel and Kotin 1957), and no findings on the growths on dover sole that would justify use of the term "cancerous" have been published. Such reports illustrate the need for careful differentiation between descriptive and functional terminology in reports on disease studies.

Young concluded that poor water quality, especially from wastewater discharge, was responsible for the anomalies he observed. His conclusions were partially based on a study in which lesions similar to those that he observed on white sea bass from the outer Los Angeles-Long Beach Harbor were produced experimentally in California killifish (*Fundulus parvipinnis*) through exposure to Dominguez Channel effluent. However, because of the lack of detailed quantification and description of the lesions, the apparent rapid course of the disease, and susceptibility of the killifish to bacterial infections that produce lesions of grossly similar course and description (Wells and Zobell, 1934), reports ascribing these lesions to wastewater effects or describing them as cancerous seem to be quite unjustified.

Observations on diseases in southern California fishes were made in the 1969-72 trawling surveys described in Section 7.2. In their surveys for the Orange County Sanitation Districts, Marine Biological Consultants verified reports of tail erosion and lip papillomas in white croaker and papillomas in dover sole from the Orange County area and quantified the frequency of occurrence of these diseases. The trawl data collected by the County Sanitation Districts of Los Angeles County: (1) extended the known range of tumor-bearing dover sole to both Santa Catalina Island and the Palos Verdes shelf, (2) verified a high, and apparently localized, incidence of fin erosion in dover sole off Palos Verdes, (3) revealed a difference in incidence of copepod eye parasites on Pacific sanddab from Santa Catalina Island and the Palos Verdes shelf, and (4) extended the known depth range of white croaker with tail erosion and exopthalmia to the vicinity of the Whites Point outfalls. An earlier study by Valentine and Bridges (1969) revealed a high incidence of bone deformities in southern California barred sand bass (*Paralabrax nebulifer*), a species usually not taken in otter trawls.

Data from these sources were the basis for the SCCWRP disease studies. The SCCWRP program, initiated in 1971, began with the location, retabulation, and detailed review of much of the data recently collected in local trawling surveys; several additional studies were contracted in 1971 and 1972. On the basis of this review of available data, the program focused on three disease syndromes--tumors in dover sole, fin erosion in dover sole and white croaker, and structural anomalies in three actively swimming species. The objectives of the program were (1) to determine the regional geographical and temporal range of the diseases and (2) to investigate biological and environmental relationships that would aid in identifying the causes and regulating factors of the diseases and that might permit comparisons with studies conducted outside the Southern California Bight.

As discussed in Section 7.2, use of a single method of collecting samples may bias the catch to some degree toward a particular segment of the fish community. Much of the SCCWRP disease work is based on data collected with the otter trawl, which is suspect in this regard in that diseased individuals may be less capable of avoiding or escaping the net than healthy specimens. This possible bias must be considered, especially when evaluating data on the incidence and severity of disease in a population.

7.4.1 Tumors in Flatfishes

In the SCCWRP disease studies, 267 of the 303 trawl samples taken in the 1969-72 trawling surveys of the Bight were examined for anomalous fishes. As shown in Table 7-14, tumors were found on one or more individuals from four flatfish species, and anomalous fish were found in all of the five areas surveyed. Of the four species, dover sole were most frequently affected. The overall incidence of tumor-bearing dover sole was 1.3 percent; the frequencies within the five areas ranged from 0.4 percent to 2.4 percent. The stations at which tumor-bearing dover sole have been captured are shown in Figure 7-15.

Table 7-14

FREQUENCY* OF OCCURRENCE OF TUMOR-BEARING FLATFISHES IN SAMPLES FROM THE 1969-72 TRAWLING SURVEYS OF SOUTHERN CALIFORNIA COASTAL WATERS

	Dover Sole			Slender Sole			Hornyhead Turbot			California Tonguefish		
Survey Area	N	n	%	N	n	%	N	n	%	N	n	%
Port Hueneme	126	3	2.4	24	0	0	132	0	0	86	0	0
Santa Monica Bay	1,708	7	0.41	259	1	0.39	108	0	0	345	0	0
Palos Verdes	4,287	54	1.2	342	0	0	36	0	0	71	0	0
San Pedro Bay	2,460	52	2.1	1,511	0	0	253	1	0.40	2,152	1	0.04
Santa Catalina I.	193	2	1.0	381	0	0	4	0	0	2	0	0
TOTAL	8,774	118	1.3	2,517	1	0.04	533	1	0.19	2,656	1	0.04

*N = total number of specimens observed; n = number of tumor-bearing specimens; % = frequency of tumor-bearing specimens.

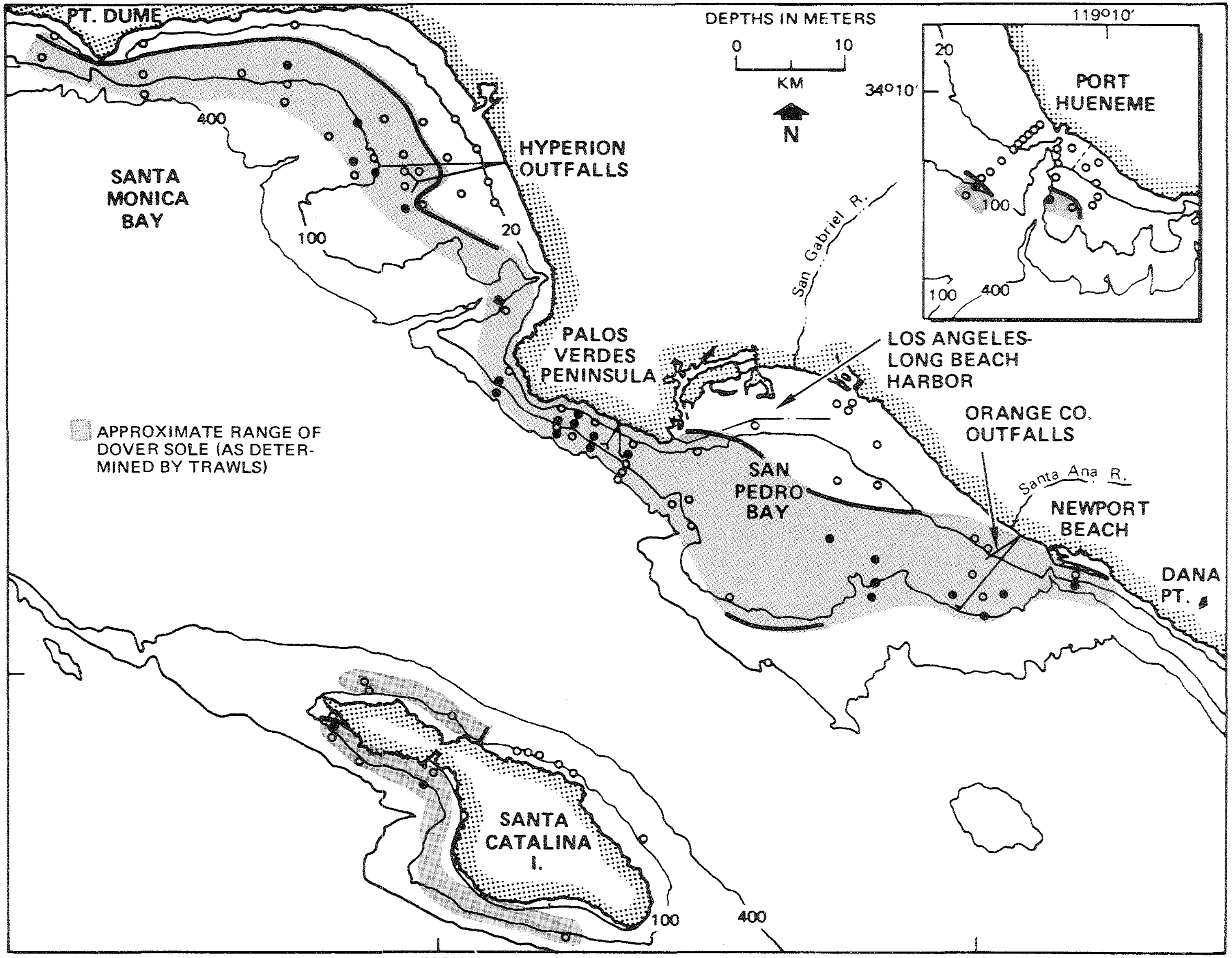

Figure 7-15. Stations at Which Tumor-*Bearing* Dover Sole Were Collected in the 1969-72 Trawling Surveys of Southern California Coastal Waters.

Tumor-bearing flatfish have been found in many coastal areas in the Pacific, including Japan, Alaska, British Columbia, Puget Sound, Humboldt Bay, San Francisco Bay and southern California. Values reported for the incidences recorded in Table 7-14 are at the lower end of the ranges of values reported from these areas. Thus, the occurrence of tumor-bearing flatfish in southern California waters does not appear to be related to any unique local condition.

Several collections of dover sole were examined in detail to determine if there was a relationship between the occurrence of tumors and fish growth characteristics. Figure 7-16 shows the size characteristics of 920 dover sole collected during a trawl survey of the Palos Verdes shelf in October and November 1971. Specimens in the collection ranged in size from 60 to 240 mm S.L., but the 22 tumor-bearing individuals did not exceed 160 mm S.L. The mean length of the tumor-bearing fish was 113 mm as compared to an overall mean length of 147 mm. Similar size patterns were found in 239 dover sole collected in December 1971 trawls off northern Orange County by Marine Biological Consultants and in the tumor-bearing dover sole collected in the 1958-63 trawl study of Santa Monica Bay conducted by the California Department of Fish and Game.

The data suggest that the occurrence of tumors in dover sole may be a function of the early life history of this species. Observations on the incidence and distribution of the disease made in surveys conducted by different agencies may reflect the effectiveness of various sampling procedures and types of equipment in capturing small fish.

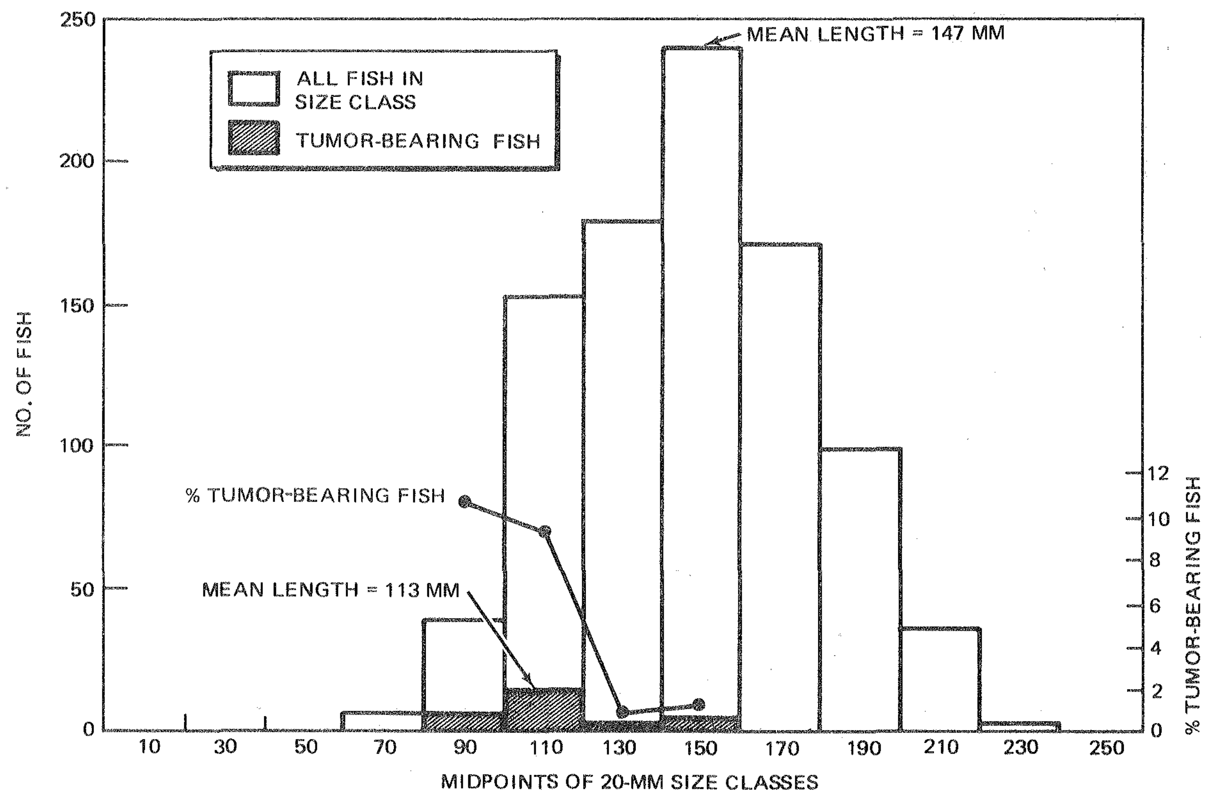

Figure 7-16. Length Frequencies for 920 Dover Sole Captured off Palos Verdes Peninsula, 5 Oct-12 Nov 71.

Examination of 45 preserved tumor-bearing dover sole collected in the 1969-72 trawling surveys showed a total of 81 tumors, or an average of 1.8 tumors per diseased fish. SCCWRP analysis of the California Department of Fish and Game 1958-63 trawl data indicated that the average incidence of tumors was also about two per tumor-bearing fish. A similar analysis of tumor-bearing English sole (*Parophrys vetulus*) in San Francisco Bay was made by Cooper and Keller (1969). Figure 7-17 shows the distribution of the proportions of tumor-bearing dover sole and English sole having a given number of tumors. The similarity between the San Francisco Bay and southern California distributions is evident; the frequencies of both dover sole and English sole with one, two, and three tumors were almost identical. These data suggest that the patterns of susceptibility and disease in two species are similar. The comparison also reemphasizes the fact that tumor-bearing flatfish populations are not specific to a particular geographic location, environment, or species.

Preliminary histopathological observations of tumors on Palos Verdes dover sole have been made by S. R. Wellings and G. E. McArn (University of California, Davis) and Bruce S. Miller (National Marine Fisheries Service, Seattle). The young dover sole had angioepithelial nodules (AEN's), and older specimens had epidermal papillomas (EP's) (both types of tumors were previously described by Wellings et al. (1965) in Pacific Northwest flatfish populations). All but one of the epidermal papillomas were composed of hyperplastic epidermal cells and were infused with the "x-cells" that were observed by Wellings and others in Puget Sound fishes. One tumor was described as an invasive, squamous-cell carcinoma, but evidence for malignancy has yet to be determined. In general, these observations verify that tumors of southern California dover sole are histologically identical to those occurring in related flatfish species in

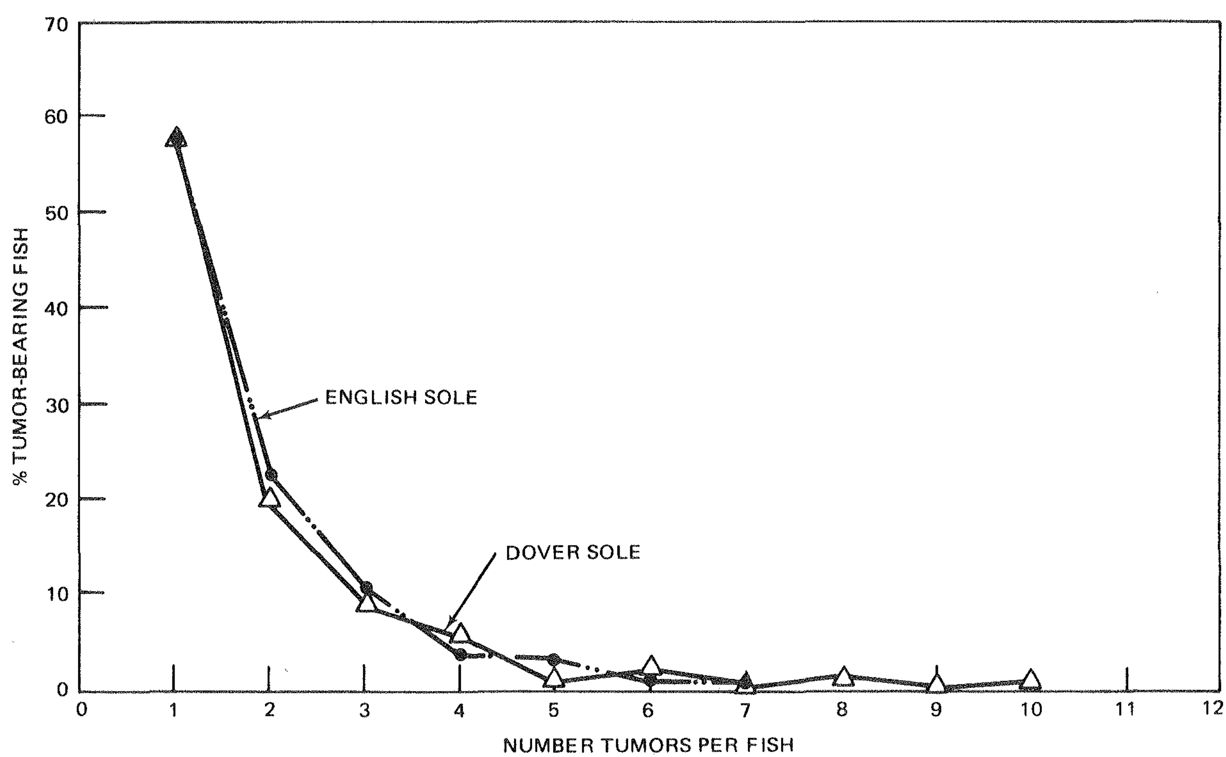

Figure 7-17. Comparison of the Number of Tumors per Tumor-Bearing Fish in Southern California Dover Sole (1958-63, 1971-72) and San Francisco Bay English Sole (1965-66).

Puget Sound. The presence of "x-cells" in the dover sole and other species suggests a viral etiology, which is presently under investigation by Wellings and Miller.

In spite of the ubiquity of this anomaly in bottom flatfishes, the factors involved in initiating and maintaining the disease in the fish population are unknown. It is possible that the environmental or genetic factors involved in tumorigenesis are associated with the areas in which the fish first settle from their planktonic stages and not necessarily with the areas from which the fish are later collected. However, poor water quality may influence either tumorigenesis or the frequency of tumor bearing fish by causing changes in competition, concentration, predation pressure, migration patterns, tumor rejection, or other factors affecting fish health.

7.4.2 Fin Erosion Diseases

Of the 121 species of fish collected during the 1969-72 trawling surveys, more than one-quarter (35 species) had at least one specimen exhibiting eroded fins. The areal distribution of the affected species was as follows:

Area	Number of Species	Number of Affected Species
Port Hueneme	51	2
Santa Monica Bay	71	10
Palos Verdes Peninsula	69	31
North San Pedro Bay	86	9
Santa Catalina Island	40	3

Two species, dover sole and white croaker, were the most commonly affected, with diseased individuals occurring in four of the five areas. Three additional species (rex sole, slender sole and California tonguefish) had affected individuals in three of the areas. The dover sole and white croaker were also the two most frequently affected species. Figures 7-18 and 7-19 show the locations in which dover sole and white croaker, respectively, were collected. As shown on the figures, the incidence of fin erosion was 10 percent or greater in two regions--on the Palos Verdes shelf and at the City of Los Angeles sludge disposal site at the head of the Santa Monica Canyon.

Quarterly trawl sampling near the Orange County outfalls (Section 7.2.4) provided an opportunity to observe changes in disease frequencies of white croaker around the old outfall before and after the use of the outfall was terminated. Table 7-15 presents the numbers of white croaker caught on each trawl between February 1970 and May 1972, as well as the number of fish exhibiting tail erosion and/or lip papillomas in each sample; these data are shown graphically

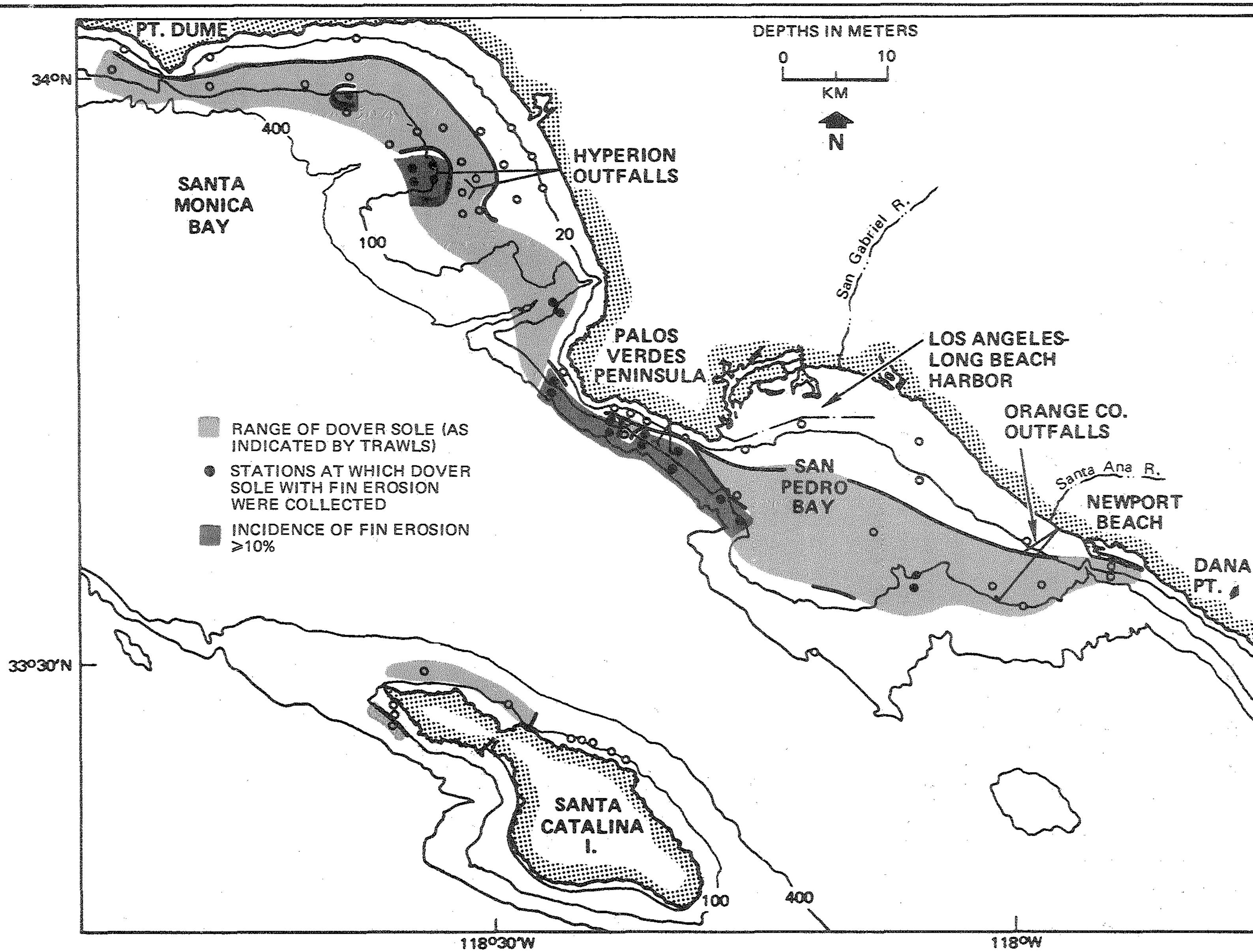

Figure 7-18. Incidence of Fin Erosion in Dover Sole Collected in the Trawling Surveys of Southern California Coastal Waters, August Through October, 1971.

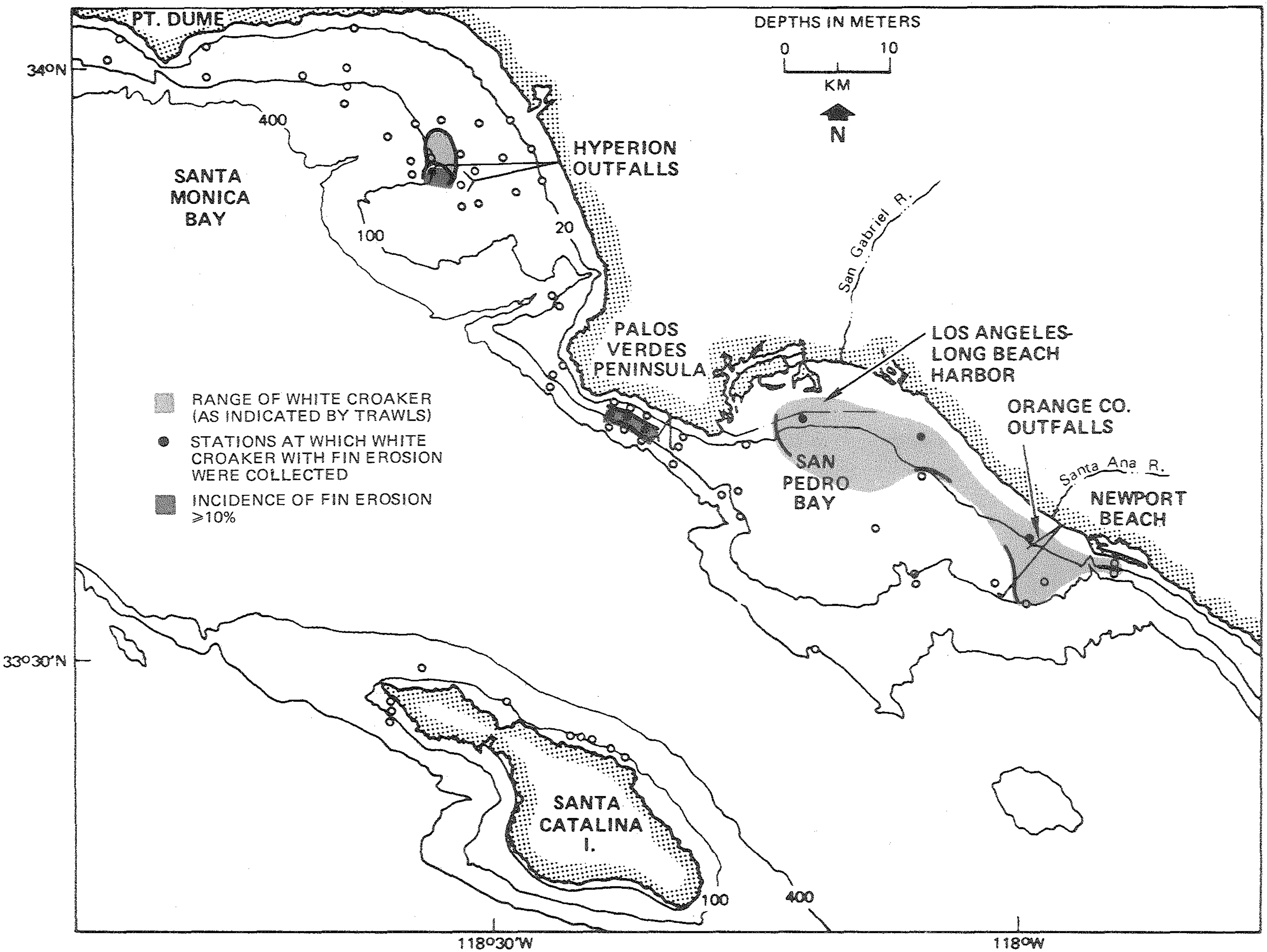

Figure 7-19. Incidence of Fin Erosion in White Croaker Collected in Trawling Surveys of Southern California Coastal Waters, August Through October, 1971.

Table 7-15
FREQUENCIES OF OCCURRENCE* OF TAIL EROSION AND LIP PAPILLOMAS IN WHITE CROAKER FROM TEN TRAWL SAMPLES TAKEN AT THE OLD ORANGE COUNTY OUTFALL, 1970-72

Sampling Date	Total No. of Specimens (N)	Tail Erosion n	Tail Erosion % of Total	Lip Papillomas n	Lip Papillomas % of Total
1970					
Feb	293	77	26	13	4.4
May	455	49	11	3	0.6
Aug	578	80	14	5	0.9
Nov	254	187	74	0	0
1971					
Feb	100	6	6	0	0
May**	6	2	33	0	0
Aug	11	1	9	0	0
Dec	0	0	0	0	0
1972					
Feb	32	8	25	1	3.1
May	0	0	0	0	0

*N = total number of specimens observed; n = number of affected specimens.
**Outfall changeover, April 1971.

in Figure 7-20. The peak incidence of the tail erosion in 1970 occurred 3 to 6 months later than the peak population abundance, suggesting that the frequency of fin erosion in white croaker may be a function of population abundance or density. Thus, if population abundance is related to wastewater discharge, the discharge may have an indirect effect on the incidence of the disease. There was no obvious relationship between fish abundance and the occurrence of lip papillomas.

Although fin erosion is seen in both dover sole and white croaker, the disease may result from or be maintained by different factors in each species. In 1971, 139 white croaker were collected from the Palos Verdes shelf. The fish varied in size from 100 to 220 mm S.L.; diseased fish ranged in length from 160 to 220 mm S.L. In a collection of 762 dover sole taken during the same period from the Palos Verdes shelf, both normal and diseased fish ranged from 80 to 240 mm S.L. The cumulative distribution of length for both dover sole and white croaker (Figure 7-21) shows that the average length of the dover sole exhibiting fin erosion was significantly less than the average length of the total sample. On the other hand, the average length of white croaker with fin erosion was slightly greater than that in the total sample. Thus, it would appear that the mechanisms governing the occurrence of fin erosion in the white croaker and the dover sole are not the same. It is interesting to note that both fin erosion and tumors in the dover sole appear more frequently in small or young fish.

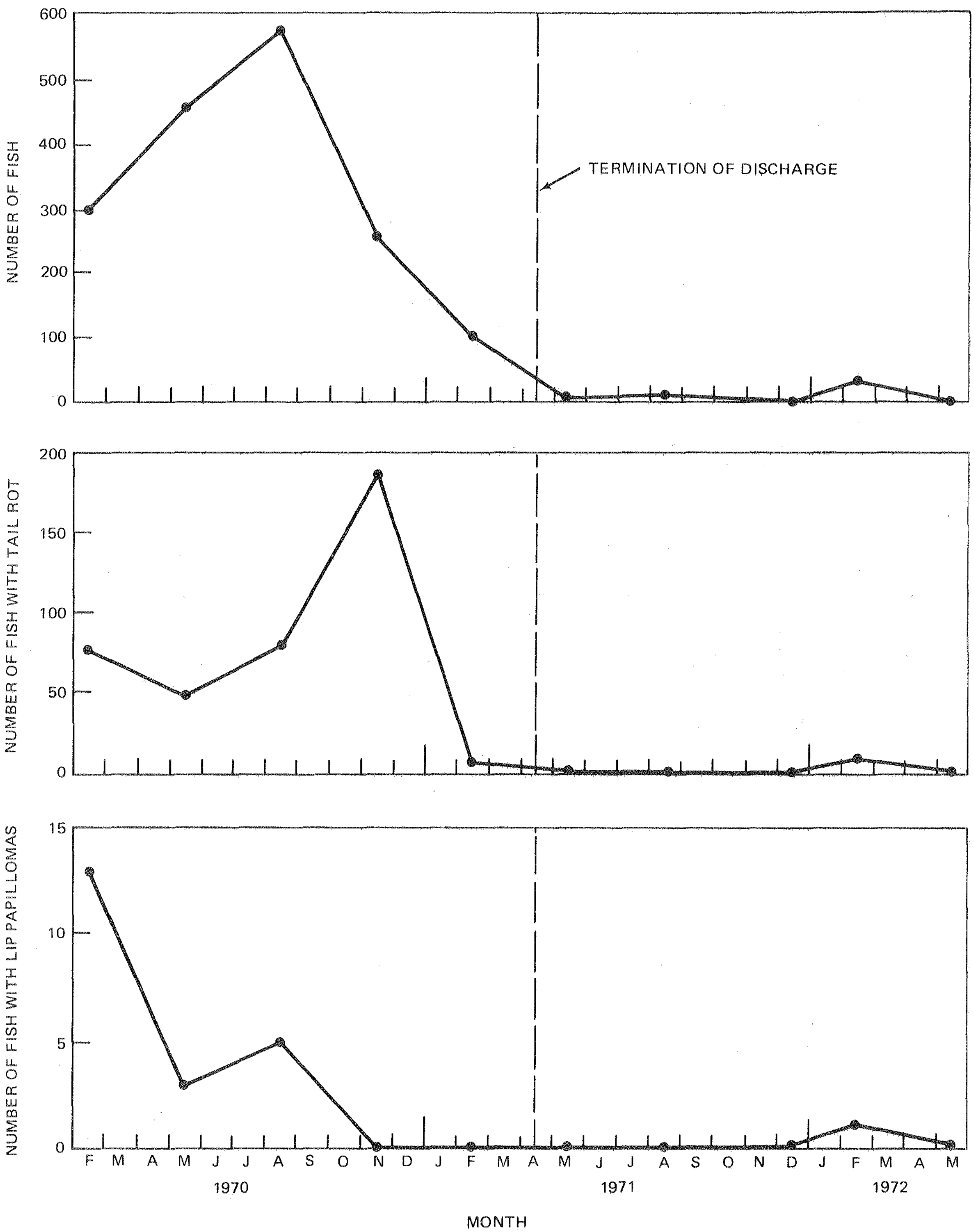

Figure 7-20. Number of Occurrences of Tail Erosion and Lip Papillomas in White Croaker From the Old Orange County Outfall Area, 1970-72.

Review of the literature indicates that fin erosion is a variable response in marine fishes. Bullock, Conroy, and Snieszko (1971) suggest three possible causes--direct bacterial infection, secondary bacterial infection following fin damage by other physical, chemical or biological factors, or development as an accessory condition of other diseases. To gain some insight into the causal factors underlying the fin erosion condition, seven affected species of demersal fishes were examined in more detail.

In dover sole, the lesions were most common on the middle portion of the dorsal and anal fins. The caudal fins were affected only in cases where the dorsal and anal fins were almost entirely missing. Pectoral and pelvic fins were only rarely affected. Lesions were manifested as thinning or loss of the epidermis on the fin tips, with resultant fibroplasia in the dermis and aggregation of melanophores along the edges of the denuded areas. Lymphocytic infiltration was sparse or absent. Application of various histological stains failed to demonstrate bacterial, fungal, or protozoal organisms associated with the fin lesions or the internal organs. No histological differences between the viscera of affected and nonaffected fish were noted. Both normal and diseased fish had large quantities of lipoid material in their hepatocytes and moderate numbers of encysted metacercaria were observed in the livers and intestinal walls. It thus appears that the fin erosion syndrome of the dover sole is not a systemic disease.

The noninflammatory nature of the lesions and the absence of any demonstrable infectious organism tend to rule against the disease being initiated through microbial processes. The fact that the severest lesions were located at the

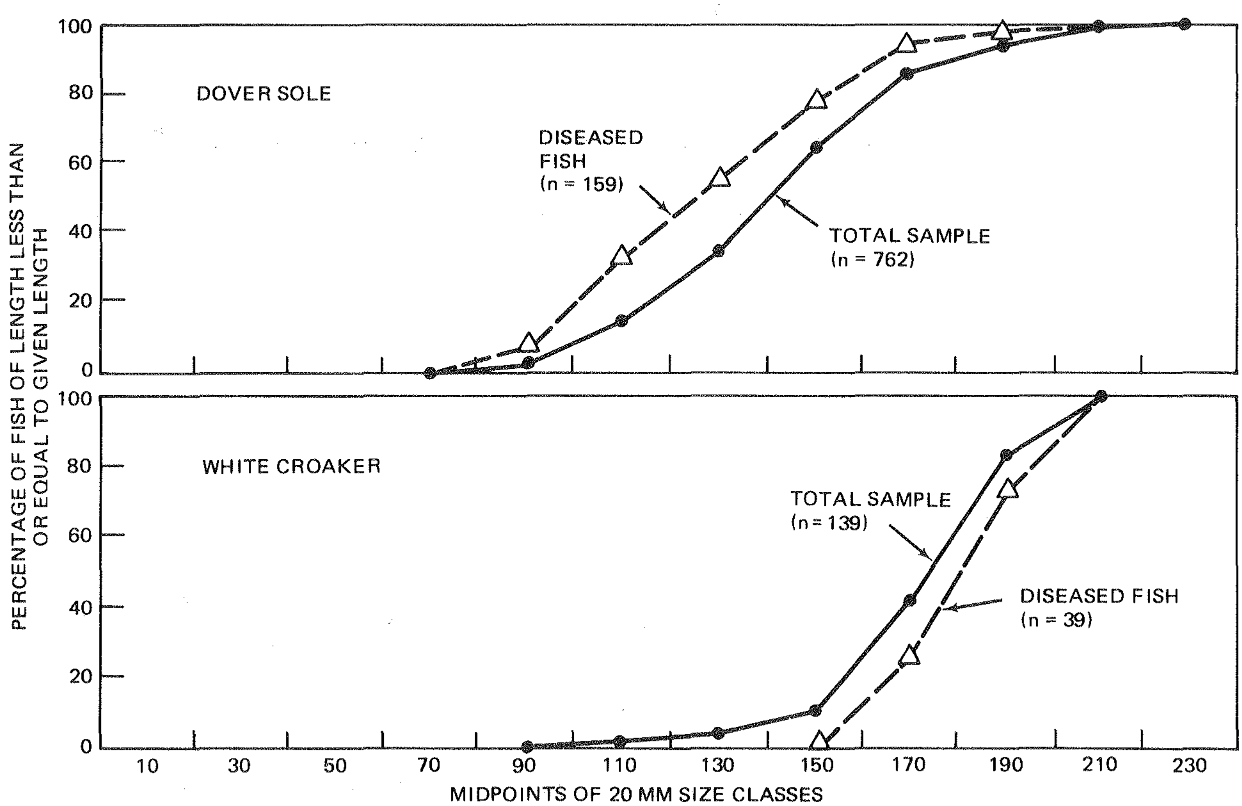

Figure 7-21. Length Distributions of Fish With Fin Erosion and Fish in Total Sample.

midportion of the dorsal and anal fins suggests that the development of the lesions might be associated with movement of the fins and contact with bottom sediment. An extreme pH, high hydrogen sulfide content, or high heavy metal content of the bottom sediment could initiate the disease by causing coagulation of the protective mucus on the skin and subsequent cellular necrosis of the fins. The undulation of the middle portion of the dorsal and anal fins during swimming and the use of these fins for burrowing into the sediment could result in a rapid loss of mucus and predispose the underlying epidermal cells to chemical irritants in the sediment.

The lesions on the pelvic fins of the rockfish could develop in a manner similar to those on the dover sole--as a result of contact with the bottom sediment. The white croakers examined, however, had bloody lesions that were common on the pectoral fins and dorsal part of the caudal fins, neither of which come in contact with the sediment. Although histopathological stains revealed no bacteria, they more closely resembled an infectious lesion than did the erosions in the dover sole and rockfish.

Tail and fin lesions are common in both freshwater and marine aquarium fishes. Reported causes include bacterial infection and fin nipping and scraping. In many cases where a bacterial agent was suspected, the course of the disease was rapid, and symptoms included development of a whitish area at the site of the lesion, followed by raising and sloughing of scales and redness or bleeding. These symptoms resemble those observed in the white croaker more than those seen in the dover sole.

Stress resulting from biological accumulation of metals has been suggested as a cause of fin erosion in fishes. As discussed in Section 7.3, fish from the Palos Verdes shelf, where sediments are highly contaminated and disease incidence is high, have metal concentrations no higher than those in fish taken off Santa Catalina Island. Also, liver tissue from both affected and apparently healthy fish from the Palos Verdes area showed no significant differences in concentrations of metals, except for zinc, which was only slightly higher in the diseased fish (Table 7-16). A comparison of DDT and PCB levels in muscle tissue of diseased and apparently healthy dover sole also revealed no significant differences in DDT, but the PCB concentrations were slightly higher in diseased fish (Table 7-16). At the present time, these data suggest that fin erosion of the dover sole cannot be attributed to the accumulation of high concentrations of any of the studied trace constituents in vital organs. This conclusion is consistent with the results of the histopathological analyses which indicate that fin erosion disease in dover sole is restricted to external symptoms. However, additional analyses of zinc, PCB, and other trace constituents in diseased and normal fish are warranted.

It thus appears that at least two types of fin erosion diseases occur in the southern California species studied thus far. The first is characterized by damage to the fin tissue and no degeneration of internal organs. The characteristics and localized occurrence of the disease in flatfishes, rockfishes, and other bottom-dwelling species suggest that it is a direct response to external environmental stresses. Analysis of fin involvement in dover sole indicates that locomotor behavior and sediment contact may be important factors in the development of the disease. As yet, no measurements of sediment pH and no recent quantitative measurements of soluble sulfides have been made in the

Table 7-16
CONCENTRATIONS OF TRACE MATERIALS IN DISEASED (FIN EROSION) AND APPARENTLY HEALTHY DOVER SOLE FROM THE PALOS VERDES AREA*

	Concentrations (mg/wet kg)						
	Healthy			Diseased			Probability (p) of Difference in Means Occurring by Chance
Trace Material	n	Mean	Std. Error	n	Mean	Std. Error	
Metals (liver composites)							
Silver	2	2.8	0.45	4	1.8	0.33	$0.1 < p < 0.2$
Arsenic	4	1.4	0.15	7	1.2	0.12	$p > 0.3$
Cadmium	4	0.24	0.05	7	0.15	0.04	$0.1 < p < 0.2$
Cobalt	5	0.03	0.003	7	0.04	0.006	$0.2 < p < 0.3$
Copper	5	1.7	0.32	7	2.3	0.24	$0.1 < p < 0.2$
Iron	5	190.	20.	7	220.	17.	$0.1 < p < 0.2$
Mercury	5	0.11	0.01	7	0.11	0.1	$p > 0.3$
Molybdenum	5	0.07	0.01	7	0.09	0.01	$0.2 < p < 0.3$
Antimony	5	0.0034	0.0008	7	0.0025	0.0004	$p > 0.3$
Selenium	5	0.69	0.13	7	0.61	0.09	$p > 0.3$
Zinc	5	23.	1.4	7	29.	1.7	$0.02 < p < 0.05$**
Chlorinated hydrocarbons (flesh composites)							
DDT	7	12.5	7.5	9	11.7	2.9	$0.2 < p < 0.3$
PCB	7	0.93	0.18	9	2.0	0.48	$0.05 < p < 0.1$†

*Includes only stations T2, T3, and T4 at depths of 200 and 450 ft.
**Zinc concentrations significantly higher ($p < 0.05$) in diseased fish.
†Total PCB concentration higher in diseased fish: $p = 0.09$.

major disease area off Palos Verdes. Qualitative measurements of sediment sulfides in 1971, however, revealed the presence of a sulfide field that approximated the disease patterns observed in that year. Similar sediment patterns were also defined for trace metal concentrations and other parameters of wastewater origin; however, it appears that occurrence of the disease is not related to the internal metal load of the dover sole (except possibly for zinc) or to the DDT content of its muscle.

The second type of fin erosion is characterized by predominant involvement of the caudal fin and by bloody external lesions. It occurs in active free-swimming nearshore species, primarily white croaker. The severity of the tail erosion in this species may stem from continuous irritation caused by increased turbulence on the fin during swimming. Factors that contribute to active swimming, to increased population density, or to decreasing natural antibacterialcidal agents in seawater (e.g., high temperature, strong localized currents, abundance of motile food organisms) should be examined. This disease appears to resemble both those observed in New York Bight fishes and a tail erosion syndrom affecting croakers in Galveston Bay (Bechtel and Copeland 1970).

7.4.3 Bone Deformities, Asymmetry, and External Parasites

The goals of the SCCWRP-sponsored research on bone deformities were (1) to determine if the structural deformities observed by Valentine and Bridges (1969) were unique to southern California fish, (2) to examine the applicability of the analytical methods developed by these researchers to the early detection and monitoring of environmental stress (whether natural or man-induced), and (3) to investigate the possible causes of the anomalies.

Museum and fresh collections of barred sand bass, California grunion (*Leuresthes tenuis*), and barred surfperch (*Amphistichus argenteus*) taken from a number of locations between San Simeon, California (approximately 300 km north of Point Conception) and Baja California Sur, Mexico were examined to determine the frequency and severity of structural deformities. The barred sand bass was the most extensively studied species. Skeletonization of 111 San Diego area and 72 Baja California Sur specimens revealed an association between deformities affecting the gill rakers and deformities of the pelvic fins, operculum, vertebral column, and cranium in the San Diego area specimens (Table 7-17). No such associations were observed in barred sand bass from Baja California; only three fish with gill raker deformities and three with asymmetric crania were noted. Occurrence of calcified knobs on the neural and haemal spines of the vertebral column did not appear to be associated with the other deformities, and the incidence of this anomaly was similar in both the San Diego and the Baja California samples (20.7 percent and 19.4 percent, respectively).

Geographical trends in the incidence of gill raker deformities were examined by grouping the sampling locations into three major areas:

Area A - Baja California Sur to U.S./Mexico border

Area B - U.S./Mexico border to the Long Beach Harbor area (Belmont Shore)

Area C - Santa Rosa Island, Carpinteria, San Simeon.

Table 7-17
ASSOCIATION OF STRUCTURAL DEFORMITIES IN
111 SKELETONIZED BARRED SAND BASS
FROM THE SAN DIEGO AREA

Deformity	Number of Fish	Number With Gill Raker Deformities
Gill raker	89	-
Ventral fin	37	36
Opercular	3	3
Vertebral	13	13
Cranial	31	30
Other	34	30

For 2 of the 3 species studied, gill raker deformities occurred in higher frequencies in samples from Area B (Table 7-18). In the barred surfperch, frequencies were highest in samples from Area C, and it appeared that in this species, incidence of gill raker deformities increases from south to north.

The barred sand bass was the species most frequently and severely affected with gill raker deformities of the three studied, and the barred surfperch the least affected. The frequency and severity of deformities in southern California barred sand bass collections were found to be a function of size (Table 7-19); both the total percentage of gill raker deformities and the percentage of badly deformed rakers increased with increasing fish length. A similar trend is suggested for deformed gill rakers in barred surfperch and for total deformities in California grunion, although additional data are needed to confirm this conclusion. Data on temporal trends in the incidence of gill raker deformities in southern California barred sand bass are inconclusive. The second most frequently observed anomaly in southern California barred sand bass involved the pelvic fins (in 381 specimens, 11.4 percent had mildly deformed pelvic fins and 3.8 percent badly deformed).

Caudal fin scars attributed to *Nerocila* (a parasite) were found in moderate frequency in barred surfperch from the Long Beach Harbor area (Belmont Shore). The mean number of scars per fish was greater in a 1958 collection (1.03) than in the 1969-70 collection (0.59). The frequency of fish with a given number of scars follows a Poisson distribution, indicating that the occurrence of one parasite on a fish did not influence the attachment of a second (Table 7-20). The preferred attachment site was the top of the caudal fin (on either side). The barred surfperch was also parasitized by the isopod *Livoneca californica*, which attached to the gill arches. None of the fish with these parasites had gill raker deformities.

Table 7-18
INCIDENCE OF GILL RAKER DEFORMITIES IN MEXICO AND CALIFORNIA SPECIMENS*

Species	Area A	Area B	Area C
Barred sand bass			
No. fish	348	399	-
No. gill arches (1st arch)	696	798	-
No. arches with deformed rakers	5	289	-
Percent arches with deformed rakers	0.7	36	-
California grunion			
No. fish	127	441	-
No. gill arches (1st arch)	254	882	-
No. arches with deformed rakers	7	89	-
Percent arches with deformed rakers	2.7	10	-
Barred surfperch			
No. fish	137	168	101
No. gill arches (1st arch)	274	336	202
No. arches with deformed rakers	3	16	13
Percent arches with deformed rakers	1.1	4.8	6.4

*Area A specimens collected from one or more locations from Baja California Sur to the U.S./Mexico Border; Area B specimens collected from one or more locations between the U.S./Mexico Border and the Long Beach Harbor Area (Belmont Shore); Area C specimens collected from Carpenteria, San Simeon, and and Santa Rosa Island.

Table 7-19
FREQUENCY AND SEVERITY OF GILL RAKER DEFORMITIES
IN 399 SOUTHERN CALIFORNIA BARRED SAND BASS

Size Class (mm S.L.)	Number of arches examined	Number		Percentage		
		Mildly Deformed	Badly Deformed	Normal	Mildly Deformed	Badly Deformed
0-49.9	60	0	0	100	0	0
50-99.9	54	3	0	94	6	0
100-149.9	218	19	2	90	9	1
150-199.9	122	10	20	75	8	16
200-249.9	124	25	53	37	20	43
250-299.9	152	41	62	32	27	41
300-349.9	32	9	14	28	28	44
350-399.9	16	4	7	31	25	44
400-449.9	20	8	12	0	40	60
Total	798	119	170	64	15	21

Table 7-20
INCIDENCE OF *NEROCILA* ECTOPARASITISM OF THE CAUDAL FIN IN BARRED SURFPERCH FROM THE LONG BEACH HARBOR AREA, 1958 AND 1969-70

Number of Scars Per Fish	Number of Fish	Expected Statistical Distribution Based on Poisson with χ = 0.82882*
0	70	71.20
1	59	58.97
2	28	24.42
3	4	6.74
4	2	1.40

*The fit to the Poisson is reasonably good, yielding a $\chi^2_4 = 1.92$, $p = 0.75$.

Asymmetry analysis[3] was applied to a number of morphometric (dimensional) and meristic (countable) bilateral characters. Asymmetry values for barred sand bass dentaries, lateral supraoccipital crests, scales above and below the lateral line, pored lateral line scales, pectoral fin rays, and total gill rakers were greater in California samples than in Mexican samples (Table 7-21). Gill raker asymmetry values in the barred surfperch suggest that increases in asymmetry have occurred with time and that values in the Long Beach Harbor area are higher than those to the north or south (Figure 7-22).

[3]The steps of the asymmetry analysis procedure are as follows: A bilateral character (any number of characters can be so treated) showing meristic variability is chosen and scored in each of the individuals in all samples. All counts taken from the left side are subtracted from the corresponding scores on the right to obtain the signed differences. Next, the standard deviation of the signed differences (s_{r-1}) is calculated for each sample. Then, the mean of the character ($\bar{x}_{r+1}$) is calculated for each sample by adding the scores for both sides and dividing by the sample size. Finally, the Standardized Asymmetry Statistic (SAS) is calculated for each population. The SAS is defined as

$$SAS = [(S_{r-1} \times 100)/(\bar{x}_{r+1})]^2.$$

The SAS is analagous to the squared coefficient of variation. An F-test is used to determine asymmetry differences between populations.

To obviate scaling problems associated with growth in morphometric characters, a different form of standardization is utilized. Instead of dividing the standard deviation of the signed differences by the mean of the bilateral character, as for meristic characters, each measurement (item) is divided by the length of the cranium before obtaining the signed differences. The variance of the resulting differences is then calculated in the normal statistical fashion and treated as normal variances when using the F-test.

Table 7-21
STANDARD ASYMMETRY STATISTICS FOR BARRED SAND BASS

Character	Southern California SAS	Southern California N	Baja California SAS	Baja California N	F-ratios	Probability (p) of Differences in SAS Values Occurring by Chance
Dentaries	0.0000806	66[a]	0.0000487	66[b]	1.621	$p < 0.05$
Lateral supra-occipital crests	0.00103	66[a]	0.000540	60[c]	1.908	$p < 0.01$
Scales above lateral line	8.55	101[d]	3.85	74[e]	2.219	$p < 0.001$
Scales below lateral line	6.92	101[d]	1.63	74[e]	4.254	$p \ll 0.001$
Pored lateral line scales	2.23	101[d]	0.543	74[e]	4.107	$p \ll 0.001$
Pectoral fin rays	1.96	295[f]	0.410	210[g]	4.780	$p \ll 0.001$
Total gill rakers	8.30	295[f]	1.96	210[g]	4.225	$p \ll 0.001$

a. Mean standard length: 288.4 ± 6.1 mm (S.E.)
b. Mean standard length: 293.7 ± 6.5 mm (S.E.)
c. Mean standard length: 292.9 ± 6.8 mm (S.E.)
d. Mean standard length: 287.0 ± 4.94 mm (S.E.)
e. Mean standard length: 293.6 ± 6.47 mm (S.E.)
f. Mean standard length: 193.6 ± 3.2 mm (S.E.)
g. Mean standard length: 193.3 ± 4.4 mm (S.E.)

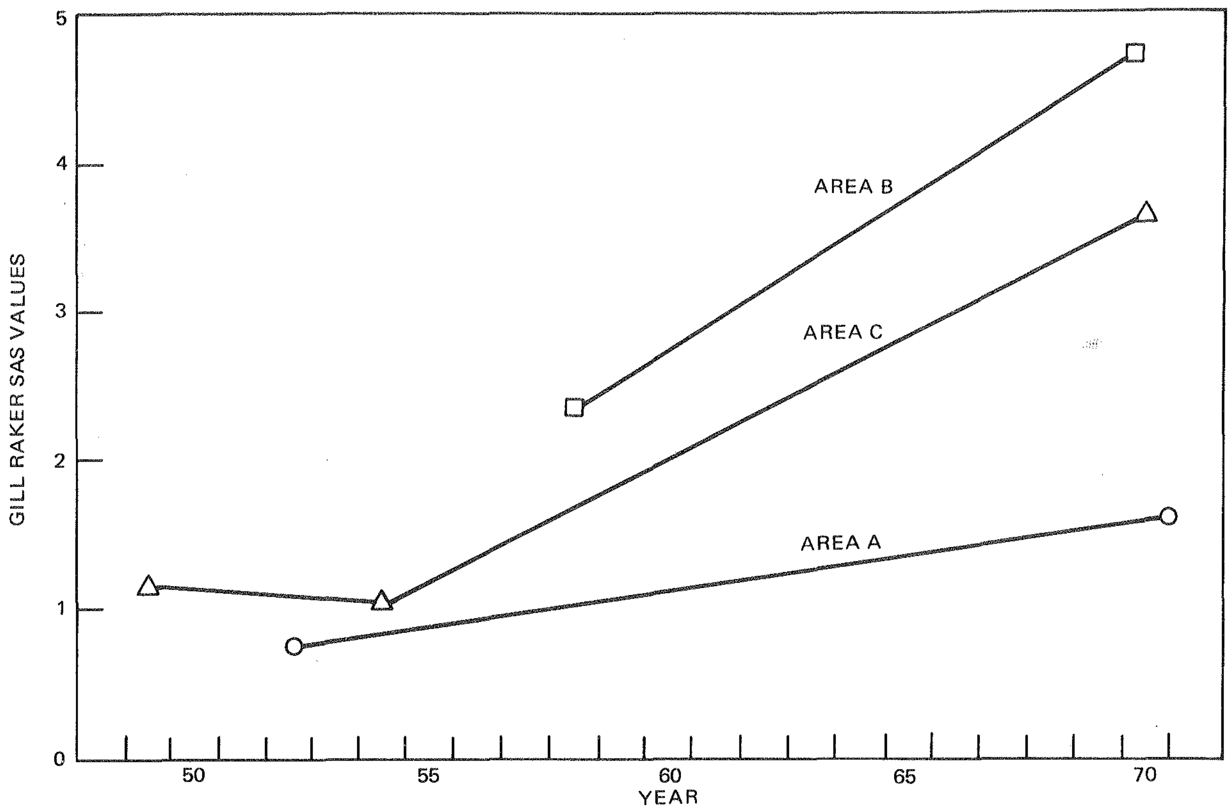

Figure 7-22. Gill Raker Asymmetry Values for Barred Surfperch, 1949-71.

Valentine and Soule (1973) considered a number of possibilities for the origin and maintenance of structurally deformed fish in southern California. On the basis of their observations, review of the literature, and preliminary laboratory experiments (in which deformities and asymmetry were induced in freshwater medaka (*Oryzias latipes*) by exposure to DDT and lead), they proposed that environmental contaminants that interfere with bone biochemistry might result in deformities. They cited substances such as DDT, thalidomide, EDTA, cadmium, mercury, zinc, lead, and phthalates as possible causes. To test this hypothesis, chlorinated hydrocarbon levels in barred sand bass collected from Baja California and southern California were measured, and preliminary results indicated that total chlorinated hydrocarbons were much higher in southern California specimens than in those from Mexican waters. It was impossible to make the necessary measurements on other substances known to alter bone chemistry during the study period.

These studies confirm the presence and association of bone deformities in southern California barred sand bass and the very low incidence of such deformities in Baja California specimens. A similar trend was suggested for total deformities in California grunion. In barred surfperch, gill raker deformities were highest in the northern most collections. Fish length appeared to be related to the incidence and severity of the deformities.

Asymmetry values for seven characters in barred sand bass were higher in southern California than in Baja California specimens; gill raker asymmetry did appear to be correlated with severity of gill raker deformity. However, in barred surfperch geographical trends for incidence of gill raker asymmetry and incidence of gill raker deformity were different. Therefore, at this time, it is unknown if an association exists between asymmetry and bone deformities.

Except for chlorinated hydrocarbons and lead, potential causative factors of deformity and asymmetry were not investigated. The causative factors cannot be identified at this time because of the general lack of knowledge of the behavior of environmental contaminants in fish and in the environment and because of the limited knowledge of the natural and man-related factors (e.g., predation, competition, fisheries) regulating the biology of coastal fish populations. Studies concerning both the population dynamics of all local disease-bearing species (including the influence of subnormal predation and competition, and the distribution of biologically active trace constituents must be continued and expanded and conclusive cause-effect experiments must be conducted before the causative factors can be identified.

7.5 SUMMARY

Data from 1969-72 trawling surveys made by various agencies and individuals in the Bight have been analyzed. These surveys resulted in 303 trawls samples and yielded some 87,000 fish, representing 121 species. It is estimated that these species accounted for about one-half of the total number of species in the southern California coastal zone.

Analysis of recurrent groups (commonly associated species) showed that there were five major groups of fish exhibiting similar behavior and response patterns. Characteristic depth ranges and areas for each group could be identified, despite the fact that the sampling was only partial due to the limited types of sampling gear used. This type of analysis can provide a rational basis for selection of fish species for further study. The overall mean species diversity index (Shannon-Weaver) was 1.46. This value falls well within the range of about 0.3 to 2.6 that has been reported for both low- and high-diversity fish communities in other coastal areas. Diversity tended to increase in a southward direction from Port Hueneme to the central Orange County coast.

Comparison of the catch statistics for the various agencies involved in the surveys showed no clear relation between catch and sampling techniques, such as net size, trawl time or speed, area covered, etc., although there was a negative correlation between fish catch per haul and the cod-end mesh size of the nets used. To ensure the validity of conclusions made on the basis of the survey data, it will be necessary to standardize the gear and trawling methodology used by the various agencies, conduct additional studies to determine the effects of these factors on the fish catch, or conduct a large-scale survey using one vessel-gear combination.

Factors affecting the distribution and abundance of fish include light, temperature, food, presence or absence of competitors and predators, population density, and the life-cycle characteristics of the individual species. Catches obtained during night and day trawls varied significantly in diversity and abundance.

Except for flatfish species, many species were found during the night trawls that were rarely or never found during the day, and the species diversity in the night trawls was much higher than in the day trawls. Upwelling along the southern California coast also affects the distribution of fish. Many demersal fish avoid upwelling waters--presumably because of low temperature and possibly because of low dissolved oxygen--by moving inshore. It is reasonable to assume other kinds of water mass changes will affect their distribution as well. Fishing effort selectivity and intensity can have a significant effect on the distribution of fish species. Although the total sport fishery catch has been increasing fairly steadily in the last 20 years, the catch of individual species has varied greatly, with no discernible pattern. The oftnoted decline in the commercial fishery, particularly in southern California, is primarily due to the decline in the sardine fishery in the early 1950's. The total commercial catch excluding sardine and anchovies has remained relatively constant, fluctuating between 25 and 70 thousand M tons/yr. These observations are important because an intense fishery can affect the health and diversity of all fish populations, not just of the target species.

Changes in sediment characteristics probably have an effect on the species distribution of demersal or bottom-feeding fish. In the last 60 years, dover sole and speckled sanddab have been caught with increasing frequency in Santa Monica Bay. At the same time, the frequency of occurrence of the Pacific sanddab has decreased. It is possible that these changes are associated with the fact that the sediments in Santa Monica Bay have become increasingly finer during this same period due to increased regulation of stream runoff and, in later years, discharge of fine material.

Studies of fish collections around the old and new Orange County wastewater outfalls showed changes in both the size distribution and abundance of demersal fish that were apparently associated with the termination of the old discharge and initiation of the new discharge in April 1971. The Orange County studies show that, with trawl surveys on a quarterly basis and with the types of gear presently in use, it is possible to discern trends in bottom fish populations.

In 1971-72, concentrations of DDT in greater than 60 percent of the dover sole samples collected in the area between Redondo Canyon and the west entrance of the Los Angeles Harbor exceeded the U.S. Food and Drug Administration limit (for commercial sale) of 5 mg/wet kg. There was a close correspondence between the levels of DDT and PCB found in fish and the levels in the sediments of the areas in which the fish were caught. However, despite the evidence of residency of the fish in contaminated areas, there was no correspondence between the concentrations of metals in fish livers and the levels in the sediments; in fact, the liver metal concentrations in fish caught in areas away from waste discharges where the metal levels in the sediments were assumed to be at natural or background levels were higher than those in fish caught around wastewater outfalls with high sediment metal concentrations. For most metals, the levels in dover sole were similar to the values reported for fishes in both the Pacific and Atlantic oceans. The reason for higher metal concentrations in fish from San Pedro Bay and areas surrounding Redondo Canyon should be investigated.

The incidence of tumors and tumor-like growths in dover sole collected in the 1969-72 trawling surveys was 1.3 percent. This incidence is similar to or lower

than that reported for flatfishes in other areas. The tumors were most prevalent in small and young fish. The disease in dover sole is similar to that observed for several species in other areas. The disease probably has a viral etiology, and conditions in the location in which the fish first settle from their planktonic stage are probably most important in the later development of the condition. The disease is not restricted to wastewater discharge sites.

Thirty-five of the 121 fish species collected in the Bight had at least one specimen with eroded fins. The dover sole and white croaker were the species most frequently affected. The incidence of fin erosion in dover sole was the greatest (10 percent or greater) in specimens caught off the Palos Verdes Peninsula and at the head of the Santa Monica Canyon. As in the case of tumors, the fin erosion was more prevalent in the small dover sole. In contrast, the specimens of white croaker with fin erosion were somewhat larger than average.

The causes of fin erosion in demersal fish are not known. Histopathalogical examination of the lesions in dover sole indicated that they were solely external and probably not infectious. One possible explanation for this observation is that direct contact with sediments with an extreme pH or high sulphide or metal content might result in coagulation of the protective mucous covering on the fins and gills, making them more susceptible to damage or secondary infection. The incidence of fin erosion was high in areas with high concentrations of wastewater constitutents in the sediments but there was no significant relationship between the appearance of fin erosion and accumulations of trace constituents (except zinc) in the vital organs.

Three species of fish, the barred surfperch, barred sand bass and California grunion, were examined in collections from Baja California Sur to Central California for bone deformities, asymmetric characteristics and ectoparasites. There was a trend of increasing gill raker deformities northward from Baja California to central California for the barred surfperch; in the barred sand bass and in the California grunion, gill raker deformities were more frequent in southern California than in Baja California collections. In the barred sand bass, gill raker deformities were related to size, with increasing numbers of deformities in the larger fish. The causative factors of these deformities have not been identified but they do not appear to be related to the occurrence of ectoparasites. In sand bass, chlorinated hydrocarbons were found in higher concentrations in fish taken near the Los Angeles area than in those taken off Baja California.

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Chapter 8

SUBTIDAL AND INTERTIDAL BENTHIC INVERTEBRATES

8.1 INTRODUCTION

Benthic organisms are those that live immediately above, on, or in the sediments. In general, they are less mobile than free-swimming fish or plankton; as a consequence, they are more subject to the effects of the physical, chemical, and biological conditions in a particular area. Thus, because of their relative incapability of movement to avoid stress conditions, benthic organisms and communities should reflect past conditions in their immediate environment.

The benthic organisms are important members of the marine ecological system. They affect and are affected by the distribution of chemicals and materials in the sediments. They are subject to fallout of materials added to or generated in the overlying waters, and they may concentrate chemicals and materials in their environment, in some cases, transforming these substances into innocuous or more toxic forms. Many of the benthic organisms are planktonic or free-swimming at some stage in their life cycles and, in this form, are a food source for other biota; most are also a food source in their adult stages. Thus, their importance lies in (1) their position in the marine food web and their role in the concentration and food-web transfer of contaminants, especially to other members of the food web and to man, (2) their vulnerability to environmental stress, (3) their usefulness as indicators of past and current environmental conditions.

The general objectives of the benthic studies described in this chapter were (1) to gain a general understanding of the response of benthic communities to natural and man-induced stress and (2) to provide a basis for specific recommendations on monitoring and environmental assessment. These objectives include the development of specific indices of benthic community health (information on disease, indicator species, body burdens of potentially toxic compounds that may be passed up the food web, and species diversity) that can be routinely used in the monitoring of municipal wastewater effects.

8.2 BENTHIC MACROFAUNA OF THE BIGHT

8.2.1 Mainland Shelf Fauna

The University of Southern California's Allan Hancock Foundation conducted the first comprehensive study of the southern California mainland shelf biota. The biological survey covered intertidal flora, plankton and benthic protozoans, and soft-bottom, subtidal (as opposed to rocky intertidal and subtidal) macrobenthic invertebrates (Allan Hancock Foundation 1959 and 1965). The SCCWRP review of the survey results focused on the deeper shelf fauna most likely to be impacted by present large municipal wastewater discharges at 50 to 100 meters depth.

In comparison with the colorful rocky bottom popular with scuba divers and photographers, the soft sedimentary bottoms appear dull and relatively lifeless. This appearance, however, is deceptive: A dense and varied population lives in these areas--for the most part, beneath the sediment surface. Sand, sandy-silt, and silty-sand constitute some 80 percent of the soft sublittoral bottom off southern California. In coarse sand, the macrofauna number about 2,500 organisms/sq m; in the fine silts, this number may be about 5,000 organisms/sq m. (These values are based only on the animals retained on a screen with mesh openings of 0.7 mm--estimated to be 60 percent of the total available macrofaunal specimens (Jones 1969); smaller animals, especially nematodes, may number one-half million per square meter.)

In detailed examination of 176 samples collected in the 1956-60 Allan Hancock Foundation survey (Jones 1967 and 1969), 1,473 different benthic invertebrates were identified, 63.5 percent of these were identified to species; 24.9 percent to genus, and 11.6 percent only to higher taxonomic categories.

Polychaetes (segmented worms) were the most numerous group of macroinvertebrate animals on the shelf; 532 species were identified, and the average concentration was 1,424 organisms/sq m. Crustaceans, especially amphipods, were the second largest group, with 419 species and a mean concentration of 1,352/sq m. Echinoderms (brittle stars, for example) form a major group on the shelf in depths greater than 10 meters. Within this group, 64 species, with an average concentration of 523 organisms/sq m, were identified. Molluscs (clams and snails) constitute the fourth group in order of abundance, with 408 species and an average concentration of 368 organisms/sq m. In terms of biomass, the polychaetes generally constitute 40 to 50 percent of the total in samples taken from the shelf; crustaceans, which may be equally as abundant as the worms, are generally much smaller and represent approximately 5 percent of the biomass.

Relatively few of the species collected in the Hancock Foundation shelf survey were both frequent (found in 40 percent or more of the 176 samples) and reasonably numerous (15 or more specimens/sq m). Table 8-1 lists the 24 species that might be designated "prevalent", in terms of their frequency of occurrence and population density. These 24 species (and the four other groups listed in the table) comprised only 1.6 percent of the total macroinvertebrate species found on the mainland shelf. Nevertheless, because they are nearly ubiquitous, relatively abundant, and found frequently with a number of other species, these organisms may be considered the major faunal elements on the mainland shelf.

The faunal associations of the mainland shelf were discussed in detail by Jones (1967 and 1969), Barnard, Hartman, and Jones (1959), and the Allan Hancock Foundation report (1965).

8.2.2 Basin Fauna

The numerous basins and troughs off the southern California coastline are a unique feature of the area. Because of their depth and their depression below the surrounding sea floor, they serve as sinks for organic detritus settling from overlying waters, and the dissolved oxygen in three of the basins is extremely low, from less than 0.1 to 0.4 mg/L. The fauna found in the basins is far less rich and diverse than that of the mainland shelf, consisting primarily of polychaetes that can evidently tolerate the low oxygen conditions.

Table 8-1
COMMON BENTHIC INVERTEBRATES IN THE SOUTHERN CALIFORNIA MAINLAND SHELF*

Species	Frequency of Occurrence (percent)	Density (no./sq m)	Density Rank
POLYCHAETES			
Prionospio pinnata	90.4	28.0	
Prionospio malmgreni	84.5	92.8	2
Pectinaria californiensis	74.5	45.3	9
Pholoë glabra	71.1	51.1	5
Paraonis gracilis	61.3	48.3	6
Spionphanes missionensis	60.8	22.8	
Tharyx tesselata	59.7	53.6	4
Haploscoloplos elongatus	59.7	31.7	
Sternaspis fossor	54.0	15.7	
Glycera capitata	53.3	17.6	
Lumbrineris cruzensis	52.3	35.9	
Cossura candida	51.7	45.8	8
Nephtys sp.	51.2	24.2	
Aricidea lopezi	45.5	28.7	
CRUSTACEANS			
Ostracods unknown	61.9	279.9	**
Tanaids unknown	59.7	26.3	
Ampelisca brevisimulata	57.4	35.7	
Heterophoxus oculatus	55.0	23.8	
Ampelisca cristata	50.5	22.9	
Paraphoxus bicuspidatus	43.8	47.6	7
Paraphoxus similis	43.2	17.4	
Metaphoxus frequens	41.5	18.0	
ECHINODERMS			
Amphiodia urtica	87.0	359.1	1
Amphipholis squamata	77.3	39.5	10
MOLLUSCS			
Axinopsida serricata	52.3	54.7	3
OTHER TAXA			
Nemerteans unknown	100.0	28.0	
Nematodes unknown	51.7	27.2	
Glottidia albida	51.7	24.2	

*From Jones (1967, 1969)
**Not ranked (comprises several species).

In studies conducted between 1952 and 1958, 149 large-volume, benthic grab samples were taken from 12 offshore basins (Figure 8-1). The analyses of these samples were reported by Hartman and Barnard (1958 and 1960). Almost half (70) of the samples were from the more accessible San Pedro Basin, between 9 and 19 samples each were taken from the Santa Cruz, San Nicolas, Santa Catalina, and Santa Monica Basins, and the other seven basins were each represented by one to five samples.

The data obtained from the 149 samples (summarized in Table 8-2) show that the numbers of species and the population density were far lower in all of the basins than on the mainland shelf. A total of 217 invertebrate species were identified from the 12 basins. Polychaetes were the most abundant, representing well over one-half of the total number of species. Nineteen species of echinoderms were found, as well as 27 crustacean and 17 molluscan species. The species most commonly found in each basin are listed in Table 8-3.

Most specimens of basin species were small, seldom more than a few millimeters in length, although large individuals were found on occasion.[1] The outer basins had faunas that were distinctively different from those of the nearshore basins. Santa Catalina, Santa Cruz, and San Nicolas Basins supported a deep-water fauna of polychaetes, echinoderms, sipunculids, sea whips, and a few other types that enjoy more extensive ranges along the continental shelf slopes of the eastern Pacific and in the cold, shallow bottom waters of the North Pacific.

8.2.3 Comparison of Shelf and Basin Fauna

Table 8-4 presents estimates of the total number of species in several faunal groups living on the shelf and in the basins. Although polychaetes represent about 50 percent of the species in basins and 35 percent of those on the shelf, they represent about three-quarters of the total number of species common to both areas. Many of the species found in the basins are considered to be "shelf" species, and further studies will be required to identify those that are actually indigenous to the basins and not merely vegetative forms derived from settlement of larvae outside of their optimum range.

In terms of frequency of occurrence in samples, basin polychaetes were eight times more common than crustaceans; on the shelf, polychaetes and crustaceans occurred with about equal frequency (Table 8-5). On the shelf, the density (numbers of organisms per square meter) was more than 10 times greater than that in the basins.

The biomass or standing crop of benthic organisms in the basins varied between about 1.5 and 12 g/sq m (Table 8-2). The biomass of similar organisms on the nearshore shelf was on the order of 500 to 4,000 g/sq m—more than two orders of magnitudes greater.

8.2.4 Submarine Canyon Fauna

As previously described in Chapter 3, the sea floor off southern California contains a number of separate canyons extending from the coastline to the deep basins

1. Large specimens were not well sampled with the technique used.

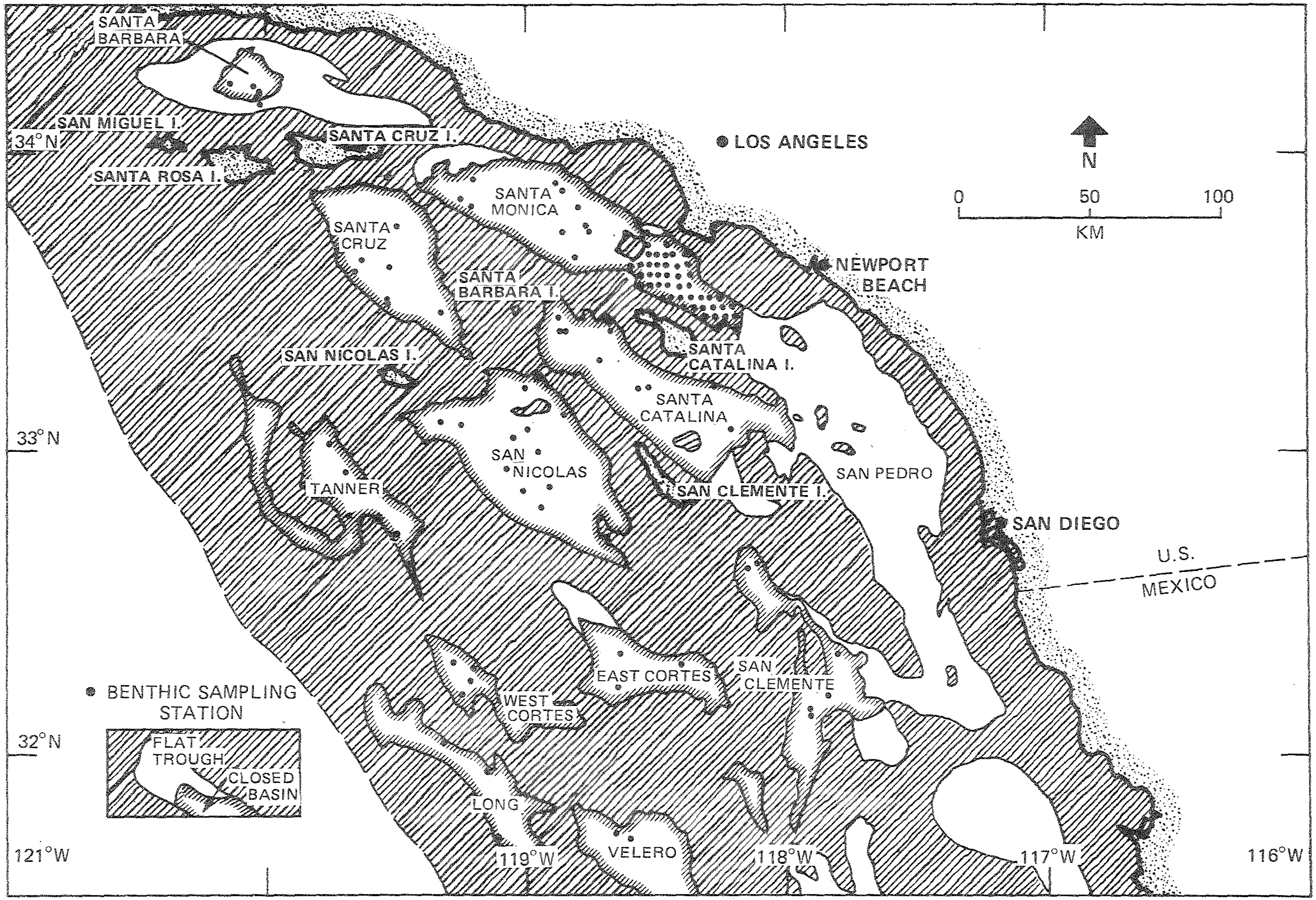


Fig. 8-1. Location of Benthic Sampling Stations Used in 1952 - 58 Study of Southern California Basins. From Hartman and Barnard 1960.

Table 8-2
PHYSICAL AND BIOLOGICAL DATA FROM THE BASINS OFF SOUTHERN CALIFORNIA*

Basin	Depths Sill (m)	Depths Bottom (m)	Bottom Temp (°C)	Bottom Dissolved Oxygen (mg/L)	No. of Benthic Samples	No. of Living Species	Mean Standing Crop (g/sq m)	Density (no./sq m)
Santa Barbara	475	627	6.3	0-0.3**	5	24	2.8 (42.0)†	50
Santa Monica	737	938	5.0	0-0.3**	19	24	4.4	11
San Pedro	737	912	5.1	0.2	70	115	5.5	31
Santa Cruz	1,085	1,966	4.2	0.8	9	55	3.2	61
San Nicolas	1,106	1,833	3.7	0.5	11	90	5.5	121
Santa Catalina	974	1,357	4.0	0.4	11	119	8.3	123
San Clemente	1,815	2,107	2.6	1.3	6	53	1.5	34
East Cortes	1,415	1,979	3.1	0.9	3	36	6.1	66
Tanner	1,165	1,551	3.8	0.6	6	71	10.0	89
West Cortes	1,362	1,769	3.4	0.8	4	42	4.2	66
Velero	1,902	2,571	2.5	2.0	2	20	4.2	43
Long	1,697	1,938	2.7	1.4	3	54	12.0 (49.7)††	98

*After Hartman and Barnard 1960. Bottom dissolved oxygen and temperature from Emery 1960.
**Water in the extreme bottoms is anoxic.
†With heavy molluscs.
††With one large echiuroid.

Table 8-3
COMMON AND CHARACTERISTIC BASIN SPECIES*

Santa Barbara

Paraonis multibranchiata (P)**

San Pedro

Phyllochaetopterus limicolus (P)
Protis pacifica (P)
Cyclopecten zephyrus (M)
Amphioteis scaphobranchia (P)
Aricidea nr. *suecica* (P)

Santa Monica

Phyllochaetopterus limicolus (P)
Protis pacifica (P)
Cyclopecten zephyrus (M)

Santa Catalina

Praxillella spp. (P)
Ophiura leptoctenia (E)
Asychis lacera (P)
Aricidea uschakovi (P)
Tharyx tesselata (P)

Santa Cruz

Aricidea uschakovi (P)
Paraonis gracilis (P)

San Clemente

Aricidea uschakovi (P)
Ceratocephala loveni pacifica (P)
Distichoptilum verrillii (O)

San Nicolas

Sipunculids (O)
Solemya spp. (M)
Ampharete sp. (P)
Aricidea uschakovi (P)
Tharyx tesselata (P)

East Cortes

Aricidea uschakovi (P)
Ceratocephala loveni pacifica (P)
Leiochrides hemipodus (P)

Tanner

Solemya sp. (M)
Aricidea uschakovi (P)

West Cortes

Ceratocephala loveni pacifica (P)
Aricidea uschakovi (P)

Velero

Not evident, too few samples

Long

Aricidea uschakovi (P)
Onuphis vexillaria (P)
Tharyx tesselata (P)

*After Hartman and Barnard 1960.
**Symbols: P = polychaete, M = mollusc, C = crustacean, E = echinoderms, O = other phyla.

Table 8-4
NUMBERS OF SPECIES IN SEVERAL FAUNAL GROUPS
FROM THE BASINS* AND COASTAL SHELF**

	Basins		Shelf	
Group	Number†	% of Total	Number††	% of Total
Polychaetes	172	53	523 (336)	35
Crustaceans	32	10	419 (272)	28
Molluscs	(50)	16	408 (268)	29
Echinoderms	17	5	64 (50)	4
Others	(50)	16	59 (11)	4
Estimated Total	321		1,473	

*After Hartman and Barnard (1960), 149 samples.
**After Jones (1969), 176 samples.
†Parenthetic numbers are estimates.
††Parenthetic numbers are actual numbers of species identified; others are total faunal elements, including those forms identified only to family or genus. Overall, only 64% were described and placed to species.

Table 8-5
RELATIVE NUMERICAL FREQUENCY OF OCCURRENCE OF SEVERAL FAUNAL GROUPS CALCULATED FROM INDIVIDUAL FREQUENCIES IN BASIN AND COASTAL SHELF SAMPLES*

	Percent Composition	
Group	Basin	Shelf
Polychaetes	62	36
Crustaceans	8	35
Molluscs	10	12
Echinoderms	5	14
Sipunculids	(1.6)**	0.3
Others	5	3

*After Hartman and Barnard (1960)
**Unique sipunculid fauna of San Nicholas Basin excluded.

and troughs. These canyons contain a unique and varied fauna (Hartman 1963). Hartman's study showed that 30 to 60 percent of the species found in one canyon were not found in adjacent canyons, indicating some degree of isolation (Fay 1972).

Canyon habitats are subject to considerable fluctuations in environmental conditions because they serve as natural channels for shoreward movements of upwelling waters and organisms and for downward transport of runoff, sand, and debris. These processes result in widely (and often suddenly) varying conditions, to which the indigenous fauna must adjust. In general, the variety and numbers of animals in canyons decrease with depth, as on the shelf and in basins. Table 8-6 shows the relative number of species in several faunal groups found in seven of the canyons. In all of the canyons, polychaetes represented the largest proportion of the total number of species; crustaceans and molluscs were present in significantly fewer and about equal numbers. Estimates of biomass in the canyons (Table 8-7) shows that the canyons are intermediate in standing crop between the basins and the shelf, with an average biomass of about 175 g/sq m.

8.3 PARAMETERS OF BENTHIC COMMUNITY RESPONSE TO STRESS

In almost any given natural environment, a balanced biological community, able to cope with the conditions and fluctuations in that environment, will develop. If the environment changes, some aspect of the community structure will change: Sensitive or inadaptive species may be eliminated, and forms that can tolerate or take advantage of the new conditions and compete more successfully with others for space or food may be enhanced.

In general, the initiation of municipal wastewater discharge in an area will alter the benthic invertebrate community in two ways:

A. A higher input of organic matter may tend to have an enhancing effect on detrital filter feeders or deposit feeders and on the species for which they are prey.

B. The changes in sediment consistency and the increased levels of heavy metals and organic toxicants, lower dissolved oxygen, and increased sulfides accompanying the buildup of organic deposts may act to inhibit larval settlement or may have directly toxic effects on settled larvae or adults of sensitive species. (These factors may also affect the populations of benthic fishes that prey on the invertebrate community.)

The resultant effect will be a function of time and will depend on the interactions of these two opposing factors with each other and natural conditions.

A problem faced by almost all ecologists attempting to determine the relationships between environmental factors and biological response has been the lack of useable, objective parameters for characterizing the biological communities. The raw data usually consists of discrete measurements of various physical and chemical characteristics taken at a given place and time, together with the numbers of identified organisms. It is extremely difficult to work with such species lists; as a consequence, investigators have attempted to identify other parameters that would characterize the condition of the communities under study. These have included various systems for identifying indicator species (i.e., species whose presence would be indicative of a particular condition), analyzing interspecific associations, and assessing species diversity.

Table 8-6
RELATIVE COMPOSITION OF CANYON INVERTEBRATES

Canyon	No. of Samples	Poly-chaetes	Crusta-ceans	Molluscs	Echino-derms	Others	No. of Species Identified
		Percent of Identified Species					
Hueneme	14	56.6	14.5	14.5	4.4	10.1	159
Mugu	10	47.1	28.1	12.8	5.8	6.2	242
Dume	10	58.2	17.6	13.2	6.6	4.4	91
Santa Monica	15	69.4	8.2	9.4	6.5	6.5	170
Redondo	13	63.1	7.7	18.4	5.9	4.8	168
San Pedro Sea Valley	15	67.9	5.2	11.8	8.0	7.1	212
Newport	16	56.9	14.5	16.4	5.3	6.9	262
Mean		59.9	13.7	13.8	6.1	6.6	(149)

Table 8-7
ESTIMATED MEAN BIOMASS (g/sq m) IN CANYON SAMPLES

Canyon	Biomass (g/sq m)
Hueneme	275
Mugu	154
Dume	145
Santa Monica	43
Redondo	367
San Pedro Sea Valley	88
Newport	151
Mean	175

*From Fay (1972)

All of these methods have been shown to be useful, but no one method alone provides a satisfactory characterization of a biological community of concern. The following sections describe the application of these methods to benthic faunal communities in the Bight. Data analyzed included:

A. A study in the Orange County outfall area, where the use of one outfall was terminated and operation of a new outfall begun. Data was collected over a period of 8 months prior to and 15 months after the switchover.

B. Data collected over a 10-year period in the Point Loma outfall area.

C. One set of recent data from the Hyperion outfall area.

D. Two sets of recent data, including a close grid survey, from the Whites Point outfall area.

Types of analysis varied between the study areas.

8.3.1 Indicator species

The use of indicator species in evaluating the degree and types of stress imposed by an outfall is based on the belief that any level of a particular kind of stress will be characterized by the absence or lack of sensitive species and the occurrence or abundance of certain tolerant species. For example, if some forms of plant life are reduced by direct toxic effects, by the silting in of the plants' substrate, or by decreasing available light caused by increased turbidity, some herbivores could no longer exist, and the forms that prey upon the herbivores would also be reduced because of the absence of their normal prey. Increased inputs of organic particulates would be expected to enhance detrital filter feeders and deposit feeders; but, at high input levels, filter feeders would tend to be eliminated by toxic conditions, leaving a community predominantly composed of deposit feeders.

If the validity of the use of indicator species in a given situation can be demonstrated, it is possible to simplify the monitoring programs designed to identify potentially adverse environmental conditions.

There are a few species known to be reliable indicators of the conditions accompanying very high inputs of organic wastes. However, such conditions are usually obvious by much simpler tests. Indicator species that are more useful (and more difficult to identify) are those that are sensitive to environmental changes too subtle to be detected by normal physical or chemical means or to have a marked effect on the rest of the biota. Selection of such species requires careful and extensive analysis.

Species said to be indicators of stressed or polluted environments can be found in areas that are at a great distance from any possible source of pollution. However, as noted by Reish (1970), such findings may reflect the fact that many "polluted" environments are virtually indistinguishable from some natural areas. For example, *Capitella*, a polychaete worm often cited as an indicator of low salinity and able to tolerate the low-oxygen, high-organic-content conditions of wastewater-polluted enclosed bays and harbors, has been found in large numbers in benthic samples taken well away from any municipal wastewater discharge.

Closer examination of the data indicates that these samples were taken either near underwater freshwater aquifers or in areas of rich organic muds--in environmental conditions not dissimilar to those found near marine wastewater outfalls.

Although there are a few indicator species that are ubiquitous (e.g., *Capitella capitata* and *Stauronereis rudolphi*), most have geographically or ecologically restricted distributions that limit their application. As a consequence, care must be taken in attempting to extrapolate the results of species response studies in one area to other areas.

Selection of Indicator Species

SCCWRP has analyzed data on faunal distribution patterns around four municipal wastewater outfalls to discern possible correlations with apparent degree of outfall-related stress, based on distance from the discharge, pre- or post-discharge conditions, or some other identifiable parameter.

At the Orange County and Point Loma outfall areas, special attention was focused on the occurrence of brittle stars (phylum Echinodermata) and the small clam *Parvilucina tenuisculpta*. In an analysis of the Allan Hancock Foundation survey of the southern California shelf, Jones (1969) found that two brittle stars, *Amphiodia urtica* and *Amphipholis squamata*, were among the most abundant and frequently occurring species (occurring in 87 and 77 percent of the analyzed samples, respectively). Barnard and Ziesenhenne (1961) noted that these species were reduced or missing in areas of "substrate complexity," such as the central shelf projection in Santa Monica Bay, the Palos Verdes Shelf, the San Pedro Shelf, and the southern portion of the San Diego Shelf. However, it should be noted that, at the time these samples were taken (1957-60), all of these areas were receiving waste discharges, were close to heavily trafficked harbors, or may have had their sedimentary regimes substantially changed by the effects of other human activities. Because of their wide distribution, dominant ecological position, and known sensitivity to stress, they are likely candidates for intensive monitoring and bioassay studies. *P. tenuisculpta*, which occurs in the vicinity of a number of outfalls, appears to be tolerant of wastewater discharges and should also be considered for use in monitoring.

At the Whites Point outfall, a close-grid benthic survey permitted detailed examination of faunal distribution patterns. Emphasis was placed on the polychaete community, and major species were ranked according to an apparent negative or positive response to existing outfall conditions.

The occurrence of certain polychaete species that are generally considered to be indicators of highly stressed conditions (e.g., *Capitella capitata*) was investigated at the four outfall areas.

Small crustaceans, somewhat neglected in the present studies, have also been suggested as a group that decreases in abundance as a response to wastewater discharge (Pearce 1970; National Marine Fisheries Service 1972). Although not as well known taxonomically as some of the other groups, small crustaceans should be considered as a potential source of indicator species.

Orange County Studies

Table 8-8 presents data on the abundance of *Amphiodia urtica* and *Parvilucina tenuisculpta* near the old and new Orange County wastewater outfalls both prior to and following the initiation of discharge through the new outfall. The location of the two outfall sampling stations referred to in the table is shown in Figure 8-2; a shallow-water control station (Station S4) is located 8 km northwest of Oceanside.

Although few samples from the control station, S4, have as yet been analyzed, all of the samples contained between 1 and 13 *A. urtica*. The average ratio of numbers of *A. urtica* to numbers of *P. tenuisculpta* ranged from 0.08 to 2.6.

At Station S1 near the old outfall during the time of discharge (August 1970 to February 1971), the ratio of *A. urtica* to *P. tenuisculpta* was about 0.2, or an average of one brittle star to five clams. The average number of *A. urtica* at Station S1 was similar to that at the control station. However, the number of *P. tenuisculpta* was approximately 10 times higher at Station S1 than at Station S4.

The samples taken at Station S1 three months after cessation of the discharge showed little change (in contrast to D1) in the numbers of brittle stars but a large decrease in the numbers of *P. tenuisculpta* (possibly due either to predation on the *P. tenuisculpta* or a lack of their successful settlement). Later sampling showed a large increase in the numbers of brittle stars, all very small, which had successfully settled. A decrease in the last sampling (June 1972) may indicate sampling variability or normal attrition as a result of predation or competition. Overall, following cessation of the discharge, the number of *A. urtica* increased seven-fold and *P. tenuisculpta* decreased five-fold; the average ratio between the two species was 9.3 *A. urtica* for each *P. tenuisculpta*, a 50-fold increase over the ratio found during the discharge period.

The sediments at Station D1 near the new, deepwater outfall are sandier and richer in organic matter than at Station S1. At this station, the ratio of *A. urtica* to *P. tenuisculpta* before initiation of the discharge in April 1971 was about 1.3. Afterwards, there was an increase in the numbers of *A. urtica* and *P. tenuisculpta;* the ratio in this period (June 1971 to June 1972) was 2.0. It will be of interest to see if the brittle stars decrease in abundance in the area of the new outfall.

Point Loma Studies

Immediately prior to and following the initiation of use of the new Point Loma wastewater outfall in 1963, an extensive monitoring program, which included biological analyses of benthic grab samples, was carried out. The data obtained in 1962, before the operation of the outfall began, is incomplete, and there is some question as to the identification of certain of the benthic invertebrate species. Consequently, the following discussion is limited to the data taken between 1963-72 at the stations shown on Figure 8-3 and at station B1, located approximately 10 km south of the outfall. The "A" and "B" stations, located 2 and 10 km from the outfall, respectively, were sampled monthly in 1963 and 1964, bimonthly in 1965 and 1966, and twice yearly from 1968 to 1972. During 1965-66 and again in 1972, a line of "Y" stations, all located close to the outfall,

Table 8-8
NUMBERS AND RELATIVE ABUNDANCE OF *Amphiodia urtica* AND *Parvilucina tenuisculpta* NEAR THE ORANGE COUNTY OUTFALLS

Station	Prior to Outfall Changeover							After Outfall Changeover					
	4 Aug 70	1 Sep 70	27 Oct 70	1 Dec 70	5 Jan 71	9 Feb 71	Mean	22 Jun 71	17 Aug 71	20 Oct 71	Dec 71	Jun 72	Mean
Old Outfall, Sta. S1													
No. *Amphiodia*/grab*	27	5	1	1	11	23	11.3	2	2	113	212	55	76.8
No. *Parvilucina*/grab	81	117	2	52	45	39	57.7	0	10	6	16	9	8.2
Ratio, *Amphiodia* to *Parvilucina*	0.33	0.04	0.08	0.02	0.24	0.59	0.20	-	0.20	18.83	13.25	6.11	9.37
New Outfall, Sta. D1													
No. *Amphiodia*/grab	84	28	69	32	66	51	55.0	111	155	108	98	126	120
No. *Parvilucina*/grab	59	34	45	35	58	19	41.7	9	59	90	82	61	60.2
Ratio, *Amphiodia* to *Parvilucina*	1.42	0.82	1.53	0.91	1.14	2.68	1.32	12.33	2.63	1.20	1.20	2.07	2.00
Control, Sta. S4													
No. *Amphiodia*/grab			10	26			18.0	1				11.8†	9.6
No. *Parvilucina*/grab			7	27			17.0	13				4.5†	6.2
Ratio, *Amphiodia* to *Parvilucina*			1.43	0.98			1.06	0.08				2.62	1.5

*Grab area: 0.11 sq m.
**Outfall Changeover occurred 1 April 1971.
†Mean of four samples.

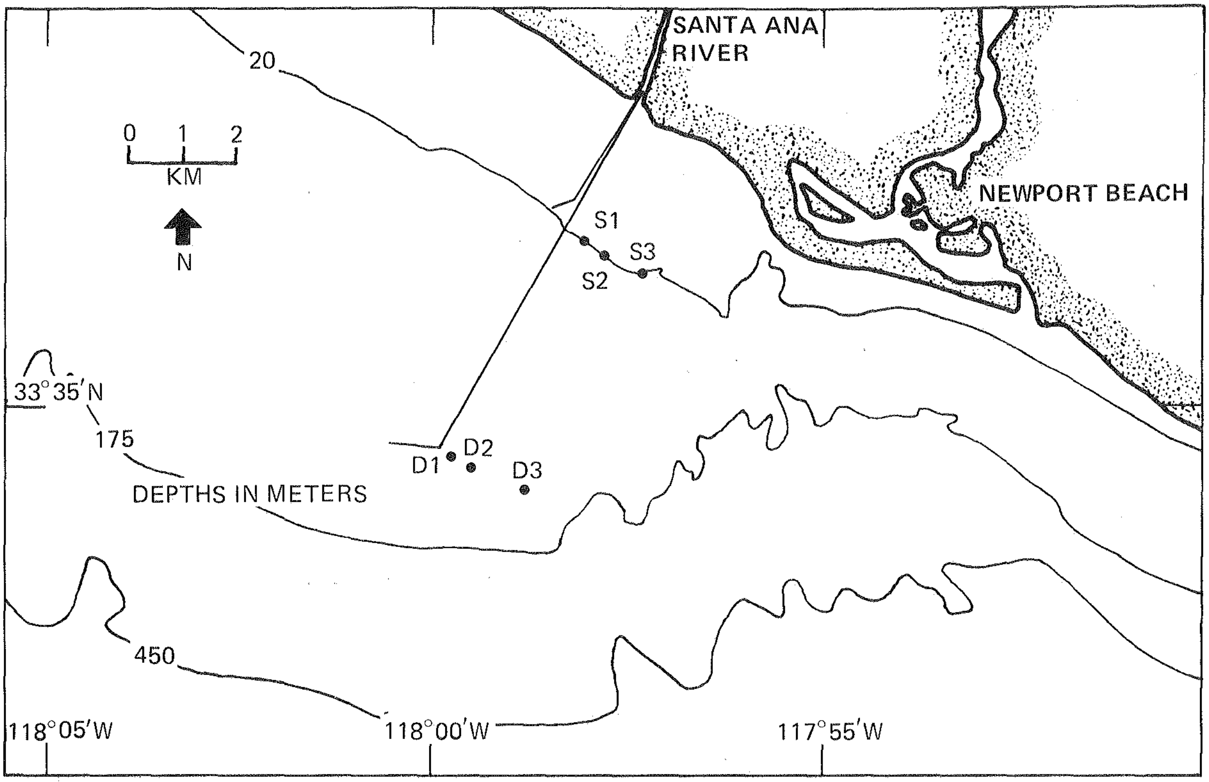


Fig. 8-2. Location of Benthic Sampling Stations Near Old and New Orange County Outfalls.

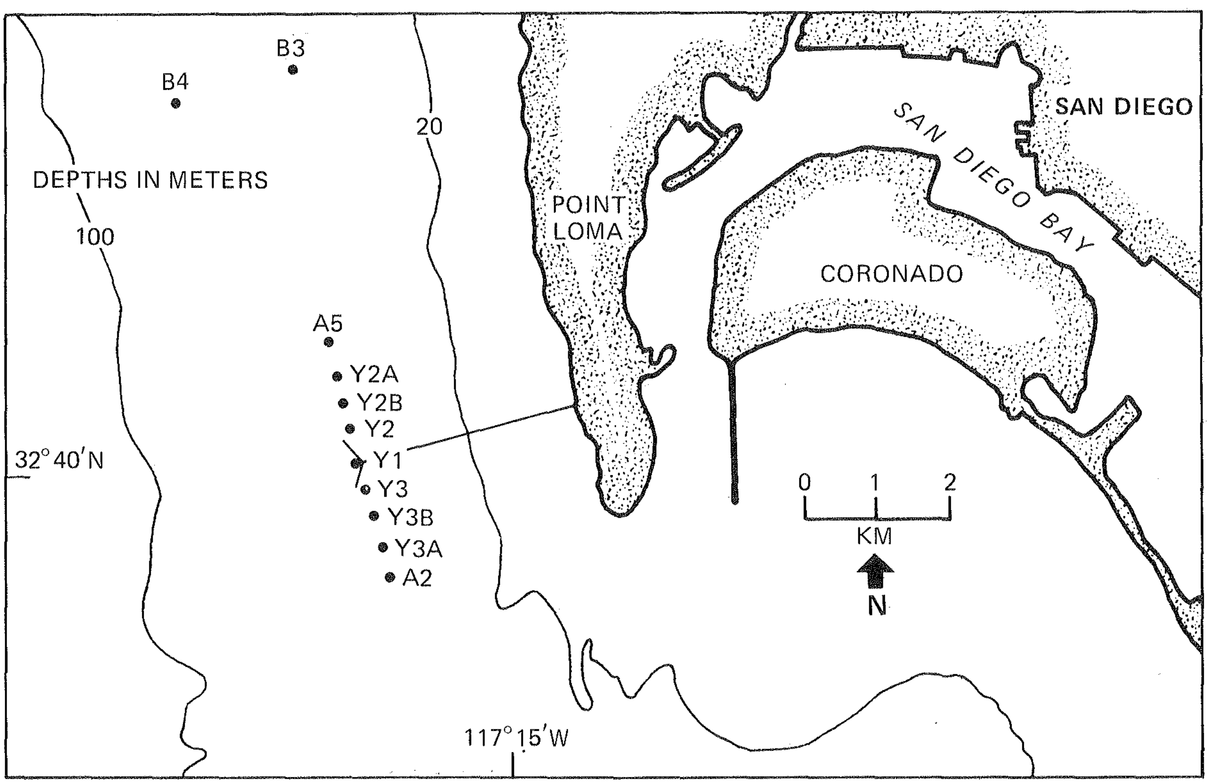


Fig. 8-3. Location of Benthic Sampling Stations Near the Point Loma Outfall.

was sampled. Generally, four replicate samples were taken at the "A" and "B" stations and one or two at the "Y" stations.

Table 8-9 presents the average number of brittle stars (*Amphiodia* spp.) per sample collected at the "A" and "B" stations from 1963 to 1972. The values for Station B1 are considerably below those of the other four stations, where the average number of organisms per grab ranged from 11.7 to 97.6. Initially, the largest numbers of brittle stars were found at Station A5; but by 1966, abundance had declined at this station and had increased at Stations A2, B3, and B4. During 1968-72, the average numbers of brittle stars at all stations declined, although the values for Stations B3 and B4 were still relatively high. The general pattern is one of early stimulation of brittle stars, followed by a decline in populations--especially around the outfall--and a shifting of peak abundances to areas farther from the outfall.

Between September 1964 and January 1967, digested sludge was discharged through the outfall. Raw sludge was discharged between August 1968 and January 1969. Chen, Orlob, and Smith (1972) noted a stimulation of benthic animals in general from 1964 to 1967, after which the number and variety of organisms decreased. They also noted an apparent inhibition of echinoderms (of which brittle stars are a type), which correlated with high levels of sediment biochemical oxygen demand.

Table 8-10 presents the ratio of the numbers of brittle stars (*Amphiodia* spp.) to *Parvilucina tenuisculpta* at "A," "B," and "Y" stations during each sampling period. The table shows that, at Station B1, 10 km south of the outfall, there were nearly always more clams than brittle stars, although the numbers of both groups were small--less than 20. At Station B4, 10 km north of the outfall,

Table 8-9
MEAN NUMBER OF BRITTLE STARS (*Amphiodia* spp.)
PER GRAB OFF POINT LOMA

		Station and Distance from Outfall				
Period	No. of Sampling Periods*	B-1, 10 km S	A-2, 2 km S	A-5, 2 km N	B-3, 10 km N	B-4, 10 km N
1963	9	1.2	46.8	61.0	44.0	33.3
1964	9	1.3	44.7	69.3	42.0	39.6
1965	9	1.8	52.7	73.0	84.0	54.0
1966	6	1.8	86.8	54.8	97.6	95.8
1968-72	6	1.6	25.3	11.7	63.6	85.3

*Normally, four grab samples were taken in each sampling period.

Table 8-10
RATIO OF BRITTLE STARS (*Amphiodia* spp.) TO CLAMS (*Parvilucina tenuisculpta*) OFF POINT LOMA

	Station and Distance (km) from Outfall											
Date	B-1, 10 S	A-2, 3 S	Y-3A, 2.4 S	Y-3B, 1.6 S	Y-3, 0.8 S	Y-1, 0	Y-2, 0.8 N	Y-2B, 1.6 N	Y-2A, 2.4 N	A-5, 3 N	B-3, 10 N	B-4, 10 N
1963												
Sep	1*	52*								72*	34	38*
Oct	0.29	74								34	42	20
Nov	0.17	98*								30	38	40
Dec	0.12	18								30	45	31*
1964												
Jan	0.25	71								36	22	20*
Feb	0.12	38*								14	36	32*
Mar	0.09	20								17	44	28*
Apr	0.20	31								16	38	40*
May	0.60	36								24	66*	37*
Jun	0.67	27								37	48*	42*
Jul	0.14	42								15	34	51
Sep	0.10	20								12	14	41
Nov	0.10	50*								8.8	49	65*
1965												
Jan	0.12	20			6.9	0.34	1.1			22	80	47*
Mar	0.14	7.3	5.4		2.5	0.05	0.01		7.8	9.2	32	40*
May	0.44	22	31	6.5	2.1	0.02	0.007	1.1	70	7.8	29	53*
Jul	0.11	11								26	66	53
Sep	0.20	11	9	3.0	0.24	0.004**	0.10	0.26	1.0	4.6	96	62*
Nov	0.17	14	8.2	17	10	0.003**	0.10	0.21	1.6	7.2	108	69*
1966												
Jan	0.07	14	6.5	1.4	0.008*	0.003	0.003**	0.10	1.3	2.6	121	71*
Mar	0.11	6.6								5.3	106	92
May	0.14	6.2	4.7	1.3	0.01		0.02	0.26	1.2	3.7	122	82*
Jul		130*								54*		
Sep	1.0									3.1	89	102*
Nov	0.29	1.7								2.8	50	132*
1968												
Feb		0.59									112*	19*
Jul	0.07	0.20								0.27	3.6	56
1969												
Jan	0.25	0.29								0.34	8.8	94
1970												
Nov	6.0	0.67								0.17	6.5	33
1971												
Jul	0.4	1*								0.47	0.88	13*
1972												
Jan	0.23	4.7								0.85	2.1	242
Jul	1**	1.5		0.32		0.008**		0.045**		5*	4.2	140*

*No clams in sample; number given is the number of brittle stars.
**No brittle stars in sample; number given is 1/(no. of clams).

there were always much greater numbers of brittle stars than clams. A similar situation occurred at Station B3 until July 1968, when the ratio decreased greatly. At the stations closer to the outfall (Stations A2 and A5 and the "Y" stations), there is a general trend of decreasing ratio of brittle stars to clams. This is discernible even at the "Y" stations, although they were sampled only between January 1965 and May 1966 (and once again in 1972).

In almost all cases, the picture that emerges in the region of the outfall is one of a declining abundance of brittle stars and an increasing abundance of *P. tenuisculpta*. This is most conspicuous at the "Y" stations, all within 1.5 km of the discharge. In fact, Station Y1, located between the diffuser legs, had more clams than brittle stars the first time it was sampled in January 1965 (5 months after sludge discharge initiated). The numbers of clams exceeded those of brittle stars at Station Y2 in March 1965 and at Station Y2B in the following September.

These data show that there was a gradient of effects, both with time since initiation of the discharge and with distance from the outfall. The effect was asymmetric--with stations to the north showing a greater effect than those to the south--and consistent with the direction of subsurface currents (Chen, Orlob, and Smith 1972).

Palos Verdes Studies

In July 1971 benthic samples were collected from 87 stations on the Palos Verdes Shelf. The station locations are shown in Figure 8-4. The sediments off the Palos Verdes Peninsula were qualitatively classified by feel as sand, silty sand,

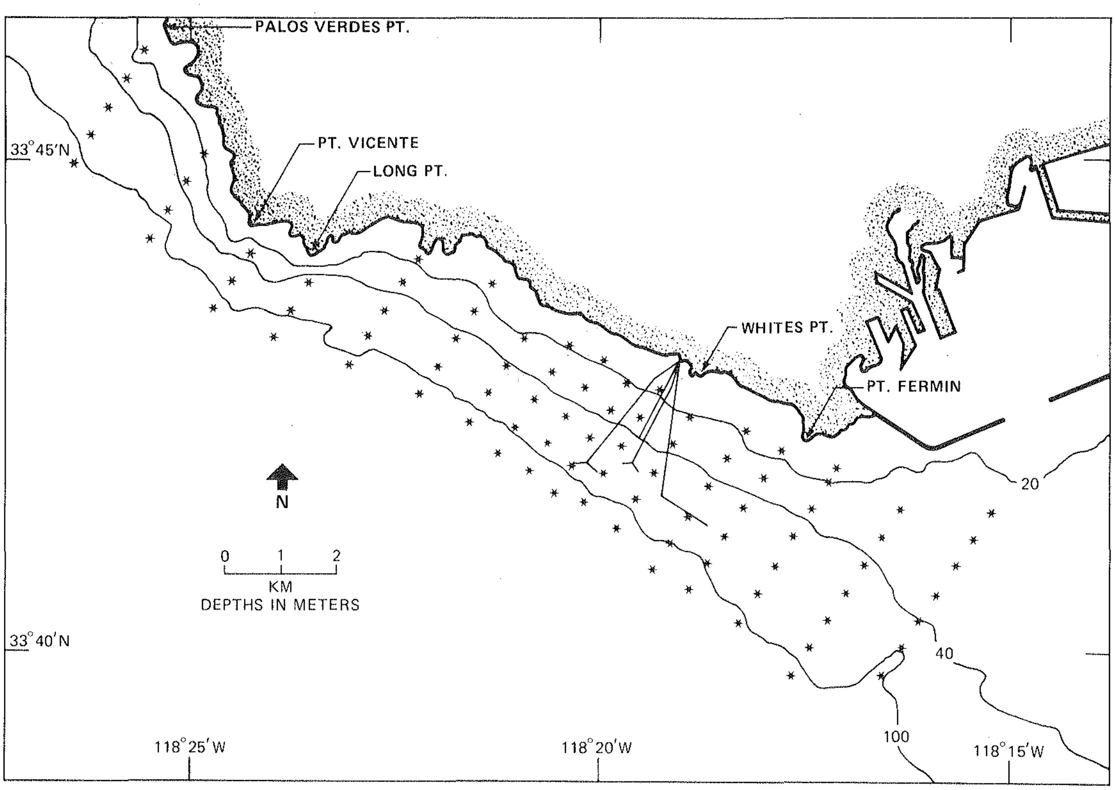


Fig. 8-4. Eighty-Seven-Station Sampling Grid Used in Benthic Survey Off Palos Verdes, July 1971.

sandy silt, silt, or clay silt. In addition, each sample was qualitatively classified as to color, level of organic matter and presence or absence of hydrogen sulfide odor. The results of these qualitative analyses are shown in Figure 8-5. Sand was observed most often at the stations nearest shore. In the areas around the outfalls, silt was most common. As would be expected, black sediments and hydrogen sulfide predominated in the samples nearest the outfalls and to the northwest.

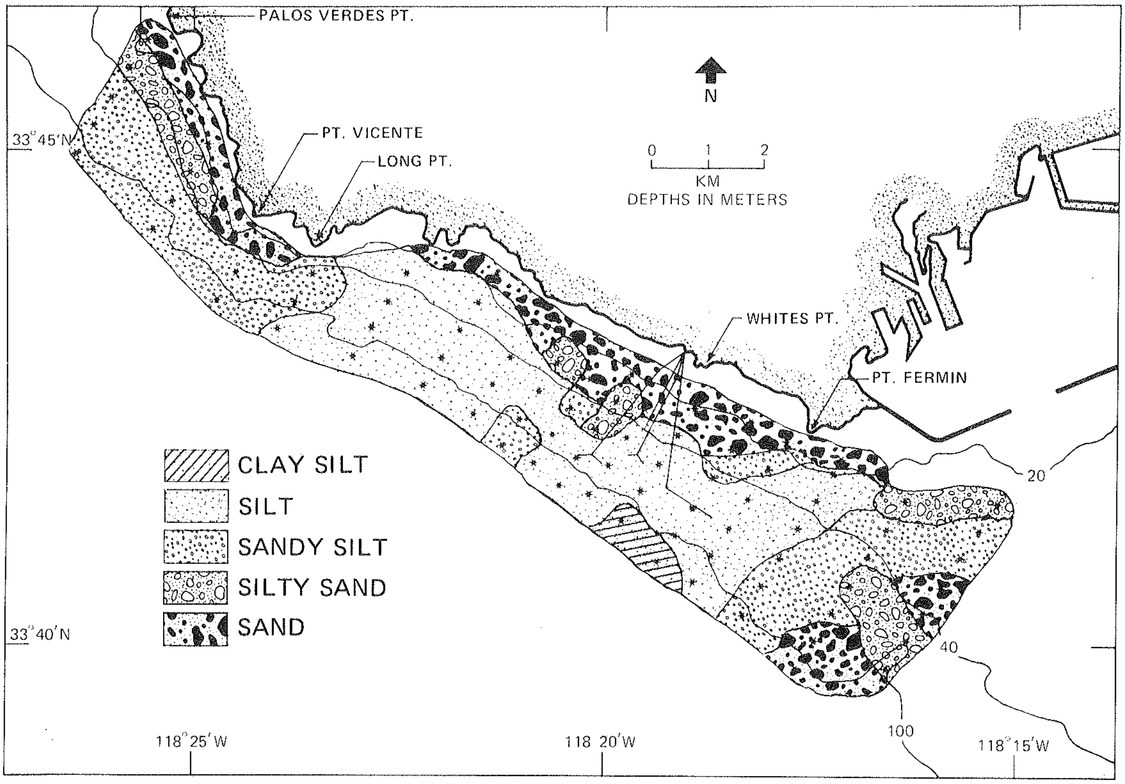
As shown in Table 8-5, the frequency of occurrence of polychaetes and crustaceans in samples from the southern California mainland shelf is about 35 percent each. Echinoderms and molluscs make up another 26 percent, and various other minor groups make up the remainder. However, in the 87 samples collected off Palos Verdes in 1971, polychaetes account for some 70 percent of the total individuals. Molluscs make up about 27 percent, and the remainder is accounted for by crustaceans, echinoderms, and the other minor groups. In a few samples near the outfall, polychaetes (Figure 8-6a) were the only organisms found. Brittle stars appeared to be absent, and other echinoderms were present in less than 6 percent of the samples. Crustaceans were present in 52 percent of the samples and were less abundant in the finer sediments, especially around the outfall (Figure 8-6b). Amphipod crustaceans were present in 31 percent of the samples.

Table 8-11 lists the 21 polychaete species occurring in 10 percent or more of the 87 samples taken in July of 1971 off Palos Verdes. The species are listed in decreasing order of frequency of occurrence.

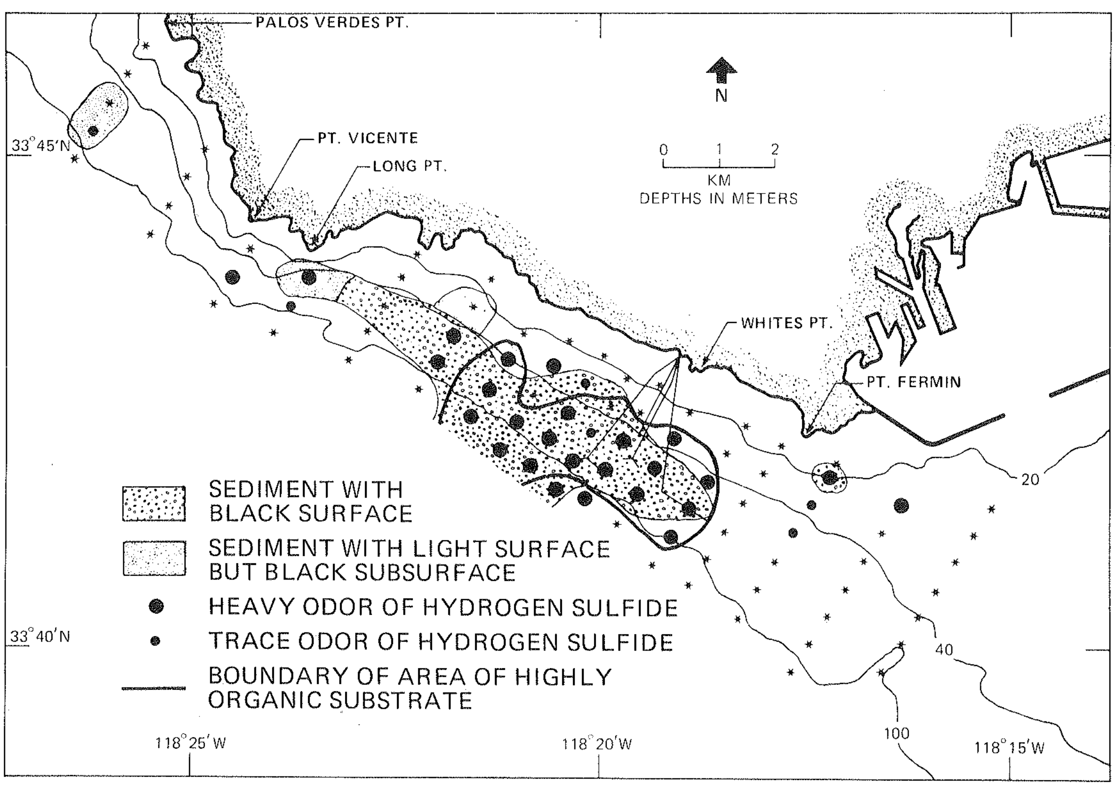
Two species, *Stauronereis rudolphi* (formerly *Dorvillea articulata*) and *Tharyx parvus*, together contributed almost two-thirds of the total polychaetes found, and the five top ranked species accounted for 84 percent. Together, the 21 species listed on the table accounted for 96 percent of the total polychaete specimens found. Figure 8-7 shows the distribution patterns of these 21 species. *Stauronereis rudolphi* (Figure 8-7a) was a dominant species in the silty areas, especially around the outfalls, while *Tharyx parvus* (Figure 8-7i) was a dominant species in the coarser sediments and was almost completely absent from samples taken near the outfall. *Caulleriella hamata* (Figure 8-7g) and *Capitita ambiseta* (Figure 8-7j) were both diminished in samples taken around the outfall. *Capitella capitata* (Figure 8-7b) favored the finer sediments and was the dominant polychaete at greater depths near the outfall.

On the basis of the data in Figure 8-7, each of the 21 polychaete species was placed in one of three categories, according to its apparent preference or avoidance of the outfall area or area of finest sediments. This categorization is shown in Table 8-12. The species in Group C on the table have been ordered from *Caulleriella hamata*, which was absent from only a small band across the outfall area, to species such as *Pherusa neopapillata*, which was absent from much of the silty areas. This does not necessarily imply that the former is more tolerant than the latter, as it is conceivable that *P. neopapillata* could be tolerant of outfall effects but inhibited by the existing natural factors, such as sediment coarseness.

Figure 8-8 shows the distribution of nine of the most frequently occurring pelecypod molluscs. Among these, *P. tenuisculpta* (Figure 8-8a) was the dominant



a. Sediment Types



b. Organic Substrate, Hydrogen Sulfide, and Blackened Sediments

Fig. 8-5. Results of Qualitative Analyses of Sediments Off Palos Verdes, July 1971.

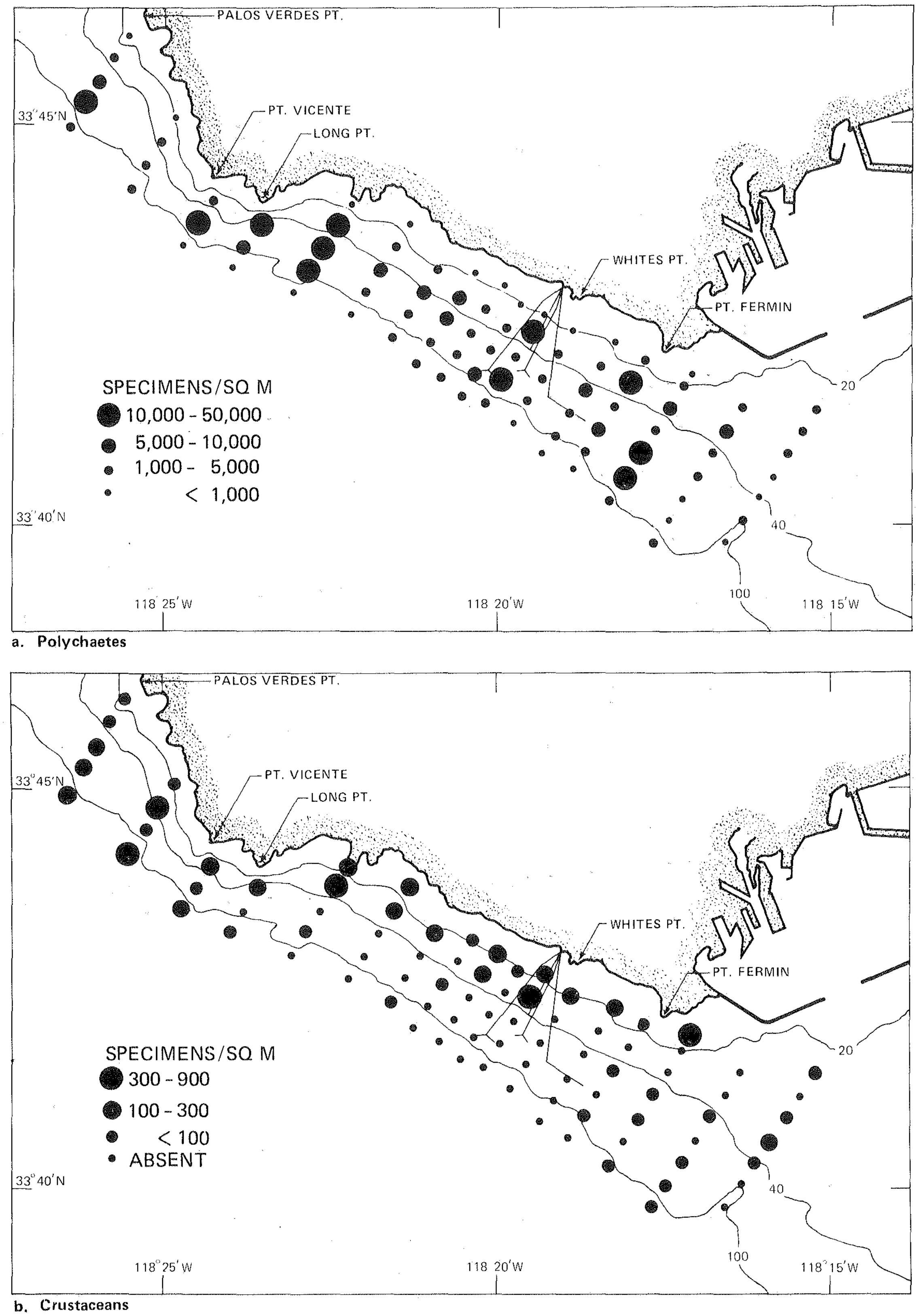


Fig. 8-6. Abundance of Polychaetes and Crustaceans Off Palos Verdes, July 1971.

Table 8-11
DISTRIBUTIONAL CHARACTERISTICS OF THE 21 MOST FREQUENTLY OCCURRING POLYCHAETE SPECIES OFF PALOS VERDES, JULY 1971

			Frequency of Occurrence		Mean Density (specimens/sq m)		
	Abundance Ranking	% of Total Polychaete Specimens	All Stations	High Organic Substrate Stations*	All Stations	High Organic Substrate Stations*	Apparent Sediment Preference
Stauronereis rudolphi	1	37.6	80	100	1678	3136	Silt
Nereis procera	8	1.2	55	58	53	58	Silt
Tharyx parvus	2	25.5	54	5	1139	12	Sandy silt
Capitita ambiseta	4	7.6	53	16	331	7	Sandy silt
Caulleriella hamata	3	12.0	53	7	549	95	Silt
Ophiodromus pugettensis	7	1.2	53	58	51	53	Silt, sandy silt
Capitella capitata	5	4.7	49	68	208	409	Silt, sandy silt
Telepsavus costarum	6	1.5	46	37	68	60	Silt, sandy silt, silty sand
Notomastus tenuis	10	0.9	36	16	39	7	Sandy silt
Spiophanes fimbriata	9	0.9	36	5	40	7	Sandy silt
Prionospio malugreni	14	0.4	29	0	17	0	Sandy silt
Ampharete labrops	12	0.5	26	0	24	0	Sandy silt
Lumbrineris japonica	13	0.5	24	0	20	0	Sandy silt, silty sand
Pectinaria californiensis	11	0.6	20	0	29	0	Silty sand
Glycera capitata	18	0.1	16	0	6	0	Sandy silt
Chloeia entypa	16	0.3	15	5	12	4	Sandy silt
Prionospio pinnata	21	0.1	15	21	4	5	None
Cossura candida	15	0.3	10	0	14	0	Sandy silt
Gyptis arenicola glabra	17	0.2	10	16	7	8	None
Lumbrineris minima	19	0.1	10	0	6	0	None
Pherusa neopapillata	20	0.1	10	5	5	1	Silty sand

*Stations in area of highly organic substrate shown on Figure 8-5b.

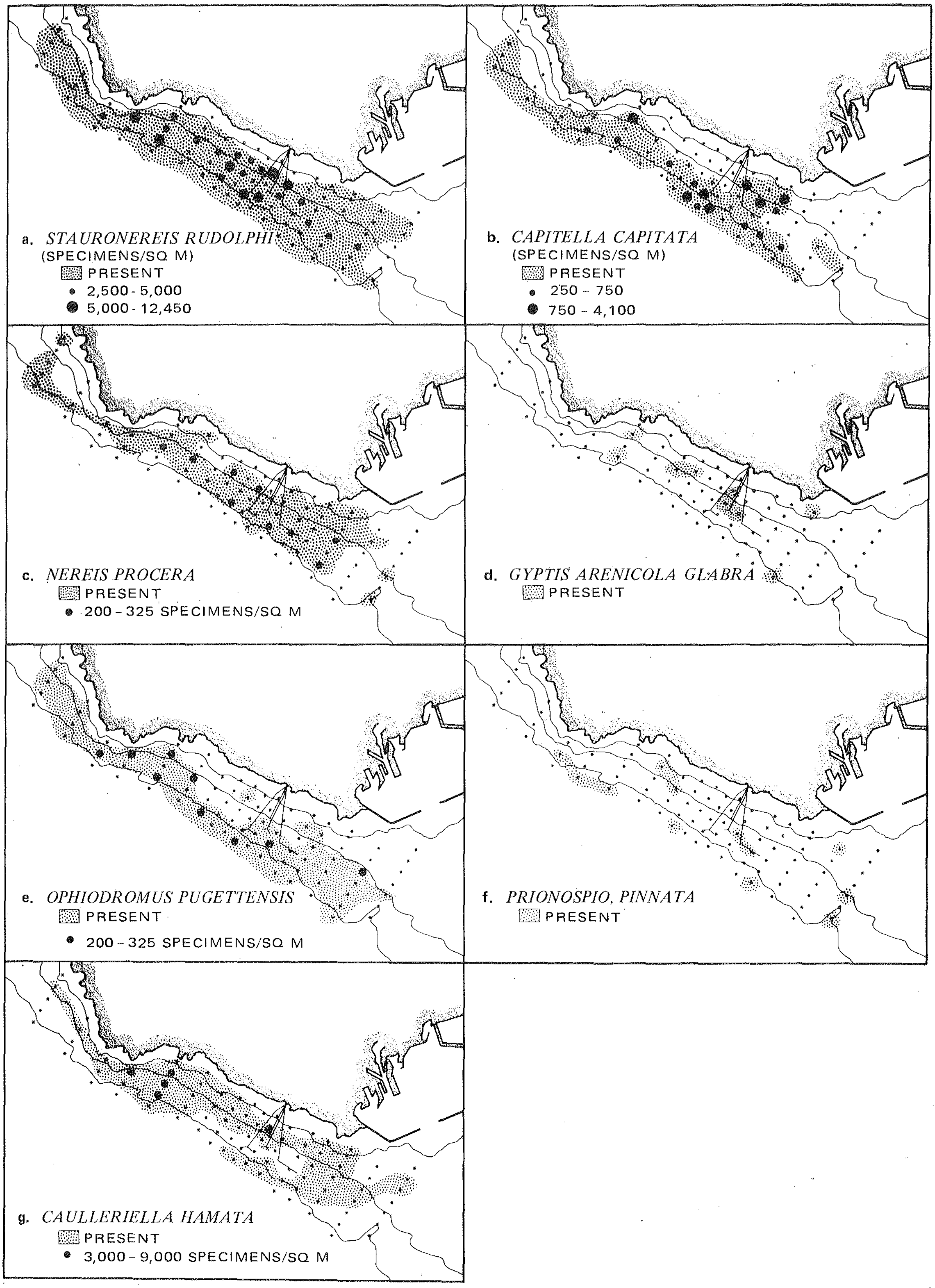


Fig. 8-7. Distribution of the 21 Most Frequently Occurring Polychaete Species Off Palos Verdes, July 1971. (Page 1 of 3)

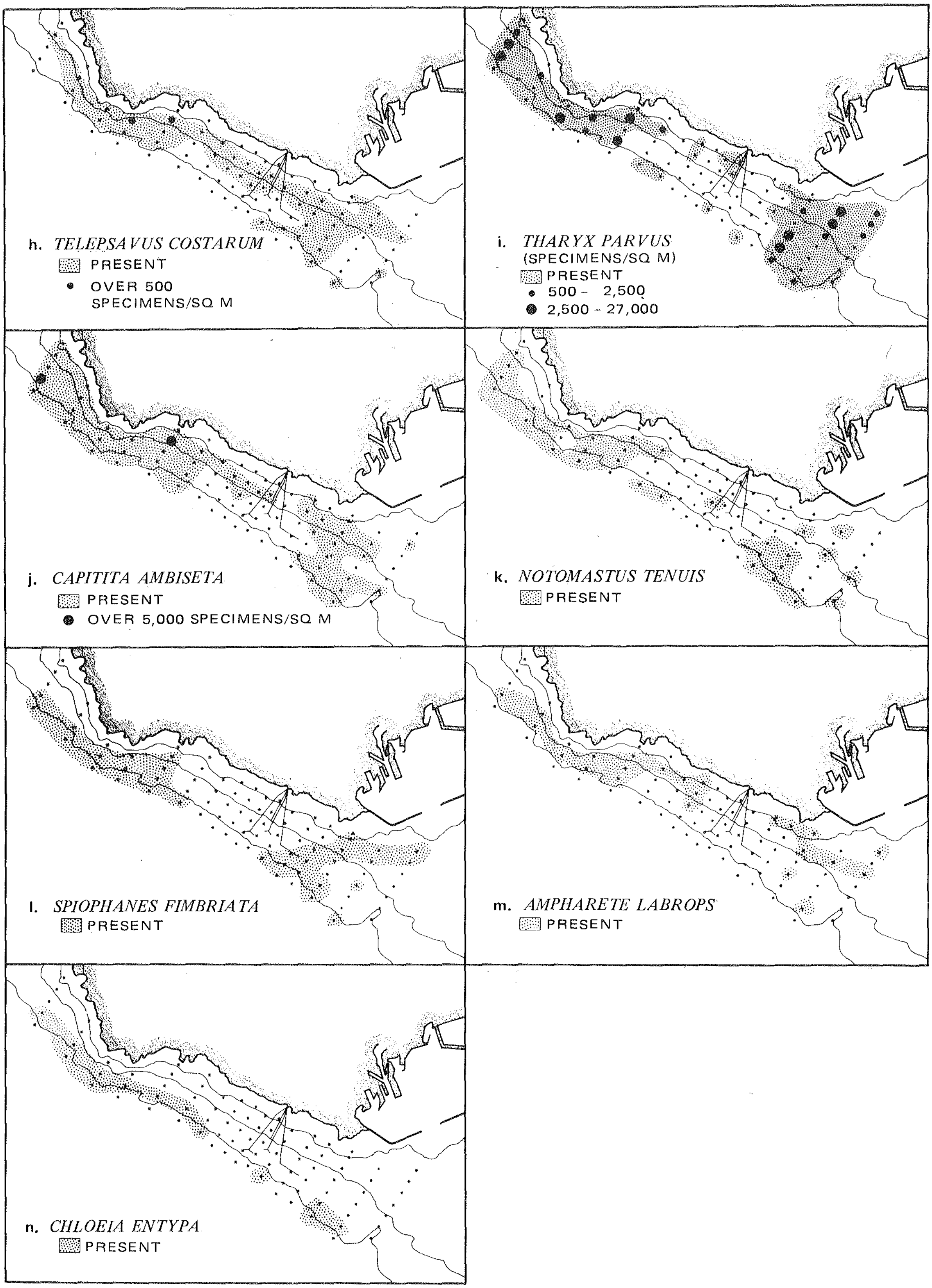


Fig. 8-7. Distribution of the 21 Most Frequently Occurring Polychaete Species Off Palos Verdes, July 1971. (Page 2 of 3)

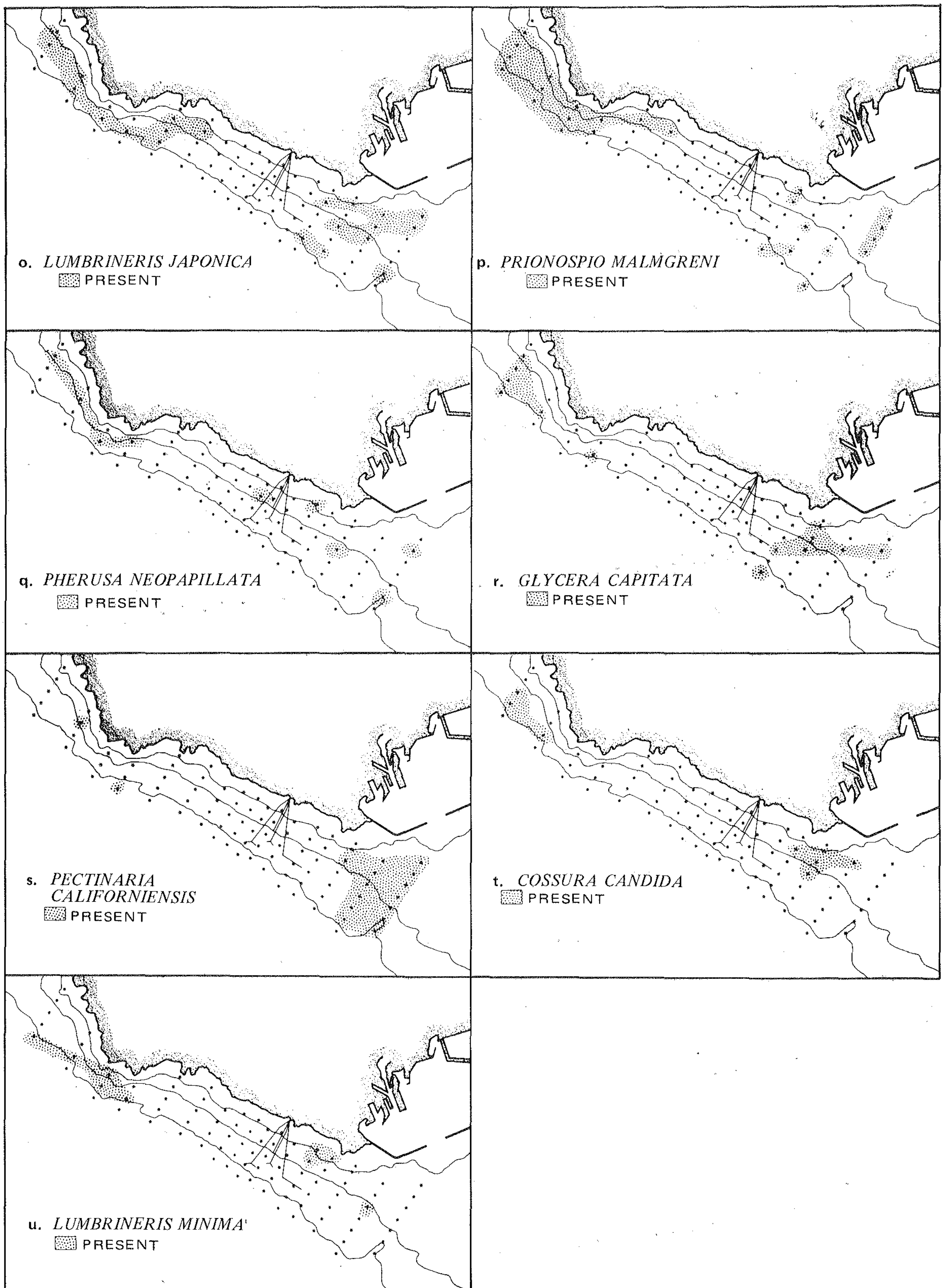


Fig. 8-7. Distribution of the 21 Most Frequently Occurring Polychaete Species Off Palos Verdes, July 1971. (Page 3 of 3)

Table 8-12
DISTRIBUTIONAL CHARACTERISTICS OF THE 21 POLYCHAETE SPECIES MOST FREQUENTLY APPEARING IN SAMPLES TAKEN OFF PALOS VERDES, JULY 1971

GROUP A--Species preferring the outfall area or areas of finest sediment:

1. *Stauronereis rudolphi*
2. *Capitella capitata*
3. *Nereis procera*
4. *Gyptis arenicola glabra*

GROUP B--Species not displaying a strong preference for or against the outfall area or areas of finest sediments:

1. *Ophiodromus pugettensis*
2. *Prionospio pinnata*

GROUP C--Species avoiding the outfall area or areas of finest sediments:

1. *Caulleriella hamata*
2. *Telepsavus costarum*
3. *Capitita ambiseta*
4. *Tharyx parvus*
5. *Notomastus tenius*
6. *Spiophanes fimbriata*
7. *Chloeia entypa*
8. *Ampharete labrops*
9. *Lumbrineris japonica*
10. *Prionospio malmgreni*
11. *Glycera capitata*
12. *Pherusa neopaipillata*
13. *Pectinaria californiensis*
14. *Cossura candida*
15. *Lumbrineris minima*

form, accounting for two-thirds of all mollusc specimens; it was most abundant at greater depth and seemed to avoid the coarser sediments. Although the clam occurred around the outfall, it was less abundant in this area and was totally lacking from samples taken from a line of stations extending from near the end of the "Y" diffuser to the northwest for about 3 km. Maximum concentrations (up to 12,000/sq m) were found off Point Vicente and Long Point, some 5 to 8 km northwest of the outfalls. Within 1.5 km of the outfall, the concentrations were an order of magnitude less. (In the Orange County area, the average number of Parvilucina was about 600/sq m at the shallow outfall and between 400 and 600/sq m off the deep outfall. At Point Loma, the maximum concentration recorded at the "Y" stations was about 3,500/sq m; concentrations at the "A" and "B" stations reached 800/sq m.)

Macoma sp. (Figure 8-8b), the next most abundant mollusc, was not found in the immediate outfall area, but was observed in high densities at the deeper stations offshore of the outfall areas. The other mollusc species of Figure 8-8 were almost completely absent from the outfall area. If pelecypod molluscs were included in Table 8-12, most would belong to Group C (avoiding outfall or fine sediment area), with *P. tenuisculpta* falling above *C. hamata*.

Changes in the distribution of polychaetes and some molluscs, especially *P. tenuisculpta*, may be a sensitive indication of changing environmental conditions. However, the degree to which natural factors may influence these patterns has not been determined; in addition, some of these species may be useful indicators in this area but of little use in other areas because of lack of occurrence due to natural factors.

Capitellids as Indicator Species

Species such as *Capitella capitata* are commonly regarded as indicators of conditions of reduced salinity, low dissolved oxygen, or highly organic substrate.

In the studies around the old and new Orange County outfalls, the capitellids decreased from 22 to 13 percent of the total number of polychaete species when the old outfall discharge was terminated. In the area of the new outfall, the ratio increased from 4 percent before discharge to 26 percent after initiation of the discharge. These determinations were based on samples taken 0.4 km from the old and new outfalls. The two capitellid species were *Capitella capitata* and *Capitita ambiseta*. However, *C. capitata* was the only species that decreased drastically in abundance following termination of the old discharge, possibly indicating that this species is particularly tolerant of high stress, but does not compete favorably in more normal communities. *C. ambiseta* remained dominant in both the pre- and post-discharge situations at the old outfall and was the first species to increase disproportionately following initiation of the new discharge.

In 1972, studies around the Hyperion outfall in Santa Monica Bay showed that capitellid species comprised between 16 and 58 percent of the total polychaete specimens at the stations closest to the "Y" diffuser. High proportions of capitellids were also found at stations to the northwest of the "Y" diffuser and sludge outfall (Figure 8-9). This distribution is similar to the distributions of chlorinated hydrocarbons and some metals around this outfall (Chapter 6) and the areas of high incidence of some fish diseases (Chapter 7).

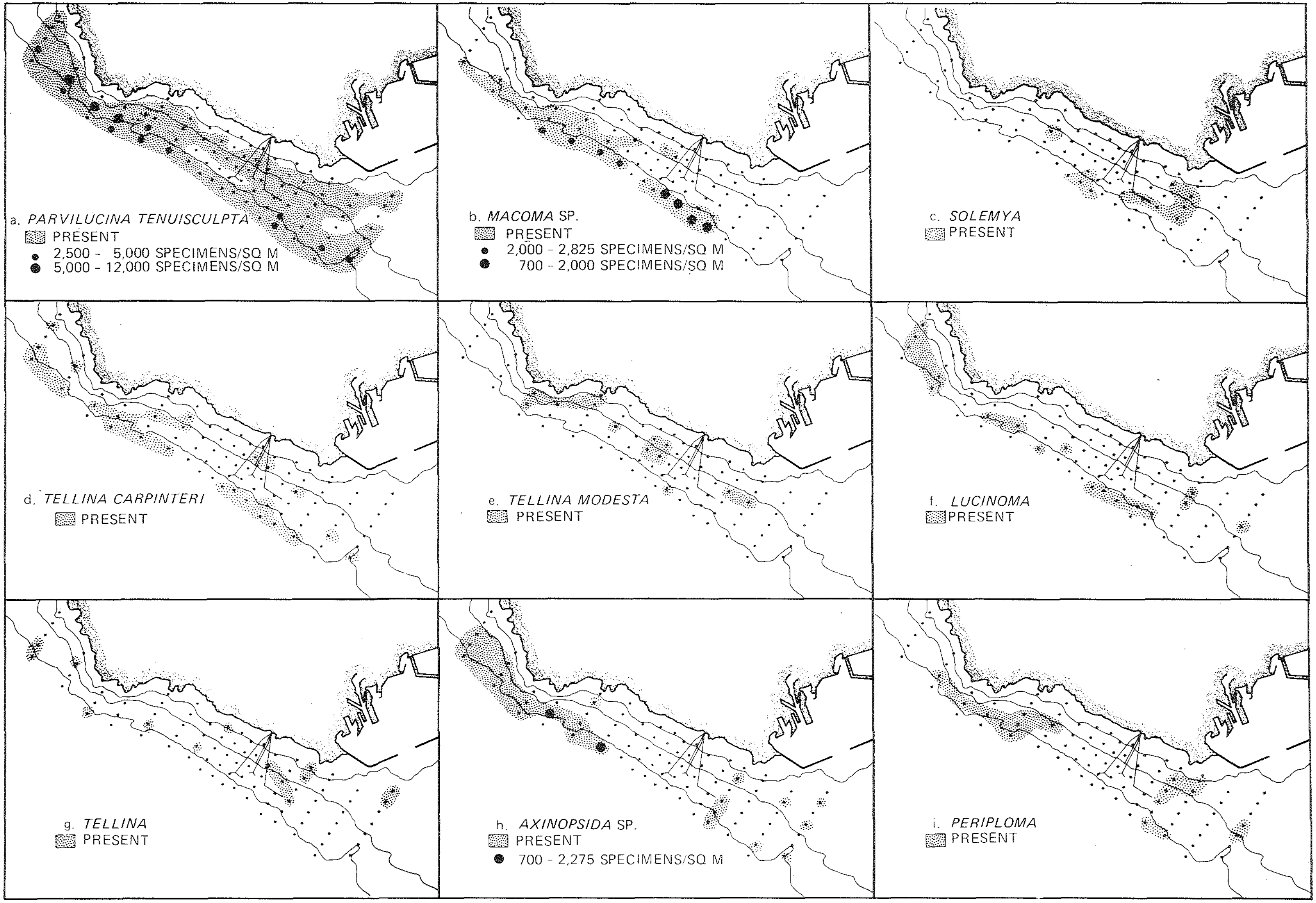


Fig. 8-8. Distribution of Nine of the Most Frequently Occuring Pelecypod Molluscs off Palos Verdes, July 1971.

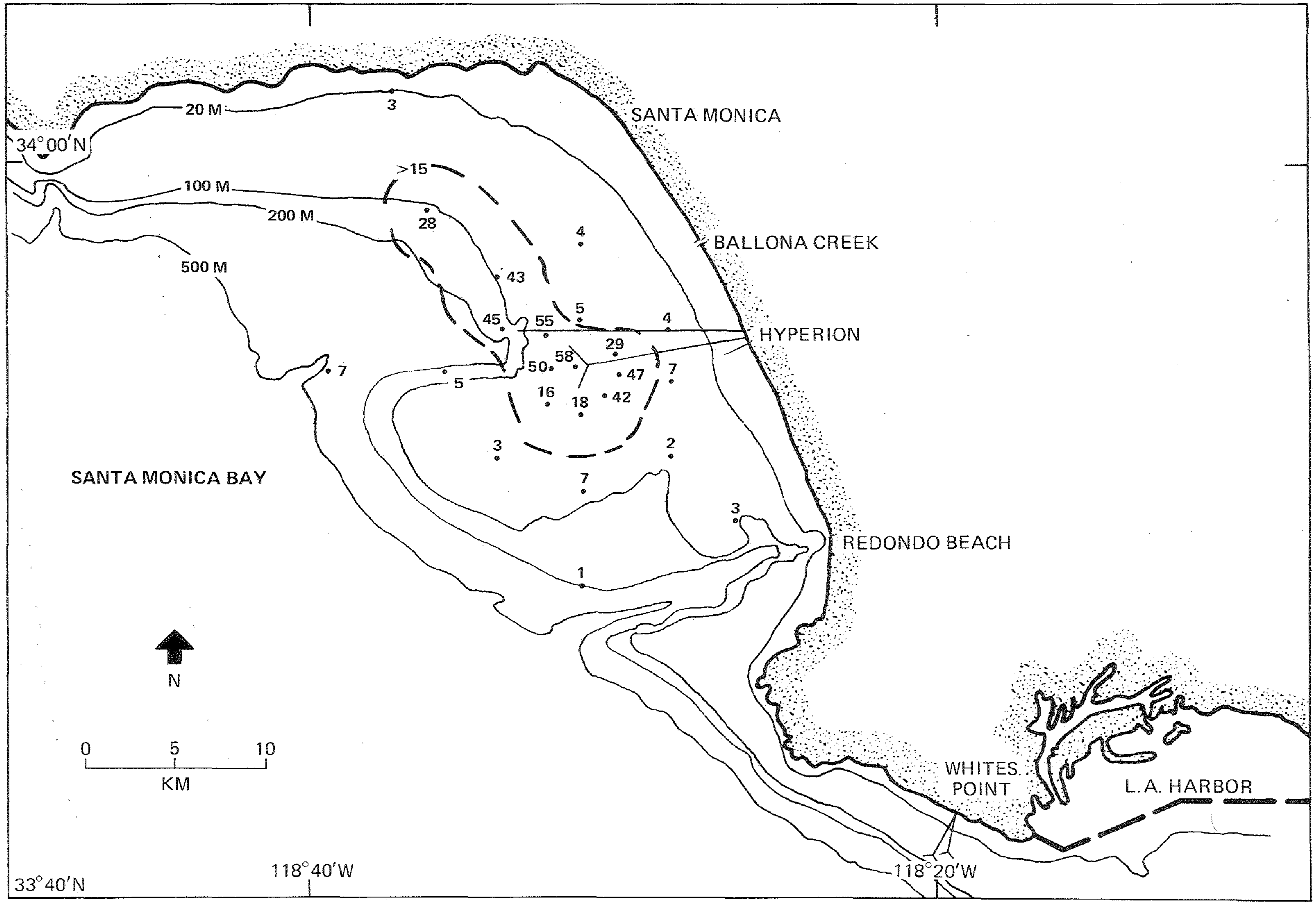


Fig. 8-9. Relative Abundance of Capitellids (Percent of Total Polychaete Specimens) in Santa Monica Bay, January - February 1972.

The highest proportion of capitellids in the polychaete fauna, 58 percent, was observed at the station within the "Y" of the effluent outfall. A somewhat smaller value, 45 percent, was observed at a sampling station at the end of the sludge outfall. Because the polychaete biomass at the latter station (69 g/sq m) was more than six times higher than the biomass at the "Y" station (11 g/sq m), it is difficult to determine whether food (organic particles from the sludge outfall) or outfall-related stress is the major factor affecting the distribution of capitellids.

Although *C. capitata* and *C. ambiseta* are found off Palos Verdes, they are both overshadowed by a third polychaete species, *Stauronereis rudolphi*. This species makes up between 80 and 100 percent of the total polychaete specimens in much of the area around the Whites Point outfalls, as shown in Figure 8-10a. *C. capitata* (Figure 8-10b) occurs over most of the Palos Verdes shelf but is less abundant than *S. rudolphi* and tends to be the dominant polychaete at the deeper stations near the outfall. The area dominated by these two species is essentially the area of black sediments, rich organic matter, hydrogen sulfide, and high sediment levels of trace metals and DDT (Figure 8-5b and Chapter 6). *C. ambiseta* is absent from the immediate area of the outfall (Figure 8-7j).

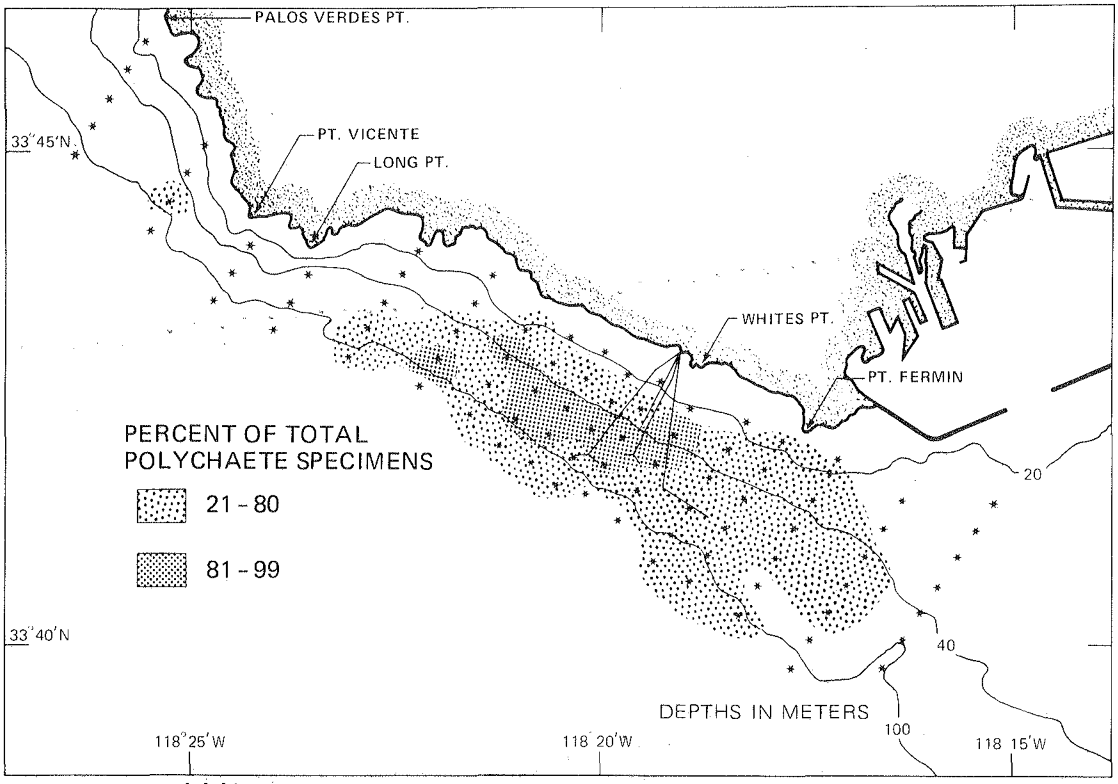
At Point Loma, *C. capitata* was identified in a few samples taken at "Y" stations but not elsewhere.

In summary, studies at the Point Loma and Orange County outfalls indicate that brittle stars, common in samples over much of the Bight, show an early enhancement at an outfall, followed by an inhibition, possibly of larval settlement. The clam, *Parvilucina tenuisculpta*, is also enhanced but shows a much greater tolerance than brittle stars to additional stress (or, alternatively, can compete for space more successfully than brittle stars). Where natural and outfall-related factors permit these organisms to co-occur, the ratio of their abundance seems to correlate with changes in outfall-related conditions. Such a relationship may be a simple yet valuable parameter for monitoring outfall areas and should be further investigated.

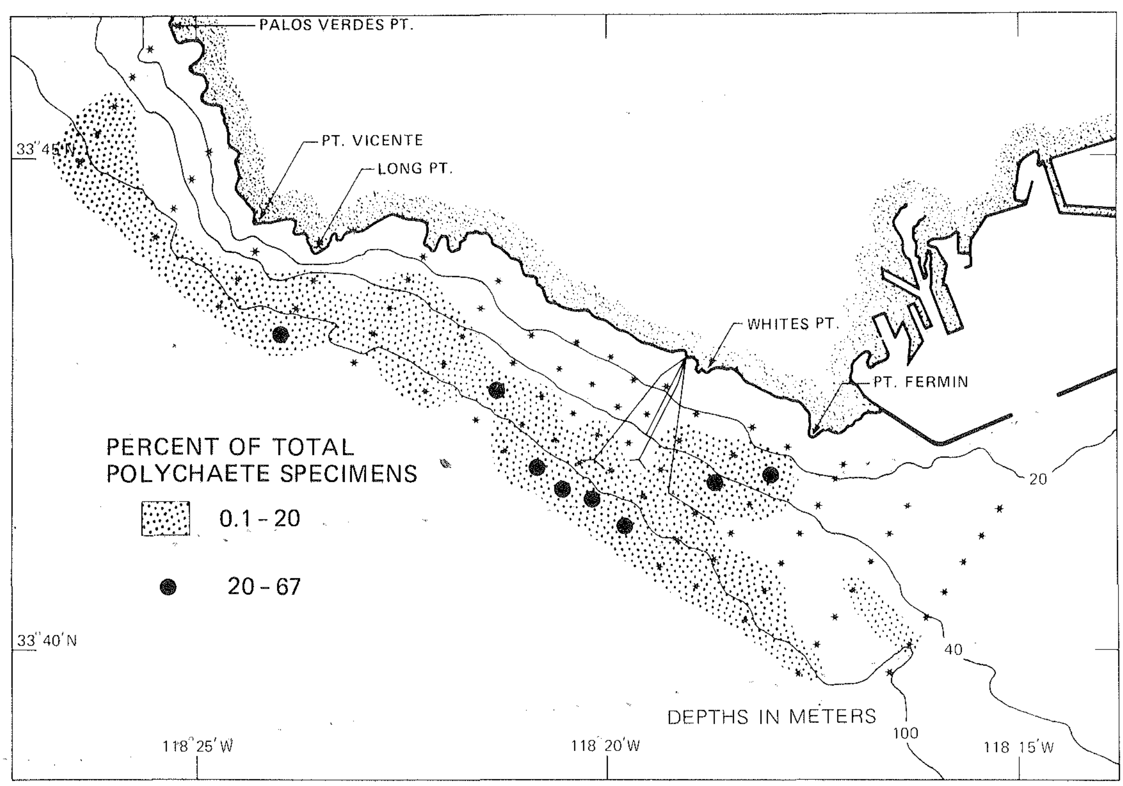
The close-grid survey of the Palos Verdes shelf outfall revealed a number of important features of the faunal patterns in this area. Brittle stars were absent, and other echinoderms and crustaceans were low in occurrence. *P. tenuisculpta*, which appeared to thrive near the Orange County and Point Loma outfalls, was abundant over much of the Palos Verdes shelf but was diminished around the outfall. All other major molluscan species were nearly absent from the immediate outfall area. Polychaetes were the dominant type of organism, especially near the outfall. *Stauronereis rudolphi* and *Capitella capitata*, species known to occur in areas of high organic matter and low dissolved oxygen (Reish 1970), were the dominant species in the outfall area. The concentric patterns for the distribution of the 21 most frequently occurring polychaete species are those that would be expected for populations responding positively or negatively to a gradient radiating from a point source.

8.3.2 Recurrent Groups and Interspecific Associations

As discussed briefly in Chapter 7, a grouping of species into frequently recurring assemblages or associations can be useful in identifying species with common



a. *Stauronereis rudolphi*



b. *Capitella capitata*

Fig. 8-10. Relative Abundance of Two Species Within the Polychaete Communities Off Palos Verdes, July 1971.

behavioral and response patterns. In this way, possibly anomalous conditions may be detected more readily.

Recurrent group analysis is a technique for identifying groups of species that are frequently found together. The technique is based on the presence or absence of species in a sample and does not directly consider the relative abundance of organisms. Briefly, the method is as follows (Fager 1963).

Given a set of samples in which the organisms have been identified, an index of affinity is calculated for every species pair by the following formula:

$$\text{Index of Affinity (I.A.)} = \frac{C}{\sqrt{AB}} - \frac{1}{2\sqrt{B}},$$

where

A = number of occurrences of species A,

B = number of occurrences of species B (and B is the larger of A and B), and

C = number of joint occurrences of species A and B.

The affinity index has a range of about 0 to 1.[2] If two species are never found in the same sample, the index would be minimum for that pair; if the two species were always found together, the index would be maximum. All species pairs with an index of affinity equal to or above a given level are said to have a positive affinity at that level.

Groups of species, all members of which have positive affinities for each other, are then found according to the following rules.

A. The group includes the greatest possible number of species.

B. If several groups with the same number of members are possible, groups that will give the greatest number of groups without members in common are selected.

C. If two or more groups with the same number of species and common members are possible, the one that occurs as a unit in the greater number of samples is chosen.

The method of recurrent group analysis was applied to the polychaete data obtained from sampling the 87-station grid off the Palos Verdes Peninsula. The analysis, using an index of affinity of 0.55, resulted in the identification of four major groups of polychaete species:

Group 1	*Stauronereis rudolphi* *Capitella capitata* *Ophiodromus pugettensis*

2. The range of 0 to 1 is approached for very large sample sizes. For a set of, say, 10 samples, the range of the index would be from -0.16 to +0.84.

Group 2	*Caulleriella hamata* *Telepsavus costarum*
Group 3	*Capitita ambiseta* *Tharyx parvus*
Group 4	*Spiophanes fimbriata* *Notomastus tenuis*

The distributions off Palos Verdes Peninsula of these four polychaete species groups are shown in Figure 8-11 (shaded areas indicating where all members of a group occur). Group 1 occurred over much of the shelf, including the outfall area, where highly organic sediments and hydrogen sulfide were present and sediment levels of DDT and a number of trace metals were highest. This group did not occur as a unit at the shallower stations in the area of highly organic sediments. Group 2 occurred at most of these shallower stations but was absent from areas where outfall-related environmental conditions may reach maximum levels (the group was not found where sediment concentrations of trace metals and DDT were highest). Groups 3 and 4 were absent from relatively large areas around the outfall.

8.3.3 Species Diversity

The number and variety of species present in a biological community and the changes in these characteristics are thought to be related to the stability and well-being of the community. In almost all biological communities, a few species (or dominants) will be found in relatively high abundance, and a large number of species will be represented by relatively few individuals per species. Community stability (generally, the ability of the community to withstand and recover from perturbations) is usually associated with large numbers of species, because of the increased number of alternative energy pathways. In general, in any given area, the numbers and types of habitats, the amounts, types, and constancy of food supply, and the range and predictability of environmental stress will be reflected in the number of species supported by the area and the degree of dominance of each species. As discussed previously, unusual or sudden changes in stress on a community will reduce the numbers of the more sensitive species and possibly permit the increase in numbers of the more tolerant species; thus, the community diversity--as reflected by the variety of species and the balance of individuals between species--will decrease. Similarly, an extreme abundance of certain food types may permit those opportunistic species most able to take advantage of the excess food to become more dominant.

Because of these factors, numerical measures of species diversity can be used to provide an objective measure of the response of biological communities to spatial or temporal changes in environmental conditions. However, some caution must be exercised in the use of species diversity as an indicator of pollution. The diversity of natural communities is not constant. It will change, for example, as a community matures, and different communities will be affected differently by similar types of stress. In addition, any numerical measure of species diversity is an artifact. The listing of species and abundances for a community depends upon a large number of variables, including sampling effort, types of sampling gear, and levels of identification. As a consequence, it is extremely difficult to compare diversity measurements made in different areas, at different times, or by different investigators unless care is taken to ensure that these variables are adequately considered.

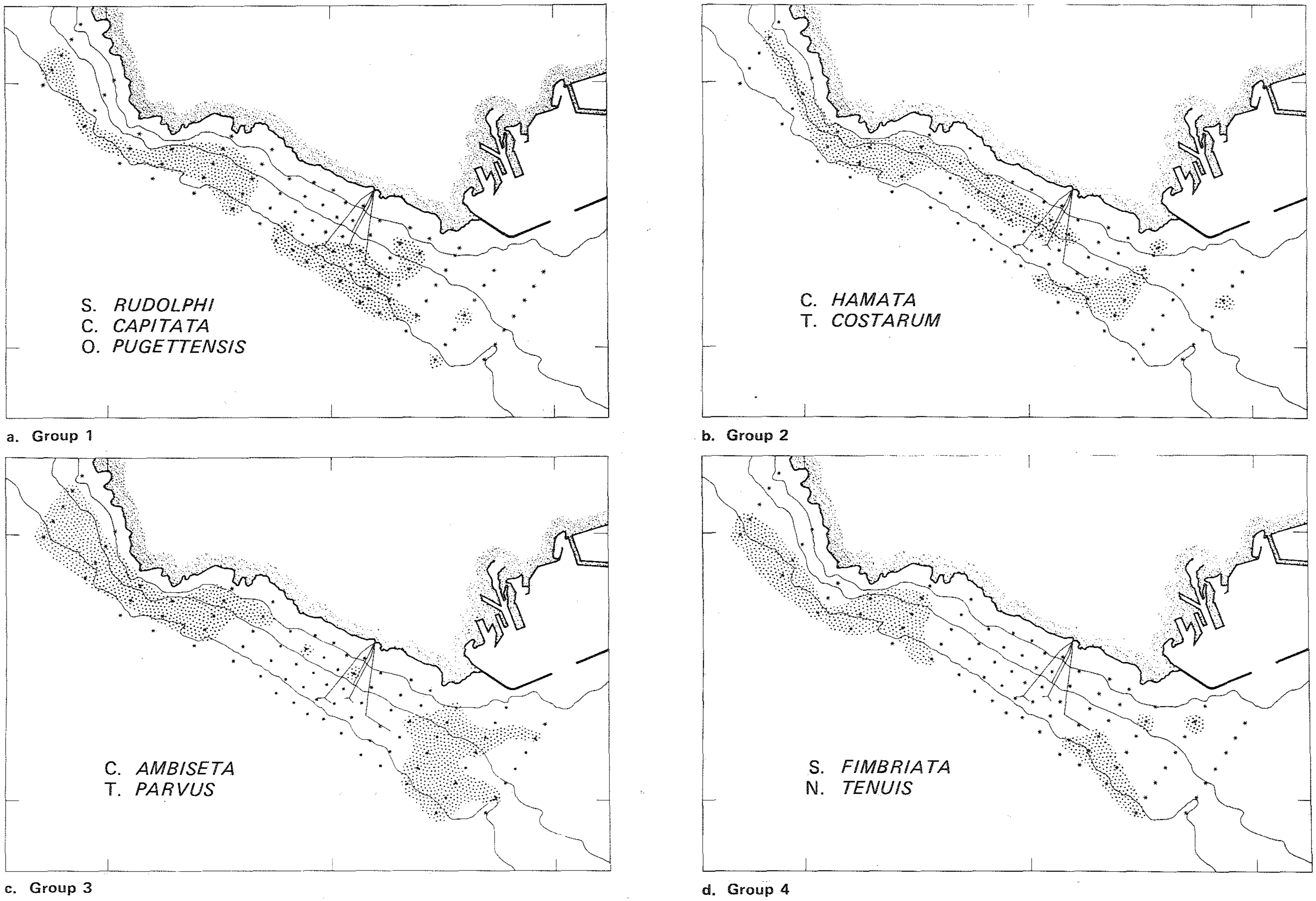


Fig. 8-11. Distributions of Four Polychaete Species Groups Off Palos Verdes, July 1971.

Species Diversity Indices

A number of investigators have developed and used different numerical measures of diversity. Numerical diversity indices are desirable for a number of reasons: (1) a numerical index calculated by a specific formula is an objective measure that can be verified by other investigators; (2) although taxonomic expertise is required for species identification or separation, knowledge of the sensitivity or tolerance of the various species to pollution or other stress is not necessary; and (3) diversity indices appear to provide a rather sensitive indication of community structural changes and are not as subject to the wide natural variability that is a problem with biomass or abundance.

Species diversity can be seen as having two distinct components:

A. The number of species present at a given location.

B. The degree of evenness of distribution of individuals within species.

Three general types of diversity indices are in current use. Those that might be termed indices of richness or variety relate to the first component of diversity. It has been observed that in many situations the numbers of organisms are exponentially related to the number of species or, conversely, the number of species are proportional to the logarithm of the numbers of organisms. For this reason, this type of diversity index is usually a ratio of some function of S, the number of species in the sample, to a function of N, the number of individuals in the sample. The Gleason richness index, D_g, is an example of this type (Margalef 1958):

$$D_g = \frac{S - 1}{\log_e N}$$

where S is the number of species in the sample and N is the total number of organisms. Some investigators have criticized the reliability of this type of index because it is highly sensitive to sample size.

A second type of diversity index is influenced by both components of diversity. In these types of formulations, the variables are the number of species, S, the total number of individuals, N, and the numbers of individuals in each of the species, n_i.

With indices of this type, for each unique value of S (or combination of values of N and S), there is a possible range of values that the diversity index can reach. The evenness of distribution of individuals within species will determine where the actual diversity value will fall in a particular range, the maximum value being reached as the number of individuals for each species approaches N/S and the minimum being assumed when one species has N - S + 1 individuals and all other species are represented by single individuals.

The Shannon-Weaver function, H', as applied by Margalef, is an example of this type (Shannon and Weaver 1963; Margalef 1968):

$$H' = - \sum_{i=1}^{S} \frac{n_i}{N} \log_e \frac{n_i}{N} .$$

A third type of diversity measurement, which might be termed an index of evenness, attempts to measure only the dominance or evenness of distribution in a sample so that samples having different values of N and S may be compared, thereby reducing the effect of sample size on the index value. These indices are generally of the form

$$\text{Diversity} = \frac{D_{calc} - D_{min}}{D_{max} - D_{min}} ,$$

where, for a diversity function, D, D_{calc} is the actual calculated D for the sample and D_{max} and D_{min} are the maximum and minimum possible values for the given N and S of the sample.

With this type of index, the evenness of distribution of individuals is placed on a scale from 0 to 1, where 1 represents the most even distribution, hence the term "scaled diversity," as suggested by Fager (1972).

Examples of two diversity indices derived by this technique follow. The first, H'_s, is based on the Shannon-Weaver diversity index and is calculated as follows:

$$H'_s = \frac{H' - H_{min}}{H_{max} - H_{min}} .$$

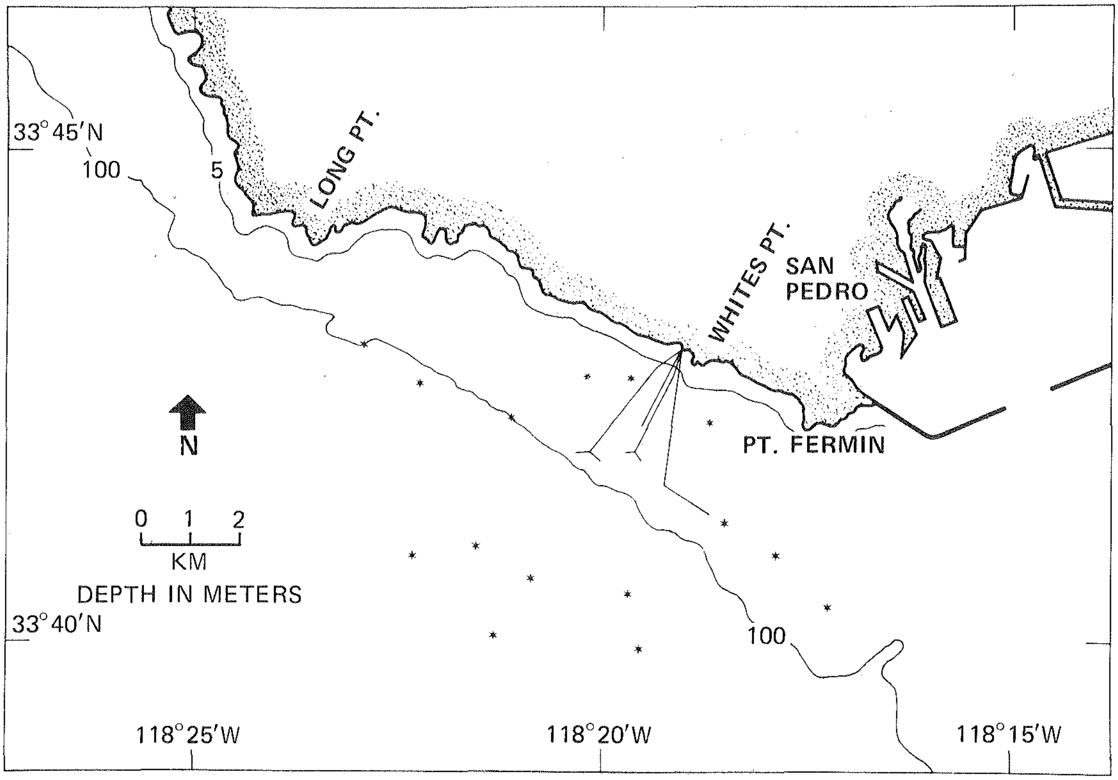


Fig. 8-12. Fifteen-Station Sampling Grid Used in Benthic Survey Off Palos Verdes, February-March 1971.

The second index proposed by Fager (1972), termed a scaled standard deviation diversity index, SD_s, is calculated from the standard deviation of the various n_i in the sample as follows:

$$SD_s = \frac{SD_{max} - SD_{cal}}{SD_{max} - SD_{min}},$$

where

$$SD = \left[\frac{S\Sigma_{i=1}^{s} n_i^{\,2} - N^2}{S(S - 1)}\right]^{1/2}$$

These four indices have been used to evaluate data obtained from the monitoring programs of the County Sanitation Districts of Los Angeles County off Palos Verdes.

Benthic Species Diversity Off Palos Verdes

In February and March 1971, one set of benthic samples (four replicates per sample) was taken with a 0.04-sq-m Shipek grab at 15 stations in the area of the Whites Point outfall by Los Angeles County. A second set of samples was taken in July 1971, with single samples being collected at an 87-station grid. The sampling locations are shown in Figures 8-4 and 8-12. Samples were washed through a 1.0-mm screen.

SCCWRP's diversity analysis of the data from the two surveys focused on the polychaete community, which was treated as an entity separate from the total benthic community. This approach was felt justified for the following reasons. Polychaetes comprised the major portion of total invertebrate macrofaunal specimens and species in recent samples taken on the Palos Verdes shelf. They are well known taxonomically, and the quality of identification in the Palos Verdes studies was considered to be high. They are a major food source for benthic fishes and large predatory invertebrates. Finally, as a group, they are known to display a spectrum of response to waste discharge and other stresses; some species are sensitive, some are moderately tolerant, and others apparently prefer conditions that the rest of the fauna avoid or find toxic. While the diversity of the polychaete segment would not be expected to be identical to the total community, it should still be considered as a meaningful parameter.

An obvious question arises as to the correlation of polychaete diversity with the diversity of other groups in communities in areas relatively free from man-related stress. Table 8-13 shows the results of calculating Shannon-Weaver diversity, unscaled (H') and scaled (H'_s), for six grabs taken at separate stations in the Santa Barbara area in 1957 and 1958 during the Allan Hancock Foundation studies. Diversities were calculated for the total sample and for individual taxonomic groups. For the scaled diversity function, very similar values were found for polychaetes, molluscs, crustaceans, and total fauna, but echinoderm diversity was much lower. For the unscaled index, mean values for the different groups varied considerably; total faunal diversity was highest, followed by polychaete diversity.

In the following, the diversity of polychaetes off Palos Verdes is presented in terms of the number of species per grab sample (per 0.04 sq m) and the four diversity indices discussed above. The numbers of species per grab is shown for polychaetes and molluscs in Figure 8-13. The numbers of species in both groups were greatest at some distance--both to the northwest and the southeast--of the outfalls, although two stations about midway between the shore and the end of the outfalls were relatively rich in mollusc species. Reduced numbers of mollusc species were observed at stations to the southeast of Point Fermin. Figure 8-14 shows the observed polychaete species diversity as measured by four diversity indices. Each of the four indices provides a fairly consistent pattern of reduced diversity in the area around the outfalls. The principal differences in the patterns shown by these four indices appear around Point Fermin. However, these samples were usually taken in sand, and the numbers of individuals and species were low. Thus, indices calculated from these samples would be expected to have a high variability.[3]

Species diversities at nine of the fifteen stations sampled in February and March of 1971 (six deepwater stations were excluded) were compared with the diversity indices at nine similar stations sampled in July 1971. These results are shown in Table 8-14. There is very little difference in the mean values at the stations over the two different sampling periods, indicating that, at least at this time of year, the polychaete populations were relatively stable with respect to diversity.

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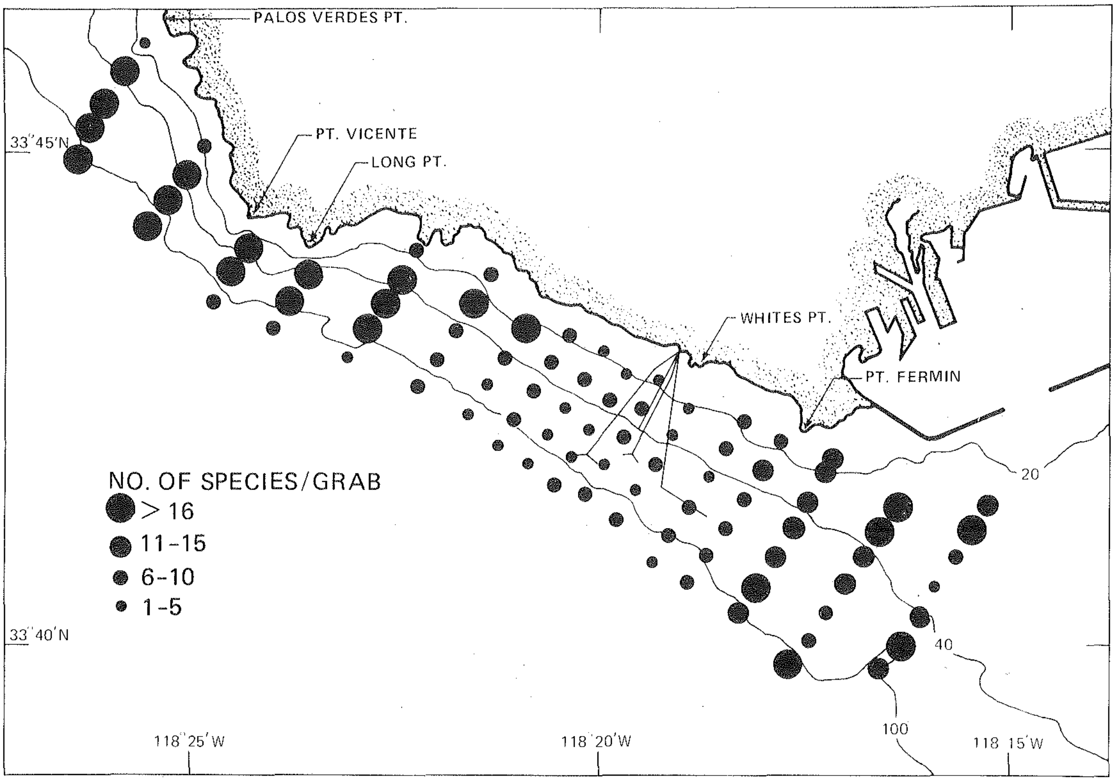
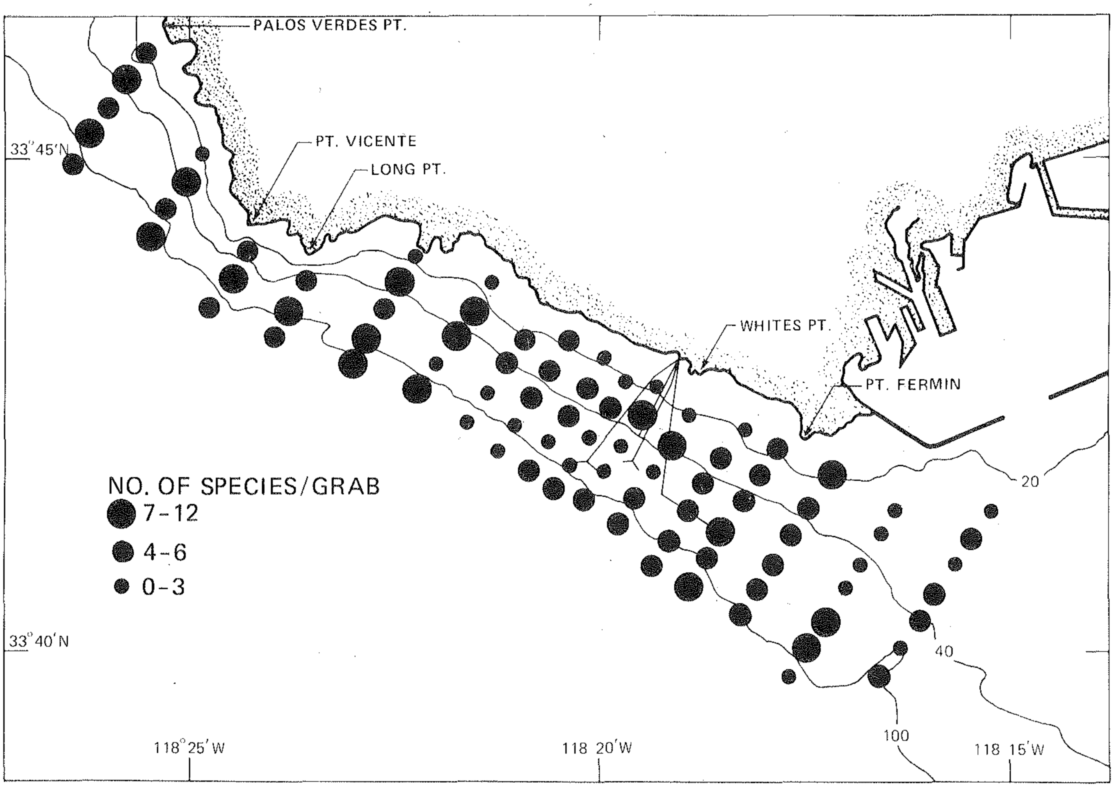
3. The two scaled indices were not calculated at some stations, including the nearshore stations in the vicinity of the outfall, because of small sample size.

Table 8-13
DIVERSITY IN BENTHIC SAMPLES COLLECTED OFF SANTA BARBARA, 1957-58

	Shannon-Weaver Function (H')					Scaled Shannon-Weaver Function (H'_s)				
Sample No.	Poly-chaetes	Molluscs	Crusta-ceans	Echino-derms	Total Fauna	Poly-chaetes	Molluscs	Crusta-ceans	Echino-derms	Total Fauna
1	3.18	2.34	2.69	0.62	3.88	0.80	0.73	0.72	0.33	0.79
2	3.08	2.21	2.48	0.30	3.14	0.79	0.58	0.72	0.14	0.61
3	2.74	1.85	2.37	0.55	3.66	0.69	0.77	0.63	0.36	0.77
4	2.35	1.69	1.84	0.46	3.22	0.69	0.77	0.69	0.15	0.77
5	2.57	2.09	1.70	0.20	3.24	0.74	0.70	0.64	0.00	0.75
6	2.61	2.24	2.15	0.19	3.40	0.66	0.75	0.72	0.13	0.74
Mean	2.76	2.07	2.21	0.39	3.42	0.73	0.72	0.69	0.19	0.74
Std. Deviation	0.32	0.25	0.38	0.18	0.29	0.06	0.07	0.04	0.14	0.07

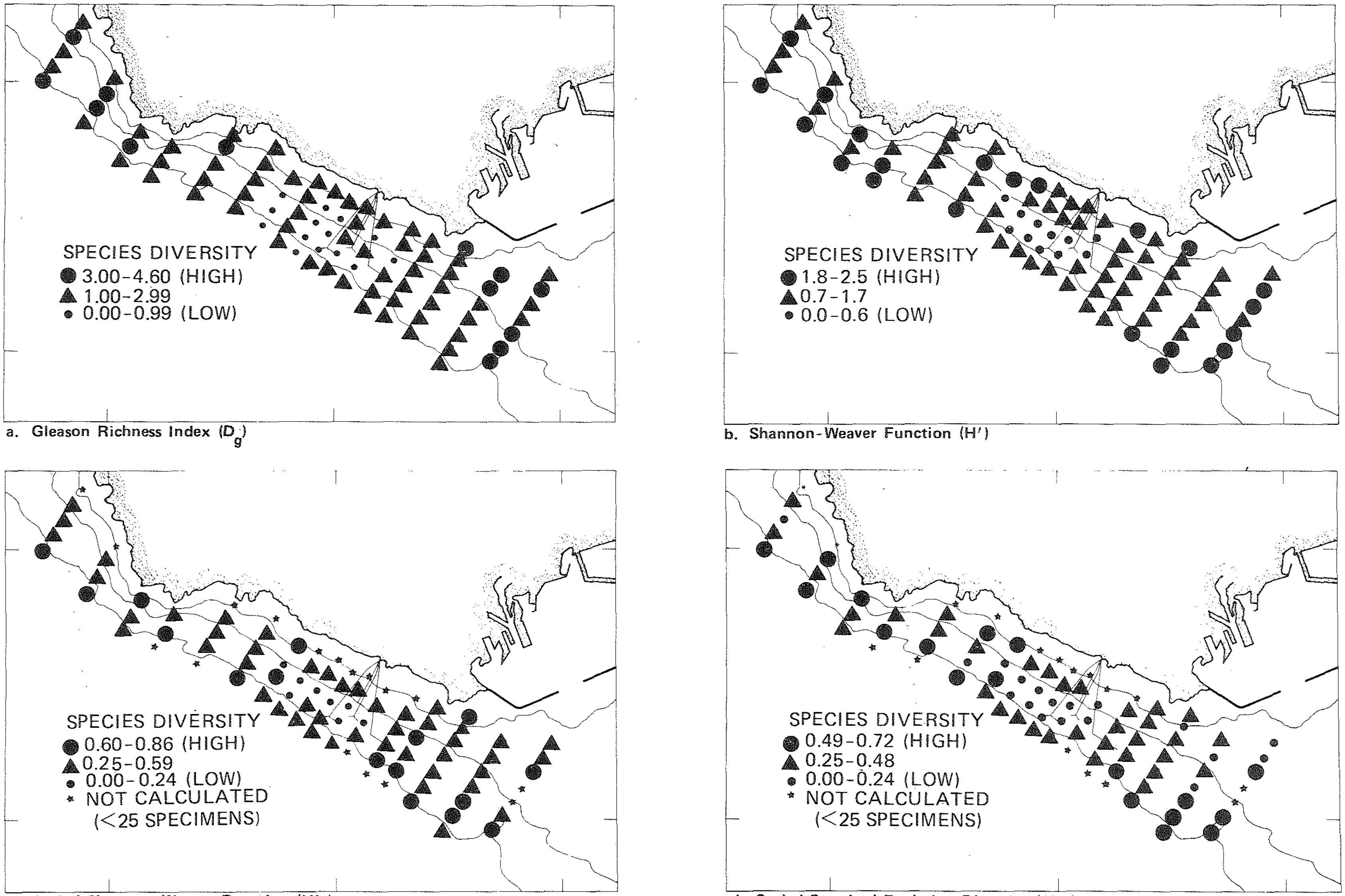


a. Polychaetes



b. Moluscs

Fig. 8-13. Species Diversity of Polychaetes and Molluscs Off Palos Verdes, July 1971.



a. Gleason Richness Index (D_g)

b. Shannon-Weaver Function (H′)

c. Scaled Shannon-Weaver Function (H′s)

d. Scaled Standard Deviation Diversity (SD_s)

Fig. 8-14. Four Analyses of Polychaete Species Diversity Off Palos Verdes, July 1971.

Table 8-14
MEAN DIVERSITY INDICES CALCULATED FROM SINGLE SAMPLES
COLLECTED IN FEBRUARY-MARCH AND JULY 1971

Sampling Period	Diversity Index D_g	H'	H'_s	SD_s
FEBRUARY AND MARCH (4 samples from each of 9 stations)				
Mean	1.71	1.24	0.46	0.36
Std. Deviation	(0.74)	(0.39)	(0.17)	(0.17)
JULY (1 sample from each of 9 stations)				
Mean	1.77	1.19	0.42	0.34
Std. Deviation	(0.60)	(0.43)	(0.16)	((0.16)

Because of the tendency of organisms to form clumped or aggregated distributions, and the resulting variability of abundance measurements for a species at a site, diversity values calculated from single samples such as benthic grabs would be expected to differ from the "true" diversity (i.e., the diversity of an infinitely large sample). The precise nature of this divergence will depend on the specific index (Fager 1972). However, diversity values for single samples from a large number of stations will probably give a good indication of the actual diversity patterns for an area. Ideally, replicate samples for a single station or area would be successively pooled together, and diversity plotted as a function of the number of pooled samples. The asymptotic value reached by this plot may be taken as the best estimate of the true diversity for the sampling location (Pielou 1966).

The similarity of distributional patterns for a number of physical and chemical environmental factors makes it difficult to identify the factors that are having the greatest influence on species diversity. The distributions of metals and pesticides around the Whites Point outfall (Chapter 6) show generally higher concentrations in the area in which polychaete species diversity was lowest. This area is also characterized by blackened sediments and relatively higher sulfide. The presence of rich organic deposits also might be expected to inhibit the larval settlement of some species and the survival of forms living on top of the sediments. Any of these potentially toxic factors could contribute to a lower diversity.

Even without toxic substances, high amounts of organic matter from the outfall would be expected to decrease diversity by permitting opportunistic detrital feeders to increase in numbers.

The possible effect of predation by fish on the polychaete diversity in this area has not as yet been investigated and may be of a complex nature. Both competition and predation can have major effects on diversity (Paine 1971; Paine and Vadas 1969), and both factors may be directly or indirectly affected by waste discharge.

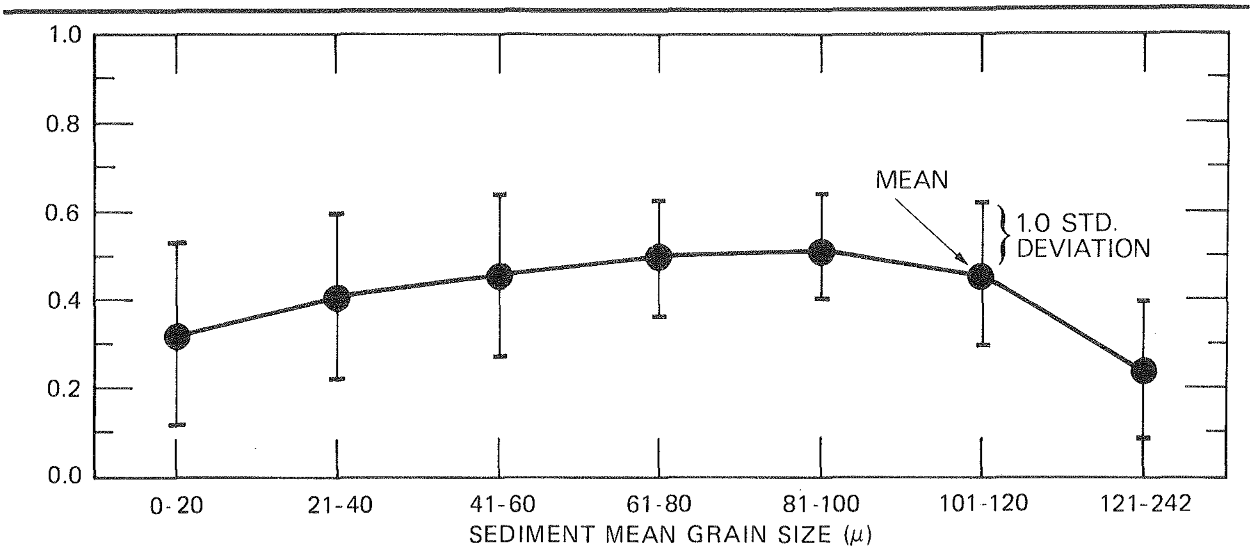
Sediment coarseness is known to be an important factor influencing the distribution of benthic organisms. To determine the possible effect of this factor on species diversity, the scaled standard deviation diversity (SD_s) was calculated for data from a study by Reish (1963) and Barnard (1962) for Bahia de San Quintin, a bay in Baja California that is relatively undisturbed with respect to man. Diversity of polychaetes (SD_s index) was plotted as a function of sediment type as designated by two different methods of sediment classification. The results are given in Figure 8-15, along with a similar analysis of Whites Point data from July 1971. From the Bahia de San Quintin data, it appears that there is some relationship between sediment type and species diversity. Although the specific relationship was influenced by the method of sediment classification, both types of sediment analyses showed the finest sediments to be associated with low diversity. On the Palos Verdes shelf, however, the relationship between sediment coarseness and species diversity was not clear: The areas in which sediments with black surfaces were found--also probably the areas of finest sediments--had lowest diversity; but, when only light sediment areas were considered, no relationship between sediment coarseness and diversity could be observed. This may indicate that the normal sediment/diversity relationships have been obscured by other, possibly outfall-related, factors.

8.3.4 Benthic Community Stress and Recovery Characterstics

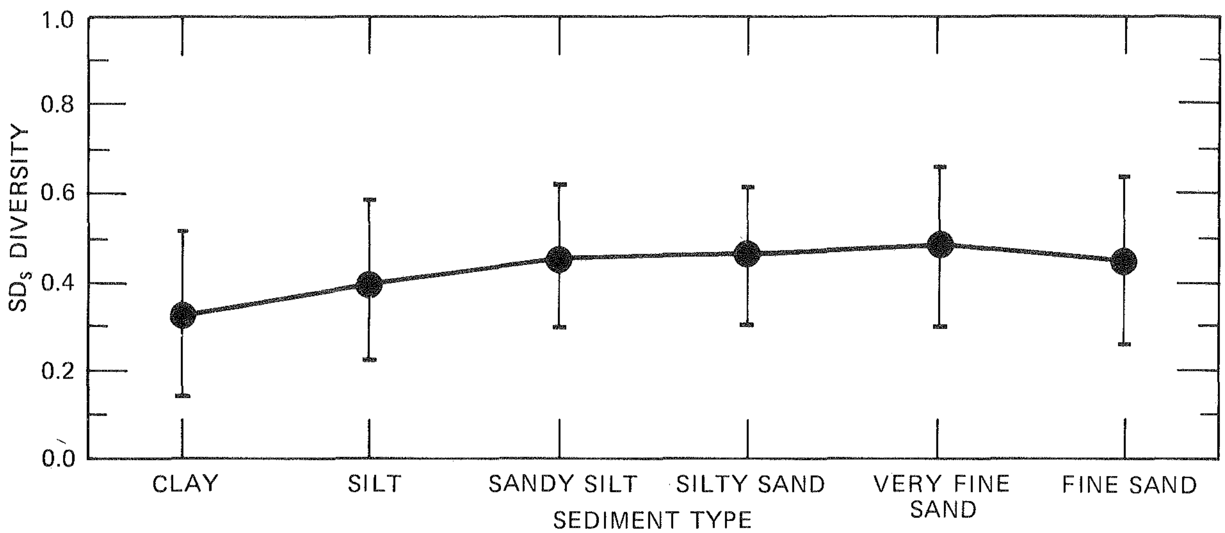
On 31 March 1971, a 120-inch diameter, 5-mile outfall system was put into operation by the County Sanitation Districts of Orange County; at the same time, the 130-mgd wastewater discharge through the old 1-mile outfall was terminated. This relocation of a major wastewater discharge provided the opportunity to study the response of a benthic community to a major and abrupt change in environmental conditions.

Sampling and Analysis Methodology

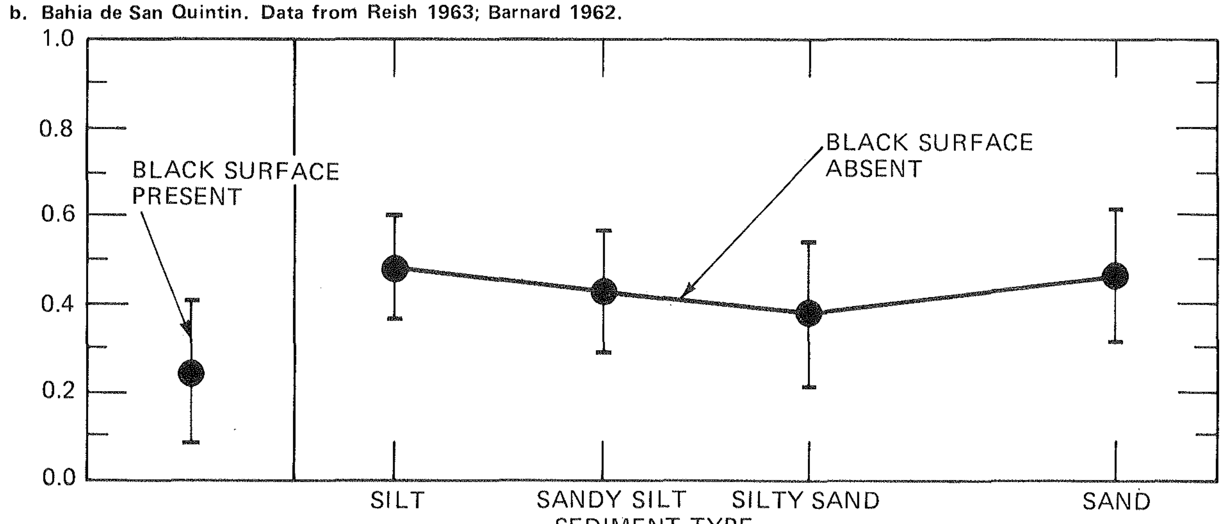
Nine months prior to the change in wastewater discharge location, a monthly sampling program was established at six stations in the old and new discharge areas and at two reference stations out of the discharge areas. After the changeover, the sampling frequency was reduced to once in 2 or 3 months. Figure 8-2 shows the locations of the sampling stations. Three stations, S1, S2, and S3, were located 0.4, 0.8, and 1.6 km southeast of the end of the old outfall diffuser; the water depth at these stations was 18 meters, and the stations were located approximately 2.1 km offshore in a silty-sand sediment. The reference station for these three stations (Station S4) was located off Oceanside at a depth of 18 meters and at a location with similar sediment characteristics. Stations D1, D2 and D3 were located 0.4, 0.8, and 1.6 km southeast of the new outfall at a depth of 58 meters; these stations were approximately 7 km offshore in a sandy-silt sediment. The reference station for these stations (Station D4) was located 18 km offshore, approximately 13.7 km east of the new outfall at a depth of 58 meters. Station D4 was 0.8 km offshore. During each sampling



a. Bahia de San Quintin. Data from Reish 1963; Barnard 1962.



b. Bahia de San Quintin. Data from Reish 1963; Barnard 1962.



c. Whites Point, July 1971.

Fig. 8-15. Relationship Between Sediment Characteristics and Polychaete Species Diversity as Measured by Scaled Standard Deviation Diversity (SD_S).

survey, five benthic samples were taken, four for benthic invertebrate analysis and one for analysis of sediment characteristics. Benthic samples were taken with a modified 0.1-sq-m Van Veen bottom grab, improved to reduce blasting effects by cutting out and screening the upper clam surfaces. The grab was weighted to increase bottom penetration, and it consistently collected 5- to 10-liter sediment samples. The samples were washed through a 0.5-mm screen and preserved in buffered formalin.

Samples for sediment analysis were taken from the surface of the grab samples. Sediment samples were analyzed for organic carbon, acid-volatile sulfides, and size spectrum. (Because this program is still in progress, only preliminary data and analyses are available.)

Results

Table 8-15 summarizes the sediment and water quality data taken at Stations S1 (0.4 km from the old outfall) and D1 (0.4 km from the new outfall) between August 1970 and October 1971, both before and after the changeover. Near the old outfall, the differences in mean characteristics before and after the changeover are all statistically significant at a 90 percent or higher confidence level. This is particularly true of sediment sulfide, which decreased from 1.3 to 0.05 mg/dry g. The organic carbon content of the sediment decreased from 0.98 to 0.27 percent. Suspended solids in the bottom waters dropped from 9.2 to 4.0 mg/L, and the Secchi disk depth increased from 4.7 to 7.7 meters.

At Station D1, near the new outfall, no significant changes in any of the sediment or water quality parameters were noted during the 16 months of postdischarge observation.

Table 8-16 summarizes preliminary observations of benthic community characteristics at Station S1, nearest the old outfall; the values are based on six samples taken before the termination of discharge and ten samples taken after the switchover. The total benthic invertebrate density decreased from 16,000 to 10,000 organisms/sq m following termination of the discharge. In this same period, the total number of species per sample increased from 65 to 84. Species diversity, as measured by the Shannon-Weaver function (unscaled, H', and scaled, H'_s), increased. Density of crustaceans increased from 1,100 to 1,700 organisms/sq m, and crustacean species increased from 14 to 21 species per sample. Polychaete species per sample increased from 32 to 40; the number of capitellids decreased from 22 to 13 percent of the total polychaete fauna. Another marked change observed in the period after termination of the old discharge was the decrease in the dominance of a few species in the samples. Table 8-17 shows the 16 species that were most abundant before and after discharge termination, ranked in order of relative abundance, as well as the proportion of the total population represented by each species. During the discharge period, the 16 species most abundant accounted for 82 percent of the total invertebrate population. However, after termination of the discharge, the most abundant species accounted for only 66 percent of the total population.

There were also major changes in the species composition before and after termination of the discharge. The polychaete, *Capitella capitata*, was the second most abundant species before termination of the discharge, but did not appear

Table 8-15
SEDIMENT AND WATER CHARACTERISTICS NEAR THE ORANGE COUNTY OUTFALLS
BEFORE AND AFTER CHANGE OF DISCHARGE LOCATION (APRIL 1971)

Sampling Location	Characteristic	Unit	Number of Samples (Before/After)	Mean (95% Confidence Interval) Before	Mean (95% Confidence Interval) After	Statistical Significance of Difference in Means
Station S1 (Old Outfall)	Sediment:					
	Hydrogen sulfide	$mgS^{=}/g$	14/10	1.30 (0.72-1.88)	0.05 (0.01-0.09)	>99.8%
	Organic carbon	%	14/6	0.98 (0.57-1.39)	0.27 (0.23-0.31)	>95%
	Water:					
	Suspended solids (bottom water)	mg/L	12/10	9.2 (4.7-13.7)	4.0 (3.1-6.9)	>90%
	Transparency (Secchi disk)	m	6/5	4.7 (2.0-7.4)	7.7 (6.0-9.4)	>90%
Station D1 (New Outfall)	Sediment:					
	Hydrogen sulfide	$mgS^{=}/g$	12/10	0.07 (0.01-0.13)	0.02 (0.01-0.03)	>95%
	Organic carbon	%	14/6	0.64 (0.52-0.76)	0.70 (0.41-0.99)	-
	Water:					
	Suspended solids (bottom water)	mg/L	12/10	2.6 (0.6-4.6)	2.2 (0.9-3.5)	-
	Transparency (Secchi disk	m	6/5	12.8 (4.7-20.9)	14.9 (11.0-18.8)	-

Table 8-16
BENTHIC COMMUNITY CHARACTERISTICS NEAR THE OLD ORANGE COUNTY OUTFALL (STATION S1) BEFORE AND AFTER TERMINATION OF DISCHARGE (APRIL 1971)

	Mean (95% Confidence Limits)	
Characteristic	Before	After
Total individuals/sq m	15,590 (7,160-24,020)	9860 (8,200-11,520)
Total species/sample	65.2 (52.9-77.5)	82.4 (77.2-87.6)
Crustaceans		
Individuals/sq m	1095 (85-2,105)	1695 (590-2,800)
Species/sample	14.0 (9.2-18.8)	21.3 (19.9-22.7)
Polychaetes		
Species/sample	32.2 (26.0-38.8)	39.6 (35.9-42.3)
Species Diversity		
H'	2.716 (2.486-2.946)	3.256 (2.927-3.585)
H'_s	0.622 (0.564-0.680)	0.723 (0.687-0.759)

in the list of 16 species most abundant after discharge termination. Two other polychaetes, *Armandia bioculata* and *Stauronereis rudolphi*, and the clam, *P. tenuisculpta*, also dropped in abundance. The brittle star, *Amphiodia urtica*, was not in the list of 16 species before discharge termination, but was the fourth-ranking species in abundance after the discharge terminated.

Table 8-18 presents a summary of the characteristics of the benthic macrofauna at Station D1, nearest the new outfall. At this station, all of the parameters except species diversity increased after discharge was initiated. The total population density more than doubled, and the number of species per sample increased from 90 to 100. The number of polychaete species per sample, however, remained nearly constant, and total community diversity decreased.

Table 8-19 shows the species that were most abundant at Station D1 before and after initiation of the discharge, ranked in order of relative abundance. Before the discharge, the most abundant species represented 70 percent of the total number of individuals. This proportion increased to 74 percent in the period after discharge. Most species changed in relative abundance. In the predischarge period, *Capitita ambiseta* accounted for 4.3 percent of the total individuals; in the postdischarge period, however, this species was the most abundant and accounted for more than one-quarter of the total number of individuals.

Table 8-17
RELATIVE SPECIES ABUNDANCE AT OLD ORANGE COUNTY OUTFALL (STATION S1)
BEFORE AND AFTER TERMINATION OF DISCHARGE (APRIL 1971)

Before			After		
Rank	Species	P*	Rank	Species	P*
1	*Armandia bioculata* (P)*	0.176	1	*Capitita ambiseta* (P)	0.127
2	*Capitita ambiseta* (P)	0.114	2	*Prionospio pygmaeus* (P)	0.100
3	*Capitella capitata* (P)	0.111	3	*Tharyx tesselata* (P)	0.057
4	Juvenile polychaetes	0.071	4	*Amphiodia urtica* (O)	0.056
5	Sipunculids	0.067	5	*Chaetonzone corona* (P)	0.048
6	*Stauronereis rudolphi* (P)	0.043	6	Juvenile polychaetes	0.047
7	*Parvilucina* sp. (M)	0.034	7	*Nereis procera* (P)	0.046
8	*Ctenodrillus serratus* (P)	0.031	8	*Tellina* sp. (M)	0.030
9	*Eulalia aviculiseta* (P)	0.029	9	*Asterope* sp. (C)	0.026
10	*Prionospio pygmaeus* (P)	0.027	10	*Olivella baetica* (M)	0.023
11	*Tharyx tesselata* (P)	0.027	11	*Argissa hamatipes* (C)	0.020
12	*Photis* spp. (C)	0.021	12	*Ctenodrillus serratus* (P)	0.020
13	Nematodes	0.021	13	*Photis* spp. (C)	0.018
14	*Asterope* sp. (C)	0.018	14	*Edotea sublittoralis* (C)	0.015
15	*Tellina* sp. (M)	0.016	15	*Munna ubiquita* (C)	0.014
16	*Anaitides longipes* (P)	0.013	16	*Ampelisca* spp. (C)	0.013
		0.819			0.660

*Proportion of mean total individuals/sq m.
**Symbols: P = polychaete, M = mollusc, C = crustacean, O = ophiuroid.

8.4 DISEASE AND ABNORMALITIES IN BENTHIC ORGANISMS

Stress of almost any form—acting at the appropriate time in the life history of an organism—can cause abnormalities. Individual organisms may vary in their genetic tolerance to stress (or may have previously acquired tolerance through exposure), and the result is a certain frequency distribution for a given syndrome in a population. This frequency distribution may be a characteristic of a particular level of stress. In the SCCWRP program, major emphasis has been placed on studies of disease, parasitism, and abnormalities in benthic fish rather than on those in benthic invertebrates. However, review of the literature and observations made during the program's sampling surveys have identified certain conditions that should be further investigated.

8.4.1 Anomalies in Benthic Algea

There has been a great deal of discussion and public concern in recent years over the condition of the giant kelp, *Macrocystus*, and an elk kelp, *Pelagophycus porra*. Problems that have been identified include growths on the kelp, wart-like enlargements, and severe fluctuations in density.

Table 8-18
BENTHIC COMMUNITY CHARACTERISTICS NEAR THE NEW ORANGE COUNTY OUTFALL (STATION D-1) BEFORE AND AFTER INITIATION OF DISCHARGE (APRIL 1971)

	Mean (95% Confidence Limits)	
Characteristic	Before	After
Total individuals/sq m	7,010 (5,580-8,440)	14,700 (9,510-19,890)
Total species/sample	89.9 (80.5-99.3)	100.6 (96.0-105.2)
Crustaceans		
Individuals/sq m	1,005 (665-1345)	2,325 (1610-3040)
Species/sample	25.3 (21.8-32.3)	31.0 (28.7-33.3)
Polychaetes		
Species/sample	40.3 (35.7-44.9)	41.6 (38.8-44.4)
Diversity		
H'	3.508 (3.368-3.648)	3.257 (3.023-3.591)
H'_s	0.729 (0.701-0.757)	0.669 (0.626-0.712)

Many species of benthic algae have either disappeared or declined greatly in abundance in the southern California coastal waters (Allan Hancock Foundation 1965; Nicholson and Cimberg 1971; Widdowson 1971). Although disease has been known to cause mass die-offs in European and East Coast eel grass, such wasting diseases have not been recorded in the Southern California Bight.

Several investigators have attributed the loss of some intertidal algae species and the decreasing abundance of others to factors such as air pollution, thermal, municipal, and industrial wastewater discharges, and oil pollution, as well as to direct mechanical damage resulting from human recreational activities in the intertidal zone. It is also possible that wastewater discharges may decrease the clarity in a local area, thereby reducing the amount of light available for photosynthesis of submerged plants, including the young of emergent adults.

It has been well document that long periods of warm waters caused extensive die-offs in subtidal kelp beds along the southern California coast between 1957 and 1960. The major kelp growth now occurring off central California may be caused by a complex set of factors, including the repopulation by sea otters,

Table 8-19
RELATIVE SPECIES ABUNDANCE AT NEW ORANGE COUNTY OUTFALL (STATION D-1)
BEFORE AND AFTER INITIATION OF DISCHARGE (APRIL 1971)

Before			After		
Rank	Species	P*	Rank	Species	P*
1	*Lumbrinereis* spp. (P)**	0.110	1	*Capitita ambiseta* (P)	0.257
2	*Prionospio pygmaeus* (P)	0.105	2	*Amphiodia urtica* (O)	0.069
3	*Axinopsida serricata* (M)	0.068	3	*Axinopsida serricata* (M)	0.053
4	*Amphiodia urtica* (O)	0.067	4	*Lumbrinereis* spp. (P)	0.051
5	*Tharyx tesselata* (P)	0.055	5	*Leptostylis* sp. (C)	0.045
6	*Parvilucina* sp. (M)	0.054	6	*Parvilucina* sp. (M)	0.042
7	*Capitita ambiseta* (P)	0.043	7	*Tharyx tesselata* (P)	0.034
8	*Glycera capitata* (P)	0.030	8	Juvenile polychaetes	0.032
9	*Leptostylis* sp. (C)	0.030	9	*Prionospio pygmaeus* (P)	0.029
10	*Aricidea neosuecia* (P)	0.023	10	Nematodes	0.024
11	*Spiophanes missionensis* (P)	0.020	11	*Pectinaria californiensis* (P)	0.021
12	Juvenile polychaetes	0.020	12	*Photis* spp. (C)	0.021
13	Nematodes	0.020	13	*Glycera capitata* (P)	0.019
14	*Ctenodrillus serratus* (P)	0.018	14	*Aricidea neosuecia* (P)	0.018
15	Ostracod sp. (C)	0.016	15	*Exogone uniformis* ( )	0.014
16	*Sthenelanella uniformis* (P)	0.016	16	*Ampelisca* spp. (C)	0.012
		69.900			74.100

*Proportion of mean total individuals/sq m.
**Symbols: P = polychaete, M = mollusc, C = crustacean, O = ophiuroid.

which feed on sea urchins, which in turn eat kelp. North and Hubbs (1968) discuss other invertebrate and fish predators of kelp. North has found that fishes can decimate kelp transplants long before a self-sustaining bed can be established.

Wastewater discharges have been implicated in the disappearance of the kelp. Based on experience gained at Point Loma, it does not seem likely that wastewater discharges, when reasonably diluted, inhibit kelp growth. At Point Loma, kelp has continued to recover following the return of colder waters in 1960, in spite of the fact that a major waste discharge was initiated in the area in 1962. Control of the sea urchin population may well have been a factor in the recovery of the kelp. It is possible that wastewaters have an indirect effect on kelp survival in that organics in wastewaters can provide up to 50 percent of the energy requirements of sea urchins, allowing them to maintain themselves in barren environments (Pearse and Pearse 1971). Studies of urchins have been a prime focus of efforts to manage southern California kelp beds. Because they have been shown to be able to decimate some kelp beds, because their normal predators (sea otters and sheepshead) are absent from many areas at present, and because they may utilize wastewaters nutritionally in the absence of the normal algal diet, the population dynamics of urchins may be considerably altered. The absence of natural controls on herbivores would be expected to

result in large fluctuations in the abundance of both the kelp and herbivore populations. Recently, scuba divers attempted to redress this imbalance off Palos Verdes with hammers, decimating hundreds of thousands of urchins in a single weekend. The future growth and survival of transplanted and naturally settled kelp in the area will be the measure of the effectiveness of this procedure.

A sea urchin fishery has recently been established in southern California. Preliminary figures show a total catch of over 70,000 pounds in 1972.[4] The substitution of man for the diminished natural predators may bring the urchin population under control.

As elsewhere, many complex factors affect the recruitment, establishment, and successful growth of algae in southern California waters. The loss of certain algal species from the intertidal zone or of an entire subtidal kelp bed will cause a concommitant loss of many other organisms that are directly or indirectly dependent on this resource for food, shelter, or substrate. This loss may be of some consequence: Kelp has never become reestablished off Palos Verdes since its demise in the late 1950's, even though transplanted plants have been shown to be able to grow and reproduce in the area.

8.4.2 Exoskeletal Lesions in Crabs

Specimens of *Mursia gaudichaudii* and *Cancer* species exhibiting exoskeletal lesions have been collected during trawls off Palos Verdes, in Santa Monica Bay, and off Newport Beach during late 1971 and spring 1972. These lesions appear to resemble the "burn-spot disease" reported in the edible European crab, *Cancer pagurus*, by Gordon (Sindermann and Rosenfield 1970). The gross pathology of this disease consists of black spots in which the exoskeleton affected becomes friable and may be destroyed.

Sindermann and Rosenfield (1967) have concluded that, because the erosion syndrome occurs in all types of aquatic environments and in all temperature regimes, more than one disease etiology may be involved. Some work has been done in identifying associated microorganisms; however, the primary causative agents and modes of infection of these diseases have not been determined. On the basis of studies of caged species, Sindermann and Rosenfield concluded that the lesions appear to be contagious and may at times be eliminated through moulting.

Population density may also be a factor. An infectious disease will be spread more rapidly in a crowded community; in addition, under conditions of crowding, male crabs will fight more frequently, with a consequent increase in exoskeletal damage.

The National Marine Fisheries Service (1972) reported necrotic lesions on the exoskeleton of a dead specimen of *Cancer irroratus* captured in the sludge disposal area of the New York Bight. Similar lesions developed on *C. irroratus* and *Homerus americanus* (American lobster) 6 weeks after they were placed in

4. L. Pinkas, California Department of Fish and Game, Long Beach, California, personal communication.

well-aerated aquaria containing two inches of sediments from either the sludge disposal or dredge spoil areas of the Bight (Pearce 1970). The etiology of these lesions is at present unknown, although an infectious agent has been suggested.

Incidence of a similar anomaly was recorded (1) during the October 1971 trawls conducted by County Sanitation Districts of Los Angeles County and (2) in the December 1971 trawl by Marine Biological Consultants for the County Sanitation Districts of Orange County, and the May-June 1972 trawling surveys off Palos Verdes and in Santa Monica Bay. The occurrence of lesions in *M. gaudichaudii* in late 1971 ranged from 0 to 70 percent. No diseased individuals were observed in samples collected during night trawls. Sample sizes during these collections were small, however--only 1 to 20 specimens were collected. Off Newport Beach, one out of a total of three *M. gaudichaudii* was affected. The May and June 1972 trawls extended the known range of *M. gaudichaudii* with exoskeletal lesions along the 450-foot contour in Santa Monica Bay and on the Palos Verdes shelf. Of 180 individuals collected at the Palos Verdes stations, 15 were affected with the disease. In Santa Monica Bay, 12 of 27 individuals were affected. There is some evidence that the disease is localized near the heads of the submarine canyons. Although the data are limited, they indicate that, near the heads of the canyons, lesions occur on small crabs and, in areas away from the canyons, it is the larger crabs that are affected; this suggests that the crabs may contract the disease near the canyons and then migrate to other areas and infect other crabs. Further studies of this phenomenon are in progress.

Little is known of disease in invertebrates, and further studies are needed to determine if disease syndromes are related to waste discharges. The limited evidence available does not indicate that this is the case. Chapter 7 discusses the intricacies of studies of this nature in fish populations; invertebrate studies are likely to be as complex.

8.4.3 Abnormalities and Disease in Sea Urchins

Johnson (1971a and b) studied unhealthy appearing urchins (*Strongylocentrotus purpuratus* and *S. franciscanus*) from Whites Point and compared these with apparently normal specimens from La Jolla and Papalote Bay, Baja California. The La Jolla urchins were collected in kelp areas and were well fed. The collection areas in Papalote Bay and at Whites Point, on the other hand, were relatively barren environments, devoid of kelp.

The abnormalities exhibited by the Whites Point urchins were listed as (1) spine loss, (2) gonadal atrophy, and (3) aberrations in the hemal axial gland and water vascular systems. Johnson speculated that these conditions were due to stress from suboptimal, food-impoverished environmental conditions rather than microbial or parasitic infection. It is also possible that these conditions are related to the high levels of DDT (more than 200 ppb, mainly as DDE) in the urchin tissues (Moitoza 1971).

During 1969 and 1970, the proportion of unhealthy looking sea urchins at Whites Point was quite small, less than 1 percent. It has been reported that Whites Point urchins are reproductively active, the largest individuals being young adults, which are well nourished although they do not appear to feed on algae

(Pearse and Pearse 1970). The condition of these urchins contrasts with the stunted adult urchins found in Papalote Bay, an area devoid of kelp but not subjected to heavy wastewater discharge.

Despite the apparently favorable nutritional aspects of wastewater discharges, there may be other detrimental factors. In contrast to Johnson's report (1971a) of lack of evidence for microbial infection, Pearse et al. (1970) found extensive yeast-like fungal infections in large urchins at Whites Point. Similar infections were found in all populations sampled, but the highest incidences (74 to 85 percent) were at Whites Point, Corona del Mar, and Todos Santos Bay. Johnson (1971b) also reported evidence that an epizootic, possibly caused by a microorganism, was responsible for urchin tissue lesions and deaths off Point Loma in May 1970.

8.5 CHLORINATED HYDROCARBONS AND METALS AND BENTHIC INVERTEBRATES

8.5.1 Chlorinated Hydrocarbons — Review of Bioassay Literature

In recent years, there have been many investigations of the effects of chlorinated hydrocarbons, particularly the DDT compounds, on a wide variety of life forms. Table 8-20 summarizes the results of a number of the more recent studies made on marine and estuarine invertebrates. Most of these studies have focused on the effects of DDT, although there have been a few that have been concerned with polychlorinated biphenyls (PCB). Many of the studies have been relatively short-term bioassays to determine the acute toxic effects: Levels at which long-term, chronic, or subacute effects might occur would presumably be lower than the levels noted in the table.

Adverse effects can be detected when the seawater concentrations are as low as 0.01 ppb. This DDT concentration was shown to inhibit the development of copepod larvae. A concentration of DDT of 0.12 ppb killed 100 percent of test shrimp in 28 days. Chlorinated hydrocarbon concentrations in the interstitial waters of the sediments of the Bight have not yet been determined; thus, the bioassay studies reported in the literature provide only limited information for making a judgment as to the seriousness of the problem posed by the sediment concentrations of these materials. Some of the laboratory studies summarized in Table 8-20 indicate that DDT, when incorporated into food for certain shrimp and crab species, was toxic at levels between 2 and 10 ppm. When food containing 2 ppm DDT was fed to shrimp and blue crab, there was a 50 percent mortality for both species within 15 days. The dead shrimp contained 0.26 ppm DDT residue (based on whole body weight); the crabs had 0.93 ppm. Crab larvae fed naturally occurring brine shrimp containing 7 ppm DDT residues showed abnormal development; those raised on shrimp with 2.3 ppm developed normally (Bookhout and Costlow 1970). These concentrations are considerably lower than concentrations of DDT in the surface sediments around the Whites Point outfall, about the same as the highest concentrations found near the Hyperion outfalls, and higher than those found around the Orange County and Oxnard outfalls.

Studies on molluscs seem to indicate that they are much less sensitive to DDT than crustaceans. Engel, Neat, and Hillman (1970) noted an inhibition of enzyme activity of the quahog clam at 2 ppb in seawater, but the ecological significance of this response is unknown.

Table 8-20

CONCENTRATIONS OF DDT AND PCB HAVING LETHAL AND SUBLETHAL EFFECTS ON MARINE OR ESTUARINE INVERTEBRATES IN THE LABORATORY*

Concentration (ppb)	Response	Organism	Reference
DDT (in seawater)			
Lethal			
3.3-10	48-hr LC_{50}	European brown shrimp, *Crangon crangon*	Portmann 1970
1	48-hr LC_{50}	Sand shrimp, *Crangon septemspinosa*	Eisler 1969
5.1	48-hr LC_{50}	Grass shrimp, *Palaemonetes vulgaris*	Eisler 1969
6	48-hr LC_{50}	Hermit crab, *Pagurus longicarpus*	Eisler 1969
0.12	28-day LC_{100}	Shrimp sp.	Nat. Acad. Sci. 1971
0.25	No long-term mortality	Crab larvae, *Cancer magister* and *C. productus*	Poole & Odemar 1970
5	72-hr LC_{100}	Crab larvae, *Cancer magister* and *C. productus*	Poole & Odemar 1970
>10,000	48-hr LC_{50}	European cockle, *Cardium edule*	Portmann 1970
>10,000	96-hr LC_{50}	Quahog clams, *Mercenaria mercenaria*, & mud snails, *Nassa obsolete*	Eisler 1970
34	14-day LC_{50}	Oyster larvae, *Crassostrea virginica*	Davis & Hidu 1969
Sublethal			
0.01	Inhibition of development	Copepod larvae, *Pseudodiaptomus*	Nat. Acad. Sci. 1971
25	50% decrease in growth, 12 days	Oyster larvae, *Crassostrea virginica*	Davis & Hidu 1969
1	20% decrease in growth, 3-4 days	Oyster adults, *Crassostrea virginica*	Butler 1966
1000	90% decrease in growth, 3-4 days	Oyster adults, *Crassostrea virginica*	Butler 1966
2	Effect on glycolytic & gluconeogenic enzymes	Quahog clams	Engel et al. 1970
PCB (in seawater)			
Lethal			
300 - >10,000	48-hr LC_{50}	European brown shrimp	Portman 1970
3000 - >10,000	48-hr LC_{50}	European cockle	Portman 1970
100	48-hr LC_{100}	Juvenile pink shrimp	Duke et al. 1970
5	20-day LC_{72}	Juvenile pink shrimp	Duke et al. 1970
Sublethal			
1	20% decrease in shell growth	Oyster sp.	Duke et al. 1970
DDT (in food)**			
10,000	Behavioral changes, 11-days	Fiddler crab, *Uca pugnax*	Odum et al. 1969
7,000	Development abnormalities & lower survival	Larvae of 4 crab spp.	Bookhout & Costlow 1970
2,300	No effect	Larvae of 4 crab spp.	Bookhout & Costlow 1970
2,000	15-day LC_{50}	Brown shrimp, *Peneaus azetecus*, & blue crab, *Calinectes sapidus*	Butler 1969

*Most experiments conducted at natural temperatures and salinities.
**Total residues in detritus or prey.

The SCCWRP literature review revealed no studies relating the effects of chlorinated hydrocarbons in sediments on adult molluscs. However, because of the ability of these species to accumulate high body burdens of pesticides without showing apparent toxic effects, a high degree of tolerance is likely. This does not rule out the possibility of sublethal effects, such as inhibited reproduction. Butler (1966) has reported that oysters with a body burden of 25 ppm showed no observable adverse effects; however, 50 percent mortality occurred to fish and shrimp within 2 days when they were fed the oyster tissue.

The amount of information on the toxicity of PCB to marine invertebrates is very small compared with that on the effects of DDT. Portmann (1970) found that DDT was 100 times as toxic as PCB in acute toxicity tests using European brown shrimp. Oysters exposed to 1 ppb of PCB for 96 hours had a 20 percent decrease in shell growth and had acumulated 8.1 ppm in their tissues.

8.5.2 Chlorinated Hydrocarbons in Intertidal Organisms of the Bight

In the summer of 1971, SCCWRP began a survey of the levels of DDT and PCB in intertidal organisms. The intent was to survey one marine community with members that were widely distributed and could be collected easily from a large number of stations in sufficient quantities to provide a good overview of distributions of DDT and PCB in the biota throughout the Bight. Two species from the intertidal community appeared to best meet these criteria: The first, the coastal mussel, *Mytilus californianus*, is a phytoplankton filter feeder. The intertidal gooseneck barnacle, *Pollicipes polymerus*, is a sedentary crustacean that coexists with *M. californianus* and filter-feeds or actively grasps small zooplankters from the surf zone. Starfish specimens, *Pisaster* spp., of the phylum Echinodermata were also obtained from a few stations. These intertidal, carnivorous invertebrates feed both on *M. californianus* and *P. polymerus* and represent a higher step in the food chain.

The Bight-wide sampling program was conducted principally in summer 1971, when samples were collected from eleven sites between Gaviota Beach, north of Santa Barbara, and Point Loma. Six of the islands in the Bight were include in this survey; two northern California stations--Big Sur (south of Monterey) and Bodega Head (north of San Francisco)--were also sampled. In the fall, additional stations at Punta Banda (south of Ensenada, Baja California) and Point Sal and San Simeon (north of Point Cenception) were sampled.

The distribution of DDT in mussels (ppm or mg/wet kg) is shown in Figure 8-16. Highest concentrations of DDT, 4.0 and 4.2 ppm, were observed at two stations on the Palos Verdes Peninsula. From this high point, there was a general decline, both to the north and to the south. DDT concentrations at Bodega Bay and at Punta Banda were less than 0.04 ppm, two orders of magnitude less than the values found at Palos Verdes. Concentrations at most of the islands were between 0.04 and 0.08 ppm; the concentration in samples from Santa Barbara Island was 0.28 ppm.

Burnett (1971) found similar DDT distributions for an intertidal sand crab (a small filter feeder used for fish bait and important prey for some surf fish) collected between northern California and Baja California. In this study, highest concentrations (approximately 6 ppm, wet weight--2 ppm above the Federal

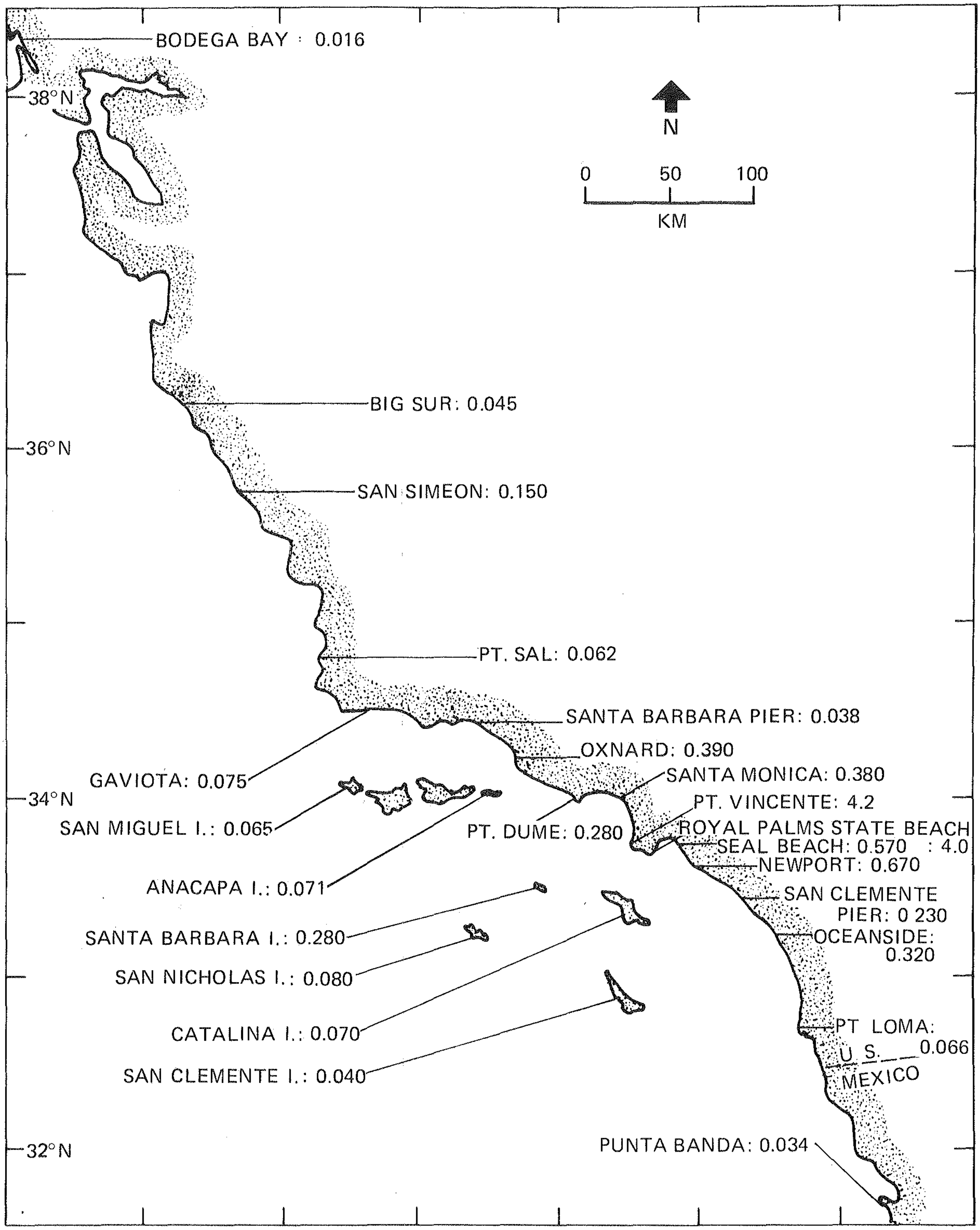


Fig. 8-16. Concentrations (ppm wet wt.) of Total DDT in Whole Soft Tissues of *Mytilus Californianus,* 1971.

limit for human food) were observed at Palos Verdes and at nearby stations. These values were an order of magnitude above those for samples from Ventura and Orange Counties, and two orders of magnitude greater than values from central California and San Diego.

SCCWRP measured wet weight concentrations of a PCB (Arochlor 1954) in the whole soft tissues of *M. californianus* collected in summer and fall 1971. The results of these analyses are shown in Figure 8-17. PCB levels in the coastal areas well away from urban centers were in the order of 0.015 to 0.025 ppm. The two highest concentrations, 0.38 and 0.53, occurred off Palos Verdes. As was the case with DDT, the highest value observed on the islands was at Santa Barbara Island.

The Montrose Chemical Company is the world's major producer of DDT. Prior to 1970, the company discharged processed wastes into the wastewater collection system of the County Sanitation Districts of Los Angeles County. At the time of the termination of this discharge, it is estimated that the discharge of DDT compounds through the Whites Point outfall exceeded 100 M tons/yr. As a basis for comparison, it has been estimated that, in 1965, the total DDT discharge through the San Francisco Bay Delta system, which drains a major portion of the agricultural lands in central California, was between 2 and 4 M tons/yr. The major discharge of DDT through the Whites Point outfall system undoubtedly caused the abnormally high concentrations observed in both the intertidal organisms, fish, and sediments of the area.

The concentrations of PCB in mussels collected near the Whites Point outfalls were approximately four times higher than those in specimens taken at Point Loma near the San Diego outfall. The collection points for both of these sets of samples were approximately the same distance (3 km) from the corresponding outfall terminus. However, as shown in Table 4-9, the mass emission rate of PCB from the Whites Point outfalls in 1971 was estimated to be approximately 50 times greater than the mass emission rate from the San Diego outfall.

Although current sources of DDT have been considerably curtailed, the PCB input is much more diffuse and difficult to control. PCB is not a pesticide and has not received the attention directed to DDT and its congeners. Although the few studies to date indicate that PCB is much less toxic than DDT, more studies are needed because of the persistent nature of one form and the widespread use of PCB. Other organics may also have important effects on marine ecosystems. Much more effort is needed to identify important compounds and effects in the environment. In particular, there is a need for studies on the effects of man-made compounds on the successful development of marine organisms in their most sensitive larval stages.

8.5.3 Trace Metals — Review of Bioassay Literature

A large number of metals enter the Bight through wastewater discharges, surface runoff, aerial fallout, and other sources. Any metal is toxic to biota at a sufficiently high concentration. Many organisms will concentrate certain metals well above the levels found in the surrounding environment.

Tables 8-21 and 8-22 provide a summary of some laboratory studies on the toxicities of certain metals to marine and estuarine organisms. Table 8-21 shows

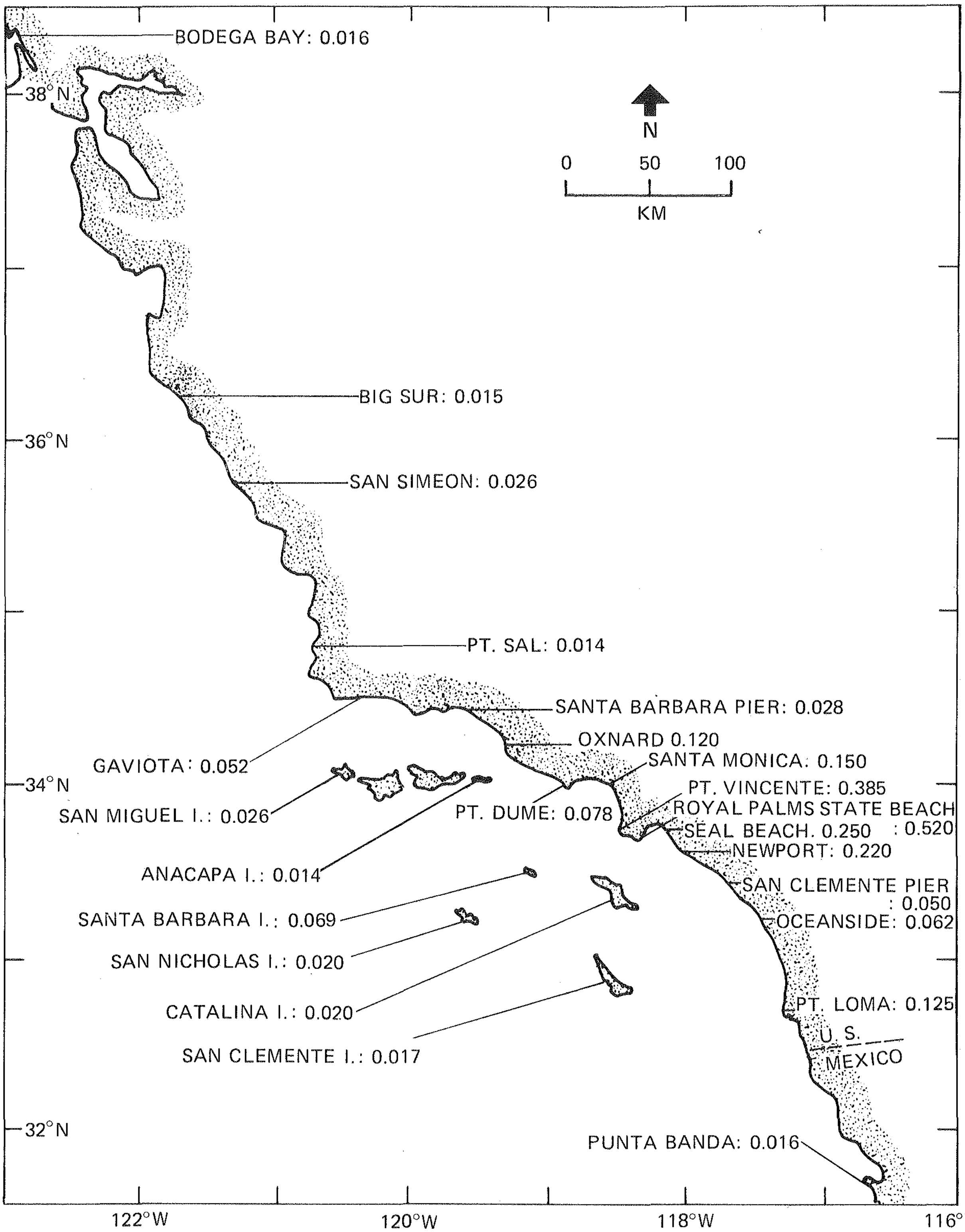


Fig. 8-17. Concentrations (ppm wet wt.) of Arochlor 1254 in Whole Soft Tissues of *Mytilus Californianus*, 1971.

the concentrations of several metals corresponding to various biological responses. The table shows that there are large differences in toxicity between the various levels. For example, mercury was about 100 times as toxic as zinc and three times as toxic as copper in causing abnormal development of oyster embryos. Of the metals listed in this table, silver is generally the most toxic, followed by mercury, copper, zinc, chromium, nickel, iron, and manganese in that order. However, this ranking is by no means invariant: The relative toxicities of metals will depend upon the species tested, the response measure chosen, and the state of the metal.

Table 8-22 summarizes the results of a number of studies of the concentrations of ten metals in seawater associated with lethal and sublethal responses in marine and estuarine invertebrates. Most of these studies were short-term, acute toxicity bioassays. Little information is available concerning chronic and sublethal responses. The results of almost all such bioassays are strongly influenced by temperature, salinity, dissolved oxygen, pH, and other factors. Lack of standardization in measuring these factors, as well as inherent variability in the test organisms, contributes to the wide variability in reported toxicity measurements.

Some marine invertebrate species show sublethal or avoidance responses to toxicant concentrations well below those causing mortality. Portmann (1970) found that adult European brown shrimp showed an avoidance to dissolved copper at 0.33 to 0.5 ppm when the 48-hour median lethal concentration was between 10 and 33 ppm. Further studies are needed to determine the significant of these observations. Laboratory concentrations tested are often well above those that might be encountered in the environment.

To date, no studies on metal concentrations in the interstitial waters of the sediments of the Bight have been reported. As a consequence, it is not possible to judge (by comparison with published bioassay results) whether or not benthic fauna are being directly affected by metal toxicity. There have also been no studies to date on metal concentrations in polychaetes or other benthic invertebrates in areas around the wastewater outfalls. The fact that dover sole (which feed on polychaetes) from the outfall areas do not show elevated body burdens of metals provides indirect evidence that metal concentrations in polychaetes are not excessive.

As pointed out earlier in this chapter, the invertebrate fauna is potentially an important link in the flux of toxic materials through the benthic food web. Invertebrates in the vicinity of outfalls might, of course, play a dominant role in this link. However, it is difficult to determine the levels of toxic materials in the tissues of benthic invertebrates because of the intestinal and adhering sediment; new techniques must be developed before unequivocal results can be obtained. As none of the invertebrates on the deep sedimentary bottoms of the Bight are employed for human food, it was deemed more prudent to examine the levels of toxic materials in the predators of the invertebrates, the benthic fish, to appraise the rate of transfer of these substances into the food web. Direct measurements of levels of toxic materials in the invertebrates were thus carried out on widespread forms that were most likely to reveal levels of these materials from all sources within the Bight, and the benthic fish were used as indicators of the transfer from the wastewater sources.

Table 8-21
RELATIVE TOXICITIES OF TEN METALS IN SEAWATER TO MARINE AND ESTUARINE ORGANISMS

Organism and Response	Metal and Concentration (ppm)						Reference
Abnormal development of sea urchin embryos	Silver	Mercury	Copper	Zinc	Iron, Chromium	Manganese	
Species 1		0.032	0.1	0.32	10	32	Okubo and Okubo 1962
Species 2		0.032	0.032	1.0			Okubo and Okubo 1962
Species 3	0.00016	0.0015					Wilber 1969
Abnormal development of *Mytilus edulis* embryos		Mercury	Copper	Zinc	Chromium	Iron, Manganese	
		0.032	0.1	1.0	10	32	Okubo and Okubo 1962
Abnormal development of oyster (*Crassostrea commercialis*) embryos		Mercury	Copper	Zinc			
		0.032	0.1	3.2			Okubo and Okubo 1962
Bryozoan larvae, 2-hr LC_{50}*		Mercury	Copper	Zinc			
		0.1	0.57	32.7			Wisely and Blick 1967
Tubeworm larvae, 2-hr LC_{50}		Mercury	Copper	Zinc			
		0.14	0.51	4.9			Wisely and Blick 1967
European brown shrimp (*Crangon crangon*) 48-hr LC_{50}		Mercury	Copper	Iron	Chromium	Nickel, Zinc	
		3.3-10	10-33	33-100	100	100-330	Portmann 1970
European cockle (*Cardium edule*) 48-hr LC_{50}		Mercury	Copper	Chromium, Iron, Zinc		Nickel	Portmann 1970
		3.3-10	1.0	100-330		>330	

*The concentration resulting in 50 percent mortality of the test organisms within 2 hours.

Table 8-22

SEAWATER CONCENTRATIONS OF TEN METALS CAUSING LETHAL AND SUBLETHAL RESPONSES IN MARINE AND ESTUARINE ORGANISMS IN THE LABORATORY*

Concentration ppm	Response	Test Organism	Reference
MERCURY			
Lethal Effects			
0.10	2-hr LC_{50}	Bryozoan larvae, *Watersipora*	Wisely & Blick 1967
0.14	2-hr LC_{50}	Tubeworm larvae, *Spirorbis*	Wisely & Blick 1967
13.0	2-hr LC_{50}	Mussel larvae, *Mytilus edulis*	Wisely & Blick 1967
180	2-hr LC_{50}	Oyster larvae, *Crassostrea commercialis*	Wisely & Blick 1967
1800	2-hr LC_{50}	Brine shrimp larvae, *Artemia salina*	Wisely & Blick 1967
5**, 20	10- & 48-hr LC_{50}	Brine shrimp larvae, *Artemia salina*	Corner & Sparrow 1956
0.1**	1-hr LC_{50}	Barnacle larvae, *Elminius modestus*	Corner & Sparrow 1956
0.1**	1-hr LC_{50}	Copepod adults, *Acartia clausi*	Corner & Sparrow 1956
3.3-10	48-hr LC_{50}	European brown shrimp, *Crangon crangon*	Portmann 1970
3.3-10	48-hr LC_{50}	European cockle, *Cardium edule*	Portmann 1970
Sublethal Effects			
0.0015-0.002	Abnormal development	Sea urchin embryos, *Paracentrotus*	Wilber 1969
0.032	Abnormal development	Mussel (*Mytilus*) and oyster (*Crassostrea*) embryos	Okubo & Okubo 1962
0.003	Modified sublethal response	Isopod, *Sphaeroma pentodon*	Klock & Pearson 1961
0.5	Modified sublethal response	Mussel, *Mytilus edulis*	Klock & Pearson 1961
1.04	Modified sublethal response	Polychaete, *Mercierella enigmatica*	Klock & Pearson 1961
COPPER			
Lethal Effects			
0.57	2-hr LC_{50}	Bryozoan larvae, *Watersipora*	Wisely & Blick 1967
0.51	2-hr LC_{50}	Tubeworm larvae, *Spirorbis*	Wisely & Blick 1967
22.2	2-hr LC_{50}	Mussel, *Mytilus edulis*	Wisely & Blick 1967
0.12	16-day LC_{50}	Polychaete, *Nereis virens*	Reish 1964
340	48-hr LC_{50}	Brine shrimp larvae, *Artemia salina*	Corner & Sparrow 1956
20	10-hr LC_{50}	Barnacle larvae, *Elminius modestus*	Corner & Sparrow 1956
1	10-hr LC_{50}	Copepod adults, *Acartia clausi*	Corner & Sparrow 1956
10-33	48-hr LC_{50}	European brown shrimp	Portmann 1970
1-2	Threshold toxicity (11-12 day exposure)	Shore crab, *Carcinus*	Wilber 1969
1.9	96-hr LC_{50}	Japanese oyster	Wilber 1969
0.8	Lethality	American oyster larvae	Reish 1964
0.14	3 to 4-day lethality after 0.5 to 3-day exposure	Mussel, *Mytilus edulis*	Reish 1964
1	48-hr LC_{50}	European cockle	Portmann 1970
Sublethal Effects			
0.01-0.032	Abnormal development	Embryos of sea urchin spp.	Okubo & Okubo 1962
0.1	Abnormal development	Mussel embryos, *Mytilus*	Okubo & Okubo 1962
0.1	Abnormal development	Oyster embryos, *Crassostrea*	Okubo & Okubo 1962
0.005	Modified sublethal response	Isopod, *Sphaeroma pentodon*	Klock & Pearson 1961
0.08	Modified sublethal response	Mussel, *Mytilus edulis*	Klock & Pearson 1961
0.08	Modified sublethal response	Polychaete, *Mercierella enigmatica*	Klock & Pearson 1961
0.33-0.5	Detection and avoidance	European brown shrimp	Portmann 1970
ZINC			
Lethal Effects			
5.2	2-hr LC_{50}	Bryozoan larvae, *Bugula*	Wisely & Blick 1967
4.9	2-hr LC_{50}	Tubeworm larvae, *Spirorbis*	Wisely & Blick 1967
100-330	48-hr LC_{50}	European brown shrimp, European cockle	Portmann 1970
100	96-hr LC_{50}	Oyster adult, *Ostrea edulis*	Portmann 1970
about 1	96-hr LC_{50}	Oyster larvae, *Ostrea edulis*	Portmann 1970
Sublethal Effects			
0.32	Abnormal development	sea urchin embryos	Okubo & Okubo 1962
1.0	Abnormal development	Mussel embryos, *Mytilus*	Okubo & Okubo 1962
3.2	Abnormal development	Oyster embryos, *Crassostrea*	Okubo & Okubo 1962
LEAD			
0.14	Modified sublethal response	Isopod, *Sphaeroma pentodon*	Klock & Pearson 1961
3.9	Modified sublethal response	Mussel, *Mytilus edulis*	Klock & Pearson 1961
1.3	Modified sublethal response	Annelid, *Mercierella enigmatica*	Klock & Pearson 1961
NICKEL			
100-330	48-hr LC_{50}	European brown shrimp	Portmann 1970
>330	48-hr LC_{50}	European cockle	Portmann 1970
SILVER			
0.4	48-hr LC_{50}	Barnacle	Wilber 1969
0.00016	Abnormal development	Sea urchin embryo	Wilber 1969
CHROMIUM			
10	Lethal in 5 hours	Bryozoan, *Bugula*	Reish 1964
100	48-hr LC_{50}	European brown shrimp	Portmann 1970
100-300	48-hr LC_{50}	European cockle	Portmann 1970
CADMIUM			
0.2	Heavy mortality 13 weeks	Oyster, *Crassostrea virginica*	Schuster & Pringle 1969
IRON			
33-100	48-hr LC_{50}	European brown shrimp	Portmann 1970
100-330	48-hr LC_{50}	European cockle	Portmann 1970
10	Abnormal development	Sea urchin embryo	Okubo & Okubo 1962
32	Abnormal development	Mussel embryo, *Mytilus*	Okubo & Okubo 1962
MANGANESE			
1,570-2,880	24-hr LC_{50}	Brine shrimp, *Artemia*	Okubo & Okubo 1962
32	Abnormal development	Sea urchin embryos	Okubo & Okubo 1962
32	Abnormal development	Mussel embryos, *Mytilus*	

*Most tests performed at natural temperature and salinity.
**Organic mercury.

There has been one pertinent study of the relationship of polychaete worms to trace metals concentrated in sediments. This study was made in the Restronguet Creek Estuary in southwest England, the area in which over one-half of the world's copper was mined in the last century. The area is still contaminated with copper concentrations as high as to 3 ppm (dry weight). (In the Southern California Bight, the natural level for copper is 0.016 ppm, and the mean and maximum values around the Whites Point outfall off Palos Verdes are 0.22 and 0.67 ppm, respectively.) Bryan (1971) discovered three facts of importance. The first was that the worm *Nereis diversicolor* concentrated copper but not zinc, lead, iron, or manganese from contaminated sediments and that this concentration was roughly proportional to the total concentration in the sediment. The second fact was that interstitial concentrations of dissolved copper reached levels found to be detrimental to other organisms only in the most contaminated sediments. The third fact was that, in tests comparing worms collected from areas of low, intermediate (similar to that near Whites Point), and high copper concentrations, the worms collected from the high concentration areas were the most tolerant to dissolved copper in static bioassays, indicating genetic or adaptive tolerance.

Laboratory and field studies on the uptake of several trace metals (including zinc, copper, and cobalt) by Chesapeake Bay oysters indicated that the oysters took up metals from seawater but not from either suspended or settled sediments.[5]

These studies, combined with the apparent lack of uptake by fishes feeding on organisms living in sediments with high metal concentrations, suggest that metals in contaminated sediments are, for the most part, unavailable to the biota.

8.5.4 Metal Concentrations in Invertebrates of the Bight

As part of the SCCWRP 1971 sampling program, mussels, gooseneck barnacles, and starfish were collected during the summer from 11 coastal and 6 island stations in the Bight. Three male and three female mussel specimens 5 cm in length from each station were dissected to obtain the digestive glands, gonads, and anterior adductor muscle. The separate tissues were analyzed by emission spectroscopy and arc examination for 25 metals:

Silver	Cadmium	Potassium	Sodium	Tin
Aluminum	Cobalt	Lithium	Nickel	Strontium
Boron	Chromium	Magnesium	Phosphorus	Titanium
Barium	Copper	Manganese	Lead	Vanadium
Calcium	Iron	Molybdenum	Silicon	Silicon

As statistical analysis of the data showed no significant sex-related differences in concentrations in digestive glands, the male and female composite values were averaged.

Table 8-23 summarizes the results of these analyses. Data from the individual stations have been combined into three categories--island, coastal, and Palos Verdes area concentrations. The Palos Verdes data are presented separately in the table because of the high metal concentrations found in the sediments around the Whites Point outfall (Chapter 6). Of the 25 metals shown in the table,

5. D. W. Pritchard, Chesapeake Bay Institute, The Johns Hopkins University, Baltimore, Md., personal communication.

Table 8-23

MEAN CONCENTRATIONS (PPM, DRY WEIGHT) OF METALS IN THE DIGESTIVE GLAND OF *MYTILUS CALIFORNIANUS*

	Island Area			Coastal Area			Palos Verdes		
Metal	No. of Stations	Mean	Std. Error	No. of Stations	Mean	Std. Error	No. of Stations	Mean	Std. Error
Silver	6	9.5	4.3	11	<20	--	2	31	1
Aluminum	6	200	40	10	410	40	2	340	100
Boron	6	29	4	11	28	3	2	26	3
Barium	6	2.2	0.5	11	10	2	2	16	7
Calcium	6	>1,500	--	11	920	96	2	1,200	50
Cadmium	6	21	2	11	20	3	2	17	9
Cobalt	6	1.5	0.2	11	<1.7	--	2	1.6	0.8
Chromium	6	2.5	0.5	11	10	3	2	11	5
Copper	6	22	2	11	31	5	2	39	5
Iron	6	270	50	11	510	50	2	420	120
Potassium	6	0.9	0.1	11	0.7	0.04	2	0.9	0.2
Lithium	0	--	--	10	<1.1	--	1	<1.0	--
Magnesium	6	2,200	95	11	3,000	270	2	2,900	830
Manganese	6	14	4	11	54	11	2	40	27
Molybdenum	6	9.9	2.4	11	5.9	1.2	2	3.8	0.4
Sodium	6	1.4	0.2	11	1.7	0.1	2	1.4	0.4
Nickel	6	10	2	11	7.5	1.1	2	8.7	2.8
Phosphorus	6	0.9	0.1	11	1.1	0.1	2	1.0	0.2
Lead	6	6.4	1.2	11	20	2	2	19	5
Silicon	4	650	79	3	490	79	1	373	--
Tin	6	1.1	0.1	11	3.1	0.5	2	2.8	1.8
Strontium	6	18	3	11	11	1	2	10	1
Titanium	6	48	17	10	180	30	2	124	84
Vanadium	6	5.1	0.7	11	5.1	0.7	2	5.4	25
Zinc	6	77	8	11	79	7	2	84	6

highest concentrations of seven or eight metals occurred at island stations. Ten metals had highest concentrations at the coastal stations, and six or seven were highest in samples from the Palos Verdes area.

Figures 8-18 through 8-20 show the mean values and standard deviations for lead, copper, and zinc at each of the sampling locations. Unlike DDT, these metals showed no obvious distribution pattern associated with wastewater discharges. For example, the mean lead concentration of 24 ppm at Palos Verdes was exceeded at Oceanside (28 ppm) and Seal Beach (31 ppm). The Palos Verdes zinc concentration of 90 ppm was equaled or exceeded at five other sampling locations.

For some of the metals, there does appear to be a coastal-to-island gradient. Most of the 11 coastal stations exhibit a high value for at least one of the 25 metals considered. In particular, lead concentrations are highest along the coast, intermediate along the first line of islands (Anacapa, Santa Barbara, and Santa Catalina Islands), and lowest along the outer line of islands (San Miguel, San Nicolas, and San Clemente Islands). The mean *M. californianus* digestive gland lead concentrations for these three station groups are about 20, 9, and 4 ppm, respectively. These data strongly suggest a land-based, diffused source of lead entering the Bight rather than specific point sources. A coastal-to-island gradient of airborne lead was observed by Rabinowitz (1972) in samples of grass collected from many of these same stations. This supports the hypothesis that the principal cause of the lead gradient illustrated in Figure 8-18 is atmospheric fallout from air pollution.

The data on metal concentrations in *M. californianus* digestive glands were separated into two station groups, coastal and island. The differences between the mean concentrations for each of these two groups were tested statistically. Of the 25 metals analyzed, eight (aluminum, barium, iron, magnesium, manganese, lead, tin, and titanium) had significantly (95 percent confidence level) greater concentrations in the coastal station group.

Except in the case of lead, for which a reasonable association with air pollution can be argued, there is no indication as to whether these coastal-to-island gradients are man-related or are a natural consequence of the proximity of the coastal mussels to a much greater surface than is associated with the island mussels.

<u>Artificial Radionuclides</u>

The intertidal invertebrates, *M. californianus* and *P. polyemerus*, have been used for years as indicator organisms for detection of radioactive isotopes in nearshore marine waters. These organisms concentrate certain metals hundreds or thousands of times above ambient seawater levels and thus are appropriate species for detecting large-scale radioactive contamination.

During the summer and fall 1971 intertidal survey, several kilograms of these mussels and barnacles were collected. Approximately 2 kg of wet tissue were homogenized and assayed for 1,000 minutes by gamma-ray spectrometry. For a number of samples, total alpha and beta activity were also measured. Samples collected from stations inshore of the three major wastewater outfalls and on

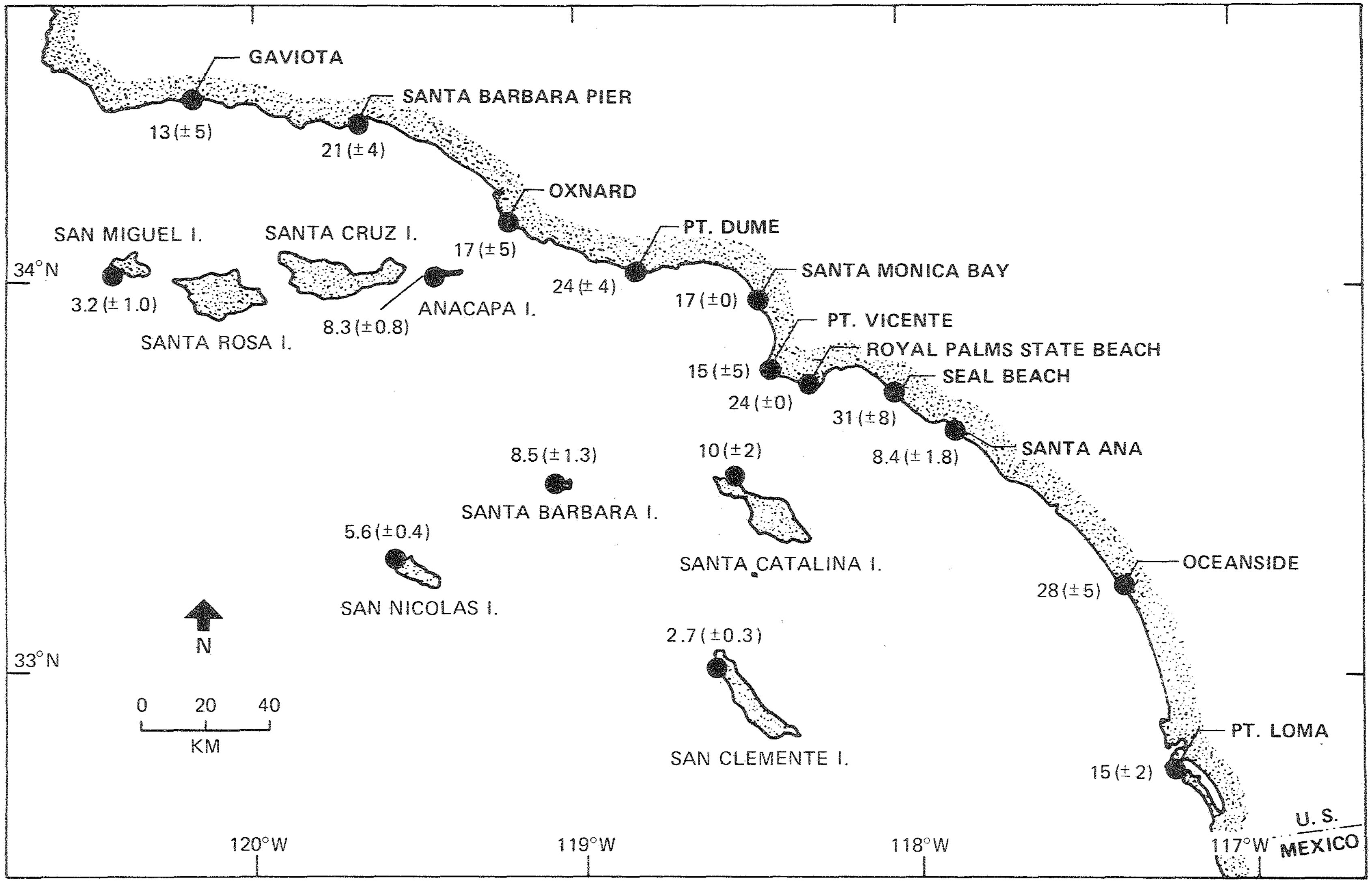


Fig. 8-18. Concentrations (ppm dry wt.) of Lead in Digestive Gland Tissue of *Mytilus Californianus,* 1971.

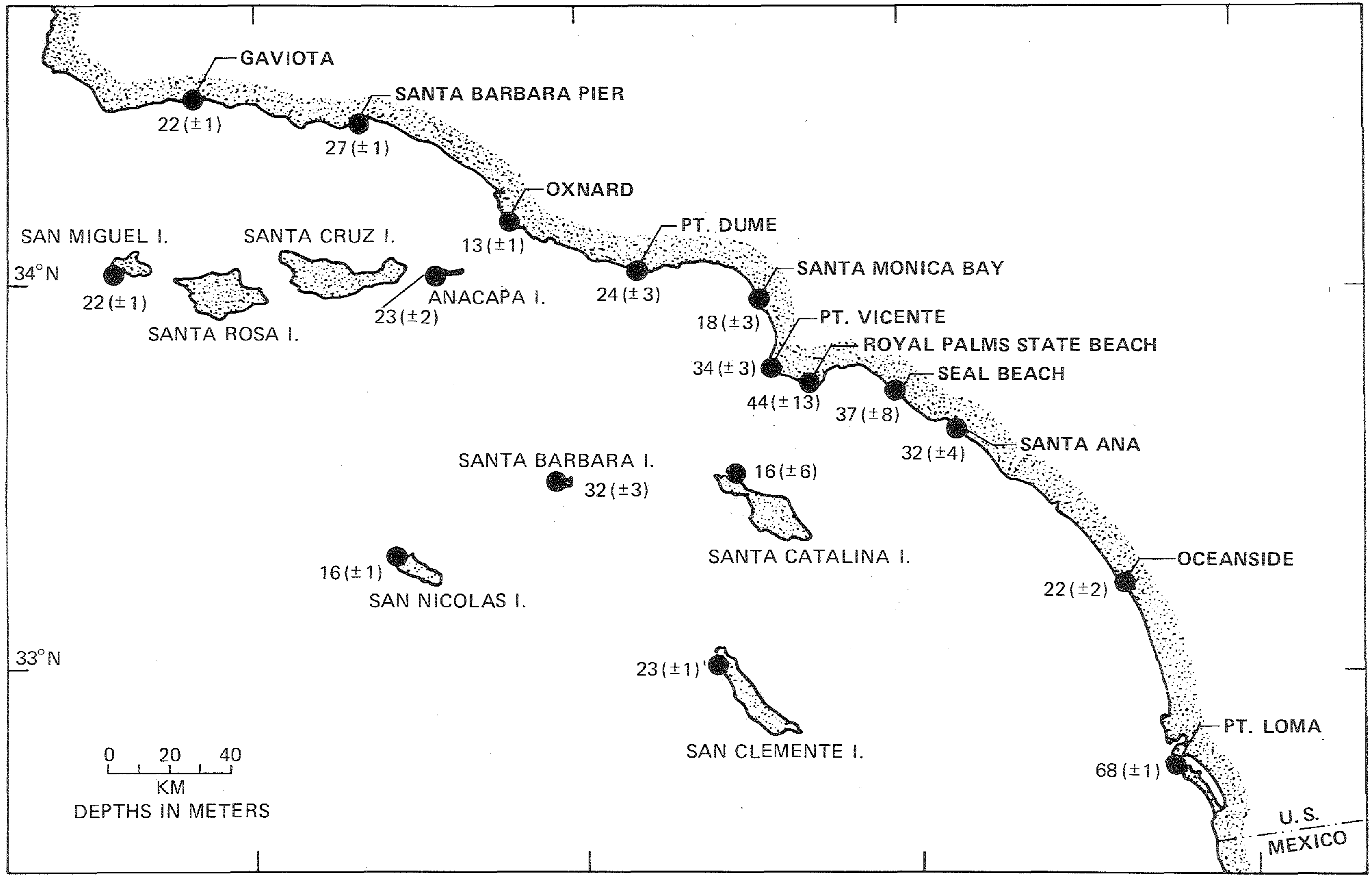


Fig. 8-19. Concentrations (ppm dry wt.) of Copper in Digestive Gland Tissue of *Mytilus Californianus,* 1971.

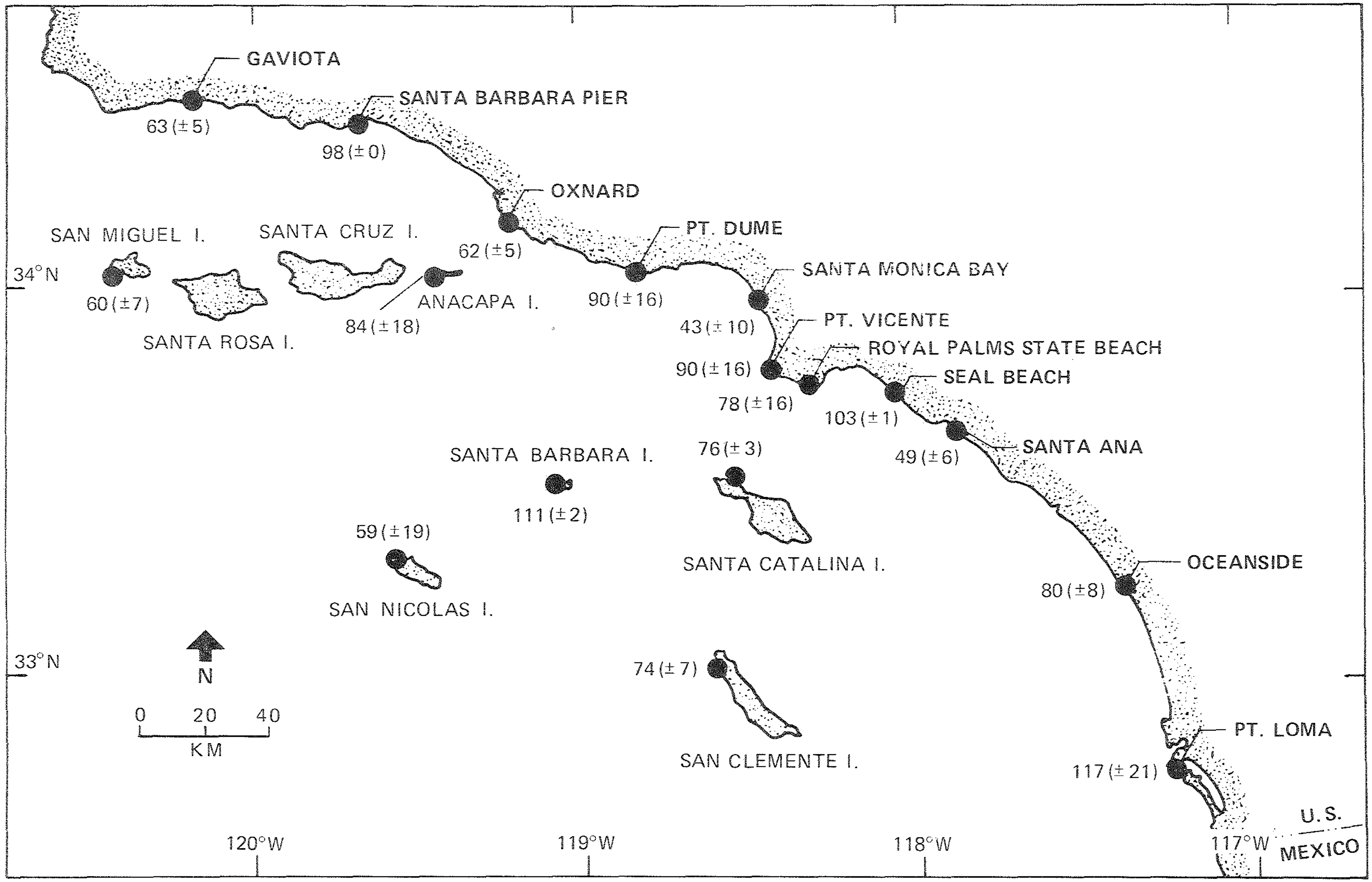


Fig. 8-20. Concentrations (ppm dry wt.) of Zinc in Digestive Gland Tissue of *Mytilus Californianus,* 1971.

each side of the San Onofre nuclear generating station were analyzed immediately after collection to detect any short-lived isotopes.

Analyses were made for five gamma-emitting radionuclides--iodine 131, cesium 137, manganese 54, zinc 65, and cobalt 60. None of the isotopes was detected in any of the samples. The only radioactivity observed was that from the natural isotopes, potassium 40 and the uranium-thorium decay series. The levels of these isotopes were natural and expected.

A recent study (Wong, Hodge, and Folsom 1971) has demonstrated some extremely low levels of radioactivity in intertidal and littoral algae samples. Minute concentrations of plutonium 239, cobalt 58, cobalt 60, silver 110, zinc 95, and niobium 95 were detected at five stations along the southern California coast between San Onofre and the Mexican Border. Higher levels of the cobalt and silver isotopes were found in algae taken near the base of the cooling water discharge outfall from the San Onofre plant. The measured activities were very low--no isotope exceeded a concentration of 455 pCi/wet kg. These concentrations do not represent a hazard either to man or to the marine communities.

8.6 SUMMARY

Background information on the soft-bottom benthic invertebrate communities of the Southern California Bight was provided by the extensive Allan Hancock Foundation studies carried out from the early 1950's to 1960. Polychaetes, crustaceans, molluscs, and echinoderms constitute the major groups of organisms on the mainland shelf. Polychaetes and crustaceans are about equally abundant, together contributing 70 percent of the total individuals; but, in terms of biomass, polychaetes constitute 40 to 50 percent. The basin fauna is less diverse, and the density of organisms and biomass is considerably below that of the shelf fauna. Polychaetes accounted for about two-thirds of the specimens in basin samples, with other groups contributing less than 10 percent each.

Recent studies conducted at the old and new Orange County outfalls, at Point Loma, and off the Palos Verdes Peninsula showed that distribution of brittle stars, principally *Amphiodia urtica*, and the small clam, *Parvilucina tenuisculpta* could be associated with effects of wastewater discharge.

At the old Orange County outfall, there was a marked increase in the ratio of brittle stars to *P. tenuisculpta* after termination of discharge: *P. tenuisculpta* was more abundant during discharge, and brittle stars were more abundant after termination of discharge. At the new outfall, a year after initiation of discharge, the ratio was not very different from predischarge values, with brittle stars outnumbering *P. tenuisculpta* and the numbers of both organisms having increased.

At the City of San Diego outfall off Point Loma, analysis of the data over nearly a 10-year period showed that, in the areas immediately around the outfall, *P. tenuisculpta* was far more numerous than the brittle stars. At stations distant from the outfall, the ratio is reversed and the brittle stars outnumbered the clams.

Species such as *Capitella capitata*, a segmented worm, are commonly regarded as indicators of conditions of reduced salinity, low dissolved oxygen, or highly

organic substrate. In the studies around the Orange County outfalls, the species decreased around the old outfall when the discharge was terminated and increased around the new outfall. In Santa Monica Bay, capitellid species were relatively more abundant near the outfalls than in more distant areas. At Point Loma, *C. capitata* was identified in a few samples taken at stations closest to the diffuser but not elsewhere.

Data from an 87-station survey on the Palos Verdes shelf indicated that, with respect to abundance of the major faunal groups, this area differed from the usual shelf faunal composition: Polychaetes contributed 70 percent of the total benthic specimens, and molluscs 27 percent. Crustaceans and echinoderms were low in abundance, and brittle stars were completely absent from samples. *P. tenuisculpta*, the dominant mollusc, was abundant over much of the area but was diminished around the Whites Point outfall and completely absent from samples taken from a line of stations extending northwest from the "Y" diffuser. Most of the distributions of the 21 major polychaete species appeared to fit outfall-related patterns: Known indicators of stress such as *Stauronereis rudolphi*, the most abundant species, and *C. capitata*, were the dominant forms near the outfall, and many other species distributed over much of the Palos Verdes shelf were conspicuously absent from the outfall area.

Polychaete data from the 87 Palos Verdes shelf samples were subjected to recurrent group analysis to identify frequently occurring groups of organisms. Four groups containing a total of 10 species were defined. The group containing *S. rudolphi* and *C. capitata* occurred extensively in the outfall area, where highly organic substrate and hydrogen sulfide were noted and sediment levels of metals and DDT were relatively high. A second group occurred in parts of the outfall area but was not found in areas where most outfall related factors may reach extremes. The other two groups were not present in relatively large areas around the outfall.

Species diversity measurements for the polychaete community of the Palos Verdes shelf showed distinctly lower values in the area immediately around the outfall as compared to more distant areas. Species diversity of samples from sediments with a black surface taken in the vicinity of the outfall was lower than in samples with lighter surfaces. Data from a relatively undisturbed bay in Baja California indicated a possible relationship between sediment coarseness and diversity, but this was not apparent in Palos Verdes data. Polychaete diversity off Palos Verdes appeared to be relatively stable from season to season.

Sulfides and organic carbon in the sediments and suspended solids and transparency in the water column were measured before and after the change in wastewater outfalls off Orange County in April 1971. The physical and chemical characteristics of the sediments and water around the old outfall changed markedly after the discharge was terminated. Sediment sulfides and organic carbon and suspended solids in the water column decreased while the transparency increased. The changes near the new outfall in the 8 months following initiation of discharge were relatively minor and, for the numbers of measurements made, not statistically significant. These small changes may be due in part to the modern design of the new outfall diffuser and the greater dilution (greater than 100 to 1) available at that location.

At the old Orange County outfall, after termination of discharge, total population density decreased, but the number of species per sample and species diversity increased. These are trends toward the conditions in unaffected areas. In the 18 months following initiation of discharge at the new outfall, total population density and number of species per sample increased, and species diversity decreased.

The few laboratory bioassay studies of the effects of DDT when incorporated into food (detritus or prey) for larval and adult crustaceans have revealed toxic responses at concentrations below the levels found in subtidal sediments and benthic fish over much of the Palos Verdes shelf.

Concentrations of total DDT in the intertidal mussels collected during 1971 from throughout the Bight clearly reflected the influence of the Los Angeles County discharge. Distinct gradients were observed in all directions away from this outfall system: Highest levels (4 mg/wet kg) were observed in specimens collected on the Palos Verdes Peninsula; lowest (0.03 to 0.04 mg/wet kg) were found at Punta Banda in northern Baja California, Mexico, at San Clemente Island, and at Bodega Bay, north of San Francisco. Levels an order of magnitude higher than these minimum background concentrations were found at Oxnard (85 km to the northwest), Santa Barbara Island (65 kg to the southwest), and Oceanside (105 km to the southeast). These high concentrations of DDT in the area of Palos Verdes were almost certainly the result of a major, long-time discharge of DDT through the Whites Point outfall system. This discharge was reduced significantly in 1970.

High concentrations of total PCB were also observed in specimens of the intertidal mussel collected from the Palos Verdes Peninsula (0.4 to 0.5 mg/wet kg). Levels generally decreased away from this location, except that a secondary peak in the distribution was observed at Point Loma in San Diego. This may reflect the influence of the large harbor there. Minimum levels (0.01 to 0.02 mg/wet kg) again were observed in Punta Banda and Bodega Bay specimens, but corresponding values also were found at all of the offshore islands in the Bight except Santa Barbara Island (0.07 mg/wet kg), and at the three coastal stations north of Point Conception. This pattern suggests that, in contrast to the case for DDT, there are several significant sources of PCB in the Bight.

The level of knowledge imparted by current bioassay studies does not permit any conclusive evaluation of the significance of the elevated levels of metals in sediments around the various outfalls to the viability of the subtidal benthic invertebrate community. The apparent lack of uptake by fishes feeding on invertebrates living in sediments with high metal concentrations in the Bight (and related studies on a polychaete and an oyster by other investigators) suggests that metals in contaminated sediments are for the most part unavailable to the biota.

Tissues of mussels and gooseneck barnacles were analyzed for a number of metals. Metal concentrations in the organisms, unlike those of DDT and PCB, did not show an obvious pattern associated with wastewater discharge.

A survey of approximately 25 trace metals in the intertidal mussel *Mytilus californianus* revealed no apparent relationship between proximity to a specific point source and elevated metal concentrations. However, for many metals, there was a general increase of coastal concentrations over levels in island specimens by approximately a factor of two. This may indicate that diffuse sources (or dispersion of discrete inputs) in the Bight are causing a detectable increase in metal levels in the marine biota along the coast between Santa Barbara and San Diego. This increase was most noticeable for lead, where the coastal-to-island ratio was approximately 3:1, apparently reflecting input of airborne lead by aerial fallout.

Radioassays of coastal mussel and gooseneck barnacle tissue from a number of coastal and island stations were made. No detectable radioactivity above natural levels was found in any of the samples. Levels of manganese 54, cobalt 60, and zinc 65 were at least an order of magnitude lower than those reported in a similar survey conducted during the period of high radioactive fallout in 1963-64.

Another recent study of radioactivity in intertidal and littoral algae samples revealed extremely low levels of radioactivity at five stations off the southern California coast between San Onofre and the Mexican border. The concentrations found do not represent a hazard either to man or to the marine communities.

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Chapter 9
PLANKTON

9.1 INTRODUCTION

The tiny, single-celled free floating plants that constitute the phytoplankton provide a dominant link between the mineral and living kingdoms of the sea. They are the ubiquitous entities that convert inorganic carbon, nitrogen, phosphorous, and a host of lesser elements into the reservoir of organic food upon which, ultimately, all animals of the sea subsist. In this role, the phytoplankton have developed powerful chemical mechanisms for the acquisition and concentration of a wide range of extremely dilute substances from seawater. For example, most phytoplankton species grow well on concentrations of the principal plant nutrients far too dilute for the survival of almost any terrestrial plants. This ability involves an increase in concentration of substances within their cells of as much as 1 million times the concentration of the substances in seawater, and this proclivity may be exercised when seawater concentration is as low as 10^{-14} (10 millionth billionths parts) for some substances.

The phytoplankton can thus be viewed as setting and providing an initial chemical repast of food, nutrients, toxic materials, and pollutants for much of the marine food web. The importance of the phytoplankton to the problems of the ecology of southern California waters hence involves three principal aspects for study: (1) As the phytoplankton are the primary producers of food material to the food web, their general well-being and level of productivity are of concern, as are any profound alterations of species abundance or composition that might deny sustenance to important herbivores or stimulate populations of undesirable organisms. (2) Too much enrichment, particularly in coastal waters with limited circulation, may result in excessive phytoplankton growth (algal blooms) that discolor the water, produce unpleasant odors, affect aesthetic values, and may create an organic overburden to the environment. The phytoplankton, sinking below the euphotic zone and accumulating on the bottom, may in extreme cases produce anoxic conditions and mass mortalities of marine life. There is concern, therefore, with the delicate balance between enrichment of coastal waters, with its implication of increased biologic productivity, and over-enrichment leading to organic pollution and biological catastrophe. (3) As a significant route of dissolved chemical substances into the food web is via the phytoplankton, their uptake of toxic substances and pollutants, and the degree to which these substances are passed on through the food web to animals and to man, are topics of importance.

As discussed later, man's principal introduced material, wastewater, contains an abundance of nutrient materials (particularly the commonly limiting nutrient, nitrogen) and low levels of potentially toxic substances. The investigations reported in this chapter have shown only modest and local increases in phytoplankton abundance associated with wastewater discharges. These same investigations have also demonstrated an important result--that this increased

productivity does not involve the proliferation of unusual species but rather only of members of the natural population. This result is in contrast to experience in freshwaters that receive wastewater, where undesirable species of algae are often greatly stimulated.

The role of the phytoplankton in introducing chemical substances into the food web is complex, involving the interactions of a multitude of phytoplankton species and a plethora of substances in many different states, each with different chemical qualities. The phytoplankton absorb chemical materials from the dissolved or fine suspended components in seawater and introduce them into the food web. In wastewater discharges, these materials are rapidly diluted and hence are mainly important as broad-scale or global sources of contamination. Inputs that are less subject to early dilution are the coarser particulates from river runoff and wastewater discharge, which can be taken up directly by the particle-feeding animals (along with phytoplankton) and the benthic creatures. The chemical substances taken up by the phytoplankton are not all passed on to the food web. Rather, various mechanisms discriminate strongly against many chemical components; hence, chemical uptake of phytoplankton by no means uniquely specifies the chemical composition of the higher food web (fish and invertebrates), where man's most immediate and direct interests are involved. The choice of the first stage of SCCWRP research has thus been to limit the investigation of phytoplankton to an inquiry into the stimulatory effects of wastewater discharge on phytoplankton and to approach pragmatically the integrated input of trace substances through the phytoplankton, water or airborne particulates, and other routes--by analyses of the levels of these substances in the higher members of the food web, which constitutes the ultimate marine link between man and the chemical reservoirs of the sea.

Except in the intertidal and shallow subtidal benthic environment, phytoplankton are the primary producers of organic material in the marine realm, and the total productivity of the marine environment is dependent on the productivity of the phytoplankton. Primary production is, in turn, dependent on a variety of environmental factors, including the availability of light, which is strongly influenced by the clarity of the water; the abundance and distribution of the many nutrients required for growth; water temperature; and mortalities from grazing or other predation.

Although phytoplankton exist in all marine environments, the areas of greatest productivity are in high latitudes (in spring and summer), along coastal boundary currents, and in the equatorial current system. Except in high latitudes in winter, when light limits productivity, the level of productivity is controlled primarily by the availability of plant nutrients. Ordinarily, the concentrations of plant nutrients are high in the waters below the euphotic zone[1] and low or depleted within it. Hence the large-scale distribution of productivity pointed out above is the result of the processes that bring nutrients into the euphotic zone from deeper waters; these include the mechanisms of diffusion, turbulent mixing, and upwelling.

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1. The euphotic zone is defined as the region of the upper waters between the surface and the depth at which the light is approximately 1 percent of the incident light at the surface.

Ryther (1969) has presented estimates of the potential fish productivity in waters in the open ocean, the coastal zone, and areas of upwelling (Table 9-1). In terms of phytoplankton, areas of upwelling are approximately three time as productive as the coastal zone and six times as productive as the open ocean. Since the fraction of the ocean surface in which upwelling occurs is relatively small, the contribution of upwelling to primary production in the world oceans is less than 0.5 percent.

This number may, however, be misleading. When the differing efficiencies and numbers of trophic levels in the three zones are included, Ryther calculated that these restricted upwelling zones may contribute as much as 50 percent of the total fish production. It is well known that more than one-half the actual fish catch is taken from upwelling areas, and it has been estimated that, when the total potential food desired by man is considered, upwelling areas such as those found off southern California may be 1,000 times more productive than the other 99.9 percent of the ocean (Hassler 1972).

The production of organic material is a result of the rapid growth rates of phytoplankton, which, under ideal circumstances, may double their populations daily. A change in the local physical, chemical, or biological environment of the phytoplankton can therefore result in rapid and substantial changes in the standing crop. One of the more visible symptoms of oscillation in the marine environment is the occurrence of plankton blooms. People living in coastal areas are familiar with one such manifestation, the so-called red tide, which is caused by dinoflagellates, a group of motile algae that may color the water

Table 9-1
ESTIMATED PRODUCTIVITY IN THREE OCEAN PROVINCES
From Ryther 1969

	Province			
	Open Ocean	Coastal Zone	Upwelling Areas	Total
Percentage of Ocean	90	9.9	0.1	100
Area (sq km)	326×10^6	36×10^6	3.6×10^5	362×10^6
Mean Primary Productivity (g C/sq m-yr)	50	100	300	
Total Primary Productivity (M tons C/yr)	16.3×10^9	3.6×10^9	0.1×10^9	20×10^9
Assumed Number of Trophic Levels	5	3	1.5	
Assumed Efficiency (%)	10	15	20	
Fish Production (M tons/yr)	1.6×10^6	1.2×10^8	1.2×10^8	2.4×10^8

when abundant. The color may not always be red; yellow tides are not uncommon, and other colors have been reported. At night, these same organisms can provide a spectacular display of "bioluminescence" along the beaches, where wave action triggers photochemical light production. These blooms are generally found worldwide, including occurrences off California and Florida, in the Gulf of Mexico and Puget Sound, in the upwelling areas off the Coast of Peru,[2] and in areas far from land, such as the Fiji Sea and the South Atlantic. Dinoflagellate blooms have been associated with areas characterized by low mixing and low nutrients.

Red tides are sometimes associated with massive mortalities of fish and other organisms, aesthetically objectionable odors, and the concommitant loss of fishing and tourist revenues. People have been reported to suffer respiratory irritation, although there is no evidence that external contact by swimmers causes more than minor discomfort from the slimy or oily cellular residues. Certain invertebrates, notably clams and mussels, ingest and concentrate the highly toxic dinoflagellate, *Gonyaulax catonella*. As the neurotoxin contained in this alga and picked up by the shellfish may be fatal to humans, even when the shellfish are well cooked, there is an annual quarantine of certain shellfish, particularly mussels, during the summer months in many areas.

9.2 PHYTOPLANKTON NUTRIENT SOURCES

Coastal waters along the western boundary of North America commonly exhibit a much higher productivity and standing crop than open ocean waters. This is due in part to nutrient inputs from the coastal land areas, but is primarily the result of upwelling, which transfers nutrient-rich deep waters into the euphotic zone. In this zone (except possibly in the late winter months, when solar radiation and water temperatures are at their lowest values), the supply of suitable nutrients for uptake is the principal factor in determining productivity, and the limiting nutrient is usually nitrogen.

A rough estimate of the magnitude of the nitrogen that may be supplied for primary productivity by upwelling can be derived from data from the California Cooperative Oceanic Fisheries Investigations (CALCOFI) program (CALCOFI 1954). Assume that (1) the upwelling occurs along 25 percent of the coast from Point Conception to the United States/Mexico border and within a zone of about 60 km from the shore, i.e., over an area of about 7,500 sq km, (2) the average upwelling rate is 40 meters/month (1.5×10^{-3} cm/sec), (3) the upwelling occurs over a 3-month period, and (4) the average nitrogen concentration in the upwelled water is 0.2 mg/L; then approximately 180,000 M tons/yr of nitrogen may be brought from the deeper waters into the euphotic zone by upwelling.

Surface runoff and drainage inputs of nitrogen into this area are on the order of 2,500 M tons/yr (Table 4-28), and hence are substantially less than the upwelling inputs. Both of these processes are intermittent—upwelling is dependent upon the strength, duration, and direction of the winds, the coastal currents and topography, and the degree of stratification in the water column;

2. Particularly during "El Nino" years, when abnormally high temperatures and low nutrients prevail.

runoff is governed by the frequency, intensity, and duration of precipitation in the drainage basins. As a result, there can be relatively large fluctuations in these inputs from year to year and lengthy periods within a year when they are absent.

In contrast, wastewater discharges tend to be relatively constant. The present total nitrogen input from municipal and industrial wastewater discharges is estimated to be about 85,000 M tons/yr (Table 4-28). On a local basis, the wastewater inputs could be the predominant source of nitrogen. Upwelling and wastewater discharge inputs, however, may not be directly comparable. If the wastewaters are discharged so that they remain submerged below the euphotic zone, the nutrients will be available to the phytoplankton in the euphotic zone only by vertical diffusion or by upwelling. Another point of difference is that upwelling occurs primarily in April, May, and June, while wastewaters are discharged year-around.

Another pontential source of nitrogen is the various oxides of nitrogen in the air over the southern California basin. It is estimated that the total emission of oxides of nitrogen (NO_x) in the basin is about 2 million lb/day.[3] Assuming an average nitrogen content of 40 percent, the annual emission rate would be about 300,000 metric tons of nitrogen. Even if only one percent of this quantity washes out of the atmosphere and enters the coastal waters, it would represent a significant nitrogen source.

Nitrogen, of course, is not the only nutrient of concern. Phytoplankton, like all plants, require a complex of materials for their growth. Many of these--some metals, for example--are essential in trace quantities but are toxic or inhibitory in greater concentrations. As a consequence, it is difficult in most situations to arrive at an understanding of the relative roles of the various nutrient sources. An additional level of complexity results from the responses of the individual plankton species to varying environmental and nutrient conditions, as well as from interactions between species.

9.3 HISTORY OF PLANKTON POPULATIONS IN THE SOUTHERN CALIFORNIA BIGHT

Over the past 25 or more years, there have been a number of small, local studies and at least one long-term, extensive investigation of plankton in the Southern California Bight. In most cases, the sampling was carried out by towing a plankton net through the water, and a wide variety of gear--including nets of different mesh-size openings--was used. Such equipment is designed for catching zooplankton (the animal constituents of the plankton), and even the finest-mesh nets (i.e., 0.10-mm mesh openings) capture only a small fraction of the phytoplankton, most of which are in the 0.01-0.05-mm size range (Mallone 1971). Thus, the biomass of plankton net tow samples (often expressed as displacement volume of plankton per unit volume of water sampled) is predominantly (and when large-mesh nets are used, almost exclusively) zooplankton.

3. Eugene Leong, TRW, Inc.--Environmental Services, Redondo Beach, California, personal communication.

The zooplankton feed upon phytoplankton or upon each other; there is obviously, therefore, a close relationship between the two groups. However, because the phytoplankton have a generation time of hours to days, and that of the zooplankton is weeks to months, there may be a considerable displacement in time and space between the growth and the resulting population sizes of the plants and animals in response to environmental conditions. That is, conditions that stimulate or enhance the growth of phytoplankton will normally be reflected by an increase in zooplankton biomass, but the latter may be observed some period of time later or some distance downstream from the point of enhancement. Thus, small-scale or short-term studies, particularly if the environmental perturbation is of short duration, may fail to show a correlation between phytoplankton enhancement and "net plankton" biomass, but long-term studies over large areas under reasonably steady-state conditions will normally reveal this cause-and-effect relationship. Several of the studies discussed in this chapter fit into the latter category, at least well enough that net plankton displacement volumes may be used as an adequate if indirect index of the presence or absence of phytoplankton enhancement.

The only satisfactory method of determining the numerical abundance and species composition of the phytoplankton is microscopic examination of preserved organisms that have been centrifuged or settled from whole water samples. This is laborious and time-consuming work requiring a high degree of specialized training and is therefore not often included in routine water quality surveys. Nevertheless, it is indispensible to the full understanding of this important group of organisms.

More recently, other simpler biochemical or physiological techniques for studying phytoplankton have come into use. Whole water samples may be filtered through membrane filters, from which the chlorophyll may be extracted and quantitatively measured fluorometrically to provide a quick and simple index of total phytoplankton biomass as well as its photosynthetic potential. The rate of uptake of radioactive carbon (^{14}C) has become a standard method for measuring directly the rate of photosynthesis (i.e., productivity) of the phytoplankton. Both techniques provide useful information, although neither reveals anything about the species composition of the plant community, an extremely important consideration that must still depend upon microscopic examination.

9.3.1 Summary of Plankton Studies, 1920 to Present

Since 1949, the CALCOFI program has conducted plankton studies throughout southern California inshore waters. Thrailkill (1969) has summarized these data and provides a list of the reports. Because the studies were oriented primarily towards zooplankton, a standard (1-meter, 505-μ mesh) net was used; as a consequence, the data do not include information on the smaller species of plankton. Figure 9-1 shows the variation in monthly net plankton biomass in the area extending from Point Conception to Ensenada, Baja California, between 1949 and 1969. As shown in the figure, variations up to two orders of magnitude have been observed in this 20-year period.

Between 1920 and 1940, Allen (1928a and b, 1936, 1941) collected net samples at La Jolla, Oceanside, and Point Hueneme. Allen's results show that there have been considerable differences in species composition from month to month as well

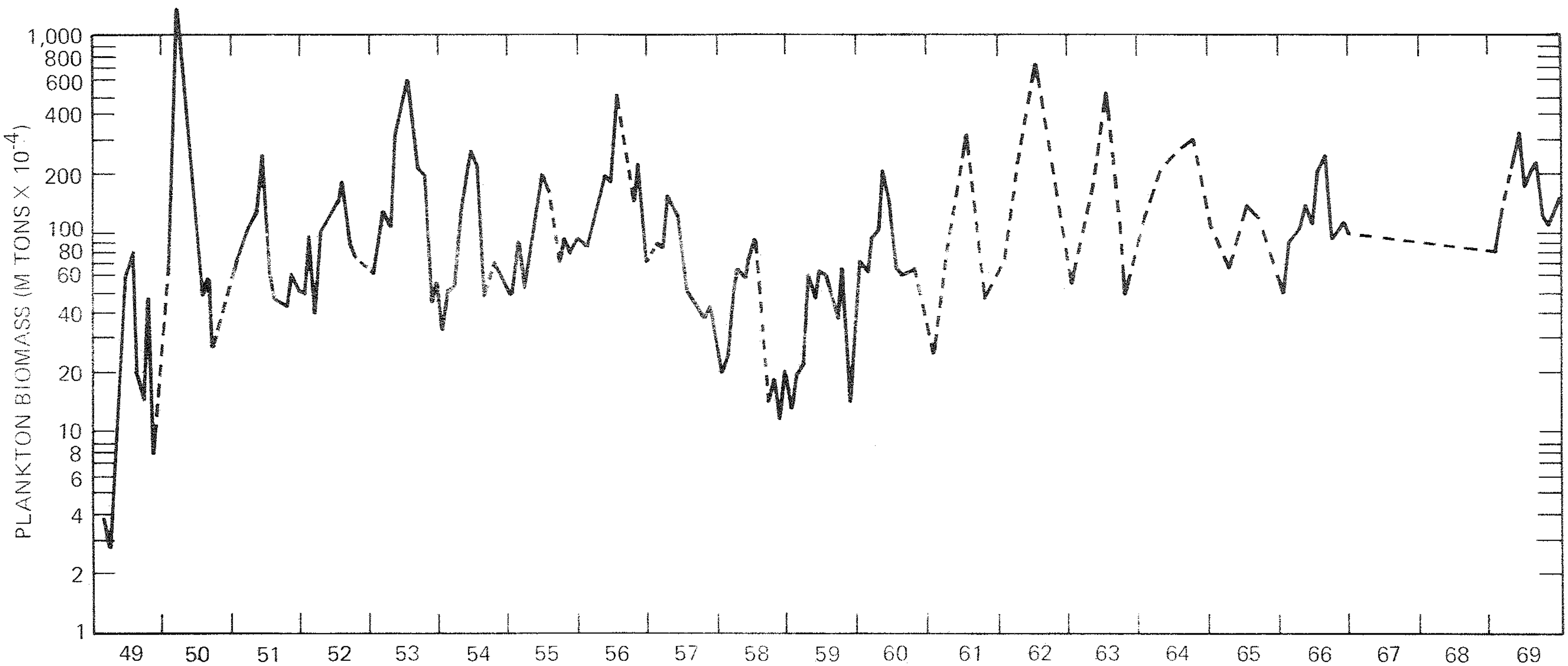


Figure 9-1. Monthly Plankton Volumes in Southern California Coastal Waters (Pt. Conception to Ensenada, Baja California), 1949-69. Based on CALCOFI Data, Southern California Inshore Region.

as annually at these three widely separated locations along the coast. Many of the differences found are related to differences in water temperatures.

Balech (1960) compared plankton collected by Allen at La Jolla in 1938-39, a period of highly abnormal seasonal fluctuations, with plankton collected in the relatively warm-water period of 1957-58. He noted significant species differences between the two periods. Similar effects were also found north of Monterey Bay (Bolin and Abbott 1963) and in Santa Monica Bay.

A number of studies have concentrated upon the areas around wastewater outfalls. Stevenson and Grady (1956) measured net plankton volume around three outfalls and noted an increase within 300 meters of the points of discharge (Figure 9-2). It was estimated that, under certain conditions, the influence of the outfall could be detected as far as 3,600 meters from the discharge. However, background levels were often observed 300 to 900 meters away. On the basis of the more recent 1957-70 data for the City of Los Angeles discharge in Santa Monica Bay (Section 9.3.2), it is likely that the observed "response" shown in Figure 9-2 could have resulted from a redistribution of the plankton standing crop (a combined physical-behavioral effect) as well as from any enhancement of the growth rates.

Between 1956 and 1959, the Allan Hancock Foundation of the University of Southern California measured plankton in its studies of the southern California mainland shelf (Allan Hancock Foundation 1959, 1965). It was concluded that the wastewater discharges enhanced the diatom population, but that the dinoflagellates were relatively unaffected, as would be expected. A portion of these data for an area encompassing the shorter, old Orange County outfall was reviewed by

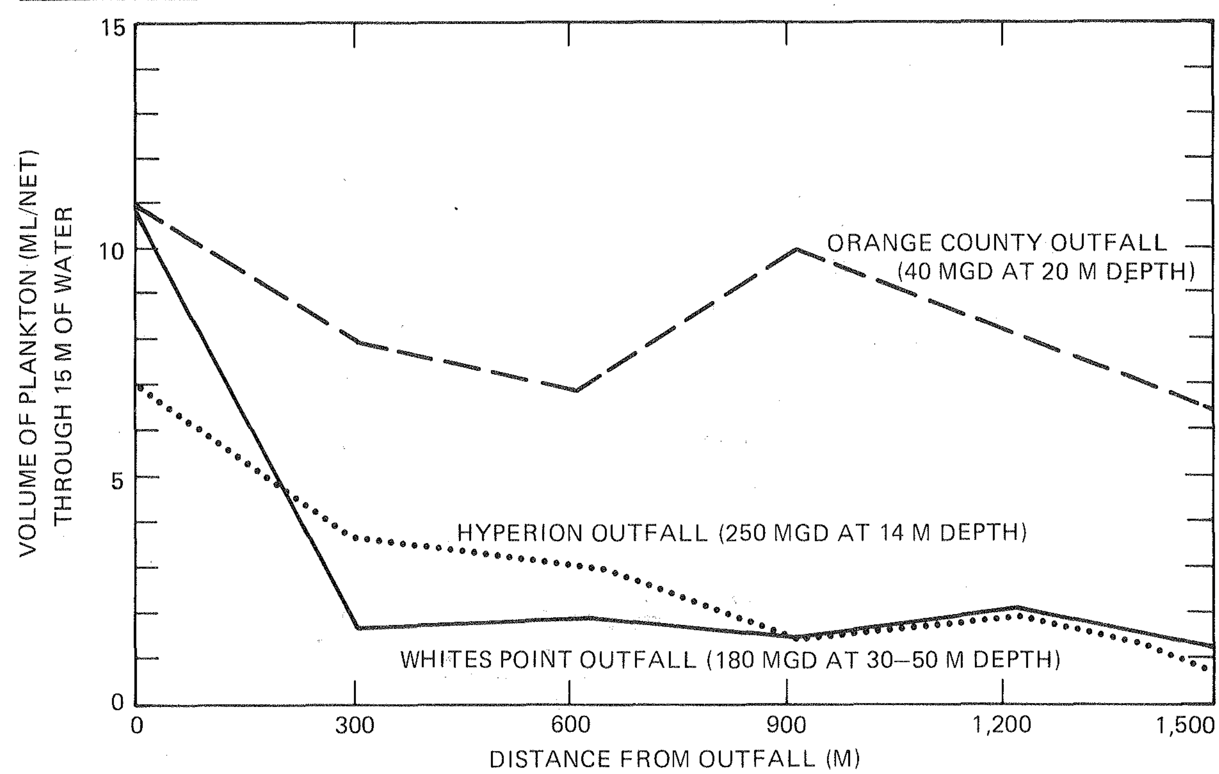


Figure 9-2. Average Plankton Volumes Near the Hyperion, Whites Point, and Orange County Outfalls, 1955-56. From Stevenson and Grady 1956.

North (1969). Although one species of diatom (*Skeletonema costatum*) occurred only over the outfall region, it was concluded that the data were insufficient to determine if this was a result of the outfall or was more related to the effects of nearby submarine canyons.

Between 1958 and 1966, plankton studies were conducted in the vicinity of the City of San Diego wastewater discharge off Point Loma (Marine Advisors 1963; Water Resources Engineers 1965). The data were divided into three periods:

Predischarge	Prior to September 1963
Effluent Discharge	September 1963 to September 1964
Effluent Plus Digested Sludge Discharge	September 1964 to December 1966

The only organism showing a consistent decrease during the three periods was the dinoflagellate *Noctiluca*. The diatoms, *Skeletonema costatum* and *Mastogloia*, the dinoflagellates, *Dinophysis*, *Prorocentrum* and *Oxytoxum*, and unidentified radiolarians all appeared to increase as a result of the discharge, some particularly during the sludge discharge period. These changes were not all statistically significant, and no grossly adverse effects were indicated. In fact, *Gonyaulax*, one of common red tide organisms, ranked high in frequency, concentration, and prominence, both before and after initiation of the waste discharge.

9.3.2 Santa Monica Bay Plankton Study, 1957-70

Between 1957 and 1970, the City of Los Angeles collected plankton data in the Santa Monica Bay area to provide a basis for determining if the Hyperion wastewater discharges affect plankton productivity or species composition. During this 14-year period, the wastewater discharge rate increased from 260 to 340 mgd, and the outfall system was changed from a 1-mile outfall in 14 to 18 meters of water to a 5-mile outfall located at a depth of 60 meters.

Over the course of the study, as many as 28 sampling stations (including the 24 shown in Figure 9-3 and four others around the 1-mile outfall) were used. Plankton were collected with a 64-μ mesh net in the upper 15 meters of the water. The samples were settled, and large organisms such as ctenophores or tunicates (comb jellies or salps) were removed. The total plankton volume was measured, as were the volumetric fractions of diatoms, dinoflagellates, zooplankton, fish eggs, etc. Additional examinations were made microscopically.

Abundance and Distribution

Figure 9-4 shows a comparison of the mean annual plankton volumes obtained from the Santa Monica Bay surveys with the plankton volumes obtained in the CALCOFI program for the same years (Figure 9-1). Although different collection gear was used in each survey, and plankton displacement volumes and biomass are being compared, the same trends are apparent in both sets of data. This suggests very strongly that the environmental factors affecting plankton abundance in Santa Monica Bay are the same as those affecting plankton abundance throughout southern California waters. The City of Los Angeles 5-mile wastewater outfall was put into operation in 1960. The old outfall used prior to

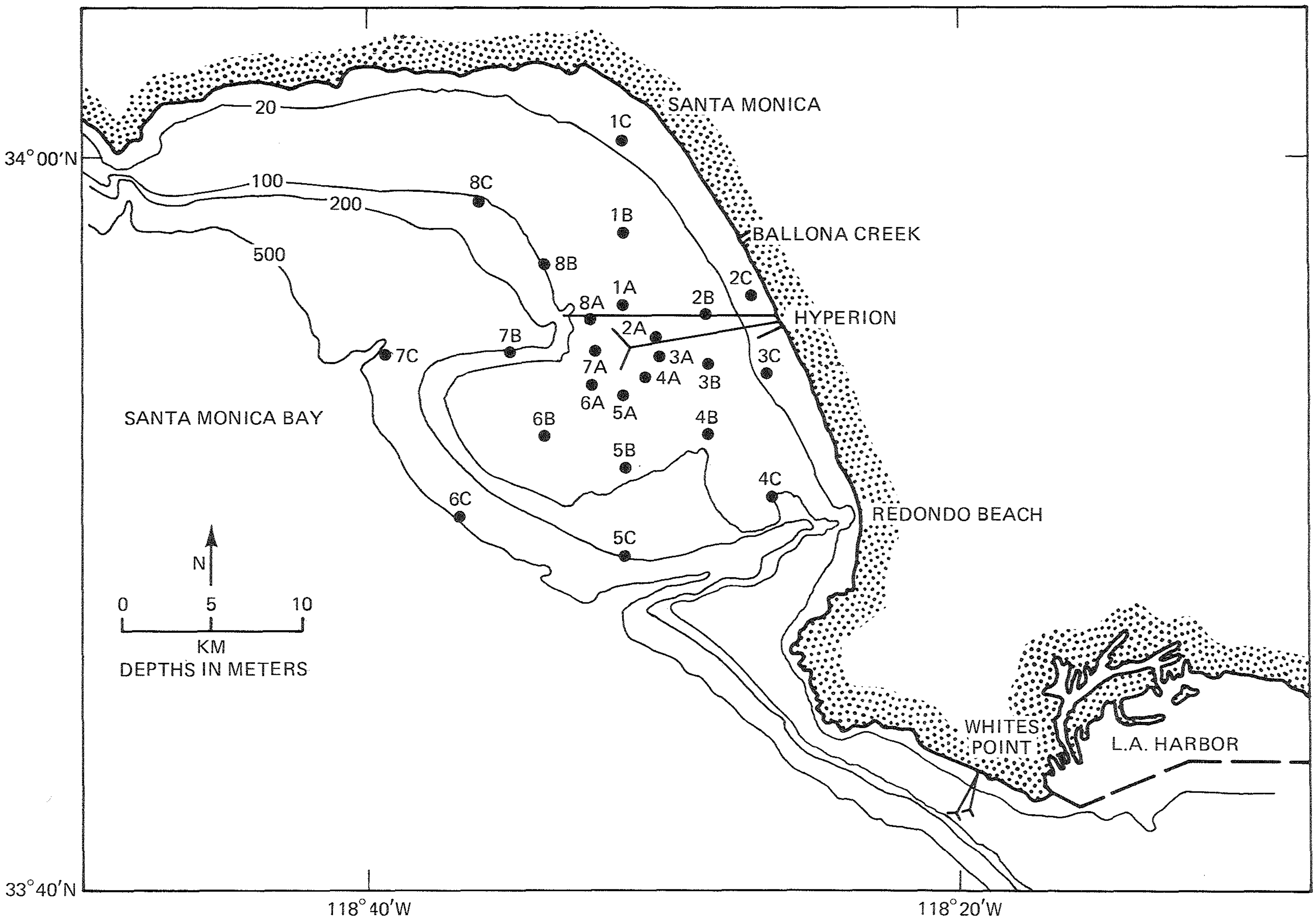


Figure 9-3. Location of Stations Sampled in 1957-70 Santa Monica Bay Phytoplankton Study.

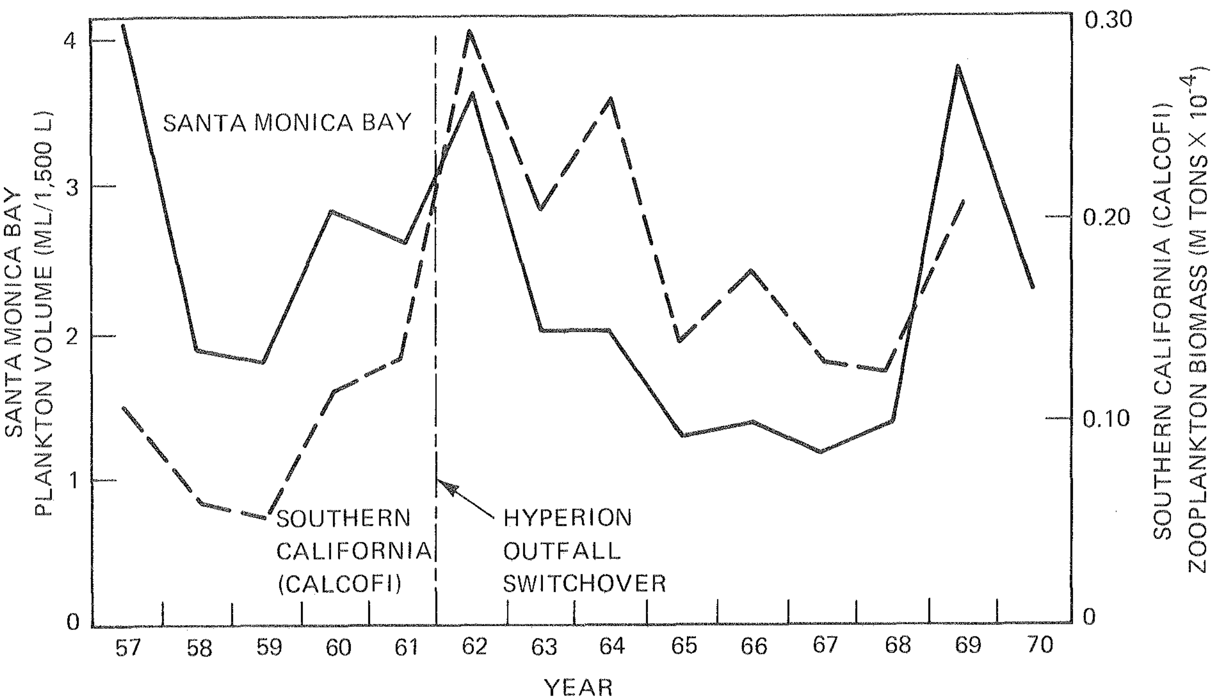


Figure 9-4. Variations in Plankton Abundance, 1957-70.

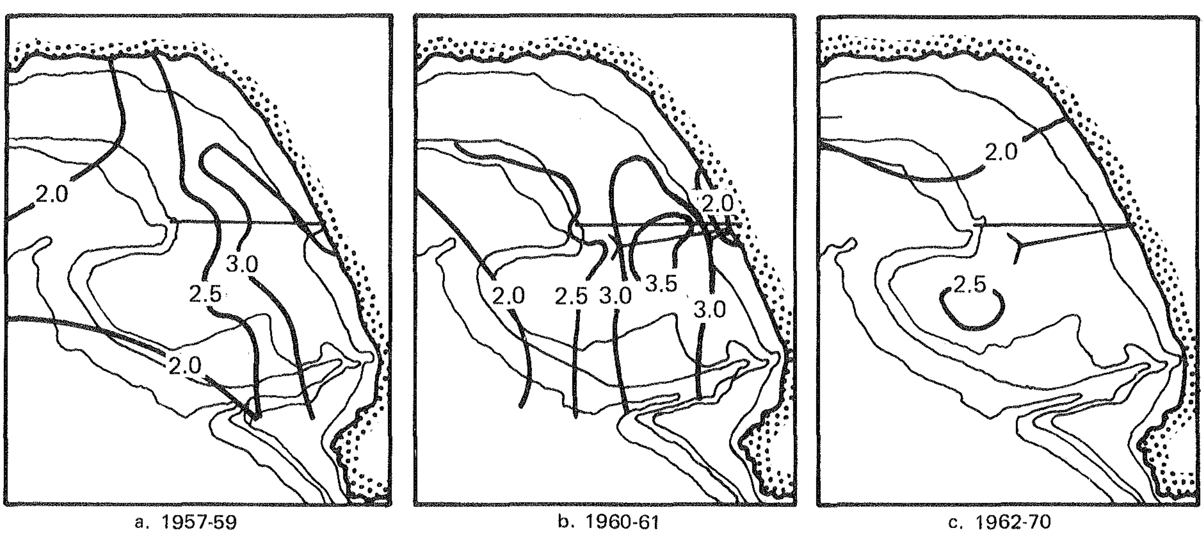
that date (and still in use in 1961) was in relatively shallow water, and the wastewater was well mixed within the surface waters in the vicinity of the outfall. In contrast, the discharge from the longer outfall normally remains submerged because of the design of the outfall and the depth at which it discharges. Thus, any nutrients that might enhance the plankton populations in the surface waters are less available; that is, they can only be transported to the surface waters by vertical diffusion or advection or by excretions of animals that have migrated into the region. That this hypothesis might have validity is suggested by Figure 9-4. If it is assumed that the zooplankton biomass estimates obtained in the CALCOFI program represent a natural or baseline condition, then the relative concentrations in Santa Monica Bay are higher than the CALCOFI data for the period 1957-61 when wastewaters were being discharged through the shallow outfall and the nutrients contained therein are presumably more available for biological uptake. Between 1962 and 1968, when the wastewaters were being discharged through the deep outfall, the plankton volumes are relatively smaller than would be expected on the basis of the CALCOFI data. The apparent relationship does not hold in 1969; however, this was a year in which exceptionally heavy rainfall and runoff was experienced, and additional nutrients were undoubtedly brought into the surface waters through that means.

Figure 9-5 presents the mean areal plankton distributions in Santa Monica Bay for the following three periods:

Period	Discharge
1957 to 1959	
Shallow outfall	260 mgd primary effluent
Deep outfall	(Not in operation)
1960 to 1961	
Shallow outfall	100 mgd secondary effluent
Deep outfall	160 mgd primary effluent
1962 to 1970	
Shallow outfall	(Not in operation)
Deep outfall	280 to 340 mgd effluent (2/3 primary treated, 1/3 secondary treated)

During the period 1957 to 1959 (Figure 9-5a), when only the old, shorter outfall was in operation, the maximum plankton volumes were observed just beyond the end of the outfall. From 1960-61 (Figure 9-5b), when both outfalls were in operation, the maximum plankton volume concentration had increased slightly,[4] and the center of maximum plankton volume had moved somewhat offshore, between the

4. A similar increase over this 3-year period was observed in the CALCOFI results.



a. 1957-59

b. 1960-61

c. 1962-70

Figure 9-5. Distribution of Plankton in Santa Monica Bay During Three Discharge Periods, 1957-59, 1960-61, and 1962-70 (mL/1,500 L).

ends of the old and new outfalls. From 1962-70, when only the new 5-mile outfall was in operation (Figure 9-5c), the maximum plankton concentration had dropped to around 2.5 mL/1,500 L, and the area of maximum concentration was offshore and southwest of the end of the new outfall.

The volume of plankton (standing crop) is the result of a complex balance between advection, growth, grazing, and a host of other factors. It is difficult to derive a coherent or consistent picture of changes in the concentration of plankton in the southern California nearshore waters as they might be related to known environmental factors. The data from this and other studies give some indication that wastewater discharges, particularly in shallow waters, may enhance phytoplankton growth. However, in many cases, the fact that wastewater discharges are located in areas where upwelling may occur makes it difficult to separate the possible effects of these factors.

Species Composition

Analysis of specific organisms in the Santa Monica Bay plankton sampling program was limited to the ranking (on the basis of biovolume) of the principal organisms found in the samples. A preliminary analysis of the data indicates that over the three periods (1957-59, 1960-61, and 1962-70), two diatoms, *Chaetoceros* and *Dactyliosolen*, probably increased in relative dominance, and *Ditylum* and *Achnanthes* probably decreased. Among the dinoflagellates, *Noctiluca* increased and *Ceratium furca* decreased. The relative ranking of *Gonyaulax* was variable and showed no consistent trend.

A comparison of these data with those collected from Point Loma over an 8-year period shows that the dinoflagellate, *Noctiluca*, decreased at Point Loma but increased in Santa Monica Bay.

From the evidence available from the Santa Monica Bay study and previous investigations, it does not appear that dinoflagellate populations are affected by the presence of wastewater discharges.

Evaluation of Study Plan and Procedures

The plankton studies carried out in Santa Monica Bay appeared to reflect adequately both the large-scale changes due to natural effects and the smaller scale effects that may be due, at least in part, to wastewater discharges. This monitoring program, however, involved the almost daily efforts of two full-time biologists, as well as the support services required for sampling. The question naturally arises as to whether or not this effort was justified in terms of the information obtained. Table 9-2 presents the results of a comparison of the plankton concentrations obtained from six selected stations to those obtained from an 18-station grid pattern. The six stations selected (Stations 3A to 3C and 7A to 7C, Figure 9-3) are in a line roughly parallel to the outfalls, including both near- and off-shore stations.

The data presented in Table 9-2 suggest that equivalent results would have been obtained from approximately one-third of the stations in Santa Monica Bay.

The results in the 1957-70 Santa Monica Bay plankton studies were biased by the plankton nets that were used. Significant savings in time and effort would

Table 9-2
COMPARISON OF MEAN PLANKTON VOLUMES (ML/1,500 L)
AT TWO SETS OF STATIONS IN SANTA MONICA BAY, 1957-70

	Discharge Time Period		
No. of Stations	1957-59	1960-61	1962-70
6 Stations			
Mean	2.72	2.77	2.07
(Standard deviation)	(0.55)	(0.75)	(0.05)
18 Stations			
Mean	2.60	2.73	2.10
(Standard deviation)	(0.52)	(0.58)	(0.19)

have been achieved if sampling and measurement of chlorophyll concentrations were substituted for the routine measurement of plankton volumes. Clearly, parallel measurements of chlorophyll and plankton volume should be made to establish a comparison between the two types of measurement, determine the relative contributions of large and small plankton, and obtain a record of the species composition in the samples.

Chlorophyll measurements provide a rough and simple quantitative index of the total phytoplankton and their photosynthetic potential, although they do not provide information on species abundance and distribution. This latter type of information can best be obtained (albeit at higher cost) by making cell counts on settled or centrifuged whole water samples.

9.3.3 Dinoflagellate Blooms (Red Tides)

Moderately to heavily enriched seawater normally supports a phytoplankton flora that is dominated by diatoms. However, at least a few dinoflagellates can usually be found at all times, and when nutrients become depleted from the water, the dinoflagellates often assume dominance.

At times, various species of dinoflagellates become so numerous that they create an algal bloom known as red tides. It is believed that localized red tides occur along the southern California and Baja California coast almost every year (Strickland 1970). The environmental conditions responsible for the production of red tides are not fully understood, but it has been suggested that they result from the physical concentration of dinoflagellates in restricted areas at the sea surface rather than from any prolific growth of the organisms. More than 15 such blooms have been documented,[5] with various degrees of detail, in the period since 1894. Organisms reported to be associated with these blooms include *Gonyaulax*, *Peredinium*, *Ceratium*, and *Polykrikos*.

5. References: Coe (1957); Holmes, et al. (1967); Abbott and Albee (1967); Ritter (1902); Torrey (1902); Somner and Clark (1946); Carlisle (1968).

In spite of the frequency of these blooms, they only infrequently result in extensive mortalities of fish, although the fish kills may be large when they do occur. In 1945, there was a red tide that extended from San Luis Obispo to the Los Angeles Harbor, and it has been estimated that approximately 4 to 5 tons of lobster died during this occurrence (Somner and Clark 1946). Organisms that have been identified as being affected by red tides are anchovy, halibut, sharks, rays, guitarfish, octopi, sea cucumbers, crabs, mussels, and barnacles.

The importance of this phenomenon in relation to the health of a number of coastal marine organisms, and the potential seriousness of the effects on people who may eat shellfish that have been affected, justifies continued study.

9.4 EXPERIMENTAL PHYTOPLANKTON STUDY, 1971-72

In 1971-72, SCCWRP conducted an experimental program to investigate the influence of southern California wastewater discharges on marine phytoplankton. The work involved nutrient enrichment experiments and measurements of chlorophyll, nutrients, and primary production near outfalls.

9.4.1 Nutrient Enrichment Experiments

The purpose of the nutrient enrichment experiments was to determine, under controlled conditions, the element or elements that are limiting to phytoplankton growth in southern California nearshore waters. Five experiments were conducted, using samples of natural surface waters taken off Camp Pendleton (near Oceanside) and La Jolla and in Santa Monica Bay. Care was taken to ensure that the water samples were taken from areas unaffected by local wastewater discharges. The water samples were analyzed for nitrogen, phosphorus, and silicon.

The seawater samples were enriched with various nutrients singly and in combination, and the growth of phytoplankton was measured (in terms of fluorescence units) over a 4-day period following enrichment in batch culture experiments. The experimental methodology is described by Thomas (1972).

The results of enriching seawater from the five sampling areas are given in Table 9-3. As might be expected, enrichment with the complete artificial medium resulted in considerably greater growth over the 4-day experimental period than did enrichment with any single ingredient of the culture medium, with the growth enhancement ranging from 8 to 37 times and averaging 19 times that of the unenriched control. The addition of Point Loma sewage by itself to the same water samples enhanced growth 3 to 45 times and averaged 16 times that of the unenriched control. Thus it is clear that sewage represents very nearly a complete growth medium for marine phytoplankton. However, the enrichment with both the complete inorganic medium and Point Loma sewage resulted in growth that exceeded that obtained by either ingredient alone in every case but one (Camp Pendleton), suggesting that each has one or more nutritional ingredients lacking in the other, or that the quantity of one or more nutrients in the combined enrichment was able to sustain growth longer than that contained in either alone.

Enrichment with the individual nutrient constituents of the artificial medium resulted in significant growth enhancement only in the case of nitrogen,

Table 9-3
GROWTH OF PHYTOPLANKTON IN ENRICHED SURFACE SEAWATER SAMPLES AFTER 4 DAYS INCUBATION IN NATURAL DAYLIGHT (EXPRESSED AS PERCENT OF CONTROL VALUES)

Enrichment	Camp Pendleton, July 1971	Santa Monica Bay, October 1971	Camp Pendleton, February 1972	La Jolla, April 1972	La Jolla, May 1972
ADDITION OF NUTRIENTS					
None (Control)	100	100	100	100	100
Plus nitrogen	300	561	204	426	679
Plus phosphorus	85	196	168	81	129
Plus silicon	100	217	166	80	212
Plus iron	85	161	134	79	125
Plus trace metals	92	191	128	104	258
Plus vitamins	100	135	154	95	217
Complete	3,715	1,787	1,155	813	2,062
Plus 1:200 Point Loma sewage	1,500	1,470	793	318	4,158
Complete plus 1:200 Point Loma sewage	4,416	3,257	983	1,154	6,796
DELETION OF NUTRIENTS					
Complete (Control)	100	100	100	100	100
Complete minus nitrogen	3	12	12	11	8
Complete minus phosphorus	10	51	27	71	79
Complete minus silicon	80	88	19	60	281
Complete minus iron	75	126	18	97	283
Complete minus trace metals	31	88	64	95	278
Complete minus vitamins	24	118	58	90	210

ranging from 2 to 7 and averaging 4 times that of the unenriched control. This was roughly an order of magnitude less than the growth obtained with the complete medium, with sewage, or with a mixture thereof, and most of the enhancement took place during the first 24 hours. These results demonstrate not only that nitrogen is the primary limiting factor to algal growth in the waters tested, but also that one or more other nutrients quickly become limiting if nitrogen alone is supplied.

Similar results were obtained in other experiments in which each of the individual constituents was deleted in turn from the complete enrichment medium. In every case, elimination of nitrogen resulted in a reduction to about 10 percent of the growth achieved in the complete medium. Omission of other nutrients produced variable results with the different water samples, reducing growth in some cases but actually enhancing growth two- to three-fold in others (i.e., omission of silicon, iron, trace metals, and vitamins from the enrichment of the May 1972 La Jolla water sample).

9.4.2 Field Surveys of Chlorophyll, Nutrients, and Primary Productivity

Between May 1971 and May 1972, five sampling cruises were carried out around three major wastewater outfalls between Point Loma and Point Conception. The sampling areas are shown in Figure 9-6. The area off Point Conception and Santa Barbara was selected because of expected upwelling conditions; areas off Camp Pendleton and La Jolla were selected as controls.

Usually, each of the cruises lasted 3 to 5 days, and each set of sampling stations near a major outfall was sampled during 1 day, although not all outfalls were sampled during each cruise. The procedure at each sampling station was first to measure the temperature structure of the water column and to estimate the depth of the euphotic zone using a Secchi disk. Usually, seven samples were taken between the surface and the euphotic depth. These samples were analyzed for chlorophyll a and ammonia and nitrate nitrogen. Carbon 14 analyses of phytoplankton productivity were made only at stations occupied about noon immediately over the outfall or in the center of station grids in the control areas.

More detailed descriptions of the sampling and analytical methodology as well as the results of these field studies are given by Thomas (1972).

A summary of the chlorophyll and nitrogen concentrations measured during the five surveys is presented in Table 9-4. It should be noted that the values given for chlorophyll and the two forms of nitrogen are integrated values, that is, the total number of milligrams of the constituent within the euphotic zone per square meter of surface area. These values will differ substantially from the average volumetric concentration.

Comparison of the data from the five cruises taken over about a 1-year period shows that the maximum chlorophyll and nitrogen concentrations were observed during the May 1971 cruise. In general, there were no major area-wide differences in the chlorophyll or nitrogen concentrations between the cruises taken in September 1971 and January-February 1972. The fifth cruise in May 1972 made

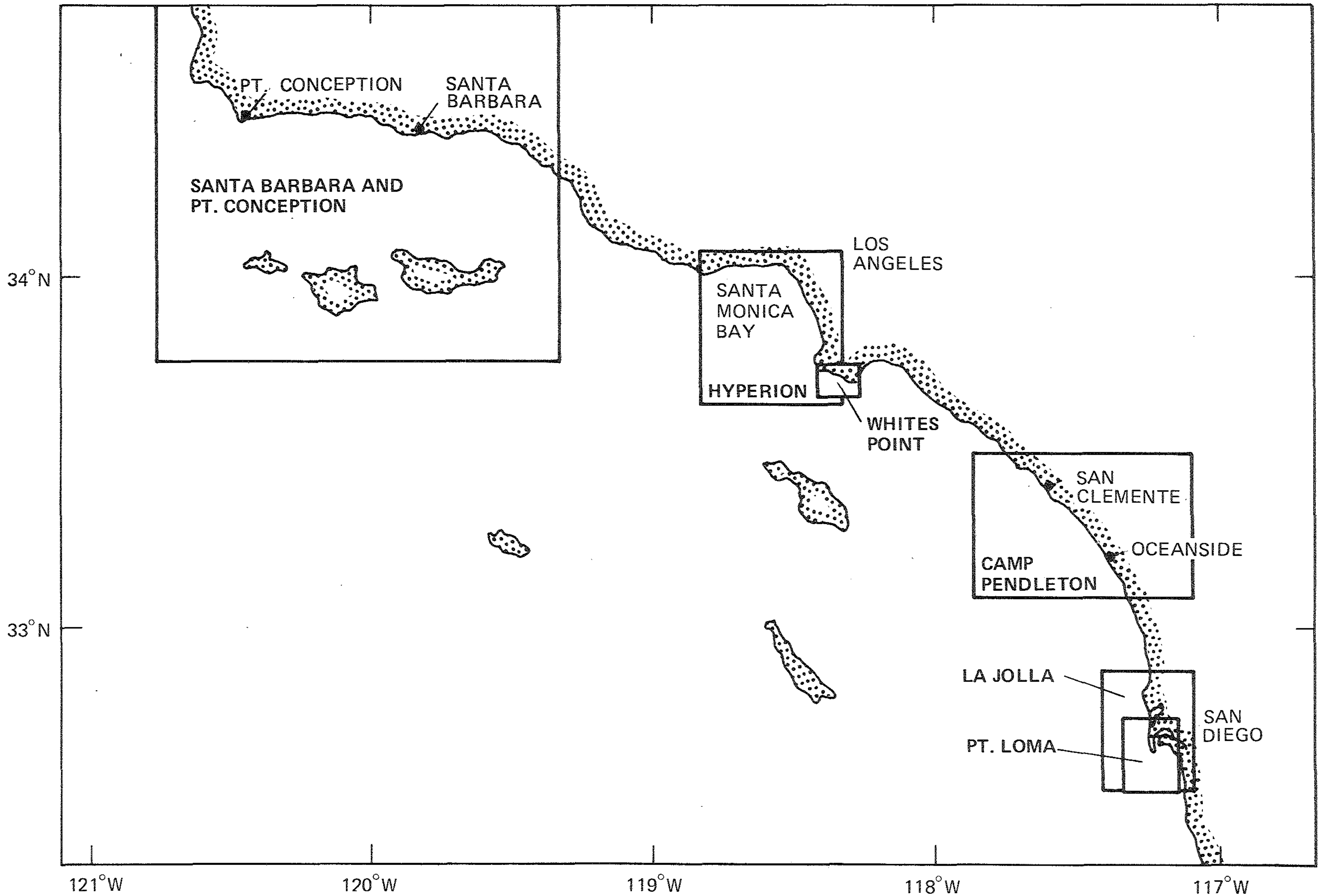


Figure 9-6. Areas Sampled in 1971-72 Phytoplankton Study in Southern California Coastal Waters.

Table 9-4

SUMMARY OF INTEGRATED CHLOROPHYLL AND NITROGEN CONCENTRATIONS (MG/SQ M) DETERMINED IN PHYTOPLANKTON FIELD STUDIES IN SOUTHERN CALIFORNIA COASTAL WATERS*

Area	Characteristic	Cruise 1, May 71	Cruise 2, Jun-Jul 71	Cruise 3, Sep-Oct 71	Cruise 4a, Jan-Feb 72	Cruise 4b, 4 Feb 72	Cruise 5, May 72
CONTROL AREAS							
Point Conception/ Santa Barbara	Chlor-a	18-101					
	NH_3-N	4-36					
	NO_3-N	31-342					
Camp Pendleton	Chlor-a	88	4-26	9-45	15-32		
	NH_3-N	74	3-36	0-2	4-52		
	NO_3-N	160	0-42	0-36	15-203		
La Jolla	Chlor-a						27-38
	NH_3-N						2-7
	NO_3-N						0-4
OUTFALL AREAS							
Hyperion	Chlor-a	28-105	10-36	23-47	16-80		
	NH_3-N	11-123	3-64	0-36	18-91		
	NO_3-N	39-341	6-192	0-67	24-191		
Whites Point	Chlor-a	63-338	26-91	32	33-52		
	NH_3-N	21-815	3-145	10	49-316		
	NO_3-N	80-515	1-45	36	28-164		
Point Loma	Chlor-a		41-82	9-38	12-43	23-60	14-50
	NH_3-N		3-52	1-50	2-42	13-38	2-193
	NO_3-N		1-16	7-156	24-169	18-104	1-605

*Minimum and maximum values

measurements only in the San Diego (Point Loma) area, so a comparison between May 1972 and May 1971 is not possible.

The high concentrations of nitrate at Point Conception and Santa Barbara in May 1971 were undoubtedly due to upwelling, which is known to be active in that area at that time of year. High nitrogen values were also observed in Santa Monica Bay and off Whites Point in May 1971. Although it is not possible in the latter case to distinguish completely between the effects of upwelling and wastewater discharge, the relative proportions of nitrate and ammonia are suggestive. The nitrogen in upwelled water is largely nitrate; that in an unoxidized wastewater is predominately ammonia. Thus, the the high ratios of nitrate to ammonia around Santa Monica Bay and Whites Point (5:1) in May 1971 (just as off Point Conception and Santa Barbara) are more indicative of upwelling than of wastewater as the principal source of nitrogen.

The situation in January-February 1972 was reversed, at least at the Whites Point stations, where the median nitrate-to-ammonia ratio was 0.9. These nitrogen concentrations were considerably lower than those observed in May 1971, but still significantly higher than those at the Camp Pendleton area, the difference presumably resulting from wastewater contributions.

The enrichment studies indicated that the doubling time of the phytoplankton (based on chlorophyll) was approximately 1 day. However, in a natural environment, there are phytoplankton losses due to grazing and sinking, and the apparent doubling times in the natural environment can be substantially longer. When this factor is considered in conjunction with average transport velocities, significant enhancement from nutrient input would not be expected to occur within perhaps several kilometers "downstream" from an outfall area. However, in several of the cruises, maximum chlorophyll values were found in the immediate areas of the outfalls. One possible explanation for this apparent anomaly is that the phytoplankton sink to the lower, nutrient-laden layers over the outfall and then move upward due to increased buoyancy (diatoms) and migration (dinoflagellates).

The average integrated concentrations of chlorophyll in each sampling area for each cruise are presented in Table 9-5. The table also shows the same values for the areas selected as reference or control areas, as well as estimated productivities and an indication of the presence or absence of phytoplankton enhancement.

The integrated chlorophyll values in the outfall areas ranged from 94 to 407 percent of the values observed in the control areas. On the basis of average chlorophyll concentration, these ratios ranged from 60 to 580 percent. To determine if these differences were statistically significant, a nonparametric statistical analysis, using ranking of the station concentrations, was made. The results of this analysis are shown also in Table 9-5. In the Whites Point area, there appeared to be significant enhancement in three of the four cruises measured. There is some indication of enhancement in the Santa Monica Bay area and at Point Loma. Three of the four cruises showed no enhancement. These results are not clear-cut, and much further and more extensive study is required. In any case, the enhancements in the outfall areas, except in periods of local upwelling, produce average volumetric chlorophyll concentrations in the area that are

Table 9-5
COMPARISON OF OUTFALL AND CONTROL AREAS

Cruise	Date	Area	Integrated Chlorophyll mg/sq m	Integrated Chlorophyll Percent of Control Area	Integrated Productivity mg C/sq m-day	Integrated Productivity Percent of Control Area	Significance of Phytoplankton Enhancement*
1	8 May 71	Hyperion	47	94	609		+?
	8 May 71	Whites Point	139	280			+
	5-7 May 71	Santa Barbara (Control)	50	100	327		
	9 May 71	Camp Pendleton (1 station)	48	96			
2	1 Jul 71	Hyperion	24	172	1,932	98	+?
	30 Jun 71	Whites Point	57	407	1,999	101	+
	28 Jun 71	Point Loma	56	400	2,298	116	+
	29 Jun 71	Camp Pendleton (Control)	14	100	1,972	100	
3	27 Sep 71	Hyperion	31	163	1,895	98	+?
	27 Sep 71	Whites Point (1 station)	32	169	-	-	+?
	30 Sep 71	Point Loma	19	100	1,165	61	-
	Oct	Camp Pendleton	19	100	1,926	100	
4	2 Feb 72	Hyperion	33	138	1,825	194	+
	3 Feb 72	Whites Point	44	183	1,257	134	+
	31 Jan 72	Point Loma	29	121	1,047	111	
	4 Feb 72	Point Loma	36	150	1,010	104	-
	1 Feb 72	Camp Pendleton	24	100	940	100	
5	22-23 May 72	Point Loma	28	94	1,500	92	-
	23 May 72	La Jolla (Control)	30	100	1,626	100	

*Definition of symbols:
- \+ Enhancement (95% confidence level)
- +? Possible enhancement
- \- No enhancement

generally comparable to or less than those observed during an upwelling period in the Santa Barbara Channel, i.e., chlorophyll concentrations of about 4 mg/cu m.

In general, the integrated productivity in the outfall areas ranged from 60 to 200 percent of the productivities observed in the control areas. No one area was consistently higher or lower than the others.

The integrated nutrient values for the five cruises are listed in Table 9-6. The relative magnitude of these values for the last four cruises compared to those observed in the control areas are also given as a percentage. The effects of water column stability (presence or absence of a thermocline) are evident in this table. During Cruise 3 in September, 1971, the thermocline was pronounced, and the ammonia concentrations in the euphotic layer were much lower than during the following cruise in February 1972, when there was no thermocline. Similar differences are observed for both nitrate and nitrite nitrogen. The fact that the differences in phosphate and silicate are not nearly so pronounced is further evidence that phytoplankton growth in these waters is limited by nitrogen. The low total nitrogen values observed during the September cruise indicate that the thermocline is effective in limiting transport from the deeper nutrient-rich waters into the euphotic zone.

In contrast, the September/February changes in the integrated ammonia and nitrate concentrations were not as large in the outfall areas as in the control areas, indicating that the supply of nutrients into the euphotic zone in the outfall areas is more uniform in time. This suggests that the higher nitrogen and phytoplankton concentrations in the outfall areas may be related to the wastewater discharges.

9.5 PHYTOPLANKTON RESPONSE MODEL

In recent years, a number of phytoplankton response models of varying degrees of sophistication have been developed. Patten (1968) describes some of these models for the open ocean. Other models have been developed for closed or well defined bodies of water (e.g., Di Toro et al. 1971). Dugdale and Whitledge (1970) have developed a two-dimensional model of the response of phytoplankton to nutrient inputs from a surfacing wastewater discharge.

In the Southern California Bight, the major wastewater discharges are so designed that they remain submerged during most of the year. As a consequence, there is a need for a phytoplankton response model capable of simulating the submerged wastefield situation. This section summarizes the work done to date by SCCWRP in the development of such a model.

Two types of wastefields have been considered in the development of the phytoplankton response model; these are shown schematically in Figure 9-7. The difference between the two wastefield types lies in the relative position of the wastewater plume and the euphotic depth. In a Type I wastefield, the euphotic depth lies below the thermocline and therefore, under the assumptions of the model, below the top of the wastewater plume. In a Type II wastefield, the wastewater plume does not rise above the euphotic depth.

Table 9-6
MEDIAN INTEGRATED NUTRIENT CONCENTRATIONS*

Cruise	Date	Location	NH_4-N (mg/sq m)	Percent of Control	NO_3-N (mg/sq m)	Percent of Control	NO_2-N (mg/sq m)	Percent of Control	PO_4-P (mg/sq m)	Percent of Control	SiO_4-Si (mg/sq m)	Percent of Control	Total Inorganic Nitrogen (mg/sq m)
1**	8 May 71	Hyperion	382.2	38	3,838.8	80	21.00	11	821.5	110	9,690.8	173	14,754.3
		Whites Point	1,043.0	101	4,565.4	95	18.20	10	1,243.1	166	9,119.6	162	15,989.3
	6 May 71	Santa Barbara	57.4	6	434.0	19	2.66	1	316.2	42	2,892.4	51	3,702.6
	7 May 71	Santa Barbara	505.4	49	4,795.0	212	39.20	21	1,689.5	225	17,511.2	311	24,540.3
	9 May 71	Camp Pendleton	(1,029.0)	100	(2,247.0)	100	(186.20)	100	(753.3)	100	(5,616.8)	100	(9,832.3)
2	1 Jul 71	Hyperion	347.2	443	236.6	94	4.90	29	207.7	131	1,909.6	44	2,706.0
	30 Jun 71	Whites Point	422.8††	539	240.8	96	4.06†	24	167.4	106	1,691.2	39	2,526.3
	28 Jun 71	Point Loma	100.8	129	51.8	21	4.34†	25	68.2	43	2,234.4	51	2,459.5
	29 Jun 71	Camp Pendleton	78.4	100	250.6	100	17.08	100	158.1	100	4,354.0	100	4,858.2
3	27 Sep 71	Hyperion	390.6††	3,986	527.8†	3,427	84.00††	6,666†	430.9†	240	2,256.8	193	3,690.1
	27 Sep 71	Whites Point	(144.2)	1,471	(508.2)	3,300	(54.18)	4,300	(582.8)	324	(3,029.6)	259	(4,319.0)
	30 Sep 71	Point Loma	74.2††	757	303.8††	1,972	32.34†	2,567	356.5††	198	3,469.2	297	4,236.0
	1 Oct 71	Camp Pendleton	9.8	100	15.4	100	1.26	100	179.8	100	1,167.6	100	1,373.9
4	2 Feb 72	Hyperion	897.4††	348	1,773.8	184	84.70	166	768.8	92	3,561.6	92	7,086.3
	3 Feb 72	Whites Point	1,198.4††	465	1,128.4	117	33.70	65	499.1	99	3,805.2	99	6,664.1
	31 Jan 72	Point Loma	334.6	130	1,257.2	131	60.90	119	421.6	131	5,045.6	131	7,119.9
	4 Feb 72	Point Loma	285.6	111	764.4	79	15.54†	30	337.9	121	4,662.0	121	6,065.4
	1 Feb 72	Camp Pendleton	257.6	100	961.8	100	51.10	100	334.8	100	3,858.4	100	5,463.7
5	22-23 May 72	Point Loma (near outfall)	117.6	187	911.4†	140	8.26	140	297.6	320	4,023.6	216	5,358.5
		Point Loma (>1.5 km from outfall)	166.6††	264	499.8†	733	43.12	733	263.5	283	4,482.8	240	5,455.5
	23 May 72	La Jolla	63.0	100	22.4	100	5.88	100	93.0	100	1,864.8	100	2,049.1

*Values in parentheses are from one station only.
**As only one station was sampled at Camp Pendleton, statistical significances with reference to this control area were not calculated for Cruise 1.
†Different from control at the 95% confidence level.
††Different from control at the 99% confidence level.

The model assumes steady-state conditions and estimates the distributions of a limiting nutrient and phytoplankton concentrations along the line of the current by calculating a mass balance for a series of cells along the current path. The steady-state condition requires that the concentration within a cell be constant; hence, the gain or loss of material across the cell interface must be balanced by internal sources or sinks within the cell.

The various processes considered in the model include advection, diffusion, nutrient uptake, the changing euphotic depth, sinking and respiration losses for the phytoplankton, grazing by zooplankton, and nutrient regeneration as a result of incomplete assimilation and excretion by the zooplankton grazing on the phytoplankton. Chemical reactions (oxidation or reduction of nitrogen forms, for example) are neglected, as are vertical movements of the phytoplankton. It is assumed that advection and lateral diffusion represent the principal transfer mechanisms; therefore, vertical diffusion is neglected for the model applied to Type I wastefields. However, either vertical diffusion or upwelling (vertical advection) must be included in modeling for a Type II wastefield as these are the means by which nutrients from the Type II wastewater plume could be transferred into the euphotic zone.

It is further assumed that nitrogen is the rate-limiting nutrient for phytoplankton growth. By expressing the phytoplankton concentration in terms of the nutrient that is incorporated into or stored in the phytoplankton cell material, it is possible to formulate two simultaneous, coupled equations for the nutrient and phytoplankton concentrations. The development of these equations is described in detail in Appendix E.

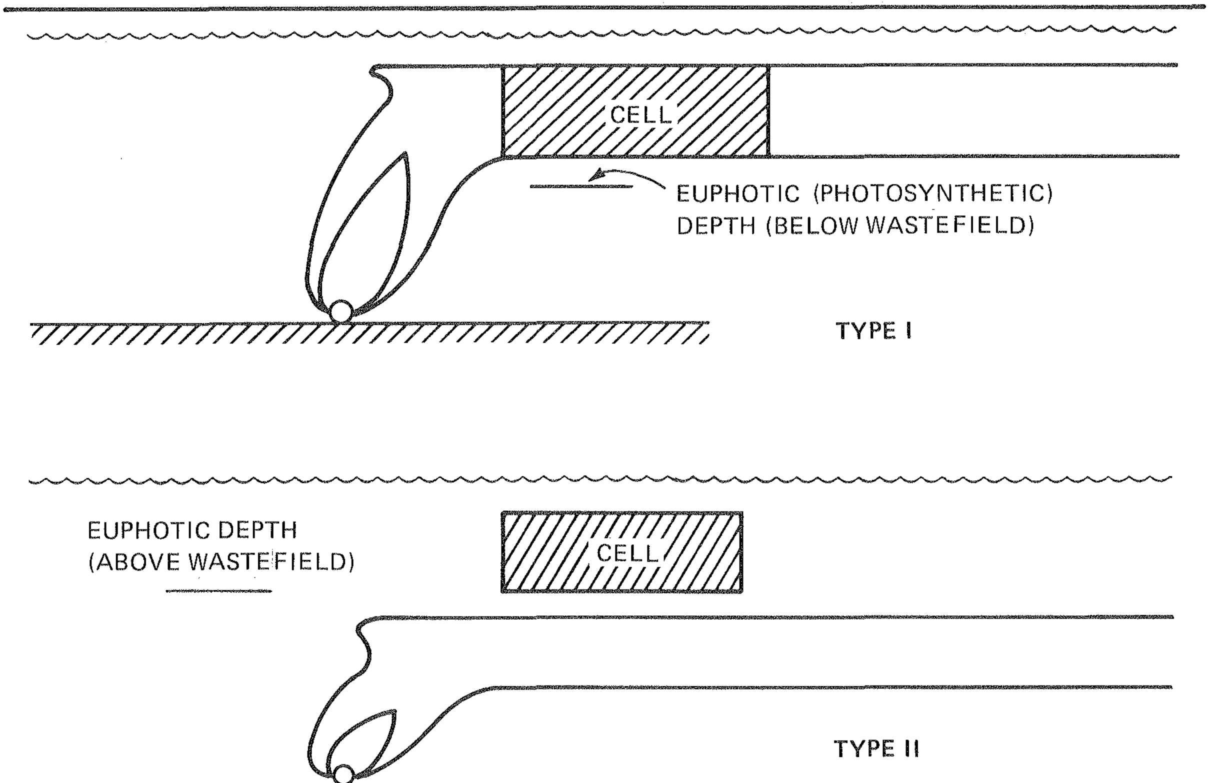


Figure 9-7. Wastefield Types Used in Phytoplankton Response Model.

The mass balance equations for the nutrient and phytoplankton concentrations in a particular cell can be written as

$$0 = 2 \frac{v_x}{l_x} (N_u - N) \qquad (A)$$

$$+ \frac{v_D}{\sigma_o + v_D t} \cdot (N_a - N) \qquad (B)$$

$$+ \frac{v_z}{l_z} (N_{T_c} - N) \qquad (C)$$

$$- \psi P V_m \frac{N}{N + K_N} \qquad (D)$$

$$+ (1 - r') G'P \qquad (F)$$

and

$$0 = 2 \frac{v_x}{l_x} (P_u - P) \qquad (A)$$

$$+ \frac{v_D}{\sigma_o + v_D t} \cdot (P_a - P) \qquad (B)$$

$$+ \psi P V_m \frac{N}{N + K_N} \qquad (D)$$

$$- GP, \qquad (E)$$

where

N, P = average nutrient and phytoplankton concentrations in the cell (μ-moles/L),

N_u, P_u = concentrations of nutrient and phytoplankton at the upstream face of the cell,

N_a, P_a = concentrations of nutrient and phytoplankton in the ambient waters,

N_{T_c}, N_{T_c}' = actual and ambient nutrient concentrations below the thermocline (for Type II),

v_x, v_z, v_D = horizontal advective velocity, vertical advective or "diffusion" velocity, and lateral "diffusion" velocity, respectively (m/sec),

l_x, l_z = length and depth of the cell (m),

σ_o = characteristic width of the wastefield at the upstream face (m),

V_m, K_N = specific uptake rate (sec^{-1}) and half-rate concentration (μ-moles/L) for the uptake of nutrient according to Michaelis-Menten kinetics,

G, G' = specific loss (grazing, sinking, and respiration) and grazing rates, respectively (sec^{-1}),

r = unsaturated assimilation fraction of phytoplankton by herbivores,

P_G = concentration of phytoplankton at which the assimilation fraction drops to one-half its unsaturated value,

ψ = fraction of cell lying within the euphotic zone,[6] and

r' = $rP_G/(P_G + P)$.

The expressions designated Terms A, B, and C represent advective, diffusive, and vertical transport processes, respectively. Term D represents the loss of nutrient, or gain in phytoplankton, as a result of nutrient-limited biological uptake with Michaelis-Menten kinetics. Term E represents the loss of phytoplankton due to grazing, sinking, and respiration, while Term F represents the input of nutrient resulting from the incomplete assimilation of phytoplankton material by the grazing herbivores.

These equations should also be valid for the same set of cells in the absence of nutrient inputs from other than natural sources. In this case, the nutrient and phytoplankton concentrations are identical in all of the cells and equal to N_a and P_a, respectively. This establishes two relationships between the various parameters that must be satisfied for the ambient waters; for example, the specific loss rate for phytoplankton is given by

$$G = V_m \frac{N_a}{N_a + K_N} .$$

6. The euphotic depth is allowed to change downstream as a result of changes in the phytoplankton concentration.

Converting the two equations to dimensionless form, utilizing the two ambient steady-state relationships, and solving for the two dependent variables, N and P, yields[7]

$$N^* = \frac{1}{2a}\left(-b + \sqrt{b^2 - 4ac}\right) \quad (1)$$

and

$$P^* = \frac{S_1 (1 + N^*)}{S_2 (1 + N^*) - \alpha N^*}, \quad (2)$$

where

$a = S_4 (S_2 - \alpha\psi)$,

$b = -\left[S_3 (S_2 - \alpha\psi) - S_1 (\alpha - S_5) - S_2 S_4\right]$,

$c = -\left[S_2 S_3 + S_1 S_5\right]$,

$S_1 = 2P_u^* + \gamma P_a^*$,

$S_2 = 2 + \gamma + \alpha G^*$,

$S_3 = 2N_u^* + \gamma N_a^* + \{\alpha\beta N_a^*\} + \alpha\beta N_T^* + S^*$,

$S_4 = 2 + \gamma + \{\alpha\beta\}$,

$S_5 = \alpha r_c G_r^*$,

$r_c = 1 - rP_G^*/(P_G^* + P_u^*)$,

$S^* = \alpha\left[G^* - (1 - rP_G^*/(P_G^* + P_a^*))G_r^*\right] P_a^*$,

$\alpha = V_m l_x / v_x$,

$\alpha_T = V_m t = n\alpha$,

n = number of upstream cells,

7. The terms within the braces, { }, are included for vertical diffusion, but absent for upwelling.

$$\beta = v_z/1_z V_m,$$

$$\rho = v_D/\sigma_o V_m,$$

$$\gamma = \rho\alpha/(1 + \rho\alpha_T),$$

$$G^* = G/V_m, \; G_r^* = G'/V_m,$$

$$N^* = N/K_N, \; N_u^* = N_u/K_N, \text{ etc.},$$

$$N_T^* = (N_{T_c} - N_{T_c}')/K_N,$$

$$P^* = P/K_N, \; P_u^* = P_u/K_N, \text{ etc., and}$$

$$P_G^* = P_G/K_N.$$

The assumptions involved in the derivations of these equations require that the derivations of the nutrient and phytoplankton concentrations in the model cell (compared with the average values) be small. Hence, a large number of sequential cells is used to obtain the downstream distributions. A computer program (requiring about 2.5 seconds per simulation on a CDC 3600) has been written to perform these calculations. A listing is contained in Appendix E.

A series of simulations were calculated for both wastefield types; values that have been observed or might be expected in the vicinity of an outfall were used for the input variables. A typical distribution for a Type II situation is shown in Figure 9-8. The figure illustrates the diffusion of nutrient (N*) into the euphotic zone, followed by an increase in the phytoplankton population (P*) as a result of biological uptake. Eventually, the declining nutrient uptake rate is exceeded by an increasing phytoplankton loss rate, and the phytoplankton concentration recedes to the ambient value.

The abscissa in Figure 9-8 is a dimensionless measure of time elapsed since discharge: α_T can be converted to distance downstream from the point of discharge when the current velocity is known.

Figure 9-8 shows that most of the phytoplankton enhancement occurs in the region of α_T = 1.7 to 12, which, for a mean transport velocity of 5 cm/sec, would correspond to a distance of about 6 to 46 km downstream. The model, therefore, predicts a large-scale (rather than a relatively localized) enhancement, unless the current velocities are low or it is a Type I (surfacing) wastefield.

Parametric studies of the phytoplankton enhancement, defined by $(P_{max} - P_a)/P_a$, for various values of the input parameters have been made to determine the sensitivity of the simulation to varied conditions. For both Type I and Type II situations, the enhancement is most sensitive to variations in the ambient nutrient (N_a*) and phytoplankton (P_a*) concentrations; however, the enhancements

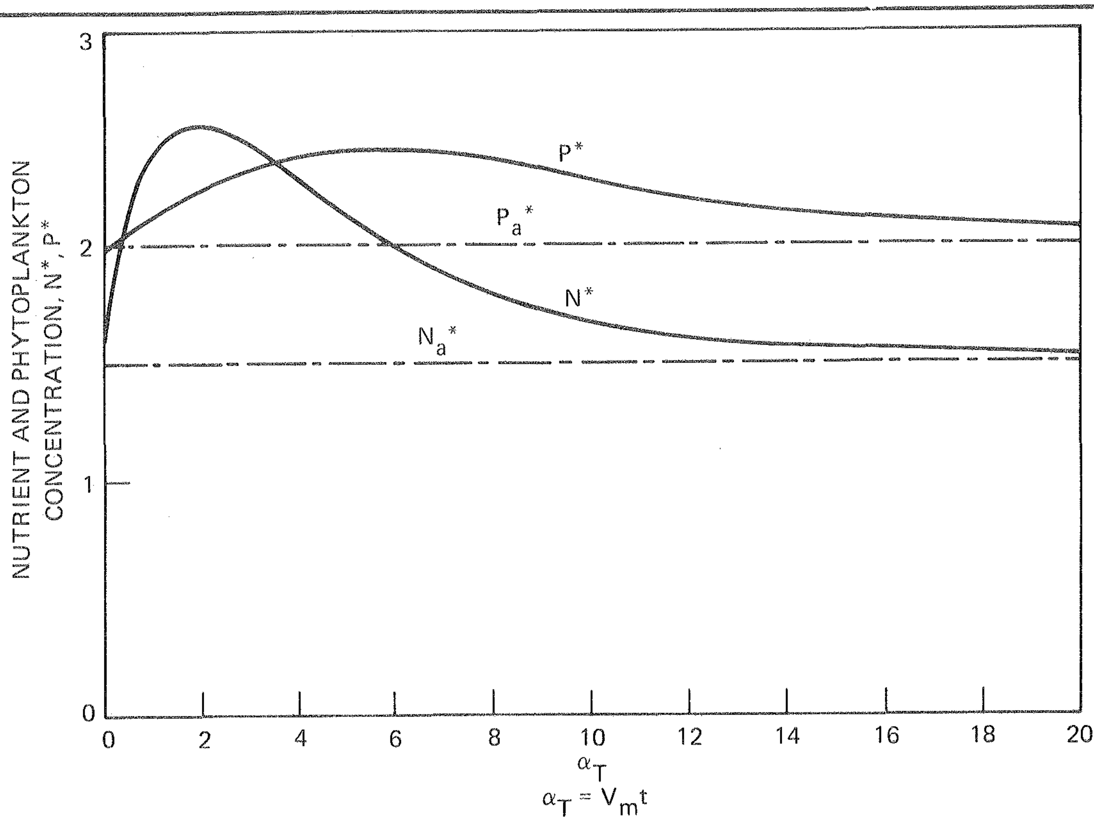


Figure 9-8. Typical Phytoplankton and Nutrient Distribution for a Type II Waste Field.

generally do not exceed a factor of 5. Because the largest enhancements occur at small ambient phytoplankton concentrations, "blooms" are unlikely to be stimulated unless already incipient.

Preliminary analyses indicate that a simple steady-state model is inadequate to describe the temporal or spatial changes in the nutrient and phytoplankton concentrations for conditions of migrating phytoplankton in a regime in which current shear exists. In addition, the effects of time-varying rates of wastewater discharge, available light, and diel (daily) variations in the uptake rates have been neglected. A time-dependent model incorporating these factors, as well as a number of other considerations, currently is being developed.

9.6 SUMMARY

Enrichment studies of natural phytoplankton populations of the Southern California Bight indicate that nitrogen is the primary growth-limiting nutrient but that other nutrients are also in short supply and quickly become limiting if nitrogen alone is supplied. Assuming that the effluent from the Point Loma traetment plant is typical, municipal wastewater appears to be a complete and well balanced nutrient medium for algal growth.

The major source of nutrients in southern California coastal waters is upwelling. However, wastewater discharges also contribute significant quantities, which may influence phytoplankton growth locally, particularly during times when upwelling is not pronounced.

Field studies in the areas around three of the major outfalls in southern California provided some indication of modest enhancement within a few kilometers of the outfall. Comparison of the average chlorophyll levels in the outfall areas with values in a control area indicated a general enhancement in the area off Whites Point and, to a lesser degree and intermittently, in Santa Monica Bay.

Data collected in Santa Monica Bay over a period of 14 years showed that natural fluctuations in the environmental conditions of the entire Bight play a dominant role in determining the plankton populations of the bay. However, the discharge of effluent was also an important factor there, particularly when it resulted in a surfacing wastefield. It is estimated that the overall magnitude, in terms of volume, of the plankton crop in much of Santa Monica Bay was reduced when the changeover to the deeper and longer 5-mile outfall was completed. This outfall, in contrast to the previously used 1-mile outfall, usually produces a submerged wastefield. After the changeover in outfalls, the area of maximum plankton concentration also moved offshore, and the concentration gradients decreased so that there was little evidence of a locally enhanced area around the newer, longer outfall.

The steady-state numerical model provides a tool for examining the importance of various physical and biological processes in the phytoplankton response mechanisms.

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Chapter 10

PUBLIC HEALTH AND AESTHETICS

10.1 INTRODUCTION

Society's concern with the condition of the marine ecosystem is based upon a number of considerations. Some of these are economic; the decline or disappearance of a particular fishery (or the rejection of its products) may represent a severe economic hardship to a large number of people, for example. Other considerations might be termed humanitarian. People become concerned over diseases in fish, even if they seldom eat fish, or with a suggested danger to sea otters, even if they have never seen one. A consideration, however, that has had a major impact on water quality management practice is the general area of public health and aesthetics. Uses of the marine and coastal environment--such as swimming, surfing, diving, sport fishing, shell fishing, hiking, picnicking, beachcombing--involve either direct contact with the waters or a direct awareness of their quality.

The aesthetic aspects of marine water quality are of great concern to coastal area residents and visitors. Odors, turbidity, refuse, or greasy or oily residues in the waters or on the beaches reduce the recreational value of the coastal area.

Of equal or perhaps even greater importance are the real, potential, and imagined problems related to the transmission of disease. Enteric pathogens and other organisms found in marine waters are potential sources of human disease; thus, the sources and behavior of these microorganisms are a primary public health concern.

The material in this chapter is divided into two parts. The first, Sections 10.2 and 10.3, contains a brief review of the literature on the public health aspects of enteric bacteria and viruses in marine waters (Section 10.2). Some of the recent data concerning the distribution of coliform bacteria around the major outfalls in southern California are presented in Section 10.3. The second part, Section 10.4 concerns aesthetics; it primarily describes SCCWRP-sponsored studies on the characteristics and behavior of floatable materials, which bear on both public health and aesthetics.

10.2 PUBLIC HEALTH CONSIDERATIONS

For many years, public health authorities have expressed concern about the possible presence of pathogenic organisms in coastal waters. In the southern California coastal area, most of the bathing beaches are located on the ocean and are used extensively by the general public throughout the year. In addition, shellfish are harvested in the tidal areas. There is legitimate concern that disease may be spread by either swimming in or consuming shellfish harvested from coastal waters that are contaminated by pathogenic organisms.

Only a small fraction of the large number of bacteria and other microorganisms that are present in wastewaters, surface runoff, and inputs from diffused sources are pathogenic. Most of these pathogens are derived from infected members of the population. Other possible sources of pathogens include domestic animals, slaughterhouses, bird sanctuaries, and farm wastes.

Potential enteric pathogens that are associated with wastewaters and land drainage can be divided into four groups:

A. Bacteria--*Escherichia coli, Salmonella, Shigella, Staphylococcus aureus, Clostridium, Leptospira, Microbacterium tuberculosis.*

B. Viruses--Polio viruses, infectious hepatitis virus, adenovirus, Coxsackie viruses A and B, ECHO virus, and reovirus.

C. Protozoa--*Entamoeba histolytica.*

D. Metazoa--Nematode and cestode ova.

10.2.1 Current Bacteriological Water Quality Criteria

Concentrations of enteric viruses and pathogenic bacteria in treated sewage and in receiving waters are generally very low, and the techniques for isolating, identifying, and enumerating these pathogens are difficult. Therefore, other more commonly found microorganisms are used as indicators of the potential presence of enteric viruses and pathogenic bacteria in receiving waters. The most commonly used indicator organisms are the members of the coliform bacteria group. As these bacteria are found primarily but not exclusively in the intestines of warm-blooded animals, including man, their presence in a receiving water is considered presumptive evidence of contamination by potentially disease-bearing wastewaters.

In an extensive review of water quality criteria, including information on bacteriological and sanitary surveys for recreational water, McKee and Wolf (1963) concluded that "present knowledge and technical procedures are not sufficient to permit the development of precise quantitative standards to distinguish between bathing beaches that are safe and those that are not safe. Despite this limitation, many state and interstate agencies have promulgated bathing water standards." As most of the numerical standards are derived from very limited or inconclusive epidemiological data (or none at all), there is a wide range of opinion with regard to the permissible coliform levels and the statistical interpretation of coliform counts for recreational and shell-fishing waters. For example, the current standards for the bacteriological quality of surface waters used for body contact sport in the United States vary from coliform counts of 50 to 2,400 most probable number (MPN) per 100 mL (Garber 1956).

Much research effort has been devoted to the search for a better bacterial indicator of fecal contamination than the coliform bacteria group. To this end, fecal coliforms and fecal streptococci have been suggested, and tests indicate qualitatively that they may provide a better measure of potential health risk. However, further quantitative evaluations are needed before these indicator organisms can be used.

In 1968, the National Technical Advisory Committee (1968) made the following recommendation:

> Fecal coliforms should be used as the indicator organism for evaluating the microbiological suitability of recreation waters. As determined by multiple-tube fermentation or membrane procedures and based on a minimum of not less than five samples taken over not more than a 30-day period, the fecal coliform content of primary contact recreation waters shall not exceed a log mean of 200/100 mL, nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 mL.

This criterion was based mainly on the results from three epidemiological surveys on bathing water quality and health conducted by the U.S. Public Health Service (Smith et al. 1952; Smith and Woolsey 1952; Stevenson 1961). The National Technical Advisory Committee report gave the following reasoning for the criterion:

> The studies at the Great Lakes (Michigan) and the Inland River (Ohio) showed an epidemiologically detectable health effect at levels of 2,300-2,400 coliforms per 100 mL. Later work on the stretch of the Ohio River where the study had been done indicated that the fecal coliforms represented 18 percent of the total coliforms. This would indicate that detectable health effects may occur at a fecal coliform level of about 400/100 mL; a factor of safety would indicate that the water quality should be better than that which would cause a health effect.

The recommended bathing water criterion drew some criticism. Henderson (1968) objected to the uniform application of the restrictive fecal coliform criteria on a National basis. His objections were based mainly upon (1) the negative epidemiological data of enteric disease linked directly to recreational water use, (2) the unrealistic public health risk of contracting enteric disease, and (3) the sewage-oriented philosophy of bathing water standards because the contributions from wildlife, farm animals, and other sources were not properly taken into account.

The present California water quality control plan for ocean waters (Calif. State Water Resources Control Bd. 1972) set the following bacteriological water quality objectives:

1. Within a zone bounded by the shoreline and a distance of 1,000 feet from the shoreline or the 30-foot depth contour, whichever is further from the shoreline, and in areas outside this zone used for body-contact sports, the following bacteriological objective shall be maintained throughout the water column:

   > Samples of water from each sampling station shall have a most probable number of coliform organisms less than 1,000 per 100 mL (10 per mL); provided that not more than 20 percent of the samples at any sampling station, in any 30-day period, may exceed 1,000 per 100 mL (10 per mL), and provided further that no single sample when verified by a repeat sample taken within 48 hours shall exceed 10,000 per 100 mL (100 per mL).

2. At all areas where shellfish may be harvested for human consumption, the following bacteriological objectives shall be maintained throughout the water column:

> The median total coliform concentration shall not exceed 70 per 100 mL and not more than 10 percent of the samples shall exceed 230 per 100 mL.

Rational bacteriological standards for recreational waters should be based upon the risk of contracting diseases by contact with sewage polluted waters. Assessment of the risk of contracting a disease through direct contact with the water is extremely difficult. The factors involved include:

A. The frequency of contact with the water.

B. The amount of water ingested.

C. The infectivity of a given pathogen.

D. The resistance of the individual to disease.

E. The concentration of the pathogen in the water.

F. If indicator organisms are being used, the relative concentrations of pathogens and indicator organisms.

G. The concentrations of indicator organisms in the water;

There is little information regarding the probability of infection or the threshold dose that will induce the disease. The ratio of enteric viruses and pathogenic bacteria to coliform organisms in sewage, treated effluent, or receiving waters has been shown to vary, depending upon many factors, including the incidence rates of infectious disease in the population served by the sewerage system. Kerr and Butterfield (1943) summarized the data from sewage and treated effluent at Epping, England, and found that, during an 8-year period (1931-38), the annual median ratio of coliform organisms to *Salmonella schottmuelleri* ranged from 160 to 5,000 for raw sewage and from 200 to 3,000 for treatment plant effluent. Because of natural variations of receiving water conditions, the ratio in receiving waters can be expected to vary over an even greater range. In some areas, a numerical coliform standard alone may not adequately protect the health of recreationists. A few investigations in the coastal regions of Israel (Shuval 1970) have isolated and identified enteric viruses and pathogenic bacteria from waters of low coliform count (i.e., lower than 1,000 MPN/100 mL).

10.2.2 <u>Viruses in Sewage</u>

Although viruses are not normal flora in animal intestinal tracts, over one hundred types of enteric viruses have been identified from feces of infected individuals. Seventy-six viruses have long been considered the primary etiological agents of certain human diseases (Derby et al. 1960). Viruses found in sewage and polluted water include the adenovirus, Coxsackie virus, ECHO virus, virus of infectious hepatitis, poliovirus, and reovirus.

Numerous studies on the isolation and frequency of recovery of enteric viruses from raw sewage and treatment plant effluent have been reported. In a study on

the source, survival, and distribution of human enteric viruses in water, Clarke et al. (1962) estimated that, in the United States, not more than 25 percent of sewage samples yield viruses. They also estimated that the average enteric virus concentration in raw sewage is probably about 5,000 virus units per liter and, in polluted surface water, not more than 10 virus units per liter. These concentrations are much less than those of either coliform bacteria or fecal streptococci. The ratio of enteric virus density to coliform density in human feces was suggested to be 15 virus units for every million units of coliform organisms.

Numerous studies on virus reduction or removal from various sewage treatment processes have been reported. For example, Kelly et al. (1957) reported that the activated sludge process appeared to be consistent in removing viruses from sewage. They detected 70 percent virus positive samples from effluent of trickling filter and only 20 percent from the effluent of the activated sludge process. Conventional chlorination, in combination with primary treatment, yielded an effluent from which viruses could be isolated 39 percent of the time. At an East Lansing, Michigan, treatment plant, Bloom et al. (1959) found that, as the sewage progressed through the various treatment stages, there was a progressive decrease in the percentage of virus isolation. With 33 percent of "virus-positive" samples in the influent, only 5 percent of the samples in the final settling tank were virus-positive. England et al. (1960) found that, at Santee, California, primary settling was ineffective in removing virus. Activated sludge treatment reduced virus concentration significantly but did not reduce the frequency of virus-positive samples. Retention of sewage effluent in an oxidation pond after activated sludge treatment greatly reduced the number of virus-positive samples; 19 percent of the samples from oxidation pond effluent contained viruses and less than 10 percent of the chlorinated effluents yielded viruses. The results suggested that the virus levels following secondary treatment can be expected to be about 1 plaque-forming unit (PFU) per milliliter, with a ratio of 1 virus particle per 10,000 fecal coliforms.

Shuval (1970) studied the virus removal efficiency at two sites in Israel--the Mefachim stabilization ponds (20-day detention time) and the Tiberias municipal wastewater treatment plant (Imhoff tanks, biological filters, and final sedimentation tanks). In both locations, the BOD removal efficiencies were about 80 to 85 percent, and coliform reductions were about 90 to 92 percent. The average overall virus removal efficiency was calculated to be 68 percent at Mefachim and 24 percent at Tiberias.

Other studies (Lund 1966, Malherbe and Strickland-Cholmley 1966) have indicated that the efficiency of virus removal in conventional wastewater treatment processes is generally less than that of coliform removal.

10.2.3 Viruses in the Marine Environment

Enteric viruses may enter the marine environment through wastewater discharge, surface runoff, and other routes; users of coastal waters for recreational and shell-fishing purposes should be concerned with the potential for diseases associated with viruses in waters.

Shellfish have long been recognized as carriers of bacteria that may be pathogenic to man[1] but ingestion of raw shellfish as a mode of transmission of infectious hepatitis is a relatively new epidemiological concept. Between 1955 and 1966, nearly 1,700 cases of shellfish-borne hepatitis were reported (Table 10-1). Raw oysters were incriminated in a Swedish episode resulting in over 600 cases (Lindberg-Broman 1956). In 1961, raw clams and raw oysters were incriminated for the first time in the United States. This pattern of shellfish-associated disease has recurred in two subsequent epidemics along the Atlantic coast (Mosley 1964a and b; Ruddy et al. 1969). Among the reported outbreaks of raw shellfish-induced infectious hepatitis, only the 1961 oyster cases had been preceded by a recognized outbreak of gastroenteritis (Mason and McLean 1962). In this outbreak, about 40 percent of the patients who developed hepatitis had gastroenteric illness 15 to 24 hours after ingesting raw oysters.

Although the data presented in Table 10-1 indicate that major outbreaks of hepatitis related to viral pollution in the marine environment are rare, cases involving a small number of individuals probably have not been reported or recorded in the literature. Therefore, the extent of enteric-virus disease attributable to the polluted marine environment is bound to be greater than is generally recognized.

Viruses in Coastal Waters

Data on the concentration of viruses in estuarine or coastal waters are meager. Most of the studies so far have involved the qualitative isolation of viruses from coastal waters or the accumulation of viruses in shellfish.

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1. According to the National Communicable Disease Center report, the past 70-year average number of all enteric disease attributed to contaminated shellfish waters is in the order of 400 cases and 10 deaths per year (Henderson 1968).

Table 10-1
EPIDEMICS OF INFECTIOUS HEPATITIS ATTRIBUTED TO CONSUMPTION OF RAW SHELLFISH, 1955-66

Year	Shellfish	Minimal No. of Cases	Location	Source of Data
1955	Oysters	629	Sweden	Lineberg-Broman (1956)
1961	Oysters	84	Mississippi, Alabama	Mason & McLean (1962)
1961	Clams	459	New Jersey, New York	Doughtery (1962)
1963	Clams	252	Pennsylvania, New Jersey	Mosley (1964a and b)
1963	Clams	119	Connecticut, Rhode Island	Mosley (1964a and b)
1966	Clams	128	New Jersey	Dismukes et al. (1969)

Metcalf and Stiles (1965) studied viral transmission in estuarine waters in the New Hampshire coastal area and found enteric viruses 6 km from the sewage outfall. In a later study (1968), they found that 27 to 52 percent of water samples taken from polluted tidal rivers and 27 percent of the receiving bay water samples were virus-positive. Akin et al. (1971) reviewed and collated the available information from previous study reports. They estimated that approximately 36 percent of the surface water and coastal water samples collected for virus studies contained enteric viruses.

Table 10-2 summarizes the results of several investigations on the loss of viral infectivity in estuarine and marine waters. A wide variety of methods were employed in these studies, ranging from holding virus suspensions in dialyzing bags in the open sea to inoculating virus suspensions into seawater in the laboratory. From the table, it is obvious that temperature is an important factor in determining the length of time required for reducing virus infectivity. To achieve a 99.9 percent virus inactivation in seawater, from 30 to 90 days are required at 4 to 6°C, from 8 to 25 days at 15 to 16°C, and from 2 to 15 days at 20 to 25°C.

Shuval et al. (1970) reported that enteroviruses were detected frequently in seawater samples collected off the coast of Tel Aviv at some distance from a sewage outfall. The average virus concentration of raw sewage was approximately 660 PFU/L. The average virus concentration detected at the sea surface immediately above the diffusers of the outfall system was about 8 PFU/L. The apparent dilution ratio of 1:80 was confirmed by a tracer study. Viruses were detected in 14 of the 48 samples collected within 1.5 km from the point of discharge. Two of the virus-positive samples were collected at a station 1.5 km from the point of discharge; one of them contained an unexpectedly high virus concentration of 32 PFU/L. The results from laboratory studies indicate that the time required for a 90 percent decrease of polioviruses in seawater off Tel Aviv may be on the order of 12 to 48 hours.

Viruses in Marine Shellfish

Filter-feeding shellfish live by the filtration and concentration of particles as small as 1 μ. These particles will include bacteria and viruses that do not infect the shellfish but are taken in and eliminated in the natural feeding and elimination processes. If the animals are not feeding, the organisms may be retained in their guts for long periods of time. For example, Metcalf and Stiles (1965) isolated Coxsackie virus B4 and ECHO virus 9 from the eastern oyster (*Crassostrea virginica*) in estuarine waters as far as 4 miles from a sewage outfall. They found no apparent virus die-away or multiplication occurring (at 5°C) during the 28 days of observation; such a finding is reasonable, as oysters do not pump water at 5°C and therefore do not concentrate or purge virus. Bendinelli and Ruschi (1969) studied enterovirus from 68 batches of mussels from a sewage disposal area near Pisa, Italy. Viruses were isolated in 36 batches that had been kept in grossly polluted areas for 3 days. Five batches of mussels were found to harbor ECHO virus 5, 6, 8 and 12 and a mixture of ECHO virus 6 and Coxsackie virus A18.

Evidence of the uptake and accumulation of virus by various species of molluscs has been shown in several laboratory studies. Liu et al. (1966) reported that,

Table 10-2
RATE OF ENTERIC VIRUSES INACTIVATION IN ESTUARINE AND MARINE WATERS
(DAYS REQUIRED FOR 99.9 PERCENT REDUCTION OF INFECTIVITY)

		Laboratory Test			Field Experiment	
Investigator	Type of Viruses	4-6°C	15-16°C	20-25°C	4-6°C	15-16°C
Cioglia & Loddo (1962)	Coxsackie B3	90	8	2		
	ECHO virus 6	30	15	15		
	Poliovirus 1	45	15	8		
	Poliovirus 2	60	15	8		
	Poliovirus 3	30	8	8		
Lycke et al. (1965)	Poliovirus 3			4		
Metcalf & Stiles (1966)	Coxsackie B3			28	45	25
	ECHO virus 6	88			35	20
	Poliovirus 1	50			30	18
Matussian & Garabedian (1967)	Poliovirus			3-6		
McLean & Brown (1968)	Poliovirus 2		9	5		
Shuval et al. (1970)	Poliovirus 1		9	2-6		
Akin et al. (1971)	Coxackie B1			3		
	ECHO virus 6			4		
	Poliovirus 1			5		
	Reovirus 1			4		

in an aquarium, the hard clam (*Mercenaria mercenaria*) accumulated poliovirus to concentrations three to nine times higher than those in the water. They also found that the hard clam could pick up greater amounts of poliovirus 1 when exposed in a contaminated running water system.

Mitchell et al. (1966) studied the accumulation of poliovirus by the eastern oyster in a flow-through aquarium and found the concentration of poliovirus by the oysters to be 20 to 26 times the levels of contamination in the seawater. They noted the similarity of results from the virological and bacteriological studies and supported the hypothesis that the mechanisms of accumulation (and elimination) of both enteric bacteria and viruses by shellfish are similar, if not identical.

In a study of the uptake of enteroviruses by the mussel, *Mytilus edulis aeteanus*, Duff (1967) suggested that virus particles with charges opposite to that of the mucoidal lining on the gills might be absorbed more effectively. It was observed that poliovirus uptake was approximately three times greater than that of Coxsackie virus A. This may be the result of differences in surface charges between the two types of viruses.

10.2.4 Enteric Bacteria in the Marine Environment

There are some isolated instances of epidemic outbreaks attributed to unsanitary conditions of bathing waters. In 1958, an outbreak of typhoid fever at Perth, Australia, was attributed in part to bathing on city beaches (Commission for Western Australia 1961). The studies made on the coastline of Var in southern France, have shown that the illnesses most frequently observed after bathing in unsanitary waters were pulmonary abscesses, rhinopharyngitis, otitis, and pyoderma; these appeared to attack children particularly (Aubert 1966).

An examination of the reports of enteric diseases during 1952-56 from some 80 coastal communities of England and Wales (Committee on Bathing Beach Contamination 1959) revealed that the incidence of enteric disease was not high in coastal areas and that, of the known cases, a small number occurred in age-groups most likely to engage in water contact sports. A further study of records of enteric disease obtained over 5 years revealed four cases of paratyphoid B in persons bathing on grossly polluted beaches, four additional cases of this disease with a history suggesting possible sea bathing, and two cases of typhoid fever in persons who had swallowed considerable amounts of seawater.

In the United States, the reported cases of enteric disease associated with bathing in polluted coastal waters are very few. According to the California State Department of Public Health (1942), no epidemic disease traceable to the use of Santa Monica Bay beaches for bathing was reported, in spite of heavy pollution in the early 1940's as evidenced by grease on the beaches and by floating grease and coliform counts exceeding 11,000 MPN/100 mL in surf waters near the Hyperion wastewater discharge area.

The three epidemiological surveys conducted by the U.S. Public Health Service to study the relations between illness and bathing water quality showed that swimmers may be expected to have an appreciably higher incidence of all illness

(eye, ear, nose, and throat ailments, gastrointestinal illness, and skin irritations) than nonswimmers, regardless of water quality. A comparison of enteric disease incidence following swimming in waters of different quality showed no significant correlation between illness and water quality.

There are a few reported cases of enteric disease outbreaks due to the consumption of raw or inadequately cooked shellfish (such as oysters, cockles, clams, mussels, and scallops) harvested from sewage-polluted waters. Table 10-3 presents a summary of some reported cases from available literature.

Survival of Enteric Bacteria in Coastal Waters

The survival of enteric bacteria in seawater has been the subject of study for more than three-quarters of a century. Before the turn of the century, in studying the Bay of Naples, de Giaxa (1889) reported that enteric bacteria die off rapidly in seawater. He found that the typhoid bacillus and the cholera vibrio survived in seawater for 9 and 4 days respectively, while in heat-sterilized seawater, they persisted for 25 to 36 days. He isolated a number of strains of marine bacteria that were antagonistic to the enteric bacteria and also to the nonenteric anthrax bacillus. From these observations, he concluded that the open sea could probably not be a means for spread of disease, but that water in a harbor may be infectious, and that disease transmission through fish and shellfish from such waters is possible.

Studies on the survival of enteric bacteria in seawater have been stimulated by the use of coastal waters for wastewater disposal. Most of the studies were aimed primarily at determining the survival times or disappearance rates and the factors affecting survival of enteric bacteria in seawater. The results of several studies are summarized and presented in Table 10-4. Because of the wide range of testing methods and conditions and test organisms used, it is very difficult to generalize whether the enteric pathogenic bacteria survive longer than the indicator organisms such as coliform group or *E. coli* in seawater. However, greater disappearance rates are generally observed in the field than in the laboratory. In laboratory studies, the disappearance rates in natural seawater are higher than those in the sterilized or synthetic seawaters. Some researchers noted relatively lower bacterial disappearance rates in artificially enriched seawaters than in the plain seawaters. From the results of these and other studies, the environmental factors affecting survival of enteric bacteria in seawater can be summarized as follows:

A. The presence of toxic substances lethal to the nonmarine bacteria.

B. The bactericidal effect of solar radiation, osmotic stress, and extremes of pH and temperature.

C. The presence of bacteriophage, parasites, protozoa, filter-feeding metazoans, and other bacterial predators in seawater.

D. The lack of sufficient nutrients and/or organic substrate in seawater.

The number and complexity of the factors that have a direct bearing on bacterial death or disappearance rates in seawater are so great that the idea of using

Table 10-3
EPIDEMICS OF ENTERIC BACTERIAL DISEASES ATTRIBUTED TO CONSUMPTION OF RAW SHELLFISH

Disease	Shellfish	Location	No. of Cases	Source of Data
TYPHOID FEVER				
1931		San Francisco		Geiger & Grey (1932)
1920-34		France	100,000	Berlin (1934)
1910	Clams & oysters		41	Old & Gill (1940)
1925	Oysters			Lunsden (1925)
1939	Oysters		87	Old & Gill (1940)
1900	Clams	Connecticut	1,178	Hart (1945)
1942-45	Clams	Connecticut	96	Hart (1945)
GASTROENTERITIS				
1966	Clams	Connecticut	200	Hart & Christine (1966)
1966	Clams	New Jersey	33	Dismukes et al. (1969)
SALMONELLOSIS				
1955	Mussels	Toulon, France	14	Brisou (1955)

Table 10-4
SUMMARY OF STUDIES OF BACTERIAL VIABILITY IN SEAWATER

Investigator	Year	Source of Seawater or Location	Test Organism	Laboratory Study (Treatment)	Field Study (Method)	Lag Time (days)	Survival Time: Percent Disappearance	Survival Time: Days	Disappearance Rate* (per day)
de Giaxa	1889	Bay of Naples	*Vibrio comma*	Raw			100**	4	
				Heat sterilized			100	36	
			E. typhosa	Raw			100	9	
				Heat sterilized			100	25	
Klein	1905		*E. typhosa*				100	>30	
Soper	1909		*E. typhosa*				100	20	
Trawirski	1929		Typhoid				100	0.7	
			Dysentery				100	0.7	
			Paratyphoid				100	>21	
Kiribayashi & Aida	1934	Kellung Harbor, Taiwan	*Vibrio comma*	Not specified			100	>10	
					Not specified		100	10	
Beard & Meadowcroft	1935	San Francisco Bay	*E. typhosa*		Semiperm. flask	0.3	90	0.8	1.8
						0.3	100	20	
			E. coli		Semiperm. flask	0.4	90	3.5	0.32
						0.4	100	>35	
Zobell	1936	Pacific Ocean	Sewage bacteria	Filtered			64	0.08	
				Autoclaved			81	0.08	
					Semiperm. tube		90	0.07	
Carpenter et al.	1938						80	0.02	
Weston & Edwards	1939	Boston Harbor	Sewage bacteria	Raw			50	0.17	
			Coliform group	Raw			90	0.17	
Calif. Dept. Public Health	1942	Santa Monica Bay	Coliform group	Raw			90	1.0	
Orlob	1949	Elliot Bay, Wash.	Coliform group	Raw		0	90	0.95	1.1
Vaccaro et al.	1950	Vineyard Sound, Mass.	*E. coli*	Raw		1.0	90	2.2	0.85
				Peptone added		3.1	90	4.5	0.70
				Autoclaved		15	90	23	0.12
				Pasteurized		6	90	9	0.3
				Chlorinated		1.5	90	3.6	0.47
Williams	1950	Puget Sound, Wash.	*E. coli*	Raw		0	90	1.5	0.67
			Coliform group		Dialysis tube	0.5	90	1.25	0.3
Orlob	1951	Budd Inlet, Wash.	Coliform group	Raw		0.2	90	0.8	1.7
Orlob	1953	Pacific Ocean, near San Francisco	Coliform group	Raw		0.4	90	1.6	0.8
Buttiaux & Leurs	1953	English Channel	*S. typhi*	Raw			38	1.8	
			S. paratyphi B	Raw			47	1.8	
			S. enteritis				43	1.8	
Nusbaum & Garver	1955	San Diego Bay	Coliform group	Raw		0.8	90	1.4	1.6
					Dialysis tube	2	87	4	0.45
Coetzee	1963	Durban, So. Africa	*S. typhi*		Not specified		90	0.2	
							100	4	
Engineering-Science, Inc.	1965	Accra, Ghana	*E. coli*		Dye study		90	0.05	20
Hanes & Fragala	1967	Salisbury, Mass.	Coliform group	Raw		0	90	1.0	1.0
			E. coli	Raw		0	90	0.75	1.3
			Enterococci	Raw		0	90	1.9	0.5
Engineering-Science, Inc.	1970	Oxnard, Calif.	*E. coli*		Dye study		90	0.12	8.3
Won & Ross	1971		*E. coli*	Synthetic			90	30	
				Seawater, 125 ppm peptone			90	45	
Engineering-Science, Inc.	1972	Pacific Grove, Calif.	*E. coli*		Dye study		90	0.10	10

*Disappearance rate, assuming first-order reaction: $K = [\log_{10}(N_0/N)]/(t - t_1)$, where N_0 is initial concentration, t_1 is lag time, and N is concentration at time t.
**Bacterial concentrations not detectable at end of test.

laboratory studies to isolate, identify, and quantify the variables becomes very attractive. Unfortunately, however, laboratory studies have proved to be useful only in establishing qualitative relationships, and numerous attempts to extrapolate the results of laboratory--and even many controlled-variable field experiments--have met with only marginal success. Crude as they may be, field studies to determine the gross disappearance rate in the area of concern, using existing wastewater sources, appear to be the best and most practicable way to obtain data for use in the design of marine wastewater disposal systems.

Survival of Bacteria in Shellfish

Bacteria or viruses in the body and shell cavity of shellfish are removed in the normal shellfish feeding processes by being used as food or eliminated in the feces. The length of time required for the cleansing process is influenced by many factors, such as original level of pollution, water temperature, presence of chemicals inhibitory to physiological activity of the shellfish, salinity, and varying capabilities of the individual animals (Houser 1965).

Kelly and Arcisz (1954) studied the survival of enteric organisms in shellfish and reported that *Salmonella schottmuelleri* were recovered from clams in significant number after the clams had been stored for 12 days. Bacterial survival of 15 to 60 days in the shell liquor of the harvested shellfish was noted. Later they reported on the depuration of soft clams, *Mya arenaria*, which were experimentally contaminated with *E. coli* and *Salmonella schottmuelleri*. It was observed that the temperature of the surrounding water plays an important role in determining the amount of water an oyster or clam will filter. At 6°C or below, oysters become almost inactive. However, the clam can purify itself as effectively (although probably not as rapidly) at 2.5°C as it can at 20°C. Experiments demonstrated an enteric pathogen, as represented by a strain of *S. schottmuelleri*, could be adequately purged from contaminated clams (reaching the U.S. Public Health Service standards of a coliform count of 2,400 MPN/100 mL) in 24 hours or less. Thus, this level appears to be a readily attainable standard.

10.3 OBSERVED COLIFORM CONCENTRATIONS IN SOUTHERN CALIFORNIA COASTAL WATERS

10.3.1 Coliform Concentrations off Point Loma

The City of San Diego has monitored coliform concentrations in the Point Loma wastewater discharge area at the stations shown in Figure 10-1 since its marine outfall became operative in 1963. Twelve monitoring stations ("A" and "B" stations) and seven nearshore ("C") stations were sampled at the surface (0.5 meters) and at a depth of 5 to 6 meters once or twice a month. Nine beach stations ("D" stations) were sampled once or twice a week.

Table 10-5 summarizes the frequency of occurrence of coliform concentrations exceeding a level of 1,000 MPN/100 mL at the sampling stations between 1963 and 1970. At all but one of the sampling stations, the criterion of 1,000 MPN/100 mL was not exceeded 86 percent or more of the time. At Station A-8, immediately south of the wastewater outfall terminus, the criterion was exceeded in 42 percent of the subsurface samples. However, all of the 39 samples collected from the surface waters at this station had coliform concentrations of less than 1,000 MPN/ 100 mL.

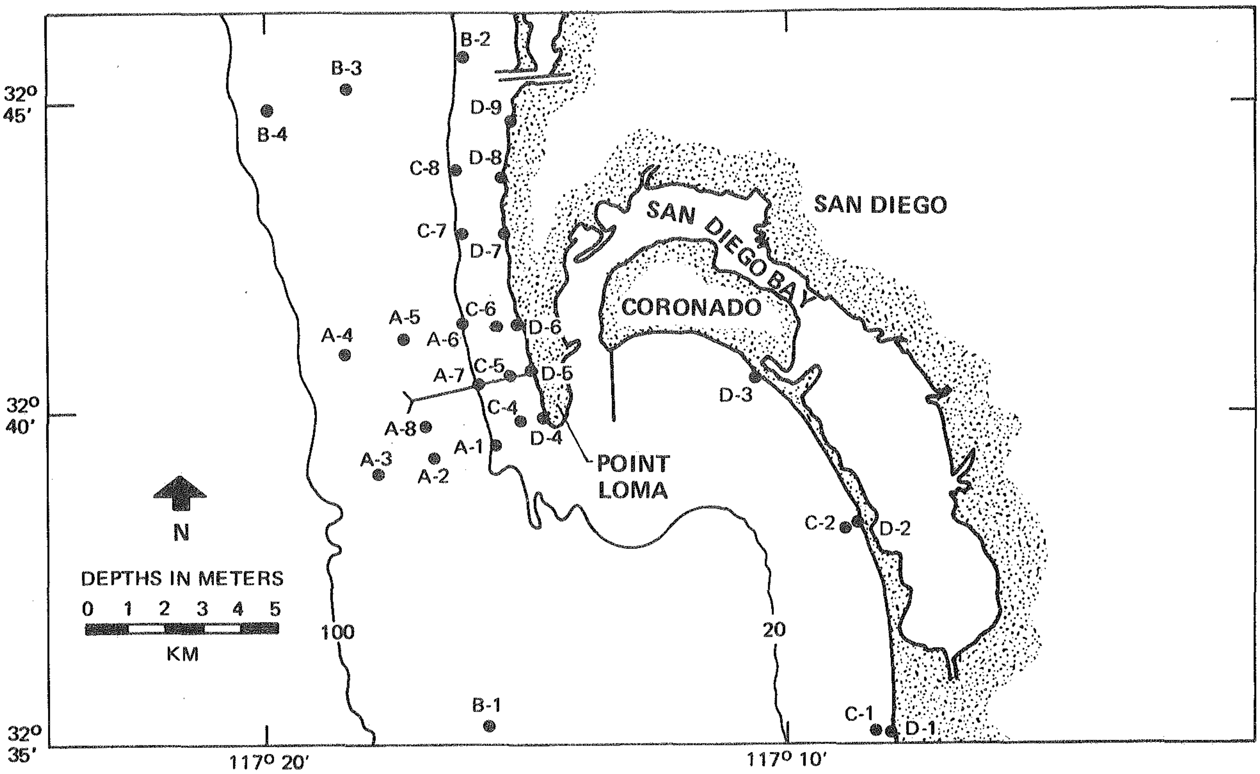


Figure 10-1. Point Loma Coliform Monitoring Stations

As expected, the frequency of occurrence of coliform counts exceeding 1,000 MPN/100 mL was greater in the subsurface samples than in the surface samples. In the area of this wastewater discharge, the wastewater-seawater mixture is normally below a depth of 15 to 20 meters. If the samples had been taken at this depth, the coliform concentrations might have been significantly higher than indicated in Table 10-5. The table also shows that the surface and subsurface waters at Stations A-3 and A-4 (both located west of the diffuser system) had a lower incidence of coliform counts exceeding 1,000 MPN/100 mL than did the waters at other "A" stations. These lower concentrations reflect the fact that, at this location, the net mean subsurface current over the outfall has a shoreward component with a speed of about 3 cm/sec (Water Resources Engineers 1965).

10.3.2 Coliform Concentrations in Santa Monica Bay

Since 1960, the City of Los Angeles has monitored coliform concentrations at 17 beach or surf stations between Malibu Canyon and Palos Verdes Point, as well as at 24 offshore stations around the 5-mile outfall system in Santa Monica Bay. The beach stations have been sampled daily, and the offshore stations have been sampled weekly at three depths, 0.5, 15, and 43 meters. The location of beach sampling stations is shown in Figure 10-2.

During the period 1960 to 1970, the median coliform concentration in surface water samples at the offshore stations was 0.6 MPN/100 mL. On an annual average basis, 4 to 11 percent of the surface samples had coliform concentrations exceeding 100 MPN/100 mL during the 11-year period, and 0.5 to 2.5 percent had

Table 10-5
FREQUENCY OF OCCURRENCE OF COLIFORM COUNTS EXCEEDING 1,000 MPN/100 ML IN THE POINT LOMA WASTEWATER DISCHARGE AREA, 1963-70

		Surface (0.5 m)		Subsurface (5-6 m)	
Station*	Distance From Outfall (km)	Total No. of Samples	% of Samples Exceeding 1,000 MPN/100 mL	Total No. of Samples	% of Samples Exceeding 1,000 MPN/100 mL
Offshore					
A-1	2.2	128	1.5	126	8.0
A-2	1.5	143	0.7	145	8.3
A-3	2.2	96	0	93	1.1
A-4	2.2	94	0	93	0
A-5	1.5	144	0.7	143	10
A-6	2.2	143	0	138	11
A-7	1.5	145	0.7	140	14
A-8	0.7	39	0	38	42
Offshore (Control)					
B-1	9	135	0	135	2.2
B-2	9	93	0	91	2.2
B-3	9	137	0.7	137	6.0
B-4	9	91	0	90	0
Nearshore					
C-1	15	85	0	31	3.2
C-2	12	86	0	26	4.0
C-4	3	125	0.8	56	3.6
C-5	2.5	120	0	61	10
C-6	3	124	0	67	6.0
C-7	4.5	132	0.8	134	6.0
C-8	6	133	0.8	131	11.5
Beach					
D-1	15	149	5.4		
D-2	12	149	2.7		
D-3	9	147	11.5		
D-4	3	176	2.8		
D-5	3	176	14.0		
D-6	3	170	1.2		
D-7	5	174	4.6		
D-8	6.5	176	6.2		
D-9	7.5	173	1.7		

* Station locations shown on Figure 10-1.

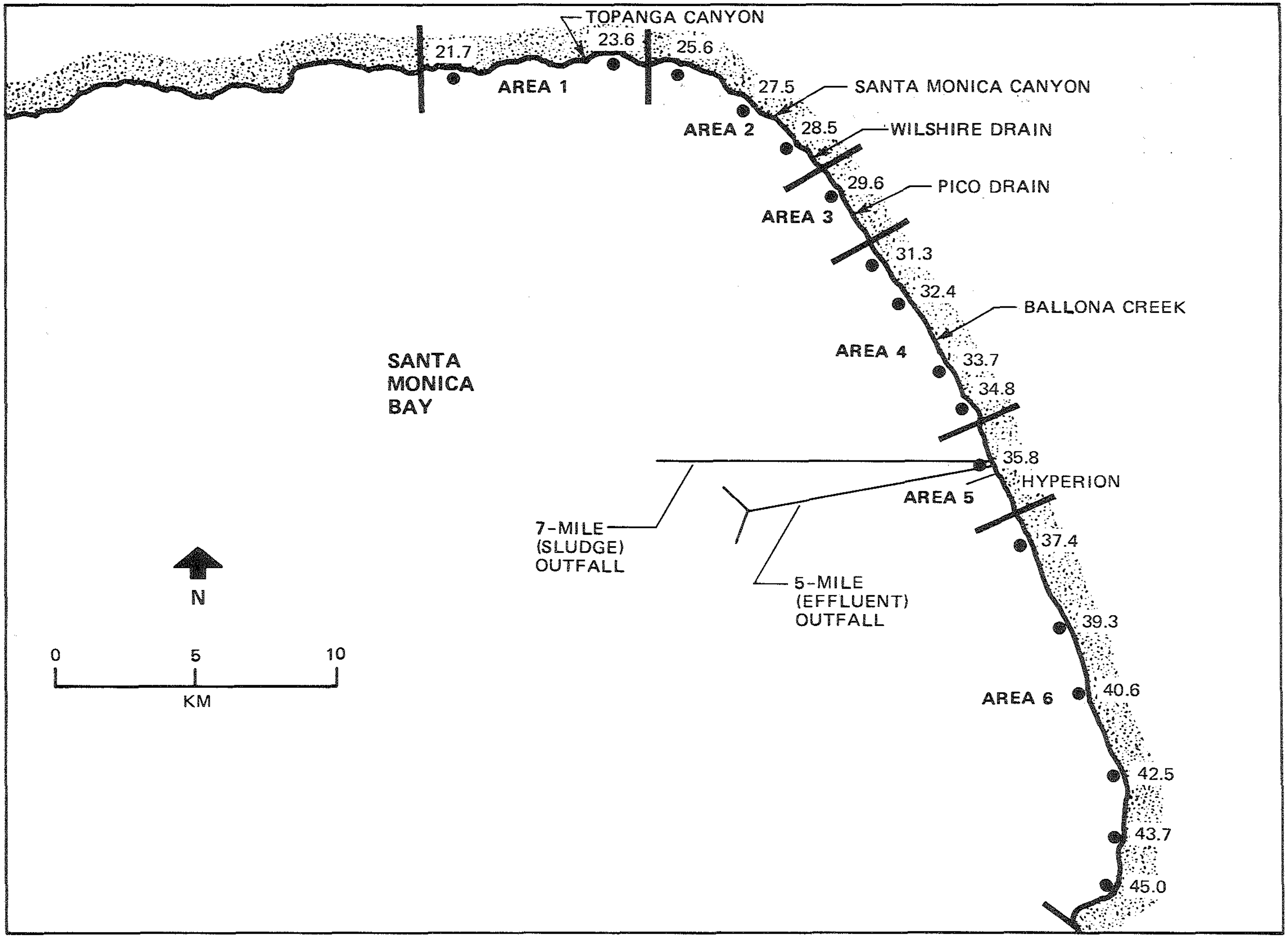


Fig. 10-2. Beach Coliform Monitoring Stations in Santa Monica Bay.

concentrations exceeding 1,000 MPN/100 mL. Detailed analysis of the coliform monitoring data for seasonal trends and differences between surface and deep-water samples showed the following:

A. Coliform concentrations in the surface water samples are generally higher in the December to March period than during the June to October period. These differences are undoubtedly associated with the seasonal stratification of the waters during the summer.

B. Coliform concentrations in both surface and subsurface samples tend to be higher at stations closer to the shoreline than at the more westerly stations. This distribution may result from a predominant onshore subsurface current and/or from coliform organisms reaching the waters through surface runoff during the winter months and from beach washout during spring flood tides.

C. The subsurface samples nearly always have a higher coliform concentration than the surface water samples at the same location.

Table 10-6 shows the percentage of beach station samples exceeding 1,000 MPN/100 mL. The percentages ranged from nearly zero to 15 percent. Stations located along the north shoreline of Santa Monica Bay (Stations 21.7 to 35.8) had higher incidences of high coliform counts than those located along the southern shoreline. The difference was more pronounced in the period 1967 to 1969 than in earlier years. Analysis of the monthly sampling results coupled with consideration of the location of the beach sampling stations shows that there is a high correlation between the coliform concentrations observed on the beach and the rainfall and runoff from the storm drains. Station 29.6, which is located near the Pico drain, provides an example. Table 10-6 shows that, between 1960-69, the percentage of samples from this station exceeding 1,000 MPN/100 mL ranged from about 3 to 15 percent. However, a month-by-month comparison of rainfall in 1969 and coliform counts at Station 29.6 during this year (Figure 10-3) reveals a correlation: During the months when the rainfall was less than 0.1 cm, the percentage of the samples exceeding 1,000 MPN/100 mL was 12 percent; in the remaining months, with rainfall exceeding 0.1 cm, the frequency of samples exceeding 1,000 MPN/100 mL was 22 percent.

Between January 1966 and May 1967, the City of Los Angeles conducted an intensive coliform monitoring program at five major storm drains discharging into northern Santa Monica Bay. A summary of the results of this survey and a more recent SCCWRP study of storm drainage is presented in Table 10-7. The table shows that coliform counts in storm flows (median: 23,000 to 230,000 MPN/100 mL) are significantly higher than those in dry weather flows (median: 62 to 6,200 MPN/100 mL). Although samples were collected from different channels at different times, the results indicate that surface washout from the drainage basin may be a significant source of coliform organisms in surface sea water, expecially during the wet weather season.

The study showed that, along the north shoreline of Santa Monica Bay between Station 21.7 and 35.8, high coliform counts occurred after some, (but not all) of the rainstorms. High coliform counts in the surf waters usually did not occur when the intervals between rain storms were less than 20 days. The apparent explanation is that frequent rain kept the storm channel well washed and thus minimized any buildup of coliform organisms. When storm flows followed a dry

Table 10-6
FREQUENCY OF OCCURRENCE (PERCENT) OF COLIFORM COUNT EXCEEDING 1,000 MPN/100 ML
IN SURF WATERS OF SANTA MONICA BAY*

Area**	Monitoring Stations	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	Major Storm Drain
1	21.7, 23.6	3.6	2.6	6.3	2.2	2.0	3.7	4.8	6.2	3.3	7.4	Topanga Canyon
2	25.6, 27.5, 28.5	2.4	3.2	5.7	2.8	2.2	5.7	4.3	8.1	4.7	8.1	Santa Monica Canyon Wilshire Drain
3	29.6	4.1	5.5	3.6	4.9	2.7	7.9	7.9	13.0	14.8	15.0	Pico Drain
4	31.3, 32.4 33.7, 34.8	3.7	2.1	2.1	2.4	2.7	4.0	5.6	5.9	5.7	5.3	Ballona Creek
5	35.8	3.6	1.6	1.4	1.1	3.3	2.5	2.7	6.0	7.7	8.0	(Hyperion Outfalls)
6	37.4, 39.3, 40.6, 42.5, 43.7, 45.0	1.8	0.8	1.2	1.9	0.6	1.3	1.4	2.3	0.4	1.8	
All Stations		2.5	2.1	3.0	2.4	1.8	3.4	3.7	5.5	3.9	5.5	

* Data reported by Hyperion Sewage Treatment Plant, City of Los Angeles; samples were collected daily at each station.

** Areas shown on Figure 10-2.

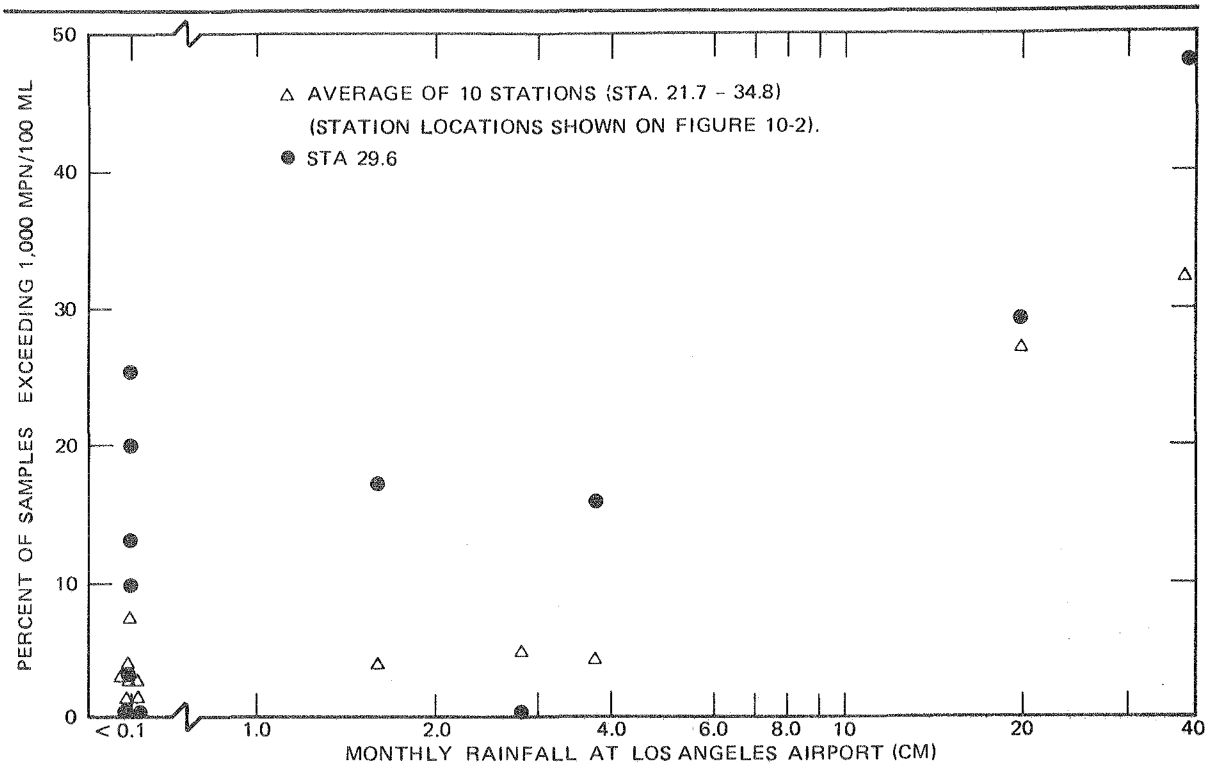


Fig. 10-3. Relationship Between Rainfall and Beach Station Coliform Count in Santa Monica Bay, 1969.

period of 20 or more days, high coliform counts were shown to persist in the surf waters for about 3 days.

10.3.3 Coliform Concentrations off Orange and San Diego Counties

Table 10-8 presents the frequency of occurrence of coliform concentrations exceeding 1,000 MPN/100 mL in surf waters near municipal wastewater discharge areas in Orange and San Diego Counties in 1970. The locations of the discharges are shown in Figure 4-1, and a general description of each is given in Table 4-2.

In general, most of the discharge areas would appear to meet the State coliform criterion for bathing waters. High coliform counts were observed at some locations, however. For example, at one sampling station in Sunset Beach, it was found that 24 percent of the samples exceeded 1,000/100 mL in 1970. Samples collected from monitoring stations located near storm drains show consistently higher coliform concentration than do those from other locations. Naturally, this is particularly evident during the winter months. As an example, Table 10-9 summarizes the frequency of occurrence of coliform concentrations exceeding 1,000 MPN/100 mL at eleven beach stations monitored by the Orange County Sanitation Districts. The eleven stations are about equally spaced along a 10-km stretch of coastline centered at the mouth of the Santa Ana River. During the dry summer months, when the precipitation was 0.3 cm or less, only 2.8 percent of the samples exceeded 1,000 MPN/100 mL. During the remaining 6 months, during which more than 98 percent of the total annual precipitation (30 cm/yr) occurred, 21 percent of the samples exceeded 1,000 MPN/100 mL.

Table 10-7
COLIFORM COUNTS IN SOUTHERN CALIFORNIA SURFACE RUNOFF

Investigator	Storm Channel*	No. of Samples	Coliform Count (MPN/100 mL) Min.	Median	Max.	Nearby Coliform Monitoring Station (Santa Monica Bay)
City of Los Angeles**	Topanga Canyon	69	6	2,300	70,000	23.6
	Santa Monica Canyon	125	<4.5	62	6,200	27.5
	Wilshire Drain	25	<4.5	620	6,200	28.5
	Pico Drain	125	<4.5	6,200	>70,000	29.6
	Ballona Creek	125	<4.5	62	>70,000	32.4, 33.7
SCCWRP†	Santa Clara River	19	600	23,000	230,000	
	Ballona Creek	18	200	230,000	7,000,000	32.4, 33.7
	Los Angeles River	27	600	230,000	7,000,000	
	Santa Ana River	13	1,300	23,000	620,000	

*Locations of storm channels are shown on Figures 3-11 and 10-2.
**1 January 1966 to 1 May 1967; samples from both storm and dry weather flows.
†October to December 1971; samples from storm flows only.

Table 10-8
FREQUENCY OF OCCURRENCE OF COLIFORM COUNTS EXCEEDING 1,000 MPN/100 ML
IN SURF WATERS OF ORANGE AND SAN DIEGO COUNTIES, 1970

Ref No.*	Discharger	No. of Beach Monitoring Stations	Total No. of Samples	% of Samples Exceeding 1,000 MPN/100 mL	
				All Stations	Maximum at single station
W15	Sunset Bch. San. Dist.	9	315	11	24
W16	Orange Co. San. Dist.	11	4,003	10	18
W17	City of Laguna Bch.	6	118	4.3	15
W18	So. Laguna Bch. San. Dist.	10	95	4.2	20
W19	Dana Pt. San. Dist.	7	114	1.8	6
W20	City of San Clemente	5	80	0	0
W22	Encina (Co. of San Diego)	5	60	0	0
W23	San Elijo (Co. of San Diego)	6	78	0	0
W24	Point Loma (City of San Diego)	9	162	11	18

*Discharger locations are shown on Figure 4-1.

During the first 3 months of 1970, the monthly rainfall was fairly uniform, ranging between 4.4 and 5.1 cm. However, the overall percentage of samples exceeding 1,000 MPN/100 mL in these 3 months declined from 39 percent in January to 16 percent in March, suggesting that the findings in the Santa Monica Bay storm drainage study (Section 10.3.2) might also be applicable here. In other words, although the rainfall over this 3-month period was fairly uniform, the bulk of the contamination was washed out in the early portion of the period.

Fay (1966) conducted night surveys of surf and offshore waters near the Orange County Sanitation Districts outfall. He found that offshore subsurface waters (6 meters and below) usually showed higher coliform counts than did the corresponding offshore surface and surf waters. Coliform counts of 10,000 to 500,000 per 100 mL in the subsurface water were not uncommon in this area, while the surface water samples usually showed coliform counts of less than 100 per mL. He noted that, during the night time, the distribution of coliform bacteria in the surf zone was correlated with the nearshore subsurface population of coliform

Table 10-9
FREQUENCY OF OCCURRENCE (PERCENT) OF COLIFORM COUNTS EXCEEDING 1,000 MPN/100 ML IN SURF WATERS NEAR THE ORANGE COUNTY OUTFALL, 1970*

Month	Stations 3-5 km N of Outfall	0-2 km N & S of Outfall	3-5 km S of Outfall	Total	Precipitation† (cm)
January	34	43	38	39	4.4
February	30	24	6.0	24	5.1
March	12	20	12	16	4.5
April	0	0	0	0	0
May	0	0	1.1	0.3	0
June	5.6	8.7	0	5.4	0.3
July	12	12	2.1	9.1	0
August	4.3	2.6	1.1	2.6	0
September	3.3	1.3	1.1	1.8	0
October	0	0	1.1	0.3	0.2
November	5.6	7.3	3.2	5.8	6.9
December	9.7	19	6.5	13	8.2
Total 1970	9.6	13	6.6	10	29.6
Dry season††	3.6	3.4	0.9	2.8	0.5
Storm season§	18	26	14	21	29.1

*Data reported by Orange County Sanitation Districts. Samples were collected daily at each station.
**Stations sampled were 15N, 12N, and 9N (3-5 km N of outfall), 6N, 3N, D, 3S, and 6S (0-2 km N and S of outfall), and 9S, 12S, and 15S (3-5 km S of outfall).
†As measured at Newport Beach.
††April through October.
§January through March and November and December.

organisms rather than with those of the surface layers. He suspected that the coliform bacteria may have arrived at the surf zone by subsurface transport. Examination of the coliform data for nearshore and beach stations at Point Loma (Table 10-5) confirmed Fay's observations. The incidences for coliform count exceeding 1,000 MPN/100 mL at beach stations ("D" stations) are similar to those of subsurface waters at nearshore stations ("C" stations) rather than to those of surface waters. However, the coliform organisms in the surf zone may have arrived from surface runoff and beach washout as well as from subsurface transport of wastewater.

10.4 AESTHETIC CONSIDERATIONS

The shoreline and nearshore waters are a major recreational resource for hundreds of thousands of people, and their aesthetic characteristics--their beauty and cleanliness, their freedom from materials obviously originating in wastes--have a major effect on the enjoyment of this resource. The aesthetic aspects of water and shoreline quality include a wide range of characteristics that are both diverse and difficult to characterize quantitatively. For some characteristics, the difficulty lies primarily in the large number of associated variables; for others, the difficulty is that measurement must be subjective and depends almost entirely on the observer's likes and dislikes.

For an observer on the shore, the apparent color of the water depends only partially on the measurable color of the water itself. Other major factors include the elevation of the observer above the water, the time of day, the angle of the sun to the observer, the sky color, and the surface wave characteristics. Real discoloration in the water may or may not be observable. Transparancy (as an aesthetic factor and not in relation to problems such as plant growth) is important to swimmers and divers. In fact, to scuba divers, it is often the overriding consideration in their enjoyment of the sport. Again, this characteristic depends greatly upon factors such as wind, currents, waves, and depth.

Most people who go to the shore never enter the water. Their enjoyment will be affected most by the appearance of the beach and the nearest visible waters. Any odors or materials on the beach associated with sewage or garbage are especially repugnant. It is this aspect--the association of the observed effect or material with its presumed origin--that makes the setting of quantitative standards so difficult. For example, the odors of decaying fish or animal tissue on the beach may be unpleasant to some. However, the reaction will be much more adverse if it is thought that the fish have died as a result of, say, an industrial waste spill than if the deaths are thought to be natural. Similarly, odors associated with sewage will be more unpleasant to most people than perhaps much stronger odors resulting from the decay of seaweed or kelp.

The SCCWRP studies in the area of aesthetics have concentrated on problems related to floatable materials. The air-sea interface is a specialized environment containing enriched concentrations of macro- and micro-organisms, surface-active and water insoluble organic and inorganic substances, and floating particles. These floating materials may be objectionable for several reasons. If they are derived from wastewaters or can be identified as having their origin in garbage or refuse, they can be objectionable from both an aesthetic viewpoint and for public health reasons. Materials such as oils and tars can adversely affect the attractiveness of the shoreline and can cause damage to the intertidal and shoreline biota.

Floating materials are subject to transport and concentration by surface currents and by the winds. The varying characteristics and behavior of floatable materials make their measurement, let alone their management, difficult. Nevertheless, this class of materials represents a serious water quality problem that must be resolved.

10.4.1 Sources of Floatables

Floatable materials in the marine environment result from natural processes as well as from human activities. By far the greatest quantity of organic, slick-producing material and floating detritus comes from the marine biosphere. In the decomposition of all forms of organisms and their waste products in the sea, the insoluble parts that are lighter than water rise to the surface to become the principal source of floatables.

Airborne organic particles originate in the sea and resettle on the sea surface. The processes causing these particles to be airborne from the sea surface are bubble bursting and wind spray with subsequent evaporation. Aerosols and airborne dusts that originate from land may also settle on the sea surface.

During the storm season, shore drainage and surface runoff introduce large quantities of partially decomposed terrestrial organic material, rubbish, and other floatable materials into southern California coastal waters. Waves and tides wash and leach the floatable material that is deposited on the beaches and refloat them on the water surface. Added to the floatable materials from marine, atmospheric, and land sources are wastewater floatables and natural oil seepage, two major factors affecting the aesthetic qualities of southern California coastal waters.

Wastewater Floatables

Wastewater floatables discharged into the sea can be concentrated and accumulated on the surface, where they are subject to wind-induced surface transport, often towards the shore. Although there has been awareness of this potentially important problem for some years, there have been few investigations of the characteristics and behavior of wastewater floatables. A major reason for this apparent inattention has been the lack of a dependable standard laboratory method for the quantitative measurement of floatables in sewage and in the receiving waters. The difficulty in developing such methods, of course, lies in the diverse origins and characteristics of floatable materials. It is obvious that no one method of sampling and analysis will be equally satisfactory for feathers, cigarette filters, and fatty acid films.

Of the various wastewater characteristics that are measured routinely, only the measurements of oil and grease and methylene blue active substances (MBAS, a measure of detergents) have any direct relationship to the wastewater floatables. Some fraction of the suspended solids in wastewaters may rise to the surface attached to air bubbles or to oils and greases; however, the measurements of suspended solids in wastewaters have little relationship to this fraction.

Methylene Blue Active Substances or Surfactants

In the late 1950's and early 1960's, increasing use of detergents resulted in numbers of incidents of foaming in turbulent receiving waters. Since the almost

complete substitution of linear alkyl sulfonate for alkyl benzene sulfonate in 1965, the primarily aesthetic problem of foaming has been almost completely eliminated. However, foaming may often be due to the presence of surface-active agents of natural origin. The presence of surface active agents such as detergents in wastewaters may have some effect--at present, unknown--on the formation and behavior of films in the vicinities of marine wastewater outfalls.

Oil and Grease

The materials included in the general category of "oil and grease" include fatty acids, soaps, fats, waxes, oils, and other material extracted from the sample by the organic solvent used in the analysis. Hexane or trichlorotrifluoroethane are the standard solvents normally used. The total amount of oil and grease detected in wastewater samples will vary depending on the solvent used; thus, it is important that the solvent be specified when considering oil and grease data. Not all of the oil and grease content of a wastewater will be floatable; although oils and greases are generally insoluble in water, they may be emulsified.

In 1971, the oil and grease content of municipal wastewater discharges ranged from about 20 to 70 mg/L. The total amount of oil and grease entering the Bight in 1971 was estimated to be about 70,000 M tons (Table 4-28). More than 90 percent of this total was due to municipal wastewater discharges; the balance came from storm runoff and discrete industrial waste discharges not connected to municipal systems.

Floatable Solids

Because no standard method is available, floatable solids have not been monitored routinely in municipal wastewaters in southern California. A few preliminary studies have been carried out, however, to determine the concentrations of floatable solids in raw sewage and treated effluent. In these studies, floatable material was separated from a 1:1 wastewater/seawater mixture having a density that had been adjusted to that of ocean water by the addition of salt. The analyses were made using the equipment and procedures developed by Engineering-Science, Inc. (1965). Table 10-10 presents a summary of the results of some of these studies. These data show the wide variability in the floatable characteristics of different wastewaters. However, it appears that the floatable solids represent a maximum of between 5 and 10 percent of the total particulate solids in the wastewaters. The hexane extractable fraction of the floatable solids is extremely variable, and, in the results reported in Table 10-10, this fraction ranged from 3 to 57 percent. In these studies, the floatable hexane extractable materials amounted to between 0.6 and 14 percent of the total hexane extractable materials in the wastewaters. Thus, the potentially floatable materials are not adequately characterized by the conventional oil and grease measurement normally made in wastewater analysis.

Natural Submarine Oil Seeps

Almost all of the petroleum producing areas in the world have natural oil seeps, and southern California is noted for its many oil, gas, and tar seeps, both on the land and offshore. One of the widely known onshore seeps is the La Brea tar pits in Los Angeles. Offshore oil seeps were mentioned as early as 1776 by Father Pedro Font, who wrote, "Much tar, which the sea throws out, is found on the shores sticking to the stones and dry. Little balls of fresh tar are also found. Perhaps there are springs of it which flow out into the sea...."

Table 10-10
HEXANE EXTRACTABLE MATERIALS AND DRY SOLIDS IN WASTEWATER FLOATABLES
(24-HOUR COMPOSITE SAMPLES)

Location	Investigator	Type of Wastewater	Floatables Dry Wt.* (mg/L)	Floatables HEM** (mg/L)	Floatables HEM/Dry Wt. (%)	Floatable HEM / Total HEM (%)	Floatable Solids / Particulate Solids (%)
Ohau, Hawaii (avg. of 3 plants, 1-2 Jul 70)	Engineering-Science, Inc. (1971)	Raw sewage	1.6	0.33	21	0.6	1.0
Sand Island, Hawaii (14-15 Jul 70)	Engineering-Science, Inc. (1971)	Raw sewage	8.7	5.0	57	14	
Oahu, Hawaii (avg. of 2 plants, 29-30 Jun 70)	Engineering-Science, Inc. (1971)	Primary effluent	0.95	0.22	23	1.0	1.0
Ohau, Hawaii (avg. of 2 plants, 3-4 Jul 70)	Engineering-Science, Inc. (1971)	Trickling filter effluent	1.1	0.19	17	1.8	2.2
JWPCP, Los Angeles Co. (May-Aug 70)	Los Angeles Co. San. Dist. (1970)	Primary effluent	1.0				0.7
		Centrate	110				0.3
		Digested sludge	240				0.6
Hyperion Treatment Plant, Los Angeles	Selleck and Carter (1972)						
6-7 Apr 71		2/3 primary, 1/3 secondary	4.8	0.15	3.1	1.4	7.5
30-31 Aug 71		2/3 primary, 1/3 secondary	3.1	0.30	10	3.6	3.8

*Dry weight of solids at 40°C.
**Hexane extractable material.

Information compiled by the California Department of Conservation (1971) indicates that there are probably between 50 and 60 offshore oil seeps and seep areas between Point Conception and Huntington Beach. Most of these seeps occur in the Santa Barbara Channel and Santa Monica Bay areas. Although their existence is well known, the nature and magnitude of seepage has not been evaluated thoroughly. Estimates of the volume of oil being emitted by submarine oil seeps, and of the extent of surface and beach pollution resulting from these seeps, have been made at the Coal Oil Point, Union Oil Platform A, Manhattan, and Redondo seep areas (Figure 10-4). These investigations involved the coordinated efforts of aerial, surface, underwater and beach observation and sample collections. A summary of the data is presented in Table 10-11.

In October 1969, four separate seeps were identified at Coal Oil Point. The slick width at three of these seeps was between 30 and 75 meters wide. One of the seeps had a slick width between 300 and 430 meters wide. The estimates given for Platform A are based on oil capture by tents, hoods, and skimmers. Two separate seeps were identified in the Manhattan area in a survey in the fall of 1971; the seeps were between 20 and 30 meters wide. During this same period, three separate seeps, with slicks varying from 12 to 35 meters in width, were identified at the Redondo area. The width of the oil slicks given above is that observed near the seep area. As the slicks drift away from the area in which they are formed, they become thinner and spread wider. Evaporation, biodegradation, dissolution, and sedimentation may result in some loss of oil slick material before it is deposited on the shoreline. The total oil seep emission rate at these four sites was estimated to be approximately 13 cu m/day, or about 4,400 M tons/yr.

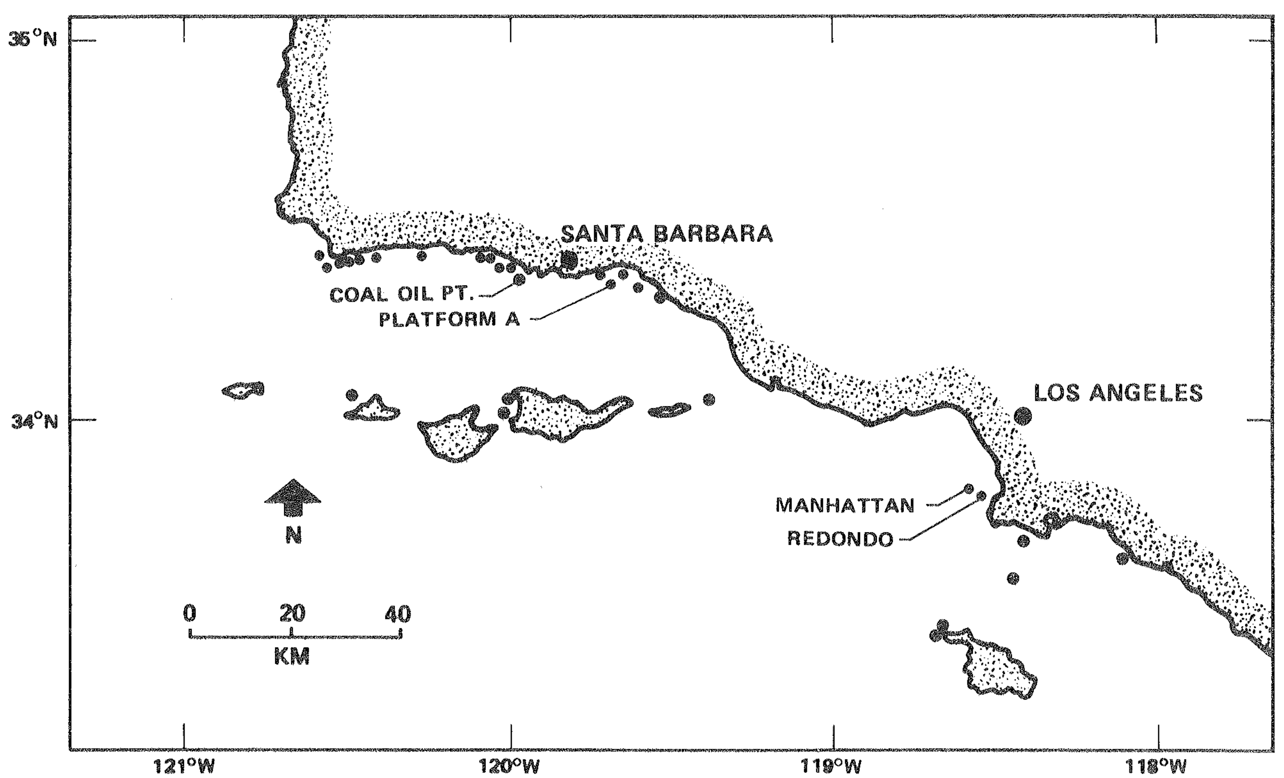


Fig. 10-4. Location of Natural Oil Seeps in the Southern California Bight.

Table 10-11
OIL SLICK OBSERVATIONS AND OIL FLOW RATE ESTIMATES FOR FOUR NATURAL OIL SEEPS OFF SOUTHERN CALIFORNIA

	Oil Slick				
Seep Zone	Drift Rate (m/sec)	Thickness (cm)	Flow Rate (cu m/day)	Survey Date	Investigator
Coal Oil Pt.	0.3	0.1-1.0	8-11	Oct 69	Allen et al. (1970)
Platform A			0.8-4.8*	1970	California Dept. of Conservation (1971)
Manhattan	0.15-0.25	0.3-1.0	0.14-1.2	Sep-Oct 71	Allen et al. (1971)
Redondo	0.15-0.25	0.3-1.0	0.19-1.7	Sep-Oct 71	Allen et al. (1971)

*During the 28 January 1969 well blowout incident, the rate of oil loss was estimated to be as high as 50 to 80 cu m/day.

The continued modification or transformation of oil slicks to the thick, black globules found on beaches is a process that has been studied only recently. Results of a 1958 investigation (California State Water Pollution Control Board 1959) along southern California beaches indicate that the depositions of tarry materials were heaviest at Coal Oil Point and other beaches near the submarine oil seeps. The average amount of tar deposits found at Coal Oil Point was 2,100 g/sq m. The next highest were at Gaviota (3.7 g/sq m) and at the southern end of Santa Monica Bay (0.9-5.5 g/sq m). The deposition at all other beach areas was less. Ninety percent of 165 samples from 15 other stations indicated concentrations less than 0.6 g/sq m, and 69 percent of the samples contained either no oil or just a trace amount.

The results of a study characterizing beach tarry material, oil from submarine seeps, and crude oils from southern California and elsewhere indicate that oil emitted by submarine seeps and deposited on beaches has compositional characteristics that allow it to be distinguished from most other oil materials likely to be discharged into the same waters (California State Water Pollution Control Board 1959). Recent results from a study of beach deposits and natural seep oil in Santa Monica Bay (Allen et al. 1971) show that approximately 86 percent of tarry beach deposits found between El Segundo and Redondo Beach could be identified as originating from the nearby offshore natural oil seeps. Results of another study (Engineering-Science, Inc. 1965) indicated that the presence of oils or greases on beach sands would not be objectionable if the concentrations were less than about 0.3 g/sq m.

10.4.2 Floatables in Southern California Coastal Waters

To determine the quantitative and qualitative characteristics of floating substances in submarine wastewater discharge areas, SCCWRP, in connection with the Sanitary Engineering Research Laboratory of the University of California at

Berkeley,[2] conducted investigations in Santa Monica Bay, off Palos Verdes and in the Santa Catalina Island area in 1971. The study areas are shown in Figure 10-5.

Surface films and floating particulates of natural origin are found in all regions of the oceans, but particularly in areas of high plankton productivity such as the nearshore waters. For this reason, sampling was conducted in the following areas:

A. From the sea surface within the immediate vicinity of a marine outfall (Stations 1 and 4).

B. From the sea surface some distance removed from the outfall and down-current from the outfall (Station 2).

C. From the sea surface in a coastal region remote from all sources of pollution, but otherwise similar to the region of the outfall being studied (control area, Station 3).

The major parameters measured in the investigation were gross hexane extractable materials, long-chain fatty acids, coliform bacteria, and certain other characteristics of floating particulates. Table 10-12 summarizes the types of sampling devices used and the analyses that were made.

Additional measurements made during the ocean surveys included determination of the vertical density structure of the water column to estimate the characteristics of internal waves and the vertical location of the submerged wastewater plume, observations of slick pattern and movement, wind velocity, surface current velocity, and sea swell. Measurements of the plankton standing crop were made to provide data on the natural production of surface-active substances. More detailed descriptions of the sampling and analytical methodology have been reported by Selleck and Carter (1972).

It was generally believed that band slicks may play a role in concentrating the floatables, especially the film materials, on the ocean surface. For example, during the weekly surveys of Santa Monica Bay from October 1957 to September 1958, Hume et al. (1959) observed that:

> A characteristic of the hydrography of Santa Monica Bay is the persistence of convergence systems throughout most of the year. A convergence is the place on the surface where two water masses meet. Since the water level remains essentially constant, there is thus a downward movement of water at the convergence, and since floating material cannot continue to move with the water, it accumulates along the line of the convergence. During the warmer months large amounts of spores, oil from diatoms, and miscellaneous flotsam may be seen forming scum lines and sleeks along the convergence. Continuous convergence systems marked in this way have been observed to be over 50 feet in width and some 5 to 10 miles in length.

2. This study was part of a program to develop sampling and analytical methods funded by the U.S. Environmental Protection Agency.

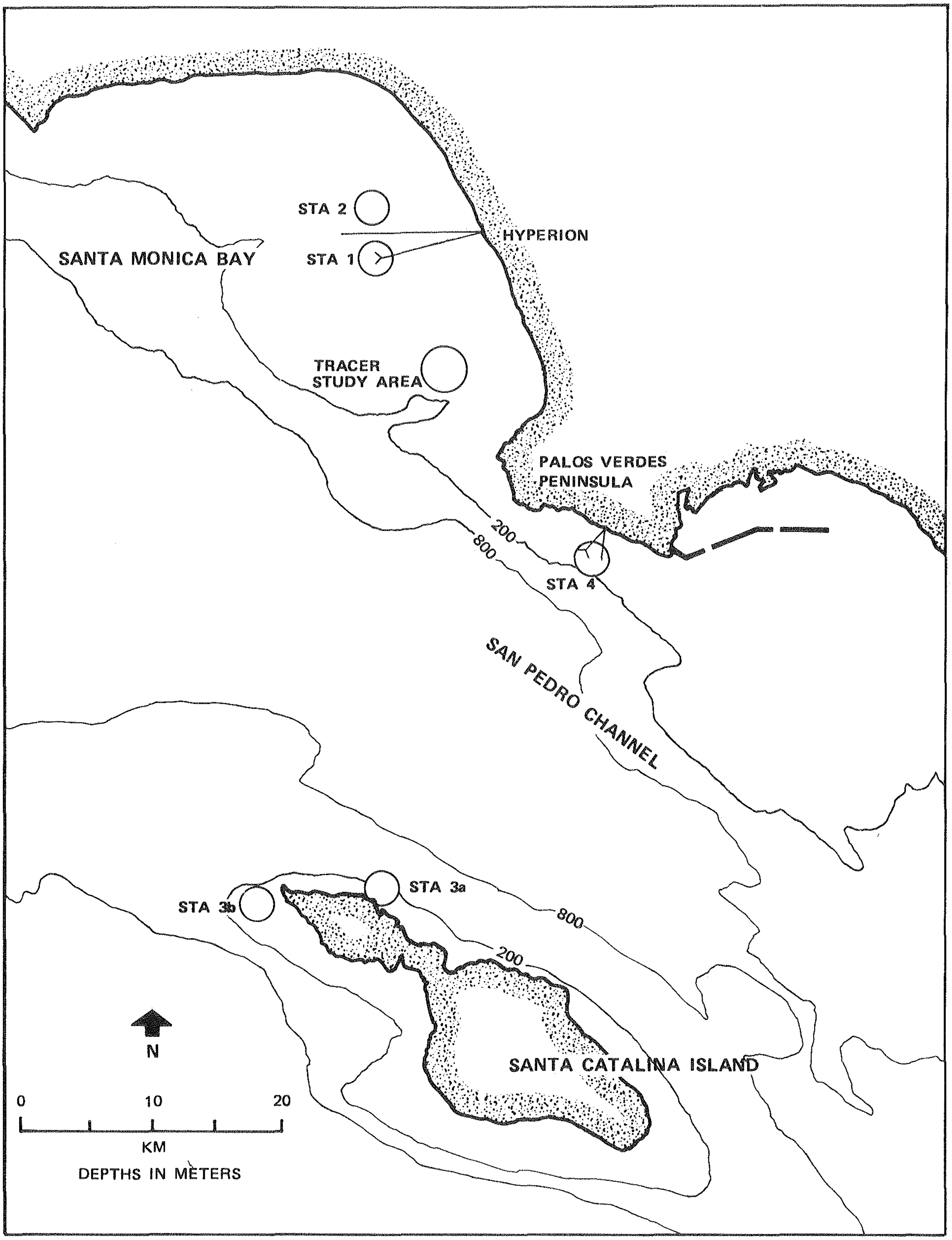


Fig. 10-5. Sampling Areas in 1971 Floatables Study of Southern California Coastal Waters.

Table 10-12
SAMPLING DEVICES AND LABORATORY ANALYSES USED IN
1971 NEARSHORE FLOATABLE SURVEY

Sampling Device	Sample Obtained	Analysis Performed
FILM MATERIAL*		
Glass screen	Film material	1. Hexane extraction 2. Fatty acid analysis
MICROPARTICULATES*		
Nylon screen	Neuston & debris	Microscopically identified and counted
	Coliform organisms	Millipore-filter technique
FLOATING PARTICULATES		
Surface trawl**	Macroparticulates	1. Identified and counted 2. Dry wt. at 40°C measured 3. Hexane extraction
	Coliform organisms	Millipore filter technique
BULK WATER		
Cornwall pipette at 10 cm	Coliform organisms	Millipore filter technique
Kemmerer sampler at 1 and 20 m	Plankton	
Plankton net at various depths below surface	Plankton	Net plankton

*To identify slick vs. nonslick materials.
**0.5-mm mesh net used.

Figure 10-6 shows the location of the most persistent convergence systems observed by Hume et al. Other systems exist, but were not routinely observed because of the course pattern followed. None of these convergence systems were noticed during the few days ocean survey in spring and summer 1971.

Sea slicks generally are readily visible only during periods of relatively calm weather. In addition, the sampling methods employed in this study required clear and calm weather (wind speeds less than approximately 7 knots) as well as the absence of appreciable sea swell. Thus, the success of the individual sampling cruises was dependent to a great extent on the weather conditions encountered during the period of sampling.

Oceanographic, weather, and surface observations made at time of ocean surface survey and sampling are summarized in Table 10-13. This information is useful for the evaluation of the observed results.

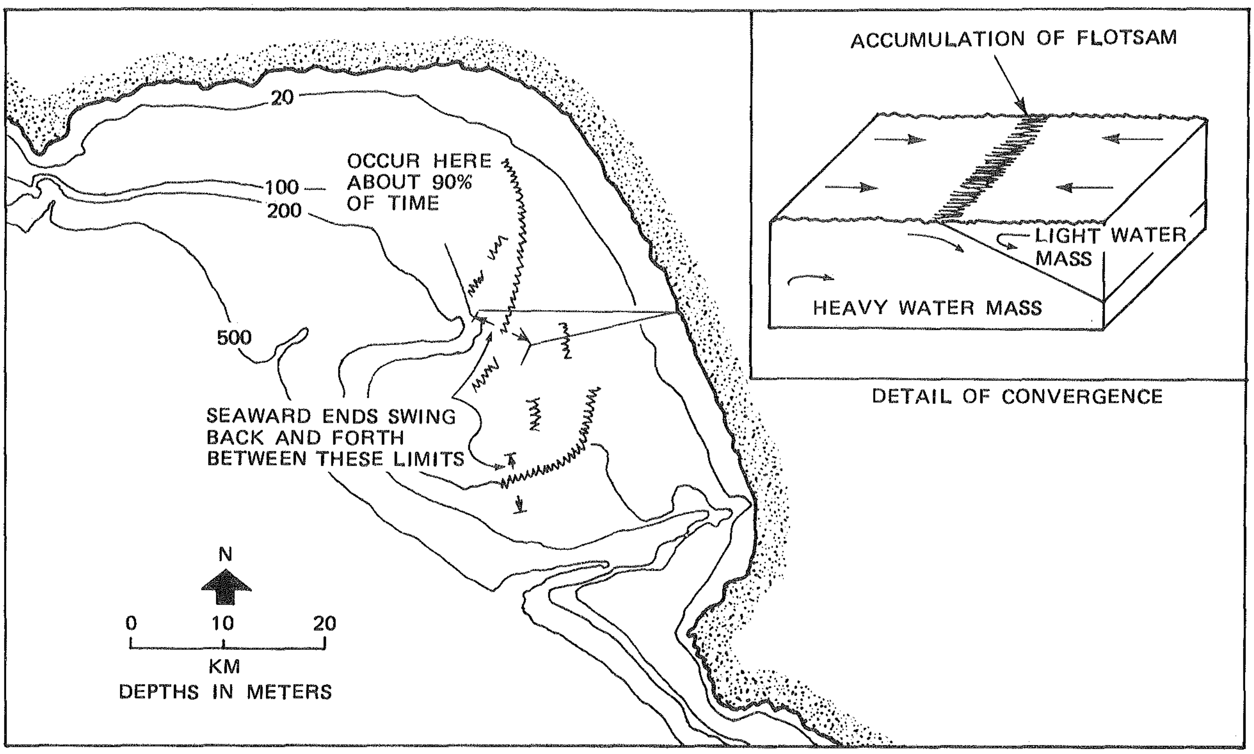


Fig. 10-6. Persistent Convergence Systems in Santa Monica Bay, October 1957 to September 1958. After Hume et al. 1959, fig. 2.

Film Material

Substances captured by the glass screen samplers were analyzed for hexane extractable materials, and these, in turn, were analyzed for long-chain, free fatty acids. The screen samples were categorized as to whether they were taken in slick or nonslick areas, except for the samples taken at Station 4 (off Palos Verdes), where no slicks were observed on the day of sampling. The concentrations of hexane extractables found in the surface film material are presented in Table 10-14.

The large variability that is seen in the individual sample results is probably due to the occasional pickup of relatively large grease particulates, which yield high values of hexane extractables. As a consequence of this high "within station" variance, the differences in mean values, both seasonally and between stations, are not statistically significant. The surface film hexane extractable concentrations ranged from 1.35 to 3.90 mg/sq m, and the mean concentrations in nonslick areas varied from 1.23 to 1.70 mg/sq m. The overall average hexane extractable concentration in the surface films was 1.9 mg/sq m. It is evident from the small differences between the concentrations in the slick and nonslick areas that the two cannot be distinguished in terms of the hexane extractable materials found on the surface. The presence or absence of a slick depends less on the total concentration of film materials than on the continuity of the film. The nature of the film materials--branch chain or straight chain and the presence of hydrophilic components--will also affect the visibility of the slick.

Table 10-13

OCEANOGRAPHIC AND SURFACE OBSERVATIONS DURING 1971 NEARSHORE FLOATABLES SURVEY

Survey Date	Station*	Wind (from)	Swell (from)	Surface Drift** (toward)	Surface Observations
SPRING					
7 Apr	1	variable, light	NW, 2-4 ft	NNE, 0.33 kn	A stationary slick in the form of a "Y" in the immediate vicinity of the diffuser
7 Apr	2	SW, 4-10 kn	W, 2-3 ft 4 sec	NNE, 0.2 kn	Several narrow band slicks running parallel with the coast
8 Apr	3a	NE, 2-3 kn	--	NW, 0.45 kn	A large ill-defined slick
SUMMER					
31 Aug	1	variable, light	NW, 2 ft	NE, 0.34 kn	Poorly defined broad and narrow band slicks moving over the diffuser system and toward shore
1 Sep	2	E, 5-7 kn at 0700 SW, 10 kn at 1230	NW, 1.5 ft 5 sec	E, 0.38 kn	A number of well-defined slicks
2 Sep	3b	E, 5 kn	NW, 1.5 ft 4 sec	NW, 0.2 kn	A number of well-defined, narrow band slicks
3 Sep	4	E, 7 kn	W, 3 ft 6 sec	NW, 0.38 kn	No visible slick

*Station locations shown in Figure 10-5.
**As measured by drogues.

Table 10-14

CONCENTRATIONS OF HEXANE EXTRACTABLES (MG/SQ M)
IN SURFACE FILM MATERIAL, 1971

	Station 1		Station 2		Station 3a,	Station 3b,	Station 4,
	Spring	Summer	Spring	Summer	Spring	Summer	Summer*
Slick Areas	12.60	1.60**	2.10	1.25**	1.30	0.80**	1.45**
	0.25	2.15	5.75	0.80	2.65	0.75	1.80
	1.40	1.55	1.20	1.45	2.80	2.25	1.10
	1.35	3.05	1.70	3.30	1.40	1.60	0.95
		0.85**					0.50**
Mean	3.90	1.84	2.69	1.70	2.04	1.35	2.30**
Std. Dev.	5.82	0.82	2.07	1.10	0.80	0.72	3.60
Nonslick Areas		0.30	0.12	0.75		1.05**	1.50**
		1.20**		1.40**		3.35	0.65
		2.12		1.05		1.30	3.10
		1.30		1.85		nil	
Mean		1.23	0.12	1.26	-	1.43	1.70
Std. Dev.		0.74	-	0.47	-	1.40	1.03

*No sea slicks apparent.
**Samples analyzed for long-chain, free fatty acids (Table 10-15).

For the 11 fatty acid analyses conducted on the hexane extractables samples collected in the summer survey (Table 10-15), the long-chain, free fatty acids (C-10 and greater) comprised about 15 percent by weight of the extractables, or an average of 0.16 mg/sq m. The composition of the remaining 85 percent of the hexane extractables was not ascertained. Two separate analyses indicated that the unhydrolyzed portion of the long-chain fatty acids (fats and soaps) was neglibible in the screen samples. Free fatty acids with carbon numbers of less than 10 were obviously present in significant quantities in many of the samples analyzed; such acids are relatively inefficient film formers, however, because they tend to increase in solubility as their chain length shortens.

The composition of the long-chain acids may vary significantly from location to location, and possibly from slick to nonslick areas. For example, the proportions of the odd carbon number acids, C-11 and C-13, were significantly greater, and the C-16 acids significantly less, in the screen samples taken over the Hyperion outfall than elsewhere in the survey region.

Table 10-15

LONG-CHAIN, FREE FATTY ACIDS IN SURFACE FILM MATERIAL, 1971*

	Sta. 1	Sta. 2	Sta. 3b	Sta. 4
Date	31 Aug	1 Sep	2 Sep	3 Sep
No. of samples	3	2	2	4
Mean total wt. of fatty acids (mg/sq m)	0.13	0.11	0.27	0.22
Mean hexane extract able material (mg/sq m)	1.22	1.33	0.92	1.44
Percent fatty acids	11	8	29	15
Composition (% of total wt.)				
Carbon Number				
10	4	11	6	5
11	24	2	1	2
12	12	14	6	11
13	20	1	1	1
14	5	11	8	11
15	3	11	13	8
16	16	36	35	32
17			4	2
18	16	15	27	29

*Values are weighted averages.

A few long-chain fatty acid analyses were also made on the hexane extractables derived from the macroparticulate (trawl) samples collected at Station 4. In the cases tested, the distributions were quite different from those shown in Table 10-15: About two-thirds of the sample by weight was C-18 acids and nearly all the remainder C-16 acids. Large quantities of short-chain volatile acids (carbon numbers less than 10) were also found.

Microparticulates

Microparticulates collected with the nylon screen sampling gear are categorized in terms of neuston (microorganisms associated with the sea surface) and fine debris. Table 10-16 summarized the data obtained from the spring and summer microparticulate surveys.

Spring and summer data are not directly comparable because of the different magnification used in the microscopic examination of the samples from the two surveys. The apparent increase in concentration between the spring and summer may be due to increased visibility of small particulates. In general the differences between slick and nonslick areas examined in the summer survey do not

Table 10-16

CONCENTRATIONS OF MICROPARTICULATES (1,000/SQ M) IN SEA SURFACE SAMPLES

	Spring Survey (200X)			Summer Survey (430X)						
				Sta. 1		Sta. 2		Sta. 3b		Sta. 4
	Sta. 1	Sta. 2	Sta. 3a	Slick	Nonslick	Slick	Nonslick	Slick	Nonslick	
NEUSTON										
Foraminifera*	28	14	35	56	63	20	40	19	102	80
Other**	31	-	10	48	37	13	46	26	23	33
Subtotal	59	14	45	104	100	33	86	45	125	113
DEBRIS										
Blue	-	37	1	-	-	-	-	-	-	-
Purple	-	-	1	-	-	-	-	-	-	-
Irradiant	-	-	1	-	-	-	-	-	-	-
Fibers	46	-	1	7	-	2	3	1	7	3
Metallic	15	11	9	-	-	-	-	-	-	-
Clumped Debris	-	-	-	1,635	391	313	419	243	715	259
Black†	-	-	-	299	44	21	29	30	55	22
Other††	-	-	-	-	3	-	-	-	3	-
Subtotal	61	48	13	1,941	438	336	451	274	780	284
TOTAL	120	62	58	2,045	538	369	537	319	905	397

*At least 8 types.

**Diatoms, dinoflagellates, sponge spicules, etc.

†Large graphite-like particulates only.

††Generally colored particulates.

appear to be significant, with the possible exception of the debris concentrations at Station 1. At this station, the debris found in the slick area was four times the concentration of that in the nonslick area. At the other two stations, the debris concentrations were highest in the nonslick areas.

There appear to be some changes in the composition of the inorganic fractions of the samples collected in the spring and summer surveys that may not be explained entirely by the change in microscope magnification. For example, the particulates classified as "metallic" in the spring samples were not noticed at all in the summer work. Also, colored particulates generally were found more frequently in the spring samples. Finally, clumps of debris encountered frequently in the summer work were encountered so infrequently in the spring samples that it was possible to count the individual particulates in the clumps. For this reason, this type of category was not used in describing the results of the spring studies.

The sizes of the debris clumps and the black graphite-like particles were measured in the samples taken during the summer survey. The frequency distributions of the sizes of both types of particles were log-normal, resembling distributions of many naturally graded particulate materials, such as beach sands. There were no significant differences between the frequency size distributions of particulates collected in the slick and nonslick samples. The mean and median sizes and relative volumes of the surface debris particles collected during the summer survey are presented in Table 10-17. The table also shows that the volumes of microparticulates collected at Station 1 were about ten times greater than the volumes collected elsewhere.

Table 10-17

SIZE AND RELATIVE VOLUMES OF SURFACE DEBRIS COLLECTED IN SUMMER, 1971

	Station 1	Station 2	Station 3b	Station 4
Clumps of Debris				
Median (μ)	5.5	3.5	2.5	2.5
Mean (μ)	12	8.2	6.5	6.5
No./sq cm	101	37	48	26
Volume Ratio*	13	1.5	1	0.5
Black Particulates				
Median (μ)	4	4	3	4
Mean (μ)	5.5	5.5	4.1	5.5
No./sq cm	17	2.5	4.2	2.2
Volume Ratio*	10	1.5	1	1.3

*Relative volume of particulates to those found at Station 3b.

The mean surface concentration of neuston over the study area was about 75,000 organisms/sq m. They were found in the greatest concentration in the slicks over the Hyperion outfall (Station 1) and in the nonslick areas of Stations 3a and 3b, the control stations. In terms of volumetric concentration, the summer surface plankton averaged about 750 organisms/mL. The concentrations in the water samples taken 1 and 20 meters below the surface was 22 organisms/mL. This represents a more than 30-fold increase in concentration at the surface over that of the subsurface waters.

Macroparticulates

The macroparticulate materials were those collected by a surface trawl having a mesh size of 0.5 mm. These samples were analyzed to determine the types, numbers, and sizes of the particles and the amount of hexane extractable material. The results are summarized in Table 10-18.

The types of macroparticulates found most frequently at Stations 1, 2, and 4 belonged to the "grease and wax" category. These particulates had an average size of about 1.3 mm and were found in concentrations ranging from 0.001 particulates/sq m at Station 3 to greater than 5 particulates/sq m at Station 1.

Other types of macroparticulates classed as being of wastewater origin included plastic, seeds, fibers, and rubber. The area/distribution pattern of the total number of wastewater macroparticulates was similar to that of grease and wax--highest concentrations at Stations 1 and 4, and lowest in the control area (Station 3). Figure 10-7a shows the relationship between the observed concentrations of grease and wax particles and the concentrations of the "other" types of wastewater particulates. The data in Figure 10-7a do not include the macroparticulates observed at the control station. In the control area, the grease and wax particulates were relatively scarce in relation to the other types, indicating that (1) the grease and wax particulates had undergone decay (assuming that their origin was over the wastewater outfalls) or (2) some fraction of the other types were natural to the control area. In general, there was a nearly linear relationship between the grease and wax particulates and the other particulates of wastewater origin.

The size and frequency distributions of grease and wax, tar, and kelp particles followed a log-normal distribution. The grease and wax particulates had a median length of 1 mm, and the sizes ranged from 0.5 to 10 mm (particles smaller than 0.5 mm were presumably not captured in the trawl). Only 55 tar particles were found; the median length was 1.5 mm, and the largest size was 35 mm.

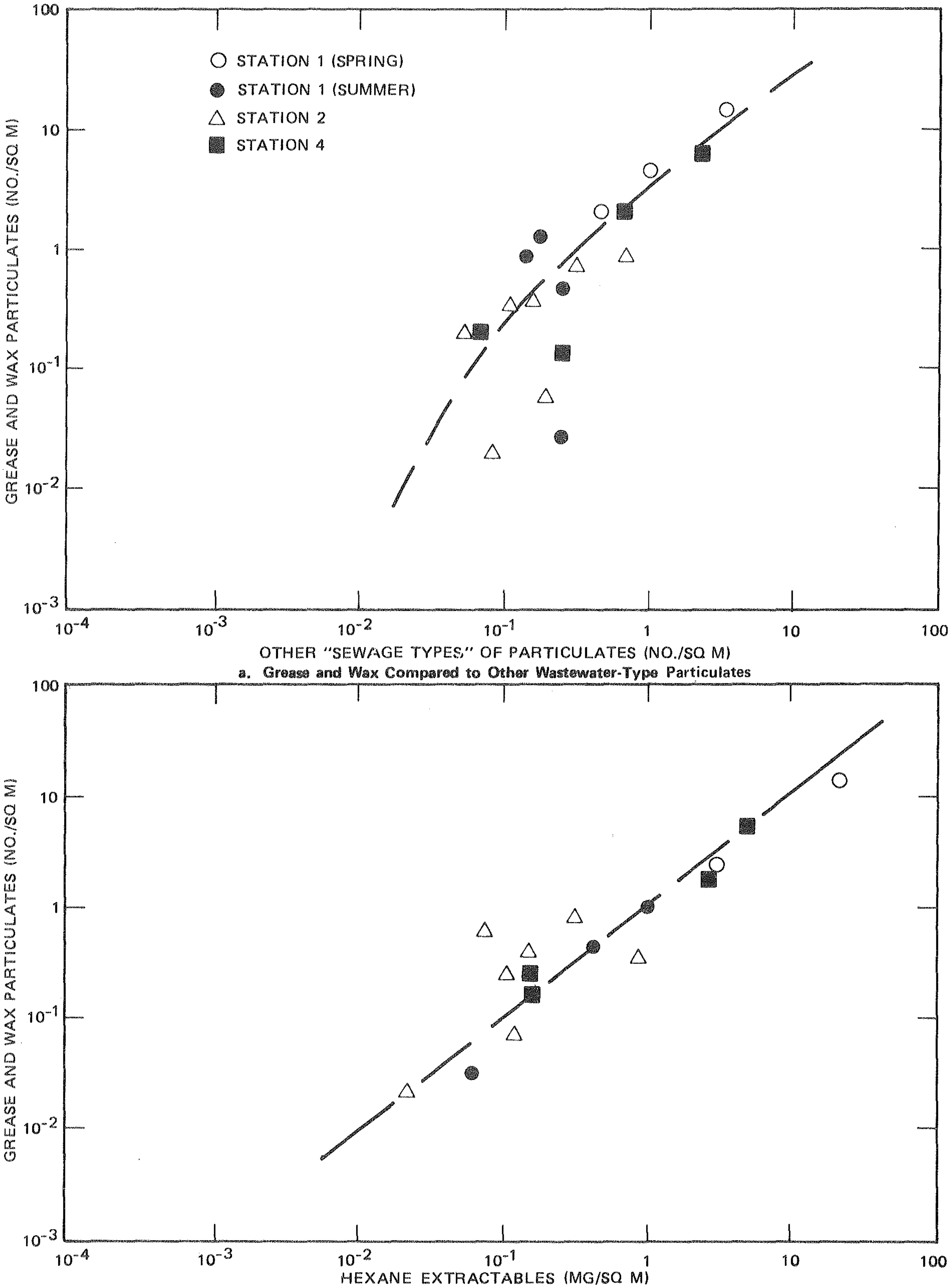
High concentrations of kelp were found in some of the trawls made at Stations 2 and 4. At Station 2, the median length of kelp pieces was 2.5 mm; at Station 4, the median length was 7.5 mm. The largest pieces caught in the trawl were 150 mm in length. Most of the small particles of plastic were 2 to 5 mm in size. The normal sizes of seeds found in the samples were 2 to 3 mm.

The dry weight concentration of the macroparticulates ranged from about 1 to 20 mg/sq m. The hexane extractable fractions of these particulates ranged from 1 to 54 percent. Highest concentrations of macroparticulates, as well as the highest percentage of hexane extractable materials, were found at Station 1 in April 1971. At the time of sampling, the effluent plume apparently was near

Table 10-18

MACROPARTICULATES IN SURFACE TRAWL SAMPLES, 1971

			Total Trawl Area		Number of Particles (per sq m)						
					Sewage Type						
Date	Station	Number of Trawls	sq m	% in slick	Grease and Wax	Total	Natural Type	Total	Dry Weight (mg/sq m)	Total Hexane Extractables (mg/sq m)	HEM/dry Weight (%)
SPRING											
7 Apr	1	3	547	100	5.7	7.1	0.7	7.8	20	10.7	54
7 Apr	2	3	944	48	0.16	0.32	0.28	0.60	0.84	0.34	40
8 Apr	3a	4	1032	52	0.005	0.026	0.29	0.32	2.4	0.025	1
SUMMER											
31 Aug	1	4	279	16	0.61	0.83	0.11	0.84	1.2	0.45	37
1 Sep	2	4	485	67	0.52	0.76	0.24	1.0	1.4	0.14	10
2 Sep	3b	4	1176	60	0.001	0.008	0.073	0.08	0.89	0.022	2.5
3 Sep	4	4	362	-	3.1	3.4	0.57	4.0	1.4	0.22	15



a. Grease and Wax Compared to Other Wastewater-Type Particulates

b. Grease and Wax Compared to Hexane-Extractable Material

Fig. 10-7. Macroparticulate Relationships in Surface Trawl Samples From the Southern California Bight, 1971.

the surface, because a stationary slick in the form of a "Y" was observed in the immediate vicinity of the diffuser.

The dry weight concentration found at Station 3 in the two surveys was similar to concentrations found at Stations 2 and 4. However, the percentage of hexane extractable material in the macroparticulates was much less at the control stations than at the other stations.

Figure 10-7b shows the relationship between grease and wax particulate concentration and the concentration of hexane extractable material for the same trawl sample. It is clear from the figure that, except for the control station, the concentrations of grease and wax particulates and hexane extractables are essentially the same. This suggests that the measurement of hexane extractables would provide a rapid, relatively accurate and convenient means of measuring the concentrations of surface particulates as long as pieces of tar are not present in significant quantities. The analysis for hexane extractable materials is far simpler and more rapid (and less expensive) than the time-consuming microscopic examination required to count particulate materials. The surface concentration of macroparticulates that could be discerned by eye was not determined because trawls generally were made through regions of both high and low concentration. A few trawls were made almost completely in high concentration regions, however, and the minimum concentration just discernible is estimated to be about 1 mg/sq m.

Coliform Bacteria

The macroparticulates, microparticulates, and bulk water samples collected 10 cm below the water surface were analyzed for coliform bacteria. Most of the microparticulate and bulk water samples analyzed for coliforms were collected in slick areas. At Station 4, where no slick was visible at the time of the survey, the samples were taken in the immediate vicinity of the outfall. The samples were cultured on membrane filters, using standard differentiating media in accordance with Standard Methods. Only bacterial colonies evidencing the typical greenish sheen of *E. coli* colonies were recorded, although numerous atypical colonies also appeared at times in all three types of samples. The atypical colonies were found most frequently in samples taken at Stations 1 and 4.

As shown in Table 10-19, no coliform colonies were obtained from any of the bulk water samples collected. In the examination of the microparticulate samples collected with the screens, coliform colonies were found in samples taken at Stations 1 and 4 (Table 10-20). There was a high degree of variance in the results from individual samples, indicating that the organisms were present at the water surface in the form of widely scattered clusters rather than uniformly distributed. At Stations 1 and 4, the coliform bacteria concentrations in the surface film were approximately 300/100 mL. At Stations 2 and 3, the concentrations were less than 3/100 mL.

Typical coliform colonies were always observed on macroparticulate samples captured by the surface trawl at Stations 1, 2, and 4. They were found in none of the samples collected from the control area. As shown in Table 10-21, the coliform concentrations associated with macroparticulates ranged from 3,000 to 150,000/sq m. In terms of the numbers of coliform bacteria per wastewater macroparticulate, the concentrations were 3,500 to 21,000 per particle.

Table 10-19
CONCENTRATIONS OF COLIFORM ORGANISMS
IN BULK WATER SAMPLES, 1971*

Survey	Station	No. of Samples	Total Volume (mL)	No. of Colonies	Approximate Concentration (No./100 mL)
Spring	1	4	75	0	<1.3
	2	4	100	0	<1
	3a	4	200	0	<0.5
Summer	1	4	400	0	<0.25
	2	4	400	0	<0.25
	3b	4	400	0	<0.25
	4	4	400	0	<0.25

*Samples taken at 10 cm depth.

Table 10-20
CONCENTRATIONS OF COLIFORM ORGANISMS
IN SURFACE SCREEN (MICROPARTICULATE) SAMPLES, 1971

Survey	Station	No. of Samples	No. of Positive Samples	Total Volume (mL)	Total No. of Colonies	Approximate Concentration* (No./100 mL)
Spring	1	4	2	21.1	75	360
	2	4	0	33.2	0	<3
	3a	4	0	33.9	0	<3
Summer	1	4	1	31.6	99	310
	2	4	0	35.1	0	<2.9
	3b	4	0	28.8	0	<3.5
	4	4	2	21.1	51	240

*Average overall concentration for each station. This value is approximately equal to number per square meter.

Table 10-21

COLIFORM ORGANISM IN SURFACE TRAWL SAMPLES (MACROPARTICULATES), 1971

Survey	Station	No. of Trawls	Total Area Trawled sq m	Total Area Trawled % in slick	Number of Coliform Colonies per sq m	Number of Coliforn Colonies per Sewage Particle*
SPRING	1	1	27	100	150,000	21,000
	2	1	114	23	6,500	20,000
	3a	1	232	100	<1	<1
SUMMER	1	4	444	22	2,900	3,500
	2	4	725	55	6,200	8,100
	3b	4	1429	56	<1	<1
	4	4	465	-	63,000	19,000

*See Table 10-18 for number of sewage-type particles in trawl samples.

10.5 SUMMARY

In spite of the many years of investigations of bacterial concentrations and behavior in marine waters, there appears to be very little epidemiological basis for currently accepted bacterial standards for water contact sports, and it would seem that the current standards are conservative. It is the general feeling that standards requiring a total coliform level of 1,000 to 2,400 MPN/100 mL are achievable at reasonable cost and that, as a consequence, there is perhaps little to be gained by epidemiological studies to explore the advisability of modification of present standards.

There is even less certainty as to the role that viruses in the coastal waters used for water contact sports may play in the transmission of disease. Again, there is almost no epidemiological data to support a standard for allowable virus levels in the coastal waters. This problem is compounded by the lack of simple, rapid, and inexpensive methods of virus measurement.

It is clear from the information presently available that both bacteria and viruses in shellfish represent a public health problem and that measures to protect the quality of waters from which shellfish may be taken are justified. Shellfish that have been grown in contaminated waters can be cleansed by transferring them to clean waters and holding them there for several days.

Not surprisingly, there is a connection between the aesthetic aspects of water quality and the aspects related to public health. There has been growing concern in recent years with the question of floatable materials, particularly those originating in wastewaters. Not only are materials of obvious sewage origin repugnant to the senses, but, as the studies described in this chapter show, higher levels of coliform bacteria appear to be associated with the floating particulate matter in the vicinities of wastewater outfalls. There is need for additional study of the problem of quantitating floatables and their relation to aesthetic and possible public health effects.

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Chapter 11

SUMMARY OF FINDINGS AND DISCUSSION

11.1 INTRODUCTION

11.1.1 Purpose, Scope and Objectives of the Study

The basic goal of the Southern California Coastal Water Research Project (SCCWRP) is to increase understanding of the ecology of the coastal waters off southern California and of the effects of human activities on the marine environment. Within this overall goal, the effects of municipal wastewater discharges to the coastal waters are emphasized, with the objective of providing information necessary for planning and management of wastewater disposal systems.

SCCWRP was founded in 1969 by the five government agencies* responsible for managing the major municipal wastewater discharges into the ocean off southern California. The sponsoring agencies delegated control of the project to a commission of local civic leaders and elected officials who could reflect the current public interest in environmental quality and exercise independent judgment on the need for improved management of factors that affect marine resources.

The specific objectives of the study are:

A. To obtain background information on the general physical, chemical, and biological characteristics of the southern California coastal water ecosystem.

B. To identify and investigate the significant physical, chemical, and biological processes and phenomena occurring in the coastal waters.

C. To identify and characterize the inputs to these waters; to describe the transport and fate of constituents suspected to be potentially hazardous to the environment or the public health.

D. To identify quantifiable responses of marine organisms to environmental stresses--at the species, population, and community level.

E. To determine the significance of findings to water quality management--specifically, to make economically and technologically feasible recommendations on receiving water quality standards and wastewater management practices and monitoring procedures.

F. To identify and define further research needed to ensure that the environment and its resources are adequately protected.

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*Ventura County, the Cities of San Diego and Los Angeles, and the County Sanitation Districts of Orange and Los Angeles Counties.

11.1.2 Summary Description of the Study Area

The Southern California Bight is the open embayment of the Pacific Oean bounded on the east by the California and Mexican coastlines between Point Conception, California, and Cabo Colnett in Baja California, and on the west by the California Current. The Bight is approximately 300 miles long and 120 miles wide, with a surface area of about 40,000 square miles. Within this general area, the primary study area is the portion of the Bight between Point Conception and the United States/Mexico border.

In the last 10 years, the population of the southern California coastal region has increased 29 percent, to a 1970 population of about 11 million people.

The southern California coastal basin draining into the Bight has a total land area of 11,500 square miles. Of the total land area in the basin, about 32 percent is devoted to residential, commercial, and industrial use, 27 percent is agricultural, and 41 percent is publicly owned (parks, governmental and military lands, wilderness areas, etc.).

Land and Submarine Physiography

There are two natural geologic provinces in the southern California and northern Baja California coastal area. The first is characterized by the Transverse Mountain Ranges, which extend from the Santa Barbara Channel Islands through the eastern boundary of the study area. The Santa Barbara Channel Islands (San Miguel, Santa Rosa, Santa Cruz, and Anacapa) are exposed peaks of the western extent of these mountains. The Peninsular Ranges, which form the second province, parallel the northwest-to-southeast trend of the coastline.

The classic continental slope to abyssal sea floor sequence outward from the coastline does not appear in southern California. Instead, the mainland shore is bordered by a narrow continental shelf, followed by a narrow slope region. Next comes a wide, complex region of basins and troughs, known as the continental borderland, which is interspersed with ridges locally piercing the surface as offshore islands. Finally, the continental slope, the transition feature between the borderland and the deep-sea floor, is found--in some places, as far as 150 miles from the coast.

The Bight's comparatively rapid geological evolution has resulted in the development of an unusual sea floor configuration--a series of coastal basins, troughs, and submarine canyons, which in a more stable system would have been smothered by a heavy blanket of sediment. The rugged underwater topography of the region allows deep, cold waters and attendent nutrients and organisms to encroach shoreward of the island-bearing continental borderland.

The total length of the shoreline, including that of the offshore islands, is 615 miles. This total shoreline is divided almost equally between the mainland shore, 303 miles, and the island shoreline, 312 miles. About 87 percent of this coastline is rocky and was formed by erosional processes. The balance, some 80 miles in length, is a depositional type of coastline, characterized by broad beaches backed by the shoreline lowlands.

Rainfall and Runoff

The southern California area has a mild and dry climate. Summers are warm and almost rainless; winters are pleasant with occasional mild storms, although heavy rains and rapid runoff from the mountains and coastal slopes sometimes cause serious flooding and large inputs to the ocean.

The long-term average precipitation over the coastal basin is 18 inches, of which 90 percent falls between November and April. The year-to-year variation in rainfall can be great. For example, the total precipitation in 1968 was only 40 percent of normal; that in 1969 was 220 percent of normal.

To control flooding and conserve water and soil, 121 dams have been built on 13 of the major streams in the basin. These dams regulate runoff from more than half of the total watershed area of the coastal basin. These practices have resulted in a substantial reduction of sand supply to the coastline and modification of the amounts and distribution of freshwater and sediment input to the Bight.

Currents

The complex current system within the Bight is influenced by winds, tides, the physiography of the bottom, and the density structure of the waters. The major influence is the offshore California Current, which is the eastern branch of the great North Pacific Gyre. This current flows eastward across the North Pacific, turns southward off the Washington coast, and departs from its coastal flow only at Point Conception. The displacement of the California Current westward from the shore results in the formation of a major return eddy, the Southern California Countercurrent.

The Southern California Countercurrent is seasonal in character; it is usually well developed in summer and autumn but weak and occasionally absent during winter and spring. The countercurrent's action as a delay or reservoir in the otherwise straight sweep of the California Current results in warming of the oceanic water in the Bight and an overall advection of food material into the Bight from further up the coast. The countercurrent contributes to the formation of a region in which organisms from southern, western, northern, and upwelling waters are found.

In the nearshore, shallow waters, the irregular topography of the bottom and the influence of wind and tidal forces result in extreme variability of the currents. These factors make it difficult to perceive the effects of the major geostrophic circulation. In addition to wind-drift currents and tidal currents, there are local water movements, including upwelling currents in submarine canyons, currents in the surf zone, internal waves, and turbidity currents.

The data obtained from individual current measuring surveys often appear inconsistent; however, considered together, they show a reasonably consistent pattern. In general, the strongest and most persistent currents are parallel to the coast. There is a slight predominance of east and southeast currents over those in the north-northwest direction above the thermocline, and in opposite directions nearer the bottom. Flow reversals occur frequently and are usually related to tidal influence.

Upwelling is a major factor in the ecology of the Southern California Bight. The northwesterly winds that blow nearly parallel to the coast are strongest off Baja California and southern California in the spring and drive surface waters offshore, causing bottom waters with low temperature, low dissolved oxygen, and high plant nutrient content to be carried inshore and brought to the surface.

The submarine canyons that connect the nearshore shelf with the deeper offshore basins often provide a route for upwelling waters. In general, however, the net water movement is down-canyon away from the shore; thus, the submarine canyons represent a path whereby nearshore sediments and beach sands moving with the littoral currents are trapped and diverted away from the shoreline area.

11.2 FINDINGS

11.2.1 Inputs to the Bight

Diffuse (Non-Point) Sources

1. There are a number of potentially significant materials entering the Bight from widely distributed sources. Large quantities of constituents--organics, nutrients, metals, etc.--are brought into the Bight by the California Current. This source is often ignored because many of the constituents are present only in extremely low concentrations. But the massive flow of the Current--on the order of 14,000,000 million gallons per day (mgd)--results in total constituent inputs that can far overshadow the quantities entering the Bight from all other sources.

2. The Southern California Bight harbors a large number of recreational, commercial, and naval vessels. Losses of bottom antifouling paint and anticorrosion anodes and spent fuel residues may represent important sources of trace pollutants (lead, mercury, copper, zinc, cadmium, polychlorinated biphenyls (PCB), etc.) to the marine environment.

3. Ocean dumping represents another source of materials entering the Bight. Materials of concern include refinery wastes, chemical wastes, refuse and garbage, and other wastes such as radioactive wastes, military explosives, oil drilling wastes, and filter cake.

4. Aerial fallout represents a category of inputs that are extremely difficult to quantify. Metals and chlorinated hydrocarbons can enter the coastal waters from both rainfall washout and dry fallout.

Discrete Sources

Wastewaters

5. Approximately 1,000 mgd of treated municipal wastewaters, 180 mgd of discrete industrial wastes, 5,600 mgd of returned cooling waters, and 500,000 acre-feet per year (equivalent to an average flow of about 410 mgd) of surface runoff enter the coastal waters of southern California. (Together, these flows are about 1/2,000th the flow of the ocean currents in the Bight.) These inflows, freshwater or saline, contribute a wide spectrum of constituents to the ocean.

6. There are 174 municipal wastewater treatment plants serving the southern California coastal basin; these discharge a combined total effluent of about 1,100 mgd. Of this total, 25 discharges (totaling about 1,000 mgd) of municipal wastewater are discharged directly into the coastal waters (See Table 4-2). Five major dischargers contribute about 94 percent of the total wastewaters currently being discharged. The following tabulation summarizes the total municipal wastewater discharges to the coastal waters in the primary study area.

Degree of Treatment	Total Flow (mgd)
None	0.3
Chlorination	6.0
Primary	869
Secondary	126
	1,001

7. In addition to the industrial wastes that are collected and treated by the municipal discharges, there are three groups of discrete industrial wastes discharged into the coastal waters: (1) thermal discharges from power plants, (2) industrial waste discharges directly to coastal waters, and (3) industrial waste discharges into San Pedro Bay (these are summarized in Table 4-14). All but one of the industrial waste discharges along the southern California coast are from petroleum-related industries, which include onshore and offshore oil production, transport, processing, and oil tanker mooring facilities.

8. A total flow of about 100 mgd of industrial wastewaters is discharged to San Pedro Bay. Seventy percent of this flow is from petroleum-related industry, and the balance is from metal processing, fish canning, and miscellaneous chemical operations.

9. Fifteen major thermal power generating stations, with a net electrical capacity of nearly 12,000 megawatts, circulate about 5,600 mgd of cooling water in the southern California coastal waters, bays, and estuaries.

Surface Runoff

10. Stream runoff, one of the major inputs to the ocean, depends upon both the regional hydrology and the regulation provided by dams and other water management systems. Within the southern California coastal basin, there are more than 150 streams discharging intermittently at points along the coastline. Nineteen streams and rivers drain approximately 70 percent of the coastal basin. In addition to the natural streams, there are between 50 and 150 major storm drains discharging to coastal waters.

Summary of Pollutant Contributions

11. Table 11-1 summarizes the estimated mass input rates from the previously mentioned sources. Except for suspended silt, nitrate nitrogen, iron, manganese, lead, and cobalt, the surface runoff mass emission rates for constituents amount to less than 10 percent of those from municipal wastewater discharges.

Table 11-1

ESTIMATED CONSTITUENT MASS EMISSION RATES (M TONS/YR) INTO THE SOUTHERN CALIFORNIA BIGHT

	Discrete Sources			Diffuse Sources				
Constituent	Municipal Wastewaters	Surface Runoff	Industrial Waste	Ocean Vessels	Ocean Dumping	Aerial Fallout	Advective Transport	Total
Silt	-	274,000	-	-	-	-	-	274,000
Total Suspended Solids	278,000	-	16,000	-	-	-	-	294,000
Volatile Suspended Solids	179,000	-	-	-	-	-	-	179,000
5-day Bio. Oxygen Demand	291,000	-	6,000	-	-	-	-	297,000
Chemical Oxygen Demand	675,000	29,000	78,000	-	-	-	-	782,000
Oil and Grease	65,000	4,400	2,200	-	-	-	-	71,600
Dissolved Silica (SiO_2)	33,000	2,800	-	-	-	-	-	35,800
Nitrate Nitrogen	530	980	-	-	-	-	-	1,510
Ammonia Nitrogen	59,400	440	9,500	-	-	-	-	69,340
Organic Nitrogen	24,800	1,090	-	-	-	-	-	25,890
Total Nitrogen	85,400	2,510	10,000	-	-	-	-	97,910
Phosphate Phosphorous	13,300	410	-	-	-	-	-	13,710
Detergent (MBAS)	7,600	66	-	-	-	-	-	7,666
Cyanide (CN)	210	11	-	-	-	-	-	221
Phenols	1,730	269	43	-	-	-	-	2,042
Heat (10^9 kwh/yr)	-	-	94	-	-	-	-	94
Silver	15	1.1	-	-	1.5	-	6,000	6,018
Arsenic	-	-	-	1.5	-	-	-	2
Cadmium	54	1.2	-	0.1	14	-	2,000	2,069
Cobalt	3.0	5.3	-	-	14	-	8,000	8,022
Chromium	649	25	-	1.0	28	-	4,000	4,703
Copper	567	18	-	386	28	400	60,000	61,399
Mercury	2.9	0.06	-	3.9	1.5	8	600	616
Nickel	313	17	-	-	28	40	140,000	140,398
Lead	211	90	-	9.5	28	3,400	6,000	9,738
Zinc	1,680	101	-	164	56	2,200	200,000	204,201
Iron	6,000	26,000	-	-	280	40	60,000	92,320
Manganese	102	183	-	-	28	480	40,000	40,793
Total DDT	19	0.119	-	-	14	2	200	235
Total PCB	9.7	0.246	-	4.1	28	2	200	244

12. Approximately 278,000 metric tons per year* of suspended solids are input through municipal wastewater discharges. This is approximately equivalent to the suspended silt mass emission rates of 274,000 metric tons from surface runoff during the year 1971-72, although the natures of these two types of solids are considerably different.

13. Three metals--iron, manganese and cobalt--are estimated to have higher mass emission rates in surface runoff than in municipal wastewaters.

*A metric ton is 2,204 pounds, or 1.1 standard short tons.

14. For cadmium, chromium, nickel, and silver, the present data suggest that municipal wastewater discharge dominates all other inputs except ocean current advection.

15. Municipal wastewater discharges, vessel antifouling paint, and direct rainfall onto the Bight all appear to contribute similar amounts of copper and mercury.

16. Municipal wastewaters and direct rainfall appear to be the predominant sources of zinc, excluding ocean current advection.

17. For lead, the surface runoff input is the same order as that of municipal wastewaters, but these sources probably contribute an order of magnitude less lead to the Bight than does aerial fallout.

18. For seven of the metals studied (cadmium, chromium, copper, iron, lead, silver, and zinc), about 90 percent of the total metals in wastewaters was found to be associated with particulate material retained on a 0.45-micron filter.

19. Municipal wastewater discharge was the principal known local source of DDT and PCB compounds to the Bight during 1972.

20. The chlorinated hydrocarbon mass emission rates from surface runoff during 1971-72 water year amounted to between 1 and 3 percent of those from municipal wastewaters during 1972.

21. As a result of source controls and sewer cleaning procedures between January and December 1972, the concentration of total DDT in the Los Angeles County Sanitation Districts final effluent decreased by a factor of six, and the concentration of total PCB apparently decreased by a comparable factor.

22. Estimates of annual PCB inputs to the Bight from vessel bottom paints suggest that the magnitude of this source may have been comparable to that of municipal wastewater inputs during 1972.

11.2.2 Water and Sediment Characteristics

General

23. As is true in all coastal areas, the characteristics of the waters in the Bight are far more variable than those of the open ocean. In general, however,

there is a thermocline at a depth of approximately 50 feet during the summer months. Below this depth, the water is often isohaline. This thermocline is important in that it reduces the rate of transfer of substances from the bottom waters to the surface.

24. Surface water temperatures vary from about 60°F in the early part of the year to around 68°F during the summer, with nonseasonal, year-to-year variations outside of this range. The bottom waters, below 200 feet, are coldest (50 to 60°F) between April and September, (i.e., during the upwelling period).

25. On the mainland shelf, the surface waters are usually saturated or supersaturated with dissolved oxygen, with the highest concentrations being found during the summer months. The dissolved oxygen at 300 feet of depth is normally between 4 and 6 mg/L, or about 50 percent of saturation. In the deeper waters, particularly in several of the basins adjacent to the shelf, oxygen values are extremely low, in the order of 0.3 to 0.4 mg/L.

26. Nitrate is the major nitrogen chemical form found in natural marine waters. In the Bight, surface water concentrations of nitrate nitrogen range from 0.01 to 0.16 mg/L. Concentrations in the deeper waters are higher. Studies have shown nitrate nitrogen concentrations at a depth of 300 feet to vary from 0.2 to 0.4 mg/L.

27. Relatively little information is available on the concentration of many trace metals in seawater, and values that have been reported for "natural" waters are extremely variable. In general, the levels of metals in the waters of the Bight, even in the vicinities of stream discharges and wastewater outfalls, are within the ranges reported for seawater in various areas around the world.

28. The coast as a whole is nearly always marked by a band of low transparency water within a mile or so of the beach. Transparencies are generally lower (20 ft or less) in the waters near alluvial land plains and higher (20 to 40 ft) near rocky shores.

29. Most mainland shelf sediments are sand or sand-silt combinations, with median diameters of 60 to 125 microns. On the basin and trough slopes, the sediments are commonly mud, i.e., either silt or clay. The bulk of the sediments deposited on the continental borderland have been eroded and transported to the area from the adjacent land.

30. In the outer basins, the rate of deposition is much slower, and the material deposited probably consists primarily of detrital mineral particles and material from chemical and organic sedimentation. In some of the basins, currents and benthic animals that might disturb the sediments are lacking, and it is possible to obtain a record of historical conditions from the sediment layers.

31. Sediments in the vicinity of major municipal wastewater discharges exhibit chemical and physical characteristics that differ significantly from those considered natural in the region (although similar sediments occur naturally elsewhere in the oceans). Sediments appear blackened and show higher concentrations of organic materials than found in unaffected areas. Extensive areas

where sulfides are present in sediments and in waters very near the bottom are characteristic near the major discharges.

Metals in Sediments

32. Between 1970 and 1972, an extensive sampling program was conducted in the vicinity of the major municipal wastewater outfalls in the Bight to measure various metal concentrations in the sediments. Samples were taken with Phleger and box coring devices; the metal concentrations obtained with the Phleger corer, which tends to "blast" away some of the surface sediments, were somewhat lower than those obtained with the box corer.

33. In general, this survey showed that the surface sediment concentrations of most of the metals measured were significantly higher around the largest outfalls (those of the City of Los Angeles and the Los Angeles County and Orange County Sanitation Districts) than in areas away from the outfalls.

34. "Enrichment" ratios (the ratios of metal concentrations at a distance of 1 mile from the outfall termini to the estimated natural background levels) were estimated. Highest enrichment ratios were found in the area of the Los Angeles County outfall. The enrichment ratios for the three discharges exhibiting the highest sediment concentration of metals are shown in Table 11-2.

35. There was no enrichment around any outfall for iron, manganese, and cobalt.

Table 11-2
SELECTED METAL ENRICHMENT RATIOS*

Metal	Los Angeles County Sanitation Districts	City of Los Angeles	Orange County Sanitation Districts
Mercury	70	5.1	5.3
Cadmium	64	13	4.9
Lead	24	4.2	3.9
Copper	11	3.4	2.0
Zinc	8.8	1.9	1.3
Chromium	6.8	1.8	1.4
Silver	4.8	5.4	1.7
Nickel	1.6	1.3	1.0
Iron	1.0	0.9	--
Manganese	0.85	1.1	1.0
Cobalt	0.85	1.2	--

*The ratios of metal concentrations at a distance of 1 mile from the outfall termini to the estimated natural background levels.

36. The concentrations of manganese in surface sediments around the Los Angeles County outfall system were significantly lower than estimated background levels.

37. Within a few miles of the discharge off the Palos Verdes Peninsula and the Hyperion 7-mile sludge discharge into Santa Monica Canyon, perturbations of trace metal concentrations clearly extended to a depth of 20 cm or more in the sediment.

38. Core samples taken from the deep, anoxic Santa Barbara Basin were used to determine the age of the layers within the samples. Analysis of the separate layers provided a means for estimating the change in concentration of metals over the last 100 or more years. The historical record of sediment concentrations of trace metals in the dated varved sediments of the basin suggest that average mercury concentrations in the ecosystem of the Bight during the last few decades have doubled over 19th century levels. The increase apparently began around the turn of the century, and probably is attributable to worldwide human activity rather than to local sources.

39. Levels of lead in the sediments also have increased by about an order of magnitude during the last few decades; this is attributed to the use of leaded gasoline in internal combustion engines in southern California. The other trace metals studied in the Basin cores showed little evidence of significant recent increases over natural concentrations.

40. Comparison of the mean metal concentrations in wastewater solids with the estimated background concentrations of metals in the local sediments showed that the concentrations associated with the wastewater solids are from 20 to 320 times greater than the estimated local background levels.

41. The concentrations of iron and manganese in the wastewater solids are less than half of the estimated background sediment levels. The cobalt concentrations in the wastewater solids and the natural levels in the sediments are approximately equal.

42. Sediments in the vicinity of the old and new Orange County outfalls were studied to determine the fate of metals in the sediments. In the period before the changeover, the mean copper concentration near the old outfall was 36.3 mg/dry kg. Approximately 1 month after the change, the concentration had decreased by approximately 40 percent to 23.3 mg/dry kg. This same phenomenon was observed for other metals, indicating a relatively rapid decrease in concentration due to exchange or mixing.

Chlorinated Hydrocarbons in Sediments

43. The distributions of DDT and PCB around the major outfalls followed the same pattern exhibited by the metals. Concentrations were high near most outfalls and decreased with distance from the outfall.

44. Data collected in the vicinity of the City of Los Angeles outfall showed high concentrations of both DDT and PCB in the sediments near the discharge. The highest PCB and DDT concentrations were found near the 7-mile sludge outfall.

45. In the area off Whites Point (the location of the Los Angeles County Sanitation Districts outfalls), maximum DDT concentrations of 130 mg/kg were found. These concentrations were probably caused by the discharge of DDT from the Montrose Chemical Company (and possibly others) in the years preceeding 1970, at which time the Montrose discharge was eliminated.

46. The large discrepancy in concentrations of total PCB in surface sediments collected off the Los Angeles County and Orange County wastewater outfalls suggests that the apparent similarity in the estimated 1972 mass emission rates of PCB via these two systems (6,000 and 3,000 kg/yr, respectively) is not representative of the long-term situation.

47. Within about 3 miles of the Los Angeles County outfalls, the bulk of the total DDT contained in the sediments occurs in the top 20 cm.

11.2.3 Coastal Fish Populations

General

48. Analysis of party boat fish catches since 1947 showed that there has been a general increase in catch of about 80,000 to 100,000 fish per year. However, the catches of individual sport fish species have fluctuated greatly, with no apparent relationship to either the overall effort or the overall landing.

49. Local commercial fisheries landings have fluctuated greatly, and the total catch during the last two decades has been substantially less than the catch during the 1940's. The major decline between 1950 and 1952 was due primarily to a reduction in the abundance of sardines and the failure to utilize competitive species that concomitantly increased in abundance.

50. Excluding the sardine and anchovy catch, the landings of the remaining commercial fishes have been fairly uniform, ranging between 60 and 150 million pounds per year over the last 30 years.

51. The SCCWRP studies of the coastal fish populations have been concerned with the following three areas:

A. Defining the types and varieties of fish, their apparent associations into community assemblages, and their periodic movements on and off shore, and comparing the relative abundance and diversity of fish populations in different areas of the Bight.

B. Determining the concentrations of metals and chlorinated hydrocarbons in demersal fish populations.

C. Analyzing the diseases and abnormalities in local fish populations.

52. Between August 1969 and March 1972, 303 samples were obtained by trawling from 119 stations. A total of 121 species were found; this is estimated to be one-quarter to one-third of the total fish species in the Southern California Bight and approximately one-half of the coastal zone species.

53. Dover sole, a flatfish locally affected with disease problems, was the most frequently encountered species.

54. The speckled sanddab (the most abundant species), the Pacific sanddab, the dover sole, and the stripetail rockfish accounted for nearly 50 percent of all the coastal fishes captured during the surveys.

55. Analysis of frequently found associations of species revealed five major groups. Three of the groups were composed primarily of bottom flatfish and had distributions that were to some extent depth-dependent. The group dominated by the speckled sanddab was usually found in waters of 30 to 300 feet in depth. The slender sole/rex sole group appeared primarily in deeper water between 225 and 1,100 feet, and the Pacific sanddab/dover sole group was usually found in waters of 110 to 300 feet in depth.

56. Analysis of the species diversity in the samples suggested that the diversity was higher in the southern areas sampled (Dana Point) than in the northern areas around Point Hueneme.

57. In general, the diversities observed in the Bight are consistent with those found in similar fish populations in other coastal areas.

58. Significant differences were found in both the numbers of fish and the numbers of species caught in day and night trawls. More than twice as many species per sample were found at night, and the median catch per sample was more than six times greater at night than during the day. These differences were accounted for by species other than the flatfishes. Apparently most flatfishes at these depths do not migrate significantly on a daily basis or do not depend upon vision to avoid or escape the trawling net.

59. Upwelling was found to effect significant changes in the distribution of demersal fish. In upwelling areas, the demersal fish tend to move in shore to more shallow waters, probably to avoid the lower temperatures.

60. In April 1971, the Orange County Sanitation Districts began discharge through a new 5-mile outfall and terminated the discharge through the old 1-mile outfall. Quarterly trawls were made in the vicinity of the outfalls for more than 1-1/2 years before the changeover, and five trawl surveys were made after the changeover. Analysis of the white croaker catch data showed that relatively large numbers (100 to 1,000 fish per haul) were caught at the station near the end of the old outfall prior to termination of the discharge. After the discharge was terminated, the white croaker catch at that same station dropped to between 0 and 32 fish per haul, suggesting that the white croaker either avoided or at least no longer selected that location.

61. Changes in population abundance and size composition of the dover sole were also observed at three stations close to the new outfall. Following initiation of the new discharge in April 1971, the abundance of dover sole appeared to increase, particularly at the station downstream from the discharge.

Trace Constituents in Nearshore Fishes

62. The levels of total DDT in flesh of dover sole during 1972 were clearly related to proximity to the Los Angeles County outfall system. Levels ranged from a maximum of 24 mg/wet kg (ppm) off Palos Verdes to levels two orders-of-magnitude lower off Ventura and Orange Counties. Fishes sampled near Santa Catalina Island exhibited concentrations below 0.1 ppm.

63. About 60 percent of the dover sole sampled during 1971-72 between Redondo Canyon and the western entrance of Los Angeles Harbor exceeded the maximum total DDT concentration of 5 mg/wet kg (parts per million, or ppm) permitted in fish for commercial sale by the U.S. Food and Drug Administration. White croaker taken from the Los Angeles Harbor breakwater area also had concentrations exceeding that considered safe for human consumption.

64. The pattern for PCB is similar in that the concentration in the shoreline areas ranged from 0.06 to 4.1 ppm, with the highest concentration found in the immediate vicinity of the Los Angeles County outfall system. Three samples near Santa Catalina Island were all less than 0.04 ppm.

65. The excellent correlation between pesticide levels in fish and in sediments and their local abundance strongly indicates that the fish remain in the area from which they are collected long enough to reflect the local environmental conditions.

66. Thirty-nine composite samples of liver tissue from dover sole were analyzed for twelve metals. For all of the metals except iron, the metal concentrations in fish taken from areas immediately around the Los Angeles County outfall system were less than or equal to those in fish taken from the control areas around Santa Catalina Island. In fact, the highest concentrations of six of the metals were found in the fish from the control areas. The data indicate that, for the metals studied, concentrations in dover sole livers do not increase as a result of exposure to the sediments with high metal concentration or to the waters found in the vicinity of southern California wastewater outfalls.

Diseases in Nearshore Demersal Fishes

67. The study program focused on three disease syndromes: tumors in flatfish, fin erosion in dover sole and white croaker, and structural anomalies in three actively swimming species. Four flatfish species were found with one or more tumor-bearing individuals, and anomalous fish were found in all of the five survey areas. Of the four species, dover sole were most frequently affected.

68. In general, tumor-bearing dover sole tended to be smaller than the fish in the total population, suggesting that the occurrence of tumors in dover sole may be a function of the early life history of the fish. Histological examination of the dover sole tumors showed that they were identical to those from related flatfish species in Puget Sound. The factors involved in initiating and maintaining the disease are unknown, although there is some suggestion that a viral agent may be responsible.

69. The overall incidence of tumor-bearing dover sole was 1.3 percent. This incidence is similar to or lower than that reported for flatfish in other areas.

70. Of the 121 species collected in the trawl surveys, 35 species had at least one specimen with eroded fins. Nearly half of the 72 species caught off the Palos Verdes Peninsula were affected with this syndrome. The next highest percentage of affected species was 14 percent for fish caught in Santa Monica Bay. Dover sole and white croaker were the most commonly affected species. The overall incidence of fin erosion in the species studied is about 1 to 2 percent.

71. Although there is a definite association between fin erosion and wastewater discharges, the causal factors are unknown. The disease does not appear to be associated with levels of chlorinated hydrocarbons or metals in fish tissues. It has not been possible to demonstrate infective bacterial, fungal, or protozoal organisms associated with the fin lesions or the internal organs of affected fish. The histological evidence of fin erosion in the dover sole indicates a localized condition and not a systemic disease.

11.2.4 Public Health and Aesthetics

72. A major consideration in water quality management practice is the concern over the possible transmission of disease through viruses, bacteria, and other pathogens in the coastal waters. All coastal states have regulations governing the permissible concentrations of coliform bacteria in the nearshore waters. These limits vary from 50 to 2,400 MPN (most probable number) per 100 mL.

73. There is little epidemiological basis for these standards; most studies attempting to relate disease to coliform levels in the marine waters have proven inconclusive. Indeed, in many cases, these standards appear to be best correlated with aesthetic considerations. In California, for example, studies conducted in the 1940's in Santa Monica Bay indicated that, when the coliform concentrations in the nearshore waters were 1,000 MPN/100 mL or less, there was little or no visible evidence of sewage on the waters or on the beach.

74. Isolation and identification of enteric viruses in wastewaters or in receiving waters is extremely difficult because of the relatively low concentrations of such viruses and the analytical problems connected with determining their concentration.

75. Data on the concentration of viruses in estuarine or coastal waters are meager. Under natural conditions, viral infectivity in estuarine and marine waters will be reduced with time.

76. Various laboratory studies have shown that temperature is an important factor in determining the length of time required for reducing virus infectivity. The results of the number of studies have shown that, to achieve a 99.9 percent virus inactivation in seawater, between 30 and 90 days are required at 5 to 10°F and that this time was reduced to 2 to 15 days at 68 to 79°F.

77. The principal public health concern in nearshore waters is the potential of disease transmission by viruses or bacteria in shellfish. However, both bacteria and viruses are removed from shellfish placed in clean waters in a matter of days through the organisms' normal feeding and elimination processes.

78. There are some isolated instances of epidemic outbreaks attributed to unsanitary conditions of bathing waters. However, it is difficult in most cases to separate other possible sources of infection from contact with polluted bathing waters. There are a number of reported cases of enteric disease outbreaks due to the consumption of raw or inadequately prepared shellfish harvested from sewage polluted waters. None of these reports involved southern California waters.

79. There have been numerous studies of the "die-off" or disappearance of enteric bacteria in seawater. The disappearance rates found in these studies have varied widely, depending upon the investigator, the types of waters studied, the bacteria used, whether the study was done in the laboratory or in the field, and other factors. In general, it has been found that levels of bacteria in natural waters decrease exponentially with time and distance from the outfall, and that the time for a reduction of 90 percent in the numbers of coliform bacteria (T_{90}) falls within the range of about 1 to 8 hours.

80. Coliform concentrations in nearshore southern California waters have been monitored extensively for many years. Studies conducted by the City of Los Angeles in Santa Monica Bay since 1960 have shown that coliform concentrations in the surface water samples are usually higher from December to March than from June to October. These differences are associated with the seasonal stratification of the waters.

81. Coliform concentrations tend to be higher in both surface and subsurface samples at stations closer to the shoreline than at the farther stations. Coliform concentrations along the beaches are affected greatly by surface runoff, and there is a strong correlation between rainfall, with its consequent runoff, and coliform concentrations in the littoral (surf) waters.

82. The coastal waters and the beaches represent a major recreational resource in the southern California region, and aesthetically offensive conditions, particularly those associated with sewage or refuse, greatly decrease the value of that resource. Aesthetic considerations that may be affected by water quality management practices include color and transparency of the water, odors, and floatable materials. The SCCWRP studies have concentrated on the problems and characteristics of several classes of floatable materials.

83. Floating materials are subject to transport and concentration by surface currents and by the winds. The floating materials present in the marine environment may result from natural processes as well as from human activities. Except in the immediate areas of outfalls, by far the greatest quantities of organic slick-producing material and floating detritus comes from natural sources.

84. In the coastal waters of southern California, shore drainage and surface runoff introduce large quantities of partially decomposed terrestrial organic material, rubbish, and other floatable materials during the storm season.

85. Natural oil seeps in the offshore waters also contribute oils and tars, which find their way to the water surface and to the beaches.

86. In the SCCWRP floatable studies, the major parameters measured were gross hexane extractable materials, long-chain fatty acids, coliform bacteria, and floating particulates. Most of the sampling was done over the Hyperion outfall in the Santa Monica Bay area, over the Whites Point outfall off the Palos Verdes Peninsula, and at the northern end of Santa Catalina Island. In the outfall areas, samples were taken in areas where visible slicks occurred as well as in nonslick areas.

87. The results of sampling film materials on the surface of the water showed that slick and nonslick areas could not be differentiated on the basis of the hexane extractable concentrations nor by the concentration of the various fatty acids measured.

88. Microparticulates collected with nylon screens were categorized in terms of microorganisms associated with the sea surface and fine debris. The mean concentration of surface-associated microorganisms was about 75,000 organisms per square meter. In terms of volumetric concentration, the surface plankton averaged about 750 organisms per mL. In contrast, the average concentration in water samples taken in the upper 20 meters was about 20 organisms per mL, indicating a more than 30-fold increase in concentration at the surface over that of the subsurface waters.

89. Macroparticulate materials were collected by a surface trawl having a mesh size of 0.5 mm. Almost all of the macroparticulates found at the wastewater outfall stations belonged to the grease and wax category. The dry weight concentration of macroparticulates ranged from about 1 to 20 mg per square meter, and the hexane extractable fractions of these particulates ranged from 1 to 54 percent. The percentages of hexane extractable materials in the macroparticulates were much lower at the control stations (Santa Cataline Island) than in the wastewater outfall areas.

90. Coliform bacteria were always observed associated with macroparticulate samples from the wastewater outfall stations. They were found in none of the samples collected from the control area. The coliform concentrations associated with macroparticulates ranged from 3,000 to 150,000 per square meter.

11.2.5 Benthic and Intertidal Invertebrates

Mainland Shelf and Basin Macrofauna--Background Data

91. Background information on the soft-bottom benthic invertebrate communities of the Southern California Bight was provided by extensive Allan Hancock Foundation studies carried out from the early 1950's to 1960. Polychaetes, crustaceans, molluscs, and echinoderms constitute the major groups of organisms on the mainland shelf. Polychaetes and crustaceans are about equally abundant,together contributing 70 percent of the total individuals; but, in terms of biomass, polychaetes constitute 40 to 50 percent. The basin fauna is less diverse, and the density of organisms and biomass considerably below that of the shelf fauna. Polychaetes accounted for about two-thirds of the specimens in basin samples, with other groups contributing less than 10 percent each.

Benthic Communities and Their Response to Stress

Indicator Species

92. Recent studies conducted at the old and new Orange County outfalls, at Point Loma, and off the Palos Verdes Peninsula showed that the distribution of brittle stars, principally *Amphiodia urtica*, and the small clam, *Parvilucina tenuisculpta*, could be associated with effects of wastewater discharge.

93. At the old Orange County outfall, there was a marked increase in the ratio of brittle stars to *Parvilucina* after termination of discharge: *Parvilucina* was more abundant during discharge, and brittle stars were more abundant after termination of discharge. At the new outfall, a year after initiation of discharge, the ratio was not very different from predischarge values, with brittle stars outnumbering *Parvilucina* and the numbers of both organisms having increased.

94. At the City of San Diego outfall off Point Loma, analysis of the data over nearly a 10-year period showed that, in the areas immediately around the outfall, *Parvilucina* were far more numerous than the brittle stars. At stations distant from the outfall, the ratio was reversed, and the brittle stars outnumbered the clams.

95. Species such as *Capitella capitata*, a segmented worm, are commonly regarded as indicators of conditions of reduced salinity, low dissolved oxygen, or highly organic substrate. In the studies around the Orange County outfalls, the species decreased around the old outfall when the discharge was terminated and increased around the new outfall. In Santa Monica Bay, capitellid species were relatively more abundant near the outfalls than in more distant areas. At Point Loma, *C. capitata* was identified in a few samples taken at stations closest to the diffuser but not elsewhere.

96. Data from an 87-station survey on the Palos Verdes shelf indicated that, with respect to abundance of the major faunal groups, this area differed from the usual shelf faunal composition: Polychaetes contributed 70 percent of the total benthic specimens, and molluscs 27 percent. Crustaceans and echinoderms were low in abundance, and brittle stars were completely absent from the samples. *Parvilucina*, the dominant mollusc, was abundant over much of the area but was diminished around the Whites Point outfall and was completely absent from samples taken from a line of stations extending northwest from the "Y" diffuser. Most of the distributions of the 21 major polychaete species appeared to fit outfall-related patterns. Known indicators of stress such as *Stauronereis rudolphi*, the most abundant species, and *Capitella capitata* were the dominant forms near the outfall, and many other species distributed over much of the Palos Verdes shelf were conspicuously absent from the outfall area.

97. Polychaete data from the 87 Palos Verdes shelf samples were subjected to recurrent group analysis to determine frequently occurring groups of organisms. Four groups containing a total of 10 species were defined. The group containing *Stauronereis rudolphi* and *Capitella capitata* occurred extensively in the outfall area, where highly organic substrate and hydrogen sulfide were noted and sediment levels of metals and DDT were relatively high. A second group

occurred in parts of the outfall area but was not found in areas where most outfall-related factors may reach extremes. The other two groups were not present in relatively large areas around the outfall.

98. Species diversity measurements for the polychaete community of the Palos Verdes shelf showed distinctly lower values in the area immediately around the outfall as compared to more distant areas. Species diversity of samples from sediments with a black surface taken in the vicinity of the outfall was lower than in samples with lighter surfaces. Data from a relatively undisturbed bay in Baja California indicated a possible relationship between sediment coarseness and diversity, but this relationship was not apparent in the Palos Verdes data. Polychaete diversity off Palos Verdes appeared to be relatively stable from season to season.

Community Stress and Recovery Off Orange County

99. Sulfides and organic carbon in the sediments and suspended solids and transparency in the water column were measured before and after the change in wastewater outfalls off Orange County in April 1971. The physical and chemical characteristics of the sediments and the water around the old outfall changed markedly after the discharge was terminated. Sulfides in the sediments and organic carbon and suspended solids in the water column decreased while the transparency increased. The changes near the new outfall in the 8 months following initiation of discharge were relatively minor and, for the numbers of measurements made, not statistically significant. These small changes may be due in part to the modern design of the new outfall diffuser and the high dilution (greater than 100 to 1) available at that location.

100. At the old outfall, after termination of discharge, total population density of benthic invertebrates decreased, but the number of species per sample and species diversity increased. In the 18 months following initiation of discharge at the new outfall, total population density and number of species per sample increased, and species diversity decreased.

Chlorinated Hydrocarbons in Benthic Invertebrates

101. The few laboratory bioassay studies of the effects of DDT when incorporated into food (detritus or prey) for larval and adult crustaceans have revealed toxic responses at concentrations below the levels found in subtidal sediments and benthic fish over much of the Palos Verdes shelf.

102. Concentrations of total DDT in intertidal mussels collected during 1971 from throughout the Bight clearly reflected the influence of the Los Angeles County discharge. Distinct gradients were observed in all directions away from this outfall system: Highest levels (4 mg/wet kg) were observed in specimens collected on the Palos Verdes Peninsula; lowest values (0.03 to 0.04 mg/wet kg) were found at Punta Banda in northern Baja California, Mexico, at San Clemente Island, and at Bodega Bay, north of San Francisco. Levels an order of magnitude higher than the minimum background concentrations were found as far as 105 km from the Los Angeles County outfalls. These high concentrations of DDT in the area of Palos Verdes around the Whites Point outfall were almost certainly the result of a major long-time discharge of DDT in the Los Angeles area. This discharge was reduced significantly in 1970.

103. High concentrations of total PCB were also observed in specimens of the intertidal mussel collected from Palos Verdes Peninsula (0.4 to 0.5 mg/wet kg). Levels generally decreased away from this location, except that a secondary peak in the distribution was observed at Point Loma in San Diego. This may reflect the influence of the large harbor there. Minimum levels (0.01 to 0.02 mg/wet kg) again were observed in Punta Banda and Bodega Bay specimens, but corresponding values also were found at all of the offshore islands in the Bight except Santa Barbara Island (0.07 mg/wet kg) and at the three coastal stations north of Point Conception. This pattern suggests that, in contrast to the case for DDT, there are several significant sources of PCB in the Bight.

Trace Metals in Benthic Invertebrates

104. The level of knowledge imparted by current bioassay studies does not permit any conclusive evaluation of the significance of the elevated levels of metals in sediments around the various outfalls to the viability of the subtidal benthic invertebrate community. The apparent lack of uptake by fishes feeding on invertebrates living in sediments with high metal concentrations in the Bight (and related studies of a polychaete and an oyster species by other investigators) suggests that metals in contaminated sediments are for the most part unavailable to the biota.

105. Tissues of mussels and gooseneck barnacles were analyzed for a number of metals. Metal concentrations in the organisms, unlike those of DDT or PCB, do not show an obvious pattern associated with wastewater discharges.

106. A survey of approximately 25 trace metals in the intertidal mussel, *Mytilus californianus*, revealed no apparent relationship between proximity to a specific point source and elevated metal concentrations. However, for many metals, there was a general increase of coastal concentrations over levels in island specimens by approximately a factor of two. This may indicate that diffuse sources (or dispersion of discrete inputs) in the Bight are causing a detectable increase in metal levels in the marine biota along the coast between Santa Barbara and San Diego. This increase was most noticeable for lead, where the coastal-to-island ratio was approximately 3:1, apparently reflecting input of airborne lead by aerial fallout.

Radionuclides

107. Radioassays of coastal mussel and gooseneck barnacle tissue from a number of coastal and island stations were made. No detectable radioactivity above natural levels was found in any of the samples. Levels of manganese 54, cobalt 60, and zinc 65 were at least an order of magnitude lower than those reported in a similar survey conducted during the period of high radioactive fallout in 1963-64.

108. Another recent study of radioactivity in intertidal and littoral algae samples revealed extremely low levels of radioactivity at five stations off the southern California coast between San Onofre and the Mexican border. The concentrations found do not represent a hazard either to man or to the marine communities.

11.2.6 Plankton

109. Phytoplankton are the basis of a complex food web supporting all members of the marine environment, including the marine fisheries. The total productivity of the marine environment is thus dependent on the year-to-year variations in the phytoplankton crop, which are sometimes large. One dinoflagellate, *Gonyaulex catonella*, is at times concentrated at the water surface and produces a coloration called a red tide. This organisms produces a neurotoxin that, if ingested and concentrated in shellfish, can be extremely toxic to humans, even causing death. Evidence does not support an association of red tides and wastewater discharges.

110. Coastal waters along the western boundary of North America usually exhibit a much higher productivity and standing crop than open ocean waters. This is due, in part, to nutrient inputs from the coastal land areas, but is principally the result of upwelling, which transfers deep, nutrient-rich waters into the euphotic zone.

111. Enrichment studies conducted in the SCCWRP program confirm the conclusions drawn by other investigators that nitrogen is the primary limiting nutrient for phytoplankton growth in California coastal waters.

112. It is estimated that the mass input rate of total nitrogen from surface runoff and drainage in 1971-72 amounted to approximately 2,500 metric tons per year. The total nitrogen input from municipal and industrial wastewater discharges during this same period was estimated to be about 85,000 metric tons per year. Upwelling represents a larger source of nitrogen than either wastewaters or surface runoff. A rough estimate of the input from this source is approximately 180,000 metric tons per year.

113. Input from both upwelling and surface runoff are intermittent and seasonal. On the other hand, the inputs from wastewaters are relatively constant throughout the year and, hence, relatively important during periods of low natural input.

114. Nitrogen is not the only nutrient of concern. Phytoplankton, like all plants, require a complex of materials for their growth. Many of these--metals such as cobalt, zinc, copper, and iron, for example--are essential in trace quantities but are toxic or inhibitory in greater concentrations, as are most materials.

115. Since 1949, the California Cooperative Ocean Fisheries Investigations (CALFOFI) program has conducted studies throughout the southern California inshore waters. These studies were oriented primarily towards zooplankton, and the nets used for plankton collection (505-micron mesh) did not catch smaller species of phytoplankton. Over the two decades between 1949 and 1969, variations in abundance of zooplankton of up to two orders of magnitude have been observed.

116. Several studies of plankton conducted in the 1950's reported increased concentrations in the vicinity of wastewater discharges. Studies that have considered the response of individual species have shown that, in the vicinities of wastewater outfalls, the abundance of some species increased while others

decreased. In general, these changes in abundance were relatively small as compared to natural variations in plankton abundance in control areas.

117. Studies conducted by the City of Los Angeles between 1957 and 1970 showed some increases of plankton caught near the old, 1-mile outfall used until 1961. After 1961, the new, deeper 5-mile wastewater outfall was put into service. Studies after initiation of discharge through the new outfall showed a smaller increase in abundance, and the area of maximum concentration had moved seaward from its location prior to 1961.

118. Maintenance of a submerged wastewater discharge below the thermocline results in smaller increases of phytoplankton because of the reduced availability of nutrients to plankton in the euphotic zone.

119. Comparison of the average chlorophyll levels in the areas around the wastewater outfalls with values in a control area showed somewhat higher levels in the area off Whites Point and, to a lesser degree and intermittently, in Santa Monica Bay around the Hyperion outfall. Because of the locations of the outfalls and the relatively small increases in chlorophyll noted, it was not possible to separate the possible effects of wastewaters from those due to upwelling.

120. Work was conducted in the SCCWRP program on the development of a steady-state phytoplankton response model. The model predicts the distributions of a limiting nutrient and the resulting phytoplankton concentrations along the current trajectory by calculating a mass balance for a series of cells along the current path. The various processes considered in the model include advection, diffusion, nutrient uptake, the changing euphotic depth, sinking and respiration.

Chapter 12

CONCLUSIONS AND RECOMMENDATIONS

12.1 INTRODUCTION

In preceding chapters, the findings of each of the SCCWRP programs have been discussed separately. The interrelationships of these findings have been considered in developing the specific conclusions and recommendations presented in this chapter. The chapter outlines the implications of the study for two sets of concerns--those of wastewater management and those of future research.

The SCCWRP findings reemphasize the fact that the waters and creatures of the sea--particularly those of a deep, open, diverse, and rather strongly circulating region like the Southern California Bight--possess a resiliency of quite a different order than the freshwaters of a continent. The sea has always been a sink for the leaching of the land, and the resultant seawater is a solution so inimical to terrestrial and freshwater microscopic and macroscopic life that few forms can effect a transition.

The creatures of the sea are in great variety and have great versatility and tolerance because of the wide range of conditions and natural fluctuations to which they have been subjected throughout their evolution. There is little evidence that the sea contains the delicately balanced and precarious communities that are thought to exist in some woodland, freshwater marsh, or other terrestrial environments.

The plant nutrients upon which primary production depends are in quite different supply in marine and fresh waters. For example, in the Pacific, the level of phosphorus seems everywhere in excess of that required for plant growth; hence, this nemesis of freshwater ecology has no substantial relevance in this marine environment. Although the general chemical basis of marine life is identical with that of terrestrial and freshwater organisms, the detailed chemistry displays differences that are fundamental and profound.[1] These chemical contrasts are great enough that environmental protection practices developed for freshwater environments have little direct applicability to marine situations. In addition, these same differences make it extremely difficult for most substances introduced into the sea to be returned to man's environment.

The SCCWRP review of available information, augmented by data obtained from field and laboratory, has provided an improved scientific perspective of the

1. For example, many marine plants and some animals produce carbon monoxide; the common metal in the blood pigments of several important marine groups is not iron (as it is in mammals) but copper; skeletal structures in some marine organisms are composed of vanadium, strontium, or silicon compounds; etc.

effects of ocean wastewater discharges and other significant input sources and influences on the Southern California Bight. However, the application of this information will be influenced by other factors, some of which are not amenable to present-day scientific determination. Even excluding consideration of social, political, and judgmental factors, there are still scientific limitations: The SCCWRP study has reemphasized the fact that the interaction of wastes---incorporating both biologically stimulatory and inhibitory components---and receiving environment is difficult to quantify in a complex, resilient, and highly variable coastal marine environment in which all of the natural compensating mechanisms operate.

Some of the clear-cut effects documented in this report are chemical and physical in nature. Findings in these areas have immediate value for coastal zone assessment and monitoring, although their ecological significance may not be fully evaluated. Chief among these are the data on trace materials in seawater, sediments and tissues. The biological studies at several faunal levels have resulted in much new data on effect of environmental changes on populations and communities and have pinpointed a few ecological effects clearly due to wastewaters. The most significant are the effect on benthic organisms (Chapter 8) and fish (Chapter 7). The nature and extent of the changes in the benthos and the reversibility of the changes were demonstrated. In the case of fish, anomalies associated with wastewaters have been identified. It is significant, however, that the levels of the 11 metals analyzed in tissues of the principal diseased fish do not appear to be related to disease in these fish.

There are many myths about the ocean and man's effect upon it: Detailed examinations of available facts and new information often result in major revisions of many hypotheses about the effects of waste discharge. This study has demonstrated the value of the broad, goal-oriented approach and emphasized the necessity to extend the investigations (especially into topics not sufficiently covered, such as kelp, transparency, suspended solids, and floatables) and to use the information gained in simulations of important segments of the coastal marine ecosystem.

12.2 IMPLICATIONS FOR WATER QUALITY MANAGEMENT

In recent years, major concern has been expressed in the public and scientific media over the possible harmful effects of waste disposal in the environment. Much of this concern has been generated by isolated incidents---oil spills, potential mercury hazards, eutrophication of inland waters, and others. Many of those concerned, laymen and scientists alike, have failed to recognize the differences between the processes in the sea and those in freshwaters and on land. These concerns have contributed to increasingly stringent regulation of wastewater discharges into the ocean, patterned largely after limits and procedures derived from freshwater and estuarine experience. In July 1972, the California State Water Resources Control Board adopted a comprehensive water quality plan for California's ocean waters, reflecting in part these origins and concerns.

The SCCWRP studies were initiated as a different response to this concern. This research pursued the problem of wastewater discharge in southern California in its context as a part of the total inputs into the marine waters of the region, the effects of man's broader activities, and the inherent fluctuations of the environment.

The components of southern California wastewaters and the related findings of the research are now considered as background for specific conclusions and recommendations. The findings and recommendations principally refer to the present practice of major southern California sewage dischargers (effluents effectively diluted with ocean water at the outfall diffusers; initial dilution of about 100 to 1 or greater) and do not necessarily apply to Mexican discharges.

12.2.1 Gross Components

Plant Nutrients

For the major part, the gross components of southern California wastewaters (their major organic and dissolved inorganic substances) have been quite competently handled by the natural systems operating in the sea. At the lowest step in the marine food web--the phytoplankton, the nutrient materials contained in the wastewaters are moderately stimulating, because the growth of most of these plants, where light is sufficient, is normally limited by the types of nutrients supplied by wastewaters. Although the chemical forms of the nutrients are somewhat different, the effects of the introduction of nutrients by wastewaters are distinguishable in no important regard from the effects of upwelling, the natural process upon which most of the basic productivity of the California marine water depends. Considering the well-established interdependence of animals and plants, the inherent "naturalness" of domestic waste products in the environment, and the universal similarity of basic plant nutrients, this is not unexpected. Indeed, the nutrient substances involved in the upwelling process and those in wastewaters have a similar origin--the breakdown of organic wastes. Domestic wastewaters have a relatively balanced mix of the gross nutrients (nitrogen, phosphorus, and silicates) required for phytoplankton growth and contribute a small but steady increment of organic production to the waters of the Southern California Bight.

High levels of available plant nutrients are a necessary condition for the development of most phytoplankton blooms. Hence, any source of nutrients can contribute to such occurrences. However, there is no established direct connection between wastewater discharge and phytoplankton blooms in the Southern California Bight. Classical "red tides," blooms of specific phytoplankton organisms, are characterized by conditions that have no connection with wastewater discharge.

> *There is now no justification for altering present treatment and discharge practice with regard to the gross plant nutrients introduced into southern California waters.*

Particulate Material

The gross organic material involved in present municipal wastewater discharge is also largely natural and differs in no fundamental way from natural detrital material, the food upon which major members of the marine food web depend. The organic materials settling to the ocean floor in the immediate vicinity of submarine outfalls are in considerably greater local supply than those of natural origin, however, and have produced substantial changes in the species and abundance of organisms dwelling in the affected sediments. Organic communities and sediments of this type occur in highly productive areas, such as the Peru and

Benguela currents, the Arabian Sea, and elsewhere, but do not now occur naturally in the California Current region (although they have in the recent geological past).

In the present case, the species composition and diversity of bottom-dwelling organisms in the affected sediments have changed, but the populations continue to serve as food and result in rather large populations of fish. These conditions were observed to reverse rapidly when the old Orange County discharge was terminated. No irreversible conditions were observed or are expected.

However, there is some factor acting in the region of the sediments off southern California outfalls that produces abnormalities in a high proportion of the populations of two species of the fish that congregate there (and in a very small percentage of the populations of most of the other species examined). The most affected species, the white croaker and dover sole, suffer from fin-erosion diseases, a non-systemic disorder in the dover sole and a possibly systemic disorder in the white croaker. Both diseases are probably initiated by some irritant to the protective mucus of the fins and exacerbated by the high population densities of these fish and by the absence of a normal level of predation that would otherwise eliminate the affected fish. The initiating factors have not been identified but possibly include some gross irritant. Similar disorders afflict fish in other areas of the world and are common in fish living in aquaria.

Neither of the affected species are important in the local sport and commercial fisheries; hence the present recreational and economic impact of this disorder is negligible. The ecological impact of the disorder is probably also minor because the fish are in abnormal abundance, are only locally affected, and are not now known to be an important component of any major food web.

One of the effects of very fine suspended particles in wastewater discharged into the sea is reduction of local water transparency. Low transparency is typical of coastal waters in general. It affects many of the marine processes, including the depth to which phytoplankton are productive and the regions and depths to which fish and other organisms migrate. The first of these effects is to reduce productivity, and in the case of wastewater, probably to moderate and slow the overall stimulation of phytoplankton. Low transparency may also increase the numbers of fish migrating into or residing in the region of outfalls. These effects do not appear to be particularly important or undesirable.

The effects of transparency on the survival of young kelp plants may be significant. The great natural kelp forests of the southern California area are habitats for communities of fish and other organisms and are important fishing and recreational areas. At least in this century, some of these kelp beds have been reduced greatly. Decreased transparency and increased temperatures of coastal waters have been proposed as causes. However, an important factor in the change in the kelp forest ecology may have been the elimination of the sea otter in the last century, which, coupled with intensive fishing on sheepshead and other fish, has allowed the grazers of kelp to multiply unrestricted by predation. Such conditions result in successive episodes of vigorous growth and collapse of dominant plant populations.

Because of the generally minor and reversible nature of the effects and the uncertainty as to the actual consequences of the most well-intentioned corrective actions, there is presently no justification for any major alteration of waste management or discharge practice from the effects of particulate materials. There is need for further study of the distribution of potentially irritating substances, the nature and causes of fin-erosion disease, benthic community alterations, and possible secondary effects of wastewaters on kelp.

Floatable Materials

Minor but important components of the wastewater constituents discharged by present practice are buoyant and, hence, find their way to the ocean surface in the areas of discharges. The materials involved include oils, waxes, tars, fats, greases, fragments of wood, plastic, and other debris. The undesirable effects of these materials are fourfold: The visible slick or oily water surface above the submerged outfalls is aesthetically displeasing; the materials can be carried into embayments, marinas, the surf zone and onto beaches, decreasing the enjoyment of these resources; the floatable materials bear sewage bacteria to the surface, where they can be readily transported onto beaches or shellfish beds; and these materials also contribute to general widespread "littering" of the ocean surface. Floatable materials thus partly negate the purposes and advantages of submerged and dispersed wastewater discharges.

Fatty and waxy substances are not foreign to the sea surface--great quantities of such materials are produced in the sea, rise to its surface, and are part of the sea's natural ecology, serving as food for a variety of creatures, including some birds. Natural marine "litter" in the form of terrestrial plant material, tar, decaying seaweed, etc., is common and widespread and serves as sites for attachment of eggs of some marine organisms. However, the nearshore location of wastewater-derived floatable materials, their association with sewage organisms, their probable content of DDT and other fat-soluble chemicals, and their general unaesthetic qualities strongly distinguish these materials from the natural ones and necessitate their further control.

The present practice of wastewater treatment and discharge should be reviewed and modified to minimize the discharge of all types of floatable materials.

Further studies on floatable materials associated with wastewater discharge are necessary.

Microorganisms

Sewage microorganisms--bacterial, parasitic, fungal, and viral--are released into the sea in present wastewater discharge. The microorganisms find seawater a hostile environment, and, with some possible exceptions, their disappearance from the water column is rapid. There is no evidence to support any significant health hazard from body contact with coastal waters from sewage organisms. Although no hazard has been demonstrated from the consumption of shellfish taken

from southern California waters that show the presence of enteric bacteria, a potential for human disease infection exists from this source. Improved control of the discharge of floatable materials will reduce the contamination of beaches and of some species of shellfish.

Present southern California practice of wastewater discharge and the achievable bacteriological standards for bathing waters more than adequately protect those using southern California coastal waters for water contact activities. The present established practices and standards for shellfish sanitation control are adequate to protect the public and the utilization of this resource. Their application and enforcement should be continued.

With the exception of further control of the discharge of floatable materials and their associated sewage microorganisms, there is no basis for alterations of present southern California waste discharge practice for reasons of bacterial and viral infection or hazard or resource damage.

Mexican practice of sewage discharge should receive further study.

12.2.2 Trace Substances

The trace substances (trace metals, organic chemicals, pesticides, etc.) discharged into the environment are potentially hazardous. The hazards stem mainly from the proclivities of organisms to concentrate such materials and to pass them through the organic system, often with further concentration, and from the potential harm to the environment and to the interests of man.

The problems of trace metals and those of trace organic chemicals and pesticides are somewhat different and will be discussed separately. Although the nature and behavior of these substances in the environment is extremely complex and relatively unexplored, recent investigations have advanced knowledge considerably.

Trace Elements

Of the trace elements involved in wastewater discharge, a considerable number are essential trace requirements of living creatures. These include iron, vanadium, copper, boron, cobalt, zinc, molybdenum, manganese, silicon, and others. These, like all substances, can be toxic in too great concentrations, quantities, or availability. Another list of trace elements, including chromium, lead, mercury, silver, uranium, transuranic elements, and others not now known to be essential to any organisms, are toxic in relatively low concentrations.

Radioactive isotopes are of especial concern because of possible damage from their ionizing radiation. Radioisotopes and radioactivity in southern California waters and sediments are not now detectable above the well-understood background radioactivity, and are lower than at any time in the last two decades. No present local hazard can be attributed to this class of substances.

The total input of the ten or so most potentially hazardous trace elements into southern California waters is totally dominated by the advective transport of the California Current. However, the current is a dilute source of most trace elements; more concentrated sources (of comparatively small total input) are wastewater discharge, runoff, ship antifouling materials, aerial fallout, and dumping (harbor dredge spoil is a potential input). Wastewater is the major source of the more concentrated inputs of some of the trace elements. The local inputs of the two commonly believed to be the most serious trace elements--lead and mercury--are dominated by aerial fallout.

The concentrations of the analyzed trace elements in the waters around the outfalls are not significantly different from those in unaffected waters. In the affected sediments around the outfalls, however, the concentrations of all of these elements (with the exception of iron, cobalt, and manganese) are considerably greater than the natural levels in similar but unaffected sediments along the California coast. Nevertheless, these levels are all within the range of the concentrations of trace elements in natural marine sediments around the world.

As previously discussed, the affected sediments support a large population of invertebrates and associated fish. It is the study of this benthic food web that becomes most important in ascertaining whether or not these trace substances are entering the general organic realm of the ocean from wastewater discharge in untoward quantities or concentrations.

For this reason, the project conducted an exhaustive study and analysis of the trace element concentration in the livers (generally known to concentrate trace metals) of the fish intimately associated with the sediments. The benthic fish in the immediate vicinity of outfalls are shown to have experienced substantial uptake from the sediments because of their elevated DDT burdens.

The results of the analyses of benthic fish are perhaps the most significant findings generated by the program, for the fish associated with the sediments that have elevated concentrations of trace elements show somewhat lower concentrations in their livers than do fish living on normal sediments far from the discharges--in most cases, lower than those reported for similar fish in areas far from man's direct effects. There is no immediate explanation for this surprising finding, although some research on East Coast oysters has shown similar results. There are a number of reasons to believe that the uptake, concentrations, and toxicity of many metals in the marine environment are quite different from those in the freshwater and land environments. These differences result from the considerably different trace element sources and requirements and from the different chemical forms, substrates, organisms, and communities in these environments. It is possible the "overcompensation" observed in this study is a characteristic of the group of invertebrates upon which the fish feed, or that the metals are sequestered by some components of the sediments.

> *There is no substantive evidence that would support major changes in present wastewater processing and discharge practice for reasons of its trace element content. Nevertheless, improved control of the discharge of highly toxic metals is a prudent and meaningful step in wastewater management.*

Inputs of trace elements from direct industrial discharge, ship antifouling treatment, dredge spoil, runoff, aerial fall-out, advection and other sources should be better quantified.

Trace Organics and Pesticides

A principal class of "unnatural" substances introduced into the environment through man's activities includes the chlorinated organic substances, such as the pesticides, and plasticisers typified by DDT and PCB. It has long been thought that substances of these types were quite outside the tolerance of creatures. The ideas of the "unnaturalness" of substances of this type are undergoing some modification, however, with the discovery of a series of naturally halogenated organic substances produced in considerable variety and range by marine plants and animals. Some fifty or more natural halogenated products are now known.

Nevertheless, no arguments of the "naturalness" or "unnaturalness" of these substances should obscure the potential hazard to the environment by the introduction of DDT and related substances in other than trace quantities. The discharge of DDT through wastewater has brought with it a number of ills that have not yet been reversed by its partial control. The demonstrated widespread high incidence of skeletal deformities in sand bass and other fish of southern California may originate from DDT, and the unacceptable levels of DDT in the flesh of fish and the effects on bird life are most probably the result of wastewater discharge exacerbated by other sources and other toxic materials (e.g., lead).

There is ample evidence to require the elimination of chlorinated hydrocarbons and other persistent organics from wastewater to lowest practical attainable levels. Strict control at the source is strongly recommended.

The thoughtful monitoring of effluents and the organisms of southern California for chlorinated organic material, other halogenated compounds and other organics is essential, and presently unsuspected substances must be considered in an active program.

12.2.3 Summary

The foregoing findings and conclusions relating to wastewater management demonstrate that the health and condition of southern California coastal waters and inhabitants are such that there is little cause for serious concern. Nor, with the several improved practices, as recommended, with a thoughtful monitoring program, and with continuing broad investigations, is it likely that serious problems will evolve in the future from wastewater discharge.

However, some undesirable, but reversible, conditions--such as floatables, elevated DDT levels in sediments and certain organisms, and some abnormalities in benthic and demersal fish--exist near some of the major outfalls. Also, there are some possibly undesirable conditions in these areas, including elevated metal concentrations in sediments and changes in bottom communities.

In summary, this report has considered all the known or suspected significant effects of current wastewater disposal practices in the Southern California Bight; the findings of this study indicate that:

1. The application of inland wastewater disposal policies and practices to marine waste disposal, such as in the Southern California Bight, is technically unsound. For example, typical inland requirements for removals of biochemical oxygen demand, suspended solids, and nutrients from municipal wastewaters have little technical justification or relevance to marine ecological problems.

2. To the best of our knowledge, no potential effects other than those indicated herein will require major investigation.

3. Similarly, no substantial modification of present wastewater disposal practices, other than those recommended herein, is justified at present. However, the investigations of the specific problem areas as recommended may indicate the desirability of future additional modifications in wastewater disposal practice.

4. Routine monitoring and competent investigations of specific problems should continue, to determine man's general effects (including those of wastewater discharges) on the environment of the Southern California Bight.

12.3 IMPLICATIONS FOR FURTHER RESEARCH

The general need and justification for an active program of continuing monitoring and research are implied in the foregoing. The briefness of the presentation of the further research needs should not deemphasize their essentiality for the continued protection and improvement of the environment of the Southern California Bight. Specifically, the future program should be aimed at:

A. Improving assessment of the mass flux of known and suspected pollutants from all significant sources in the Southern California Bight, with special attention to:
   1. Plant nutrients.
   2. Trace substances.
   3. Floatables.
   4. Toxic materials.

B. Improving bioassay techniques and assessing the possibly stimulatory or toxic properties of wastewaters on:
   1. Phytoplankton.
   2. Benthic animals.
   3. Benthic algae.
   4. Fish.

C. Investigating the microbiology of pathogenic organisms and the relationship of wastewater constituents to disease and assessing

disease risks to both man and marine organisms, with special attention to:

1. Fin erosion and other fish abnormalities.
2. Viral agents and persistent organic substances as related to man's health.
3. General health risks to man.

D. Developing measures of community health for organisms of the Bight, including:

1. Uptake and levels of trace toxicants in fish and benthic invertebrates.
2. Parameters for assessing community structure and well-being, such as indicator organisms and species diversity.

E. Determining the dispersion decay rates and fates of the components of waste fields (settleables, floatables, microorganisms, and dissolved phases), as related to discharge practice, through more comprehensive surveys and predictive modeling.

Appendix A

SCCWRP CONTRACTORS AND OUTSIDE CONSULTANTS

BODEGA BAY INSTITUTE OF POLLUTION ECOLOGY
Bodega Bay, California
Chemical Analysis of Chlorinated Hydrocarbons in Marine Samples and Storm Runoff
Robert W. Risebrough
Brock de Lapp

CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California
Measurement of Dissolved and Suspended Trace Metals in Storm Runoff
J. J. Morgan
James Raft

CDM, INC., ENVIRONMENTAL ENGINEERS
Pasadena, California
A Study of the Effects of Sludge Discharged Into the Coastal Waters of Southern California
Jack E. McKee
Richard H. Born
Albert B. Pincince

ENGINEERING-SCIENCE, INC.
Arcadia, California
Philip N. Storrs
Management Consultant

OCCIDENTAL COLLEGE
Los Angeles, California
Biology of Coastal Marine Fishes Exposed to Wastewater Discharges in the Southern California Bight
John S. Stephens

POMEROY, JOHNSTON, AND BAILEY
Pasadena, California
The Character of Storm Water Runoff Into the Coastal Waters of Southern California
Richard D. Pomeroy
Henry Cruse

TEXAS A & M UNIVERSITY
College Station, Texas

Histopathological Analysis of the Fin Rot Syndrome in Marine Fishes from Palos Verdes, California

George W. Klontz
R. A. Bendele

UNIVERSITY OF CALIFORNIA
Berkeley, California

Surface Phenomena Study

Robert E. Selleck
Ralf Carter

UNIVERSITY OF CALIFORNIA
Irvine, California

Measurements of Trace Metals in Marine Samples by Neutron Activation Analysis

Vincent P. Guinn
Jeroen de Goeij

UNIVERSITY OF CALIFORNIA
San Diego, California

Analysis of Heavy Metals in Sediments, Seawater and Municipal Wastewater

James R. Arnold
James N. Galloway

Stress and Recovery of a Benthic Community

E. W. Fager
Gary Smith

The Origins and Implications of Skeletal Deformities and Asymmetry in Sand Bass

Michael E. Soulé
David W. Valentine

Nutrients, Chlorophyll, and Phytoplankton Primary Productivity Near Southern California Outfalls

William H. Thomas

Appendix B

A SUMMARY OF COASTAL CURRENTS OFF PALOS VERDES, 1960-64

The County Sanitation Districts of Los Angeles County have maintained an extensive oceanographic observational program in the area of the Whites Point outfall system off the Palos Verdes Peninsula. Some of the results of this program for the period from June 1960 through December 1961 have been published by Parkhurst, Garrison, and Whitt (1964). The site was in the vicinity of the present monitoring Station C_1, which carried the same designation in 1960-1961; the station is about 7.5 km west of the 90-inch diffuser and 7.5 km offshore from Palos Verdes Peninsula (see inset map, Figure B-1). Among other observations, current was measured with a Savonius rotor device at depths of 2 ft (0.6 m), 10 ft (3 m), 25 ft (7.6 m), 50 ft (15.2 m), 100 ft (30.5 m), 150 ft (45.7 m), and 200 ft (61 m) from a boat anchored bow-and-stern in water about 70 m deep. Currents were initially measured at 30-minute intervals, later extended to 1 hour. Surveys of 24-hour duration were completed weekly from 1 June 1960 through May 1961, "with a few exceptions when extreme storm conditions prohibited safe operation of the vessel: (Parkhurst et al. 1964).

Los Angeles County has kindly furnished these data to SCCWRP for examination and analysis. Additional current data taken through 1964 have also been included in the material made available to SCCWRP. The data have been transferred to punchcards and analyzed by year, season, and tide phase. The results for all data, exclusive of tide phase, are shown in Figures B-1 through B-4, and Tables B-1 and B-2.

All the measurements are subject to the effect of surface waves on the Savonius rotor current meter. These are most pronounced at the near-surface levels (1, 3, 8, and 15 m) and may introduce a slight bias toward higher current speeds, however the low seas that existed during the survey are very unlikely to have a significant influence on the direction measurements.

B.1 DIRECTION

During the winter current measurement surveys (Figure B-1), the prevailing winds were from the northeast. Almost half of the 130 observations of wind speed were zero during the winter operations. The currents from 1 to 25 m did not follow the measured winds, but showed a bimodal distribution of direction, towards the northwest and the east-southeast. At 15 m, this bimodality still existed, but the current was predominantly towards the northwest. At 30.5 m, the bimodality remained, but the dominance of currents towards the northwest had increased. At 46 and 61 m, the predominant currents were setting in a general direction from northwest to west-southwest.

Again, the spring observations (Figure B-2) were made when the winds were weak, thus wind data may not be truly representative. The prevalent direction was

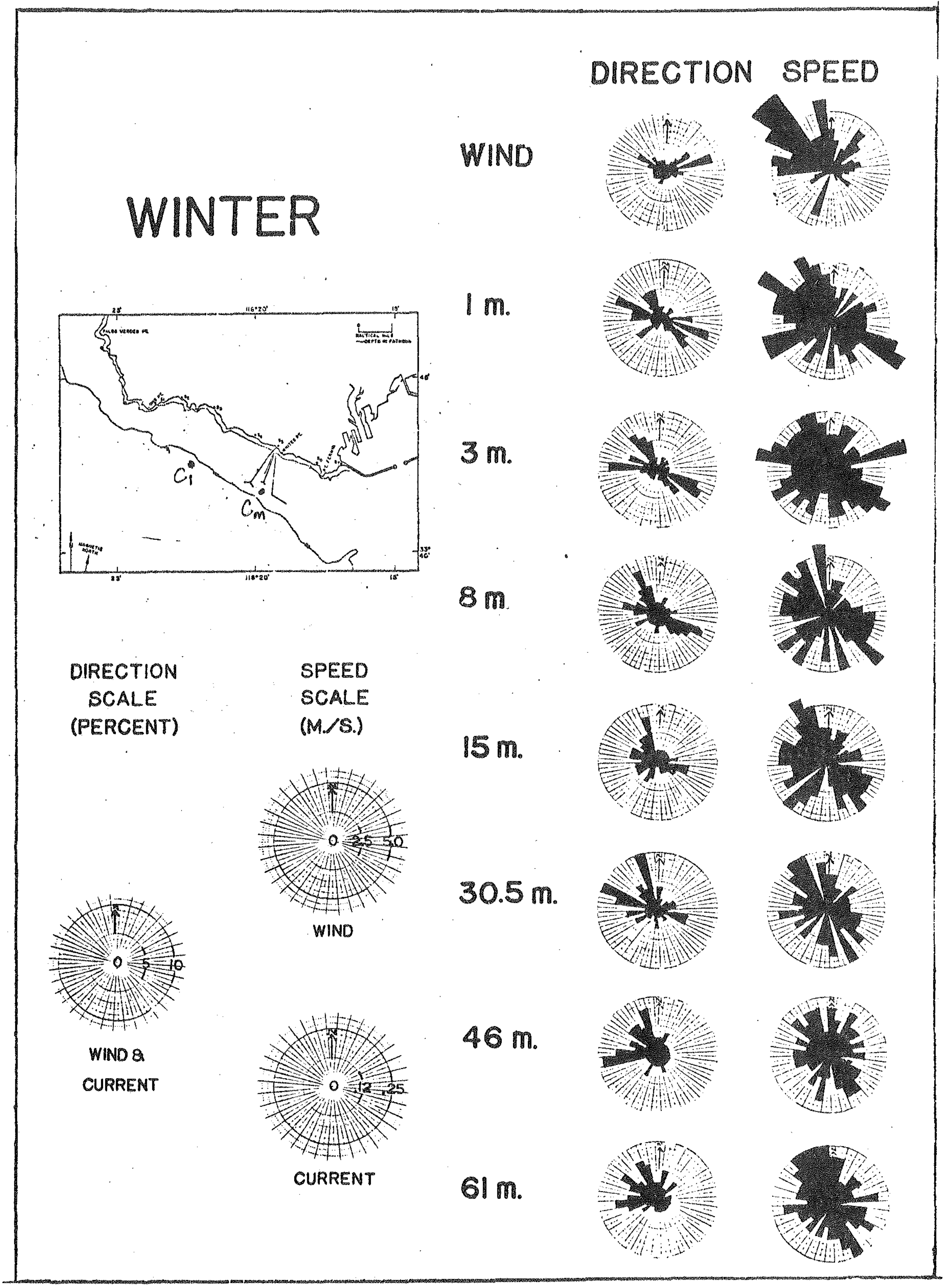

Figure B-1. Summary of Wind and Current Directions and Strengths off Palos Verdes, Winter 1960-64.

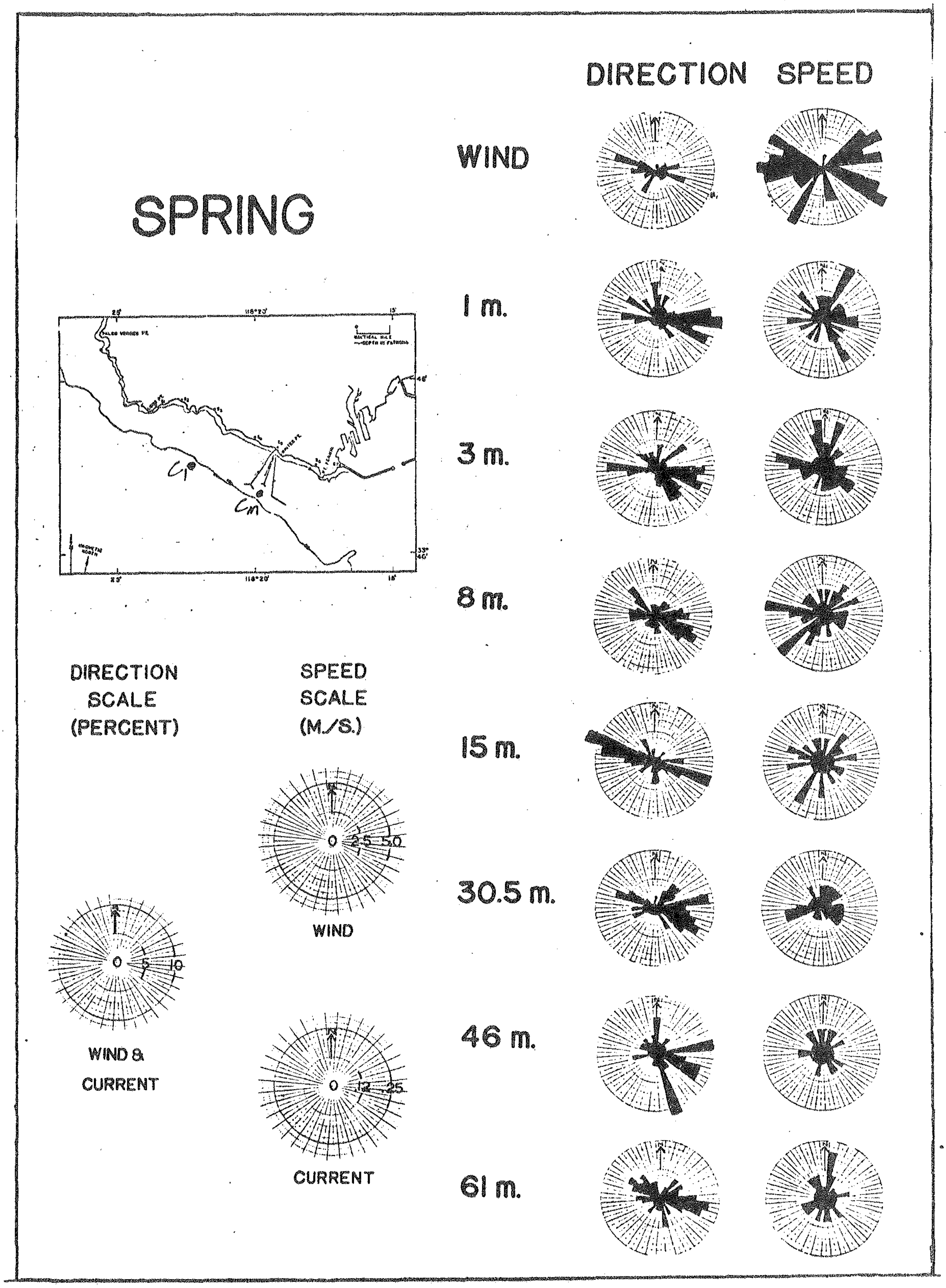

Figure B-2. Summary of Wind and Current Directions and Strengths off Palos Verdes, Spring 1960-64.

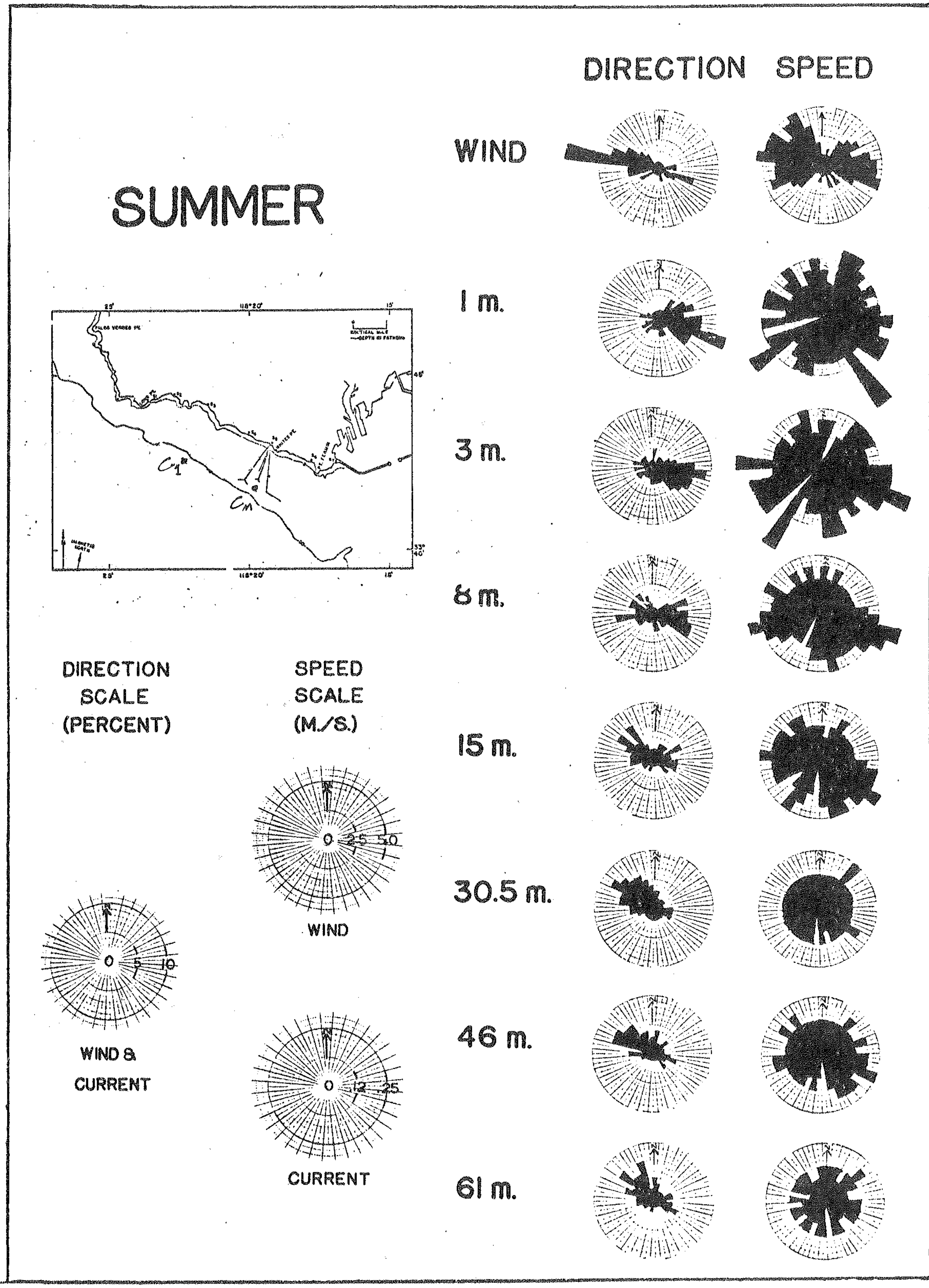

Figure B-3. Summary of Wind and Current Directions and Strengths off Palos Verdes, Summer 1960-64.

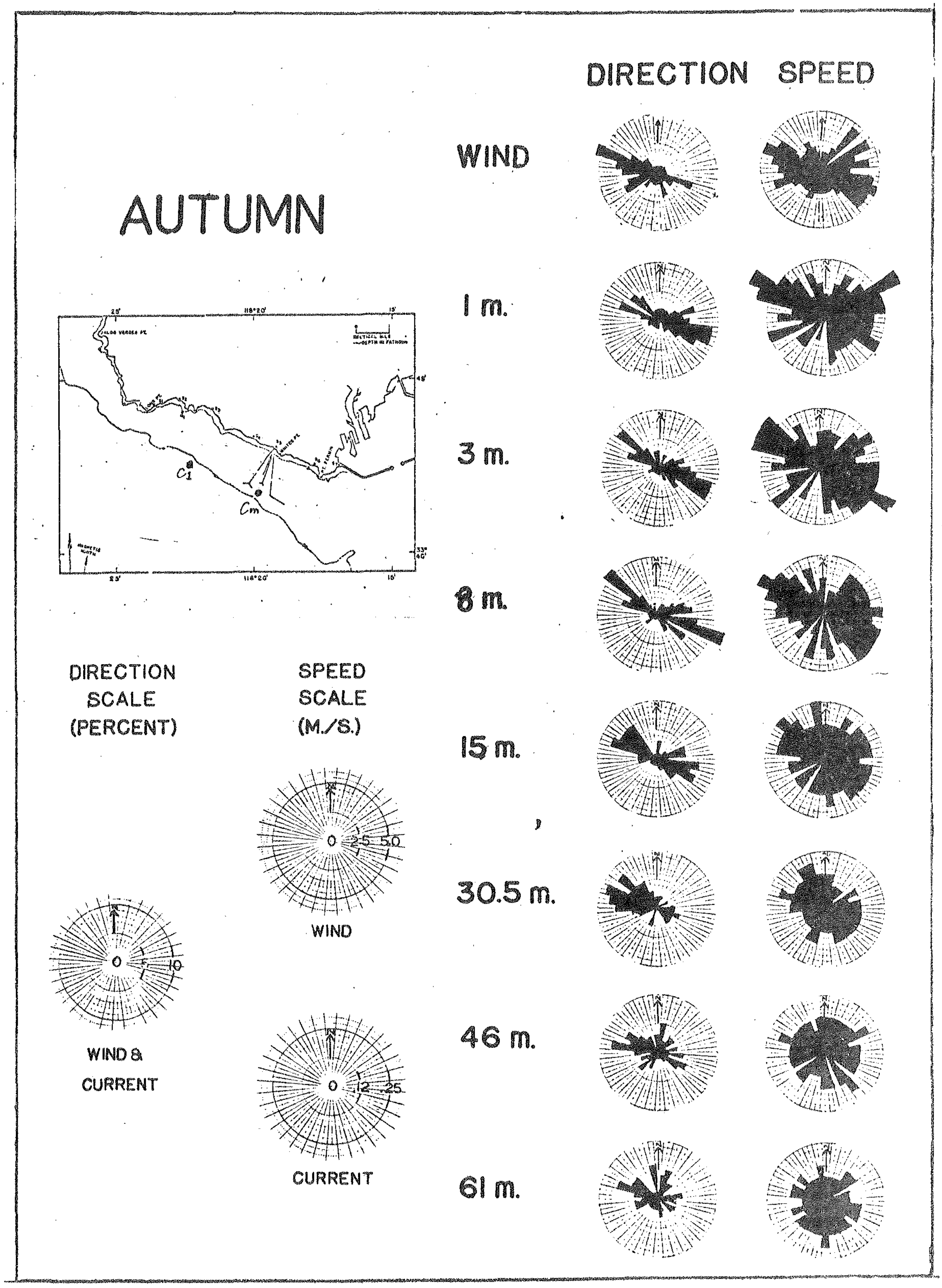

Figure B-4. Summary of Wind and Current Directions and Strengths off Palos Verdes, Autumn 1960-64.

from the west-northwest, which is the mean direction generally quoted. Although there was a tendency for the currents at 1 m to follow the wind, the familiar bimodality reappeared at 8 m and was quite pronounced at 15 m. The prevailing directions were east-southeast and west-northwest. While some semblance of bimodality in direction remained at all of the lower depths, an easterly component persisted over that towards the west.

Summer observations totaled 271, more than for any other season. Winds blew persistently from the west-northwest (Figure B-3). The currents at 1 and 3 m were also directed from northeast to south-southeast. A tendency for currents to flow towards the northwest as well as east to south-southeast appeared at 15 m; the currents at 30.5, 46, and 61 m retained some bimodality, but the prevalent direction was towards the northwest.

Autumn winds were similar to those of summer (Figure B-4). The familiar bimodality of current direction appeared at 1, 3, 8, and 15 m, with nearly equal modes for currents toward west-northwest and east-southeast. At 30.5 m, the west-northwest prevalence was much greater than the east-southeast mode. At 46 and 61 m, this dominance of west-northwest currents decreased, but was still present.

These results are similar to those found in an analysis of currents in the Orange County area, where the preferred directions were again west-northwest and east-southeast. Above 8 m, the component most nearly parallel to the prevailing winds (toward the east-southeast) was somewhat more persistent; currents at 30.5 m and below showed a definite tendency to flow towards the northwest. At 15 m, intermediate conditions exist. This sampling location was apparently in a transition layer: Possibly, it is at times in the wind-stirred layer and at other times is below this layer, depending on wind velocity and water stability.

B.2 SPEED

Mean speed in each 10° sector is also shown in Figures B-1 through B-4. In addition, wind speed and current speed at each depth are given by season in Table B-1.

The mean winds were weak in all seasons, probably because of the understandable bias of the survey towards days of good weather. The tendency of onshore winds to increase in the summer is reflected in the persistence of winds blowing towards the east (Figure B-3) and higher mean speeds. The mean winds observed in winter and spring are the most biased because these are generally the seasons of strongest storm winds.

Weakest currents were recorded during the spring. This may be due to the maximum intensity of upwelling during the season. Increased vertical flow may suppress mean horizontal flow, although total flow may not change significantly from periods when horizontal flow predominates. The strongest currents at depths above 15 m were observed during the summer. Stronger winds during the surveys are believed the cause of this effect, which was most apparent near the surface at 1 and 3 m. Currents below 30 m showed the least seasonal change, except for the decrease during the spring.

Table B-1.
MEAN WIND AND CURRENT SPEEDS (M/SEC)

	Winter	Spring	Summer	Autumn
Wind	2.0	2.0	3.5	3.0
Current				
1 m	0.20	0.10	0.25	0.20
3 m	0.20	0.10	0.25	0.20
8 m	0.20	0.10	0.20	0.20
15 m	0.18	0.10	0.20	0.20
30.5 m	0.15	0.10	0.15	0.15
46 m	0.15	0.05	0.15	0.15
61 m	0.18	0.05	0.10	0.13

A decrease of mean current speed with depth occurred in all seasons. It was most prominent during the summer when stability is highest due to density stratification; the decrease was very gradual and barely noticeable during the spring and winter when the water is poorly stratified and stability is low.

The highest mean speeds were generally associated with the predominant directions of current flow. Vector averages for all the data were also computed by season (Table B-2). As the result of two opposing predominant directions of nearly equal persistence and speeds, the net vector sum was very small. The vector average at each depth is an approximation of the mean seasonal or annual transport at that level. The spring vector average showed very low speeds and little change in direction with depth. On the other hand, current shear was well developed during the summer and autumn, the seasons of highest stability. Mean current direction reversal occurred between 8 and 15 m during the summer and between 15 and 30.5 m during the autumn.

Comparing these results to the conclusions of Parkhurst et al. (1964), based on one year of observations from June 1960 to May 1961, we quote from their paper as follows:

> "In the summer and fall period maximum wind speeds occurred from the west between 270 and 290 degrees. The wind normally blows from a westerly direction... and is much more steady and predictable than wind in winter. A westerly wind existed 68 percent of the time in summer and fall and only 38 percent of the time during winter. Maximum current speeds above the thermocline occurred in a direction from 230 degrees through 280 degrees [towards 050 degress through 100 degrees, in other words northeast to east-northeast to east-southeast] or about 30 degrees to the left of the wind. Strongest

Table B-2.

MEAN WIND AND CURRENT VECTORS, WHITES POINT, 1960-64.

	Winter (N=130)	Spring (N=102)	Summer (N=271)	Autumn (N=213)	All Seasons (N=716)
WIND					
Speed (m/sec)	3	2	3.5	2	2
Direction (deg from)	290	230	270	240	260
CURRENT					
1 m					
Speed (m/sec)	0.05	0.05	0.1	0.05	0.05
Direction (deg toward)	300	040	090	040	070
3 m					
Speed (m/sec)	*	*	0.1	0.05	0.05
Direction (deg toward)	290	090	100	070	090
8 m					
Speed (m/sec)	0.05	*	0.05	0.05	0.05
Direction (deg toward)	290	080	090	040	060
15 m					
Speed (m/sec)	0.05	*	0.05	0.05	*
Direction (deg toward)	290	030	300	010	320
30.5 m					
Speed (m/sec)	0.05	*	0.05	0.05	0.05
Direction (deg toward)	300	060	290	280	290
46 m					
Speed (m/sec)	0.05	*	0.05	*	0.05
Direction (deg toward)	290	080	310	290	300
61 m					
Speed (m/sec)	0.05	*	0.05	*	0.05
Direction (deg toward)	290	100	310	300	300

*Speed less than 0.05 m/sec.

currents below the thermocline occurred in a direction generally opposing the strongest currents above the thermocline. The currents above the thermocline travelled 64 percent of the time from the west; the currents below the thermocline were from the east 56 percent of the time indicating that a counterflow exists.

"During the winter period, trends in current direction are not as readily defined... The strongest currents occur from an easterly direction in the winter, while during the summer and fall period the strongest currents occur from a westerly direction."

Noting that Parkhurst et al. (1964) defined current and winds from, in the opposite sense to our definition of current and winds towards, we can compare results. Wind directions agree closely, and mean speeds are not compared. Using "above the thermocline" to mean "above 8 m," direction of strongest currents above the thermocline is in general agreement for the summer and autumn combined. The subsurface reversal is also in general agreement. However, the bimodality of currents is not apparent in the discussion of strongest currents by Parkhurst et al. (1964), and their mean velocities appear to be nondirectional, i.e., distributed rather evenly over 360°. The direction of strongest currents above 15 m in winter and spring according to Parkhurst et al. (1964) is in general agreement with our data for the same seasons.

The weakening of currents during the spring and the evidence of bimodality in current direction are the principal new results derived from the SCCWRP analysis of 4 years of data.

The new joint SCCWRP-Los Angeles County current data measurement program initiated in 1972 makes use of a refined method of measurement that permits closer examination of currents measured continuously over periods of time ranging from a few hours to a few days. This method is being used in the County's monthly monitoring cruises.

In the new procedure, pairs of Savonius rotor current meters are moored to a subsurface buoy at a station designated CM (see inset map, Figure B-1) about halfway on a line between the 90- and 120-inch diffusers off Whites Point. One meter is situated in the upper part of the water column, above 23 m; the other is placed below the thermocline at a depth greater than 27 m. Data are averaged over 30-minute intervals. Results of the first four surveys during February, March, and April 1972 are shown in Figures B-5 through B-8. The data are shown as vector addition diagrams; that is, vectors for each 1/2-hour average are joined. The current plot resembles a trajectory, and becomes one if currents over the surrounding area are representable by measurements at the mooring location.

On 23 February, the wind was initially less than 3.5 m/sec, but from noon until about 1930, it was from the west (260° to about 290°), with speeds ranging from 5 to 6 m/sec. Shear is evident; this was not apparent in the results of analysis of the 1960-64 data and those reported by Parkhurst et al. (1964). However, the results for mean currents over a season or longer need not agree with the type of data taken in the 1972 field measurements.

The measurements on 13 March showed a steady current at 12 m toward the west-northwest and a distinct rotary motion in the form of an ellipse, with the long axis roughly parallel to the coast at 30.5 m. The wind was light and variable, with speeds less than 2 m/sec from the east and northeast.

Two sets of data were taken during April, the first in support of a survey of phytoplankton and nutrient relationship study by University of Washington scientists on the R/V THOMAS G. THOMPSON and the second in support of the monthly monitoring cruise.

In the survey of 3-5 April, both current meters recorded a northerly flow, upon which changes to the east or west were periodically superimposed. In the absence of strong winds, these results are tenatively interpreted as showing evidence of a persistent residual flow upon which tidal currents are superimposed.

The results of the measurements the following week show a complete change in the current system. Recalling the March measurements, the current meter at 12 m recorded a steady current -- in this case, toward the southeast rather than the west-northwest. An unusual situation was recorded at 37 m--a steady current towards the southeast, in sharp contrast to the rotary current of the March cruise.

The relative wealth of data from the Whites Point area adds greatly to a reasonable understanding of mean annual or seasonal flow. Such means may be misleading, however, if applied over shorter periods of time. Obviously, much more work remains to be done, especially during periods of rough weather, but the prediction of currents on any given day or week will undoubtedly remain only probablistic for many future years.

B.3 REFERENCE

Parkhurst, J.D.; W.E. Garrison; and M.L. Whitt. 1964. Effects of wind, tide and weather on nearshore ocean conditions. In Adv. Water Poll. Res. vol. 3. New York: Pergamon Press.

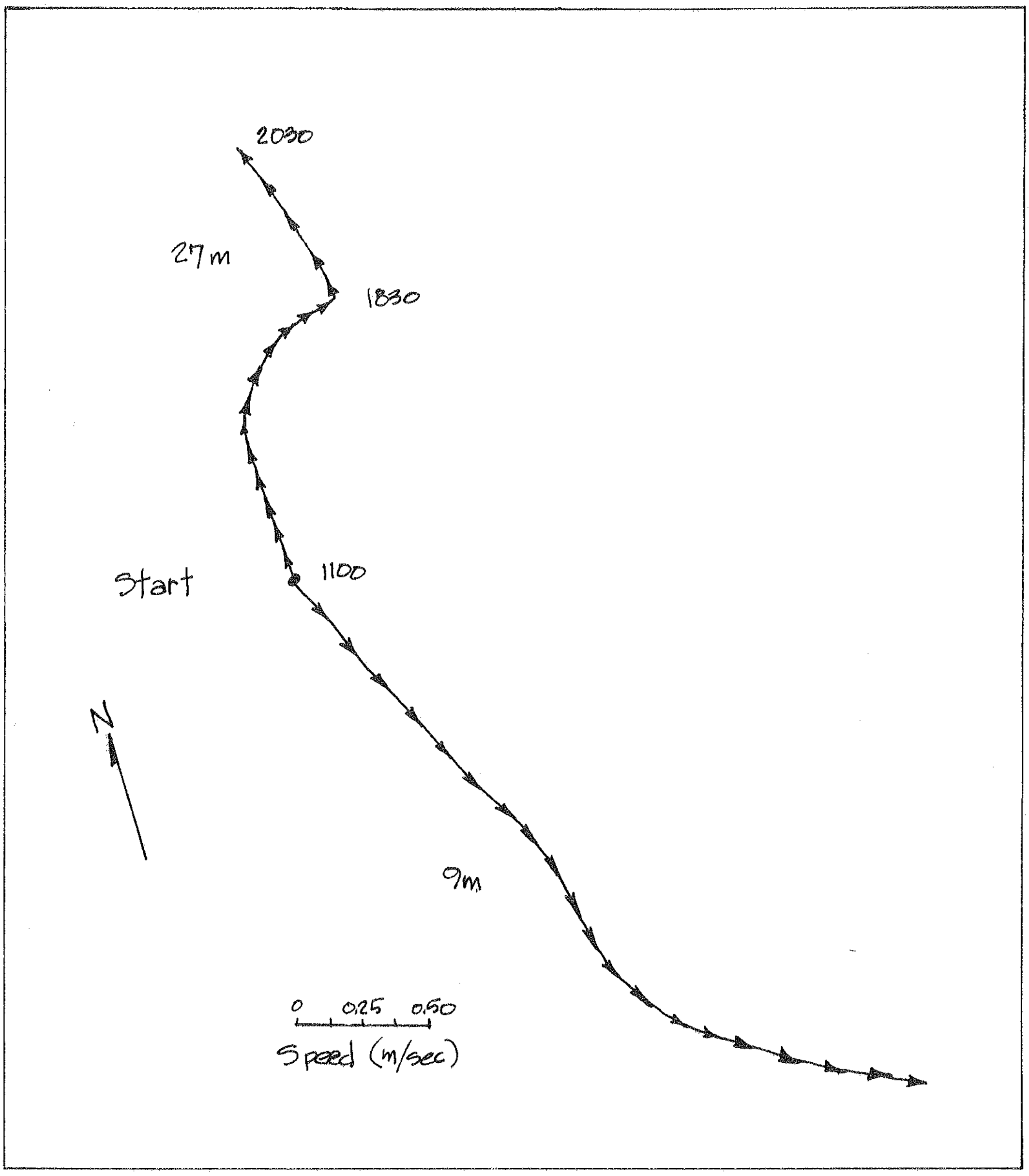

Figure B-5. Current at Station CM off Palos Verdes on 23 Feb. 1972.
Time between arrow points = 1/2 hour.

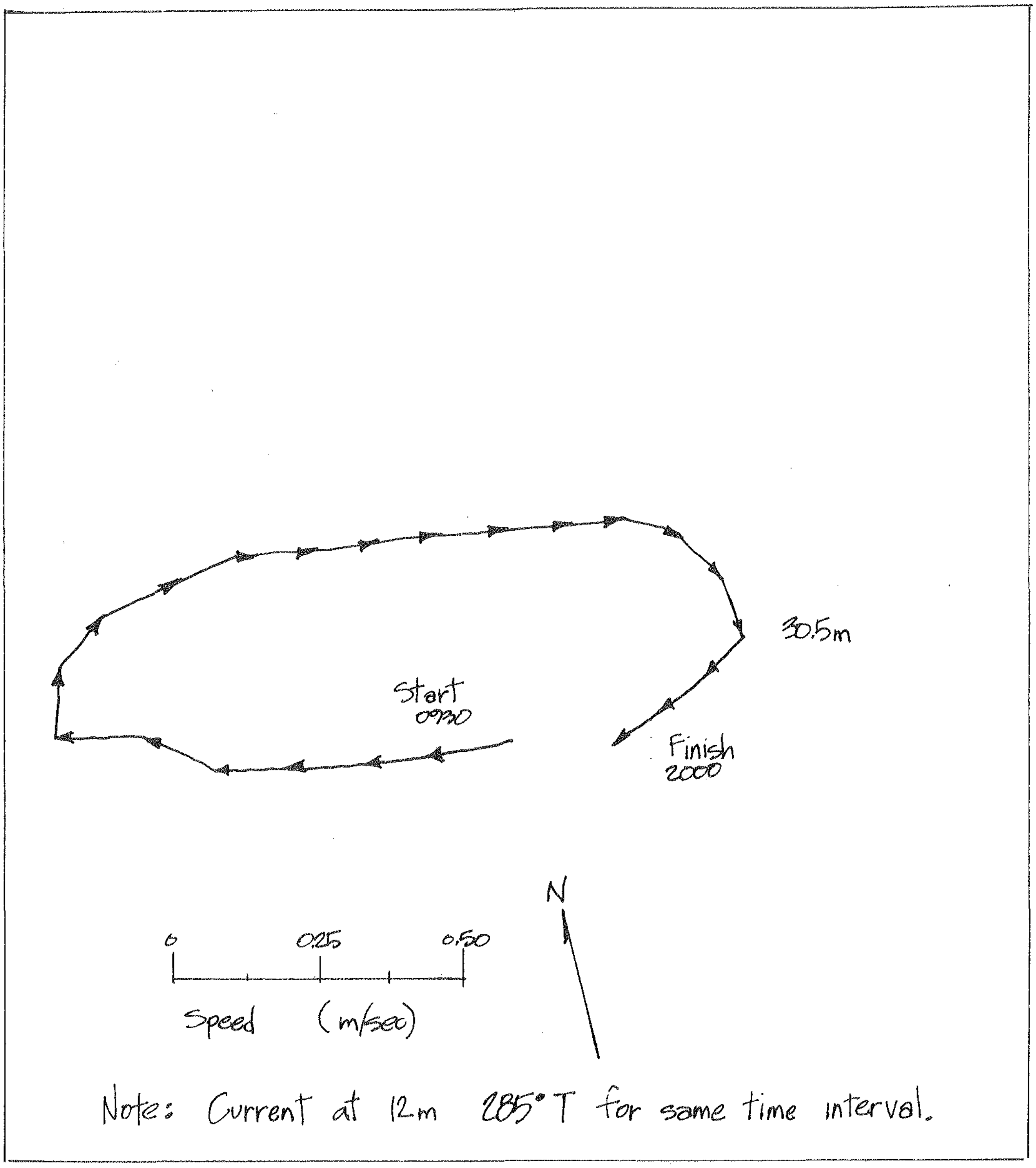

Figure B-6. Current on 13 March 1972 at Station CM off Palos Verdes. Time between arrow points = 1/2 hour.

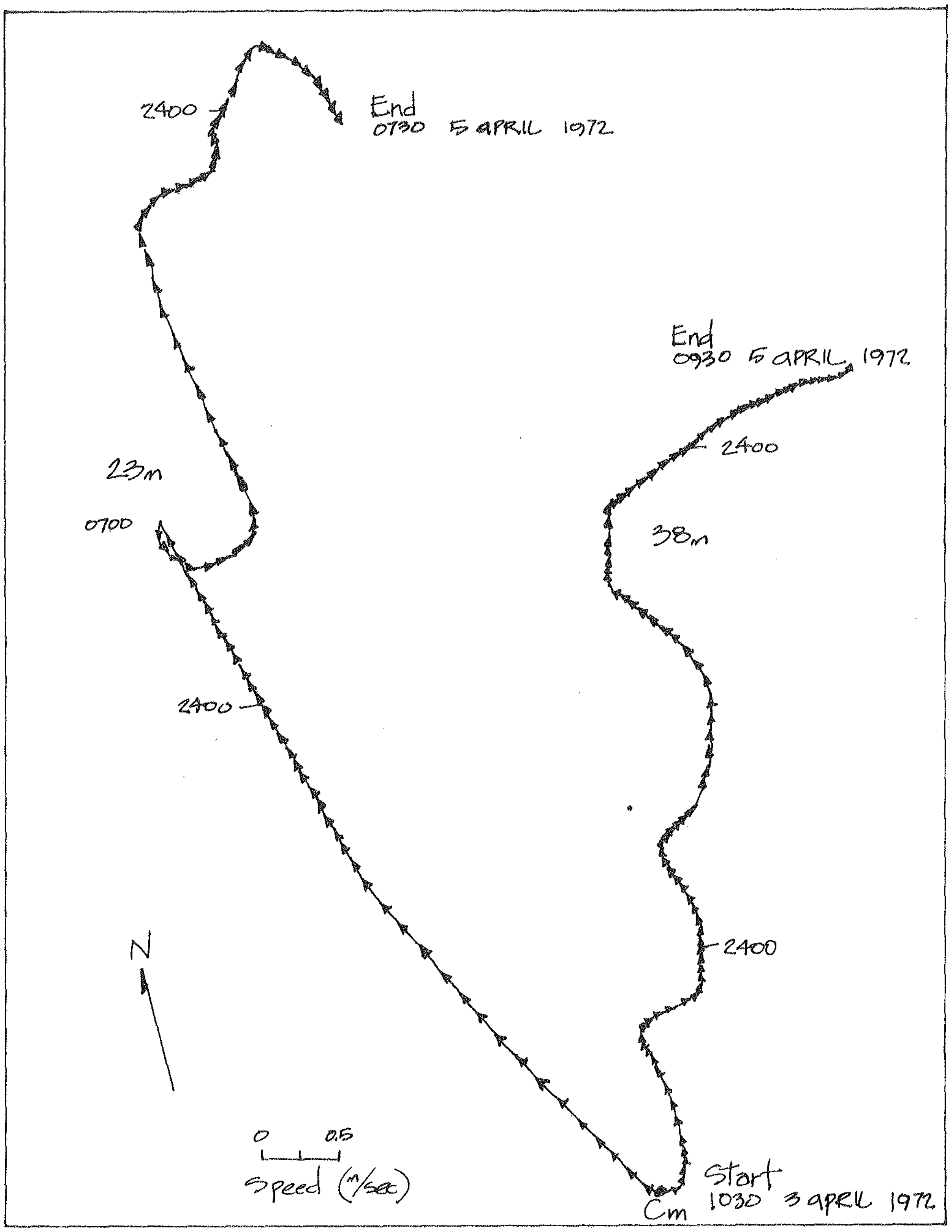

Figure B-7. Current at Station CM off Palos Verdes on 3-5 April 1972. Time between arrow points = 1/2 hour.

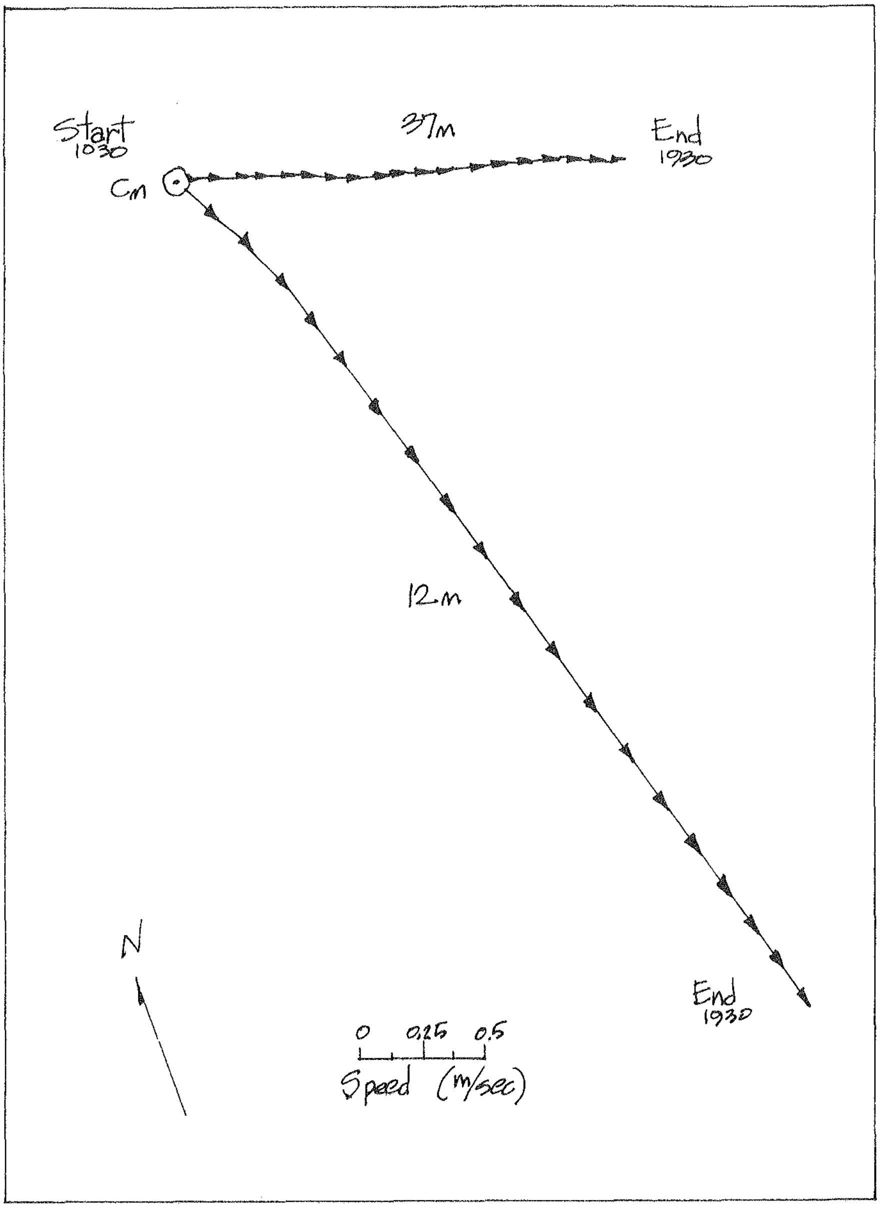

Figure B-8. Current at Station CM off Palos Verdes on 10 April 1972. Time between arrow points = 1/2 hour.

Appendix C

BROAD-SCALE DISPERSION MODEL OF THE SOUTHERN CALIFORNIA BIGHT

C.1 INTRODUCTION

A simple model of the dispersion of conservative materials within the Southern California Bight has been developed to assist in estimating flushing rates, the range of influence of various sources of waste materials, and the general distribution of these materials as a result of the action of the California Current system.

The model consists of a two-dimensional array of cells, as shown in Figure C-1. The distribution of a substance among these cells is assumed to be the result of advection, lateral diffusion, and sources or sinks internal to each cell. Vertical diffusion has been neglected, and some estimates of the consequences of this approximation are discussed later in this section.

C.2 BASIC FORMULATION

The time rate of change in the concentration, C, of a substance in a cell labeled by a pair of indices (i,j) can be calculated from the equation

$$\left.\frac{\partial C_{i,j}}{\partial t}\right)_t = \left.\frac{\partial C_{i,j}}{\partial t}\right)_a + \left.\frac{\partial C_{i,j}}{\partial t}\right)_d + \left.\frac{\partial C_{i,j}}{\partial t}\right)_{so} + \left.\frac{\partial C_{i,j}}{\partial t}\right)_{si} , \qquad (1)$$

where the subscripts t, a, d, so, and si refer to the total, advective, diffusive, source, and sink rates of change respectively. In the present model, the new concentrations are obtained from the old concentrations after an elapsed time period, Δt, by a simple, direct time stepping, i.e.,

$$C_{i,j}(t + \Delta t) = C_{i,j}(t) + \left.\frac{\partial C_{i,j}}{\partial t}\right)_t \cdot \Delta t . \qquad (2)$$

In general, this simple stepping scheme is prone to produce significant errors after a large number of time steps. Many other methods have been developed to reduce these errors (Patten 1971), however, they usually require increased computation time and memory space. The stepping errors introduced by Equation 2 can also be reduced by decreasing the elapsed time interval, Δt. In addition, if steady-state conditions exist, then $\left.\partial C_{i,j}/\partial t\right)_t = 0$, and the stepping errors will

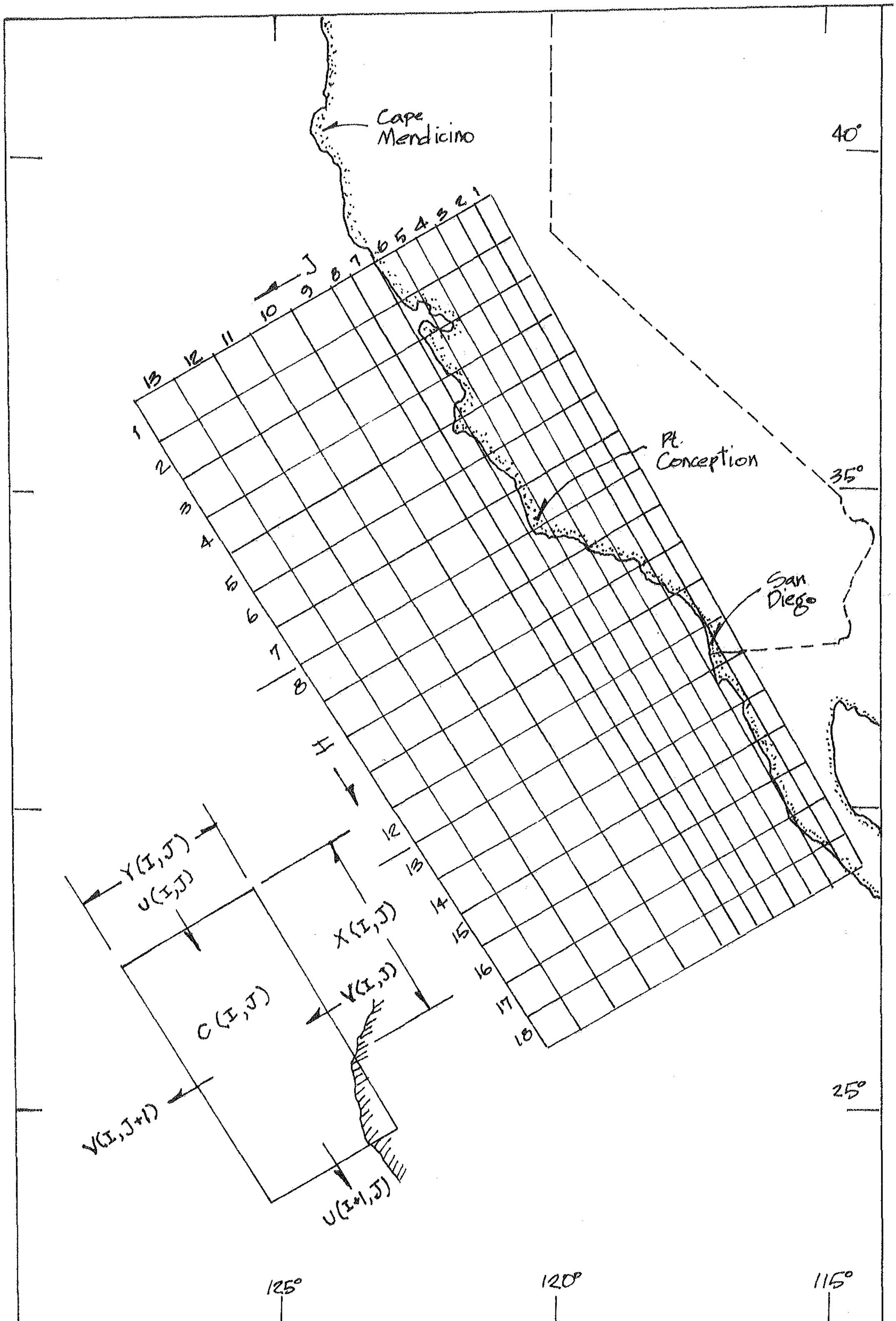

Figure C-1. Definition of Cells and Locations

not be cumulative. Instead the concentrations will tend to their steady-state values with increasing number of time steps, providing the system converges.

The primary transport process within the Bight appears to be advection; hence, one of the main tasks in formulating a dispersion model of the Bight is to obtain a suitable representation of the circulation. In principle, this could be done by solving the Navier-Stokes equations with the appropriate boundary conditions. The latter include matching the peripheral currents in the model to the circulation of the North Pacific. Effort is currently being made by other investigators (Hwang 1972) to model the North Pacific currents. A model of the Southern California Bight that could be coupled to a model of the large-scale circulation in the Pacific would have great utility because it might permit projections of coastal currents based on conditions in the North Pacific and the local weather. Unfortunately, coastal models require relatively fine spatial detail as a result of the irregular topography, tidal currents, and other phenomena with rapid changes in space or time. This, in turn, increases computation time, requires increased storage capacity, and can introduce stability and convergence problems when solving the equations.

In view of these difficulties, and the preliminary nature of the model, we have chosen to infer the current structure from observations of the temperature and salinity distributions, rather than attempt to predict them a priori.

C.3 CURRENTS

We have assumed that, with the exception of the near coastal areas, geostrophic flow is a suitable approximation to the currents in the Southern California Bight. This is equivalent to unaccelerated, frictionless flow and requires that the Coriolis forces acting on an element of water be balanced by the horizontal components of the pressure forces. The latter can be estimated from the distribution of temperature and salinity in the water column (as they determine the density distribution) if a reference surface representing a gravitational equipotential surface is known. A depth at which no, or insignificant, motion occurs is usually used as an approximation to this surface.

The cell dimensions illustrated in Figure C-1 have been chosen so that the vertices of each cell coincide with the station locations used by the CalCOFI program. Physical oceanographic data is available for these stations since 1950, and published data for the geopotential anomaly (used in the geostrophic flow calculations) is available for the period from 1950 to 1964 (CalCOFI 1966).

It is impractical to use the geopotential anomalies directly to calculate both the longitudinal and lateral current velocities as this practice would give currents which tend to flow into or out of the coastline. This is clearly unphysical and probably results from uncertainties in the experimental measurements, the lack of synoptic observations, and a breakdown of the geostrophic assumptions in nearshore waters. Since the principal component of the surface flow is

approximately parallel to the coastline (Section 3.4), the geostrophic approximation has been used to calculate this component of the flow. The strength of the longitudinal flow is calculated from the equation

$$u = \frac{10 \cdot (\Delta D_A - \Delta D_B)}{2\omega L \cdot \sin \psi} , \tag{3}$$

where

u = average velocity perpendicular to a line connecting stations A and B (m/sec),

L = station separation (m),

ω = angular velocity of earth's rotation (sec^{-1}),

ψ = station latitude, and

ΔD_A, ΔD_B = geopotential anomalies at stations A and B respectively (dynamic meters with respect to 500 m depth).

Some method is also required to determine the mean transport velocities in shallow waters because the geostrophic assumptions are no longer valid and there is a fundamental difficulty in extrapolating shallow water density profiles to the reference depth when this lies below the ocean bottom. In the present model, the longitudinal currents in the cells adjacent to the coast are specified as input variables--to be estimated from nearshore current measurements.

The transverse velocities are obtained from continuity (mass conservation), assuming that there are no appreciable vertical currents. Using the notation indicated in Figure C-1, the velocity through the left-hand side of the cell (i,j) is given by

$$v(i,j+1) = \frac{1}{x(i,j+1)} \cdot [u(i,j)\, y(i,j) - u(i+1,j)\, y(i+1,j) + v(i,j)\, x(i,j)] . \tag{4}$$

As $v(i,j) = 0$ at the coast, and the $u(i,j)$ are either specified or obtained from the geostrophic flow calculation, each of the $v(i,j)$, for i = constant, can be determined by starting at the coast and working outward. The currents for the months of January and April resulting from this method are illustrated in Figure C-2. In this illustration, the coastal boundaries appear to coincide with the cell boundaries. This was done solely for convenience, and the actual program correction contains boundary factors that account for coastal irregularities and the blockage by islands.

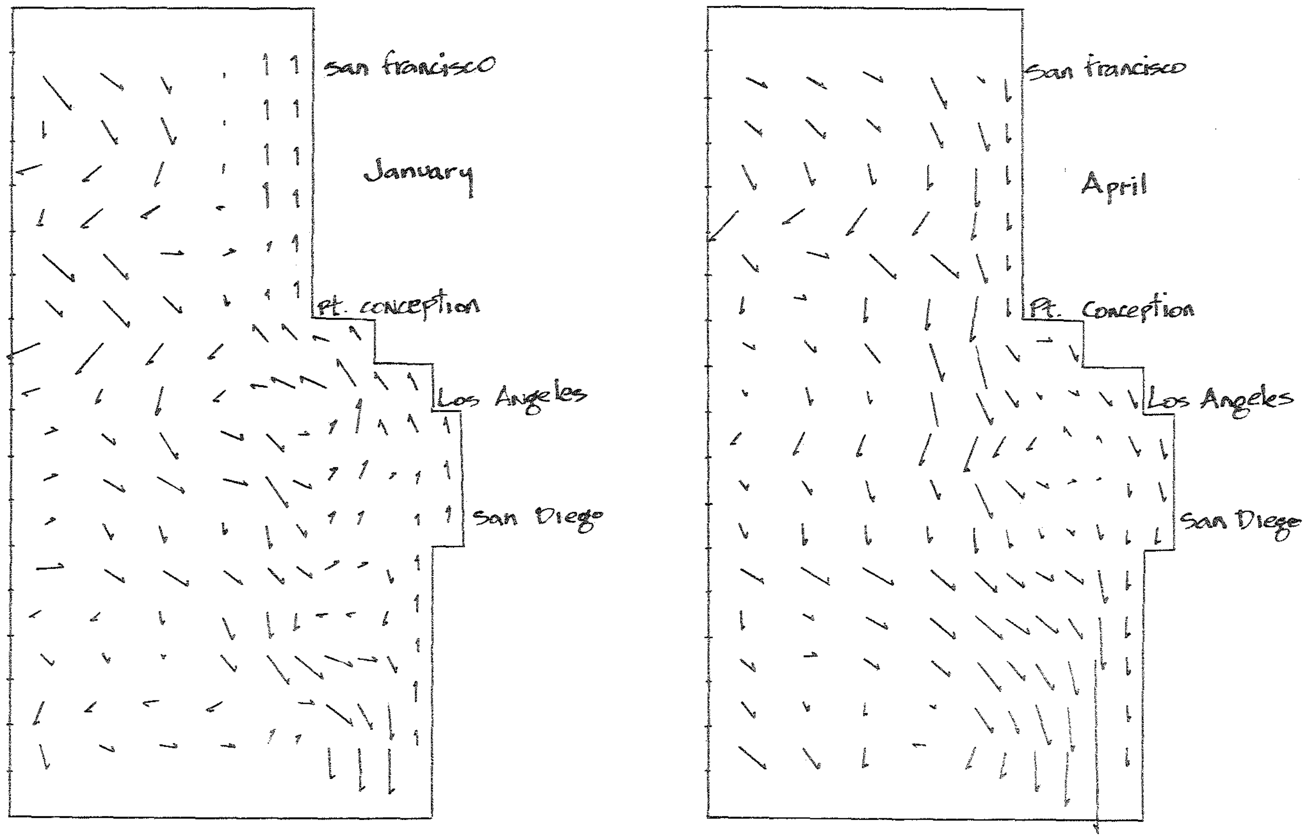

Figure C-2. Computed Currents for January and April.

C.4 ADVECTION

The rate of change in the mass of S in cell (i,j) as a result of advection through the boundary between cells (i,j) and (i - 1,j) in a linear finite-difference approximation is given by:

$$\left.\frac{\partial S_{i,j}}{\partial t}\right)_a = d \cdot y(i-1,j) \cdot u(i-1,j)$$

$$\cdot \left[G \cdot C(i-1,j) + (1-G) \cdot C(i,j)\right], \tag{5}$$

where

d = the depth of the bottom of the cell (m),

y(i - 1,j) = effective width of the cell interface (m),

u(i - 1,j) = component of velocity perpendicular to the interface (m/sec),

C(i - 1,j), C(i,j) = concentration of S in cells (i - 1,j) and (i,j) respectively (mass/cu m, moles/cu m, etc.), and

G = parameter indicating the direction of flow, i.e., G = 1 if u(i - 1,j) ≥ 0; G = 0 if u(i - 1,j) > 0.

The corresponding change in the concentration of S in cell (i,j) is obtained from:

$$\left.\frac{\partial C_{i,j}}{\partial t}\right)_a = \frac{1}{V} \left.\frac{\partial S_{i,j}}{\partial t}\right)_a, \tag{6}$$

where V = volume of cell (i,j) (cu m). The total advective change obviously can be obtained by summing the changes for each of the cell faces.

C.5 LATERAL DIFFUSION

The intercellular transfer rates for lateral diffusion processes are difficult to estimate as there is still some uncertainty about a suitable mathematical representation of eddy diffusion.

If the transfer rate across a surface is expressed terms of an eddy diffusivity, K_y, by the equation:

$$J_s = -\frac{\partial}{\partial y}\left(K_y \frac{\partial C}{\partial y}\right), \tag{7}$$

where J_s is the flux of S in the y direction, experiments indicate that K_y varies with the length scale of the experiment (Okubo, 1970). A wide variety of solutions to the basic diffusion equation that exhibit this feature have

been proposed (see, for example, Okubo and Pritchard 1969). In general, experimental observations tend to be compatable with the two representations:

$$\sigma^2(t) = \sigma_o^{\,2} + a^3 t^3 \qquad \text{(Type I)} \tag{8}$$

and

$$\sigma^2(t) = \sigma_o^{\,2} + v_D^{\,2} t^2 \qquad \text{(Type II)}, \tag{9}$$

where

$\sigma(t)$ = a characteristic width of a dye patch (m),

σ_o = characteristic width at time $t = 0$,

t = the elapsed time (sec), and

a, v_D = parameters ($[\text{m/sec}]^{2/3}$, m/sec),

Solutions of the form given by Equation 8 lead to eddy diffusivities of the form $K_y \propto \sigma^{4/3}$ (the Richardson 4/3 Power Law). Type II solutions are characterized by a parameter with the dimensions of a velocity--the so-called "diffusion velocity." Dye experiments in the coastal waters of southern California do not appear to give convincing evidence for choosing one representation in preference to the other. A diffusion velocity representation has been chosen because it is eminently compatible with a cell model (with varying currents); a Type I representation can only be used with difficulty.

In a sense, the exchange of material between cells (i,j) and (i - 1,j) by a diffusion velocity can be considered to be the result of simultaneous and equal volume flows from cell (i,j) to cell (i - 1,j) and vice versa. In analogy to Equations 5 and 6, the corresponding rate of change of material in cell (i,j) can be written as:

$$\left.\frac{\partial C_{i,j}}{\partial t}\right)_d = \frac{d \cdot y\,(i-1,j) \cdot v_D}{V} \cdot [C(i-1,j) - C(i,j)]. \tag{10}$$

Diffusion studies in the Southern California Bight indicate that typical diffusion velocities in surface waters are on the order of 1 cm/sec (Okubo and Pritchard 1969). It should be noted, however, that the presence of current shear, and a finite vertical diffusivity, can give rise to an apparent lateral diffusion velocity that can be substantially greater (Okubo and Pritchard 1969).

C.6 SOURCES AND SINKS

Wastewater discharges, surface runoff, aerial fallout, etc., can introduce additional masses of material into a cell. If m_S (i,j) is the mass (or molar) rate of input of substance S into cell (i,j), then

$$\left.\frac{\partial C_{i,j}}{\partial t}\right)_{So} = \frac{1}{V}\dot{m}_s(i,j). \tag{11}$$

The variation of $\dot{m}_S$ with i and j allows both discrete and distributed sources to be accommodated.

Sinks of material can be handled in the same manner, for example, if it is known that a certain mass of S is deposited per year in the sediments and is not remobilized. In addition, a variety of substances such as viable bacteria, suspended solids concentration, etc., frequently are found to be removed at a rate that is proportional to their concentration, so that

$$\left.\frac{\partial C_{i,j}}{\partial t}\right)_{Si} = - \lambda C(i,j), \tag{12}$$

where

λ = effective "decay" rate (1/sec).

C.7 COMPUTATION

The circulation in the Southern California Bight tends to exhibit seasonal patterns (Jones 1971) although there can be large fluctuations in these patterns from year to year. Geopotential anomalies for the period from 1950 to 1964 have been averaged for each monthly period to give the current patterns for a "typical" year. Currents for intermediate times are obtained by interpolation.

In a similar manner, the source terms for each cell can also be seasonally dependent as, for example, the surface runoff; hence, the input terms have been specified on a monthly basis.

Computation proceeds by sequentially applying Equation 1 to each of the cells, and evaluating the right-hand side of the equation at time t to obtain the concentration at $t + \Delta t$ from Equation 2. This procedure is repeated over a number of years until the concentrations at a given time during the year tend to approach a constant value. In this sense, both the instantaneous and yearly average concentrations obtained from the model can be viewed as the "quasi steady-state" values that would result from a sequence of "typical" years.

Since Equation 1 is linear in the cell concentrations, the concentration distribution from a set of sources can be obtained by summing the concentration distributions for each of the individual sources. For example, if a_{ij}^{kl} is the yearly average concentration in cell (i,j) as a result of an input into cell (k,l) of uniform strength b_{kl}, the total concentration in (i,j,) for the collection of sources will be[1]

$$C_{i,j} = a_{ij}^{kl} \cdot b_{kl}. \tag{13}$$

1. The Einstein summation convention is used here, i.e., repeated indices such as $a_j b^j$ imply $\Sigma_j a_j b^j$.

In general, the source strength may be the result of several different types of input into the same cell, for example, wastewater discharges, surface runoff, and aerial fallout. Since the yearly average concentrations will also depend on the time of timing and duration of the input, the a_{ij}^{kl} and b_{kl} will be a function of time. Equation 10 can then be written:

$$\bar{C}_{ij} = \Sigma_m^N \left[\frac{1}{T} \int_o^T a_{ij}^{kl}(t)\ b_{kl}^m(t)\ dt\right], \tag{14}$$

where T = time interval over which the distributions are averaged and the sum over m is over all types of sources. If the integration is approximated by a sum over equal, finite increments of time, Equation 11 becomes:

$$\bar{C}_{ij} \approx \Sigma_m^N \Sigma_{t_n}\ a_{ij}^{kl}(t_n) \cdot b_{kl}^n(t_n) \cdot \frac{1}{N}. \tag{15}$$

In principle, each element of the tensor $a_{ij}^{kl}(t_n)$ could be tabulated, and the averaged concentrations for an arbitrary distribution of sources (in both time and space) could be calculated. In practice, this is not feasible as even monthly time increments would result in about 2.2 x 10^5 entries for the $a_{ij}^{kl}(t_n)$.

As a result, only the following types of inputs have been calculated:

A. Advective input of uniform concentration from outside the Bight.

B. A time-independent input from each of the five major outfalls.

C. A combined input from surface runoff for the region from Point Conception to the U.S./Mexico border with the following time dependence:

1. May through September--no flow.

2. November through March--flow rate = Q.

3. April and October--flow rate = 1/2 Q.

D. A time-independent line source extending from Gaviota to the U.S./Mexico border.

C.7.1 Input Values

At the present time, little is known about the strength, or direction, of the nearshore mean transport velocities at depths comparable with the location of submerged wastefields. Meager, preliminary data from SCCWRP studies indicates that this flow may be northerly in the winter and southerly in late spring (Section 5.4.2 and Appendix B). In view of this uncertainty, we have examined some of the distributions for the following nearshore current assumptions:

A. A constant northerly flow of 0.04 m/sec.

B. A constant southerly flow of 0.04 m/sec.

C. A mean transport velocity of 0.00 m/sec.

D. A northerly flow of 0.04 m/sec for the period from October to March, and a southerly flow of 0.04 m/sec from April to September (subsequently referred to as ±0.04).

E. The same periodic flow as in Item D, but with a speed of 0.08 m/sec.

The magnitudes of the various sources of input are tabulated in Table C-1. These values are based on a discharge volume, hence the concentrations of various components of the discharge can be obtained by multiplying by the appropriate concentrations. It might be noted that the line source inputs are based on an input extending approximately 10 nautical miles offshore with a total input of 10^9 gallons/day (43.9 cu m/sec). Since this type of input is most likely to occur as a result of aerial fallout, the relevant quantity is actually the mass (or molar) input rate, and this flow is an artifact to simplify the comparisons.

C.7.2 Results

For illustrative purposes, we define the quantity, D_{10} by:

$$D_{10} = \log_{10}(D) = \log_{10}\left(\frac{C_{eff}}{C}\right), \tag{16}$$

where

D = the dilution at point (x,y),

C = the concentration of a component of the effluent at position (x,y), and

C_{eff} = the concentration of the effluent component at the time of discharge.

Figure C-3 illustrates the concentration distributions, averaged over a "typical" year, for the combined discharge of the five major sewered waste discharges. Nearshore currents are assumed to be ±0.04 m/sec. The predominant southerly flow of the California Current system is reflected in the smaller offshore dilutions in the region below the Bight compared with the region above Point Conception. The cell containing the Whites Point outfall appears to have an a anomalously low effluent concentration. This is more apparent than real and is a consequence of the different cell sizes for the cells containing the Hyperion, Orange County, and Whites Point outfalls. The model calculations give the average concentration in the cell and, in the present first-order approximation, assume that the concentration is uniform within the cell; hence, the discharge into a large cell will have more dilution water available for a given amount of intercellular transfer area and will, in general, give a lower average concentration. A more accurate comparison would result, for example, by subdividing the Whites Point cell into four smaller cells. Within the limitations of the model, it appears that the dilution within the Bight is on the order of 3,000 to 10,000:1.

Table C-1
INPUT RATES FOR THE MODEL

Source	Cell (i, j)	Time Interval			Discharge Rate (cu m/sec)		
Outfalls							
Ventura	(8,5)	All Year			0.8		
Hyperion	(9,3)	All Year			14.7		
Whites Point	(10,3)	All Year			16.4		
Orange County	(10,2)	All Year			5.7		
San Diego	(12,2)	All Year			3.6		
Line Source							
	(8,6)	All Year			4.9		
	(8,5)	All Year			4.3		
	(9,4)	All Year			9.1		
	(9,3)	All Year			2.2		
	(10,3)	All Year			6.0		
	(10,2)	All Year			1.6		
	(11,2)	All Year			6.6		
	(12,2)	All Year			5.4		
Surface Runoff		Periods (a), (b), (c) include the following months:			(a)	(b)	(c)
	(8,6)				4.2	2.1	0.0
	(8,5)	(a)	(b)	(c)	2.5	1.3	0.0
	(9,4)	Nov.	Oct.	May	14.9	7.4	0.0
	(9,3)	Dec.	April	June	4.2	2.1	0.0
	(10,3)	Jan.		July	16.6	8.4	0.0
	(10,2)	Feb.		Aug.	4.2	2.1	0.0
	(11,2)	March		Sept.	3.2	1.6	0.0
	(12,2)				3.4	1.7	0.0
Miscellaneous							
San Francisco	(2,7)	All Year			4.4		

Note: 1 cu m/sec = 22.8 mgd

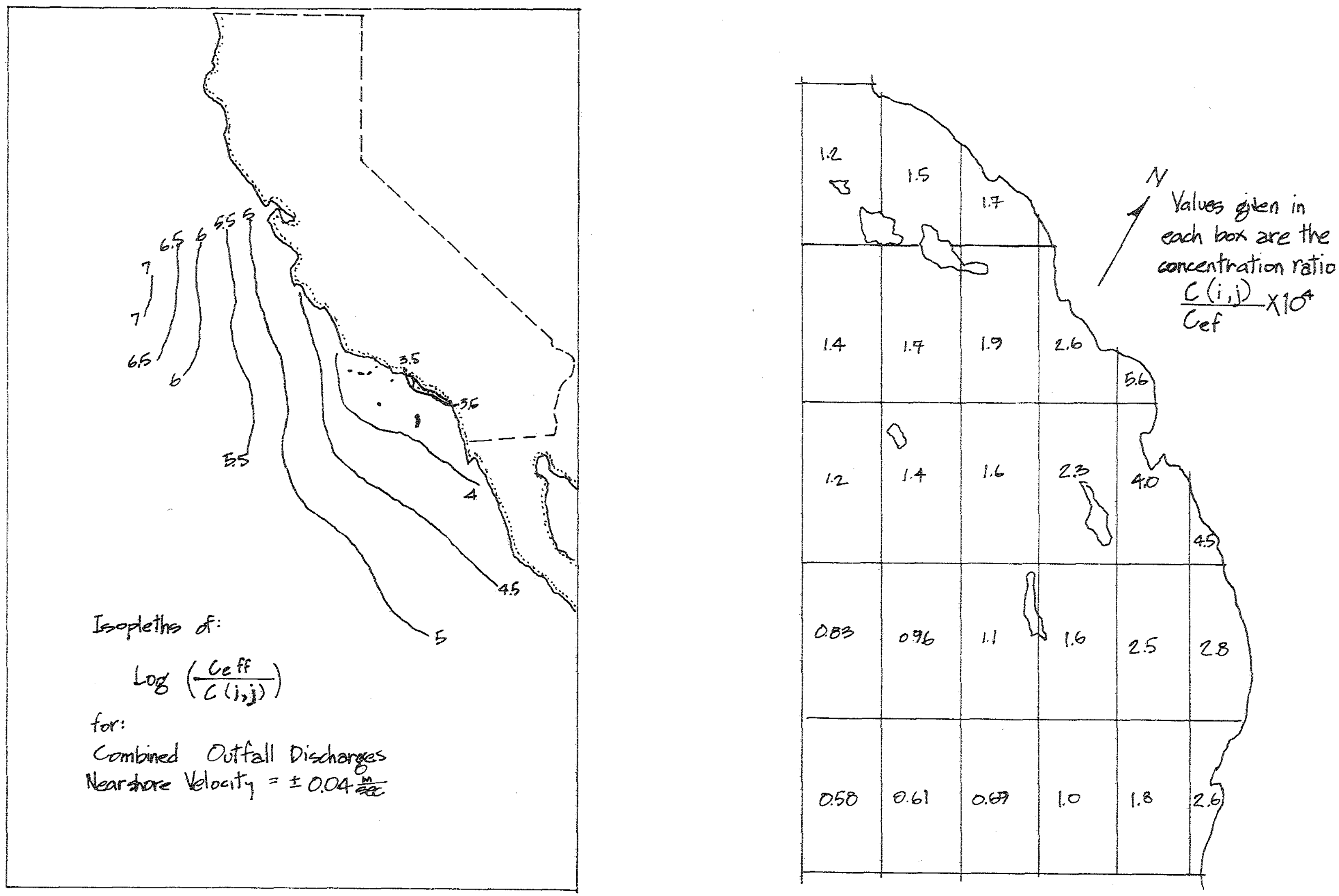

Figure C-3. Dilution Isopleths for Combined Outfall Discharge.

This average concentration can be used to estimate a characteristic "residence time" within the Bight by applying the equation

$$\frac{\partial \bar{c}}{\partial t} = 0 = \frac{1}{t_r} \cdot (C_A - C_B) + \frac{S}{V_B} , \tag{17}$$

where

t_r = residence time

C_A, C_B = volumes of effluent in regions A and B (defined by Figure C-4a) respectively.

V_B = volume of region B

S = volume rate of input of effluent into region B.

The results are contained in Table C-2, which also gives the residence times for regions defined by Figures C-4b and C-4c. It has been assumed that region A is arbitrarily large so that C_A tends to zero.[2] Results (summarized in Table C-2) indicate that the Bight residence time is on the order of 4 months for the three assumptions of +0.04, -0.04, and ±0.04 m/sec for the nearshore mean transport velocity. This is compatible with the results of other investigators (Jones 1971). If the nearshore current is reduced to zero, the residence time is increased approximately 50%, to 6 to 7 months. Substantially shorter and longer residence times of approximately 2-1/2 and 10 months are obtained for the smaller and larger areas respectively.

It is interesting to compare these times with the residence time that would occur if there were no advection and the mixing were solely the result of eddy diffusion. The corresponding distribution of concentration is shown in Figure C-5.[3] In this case, the residence time is increased from about 4 months to approximately 20 months. This would indicate that the removal by diffusion would only be about one-fifth as efficient as advection and diffusion combined.

Figure C-6 illustrates the average concentration over a yearly period for the seasonal runoff in the Southern California Bight, based on an average input (over the period of one year) of 608 mdg. The residence time is 3.9 months for

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2. For a truly "conservative" substance, the concentration in region A (the world oceans) would, over a period of time, build up to significant concentrations. The transfer equations are linear in the concentrations; hence, the present results would still be applicable as the relatively uniform background levels could be subtracted off from C_A and C_B and the new variables would correspond to the presently calculated values.

3. The decreased spacing for D_{10} = 5, 4.5, is probably a result of the boundary conditions and the limited size of the model.

Table C-2
RESIDENCE TIMES

Nearshore Current Velocity* (m/sec)	Residence Time (months)	Area††
±0.04**	4.5	B
±0.08**	3.0	B
+0.04	4.1	B
-0.04	4.0	B
0.00	6.7	B
All Currents = 0† (Pure diffusion)	20.3	B
±0.04**	2.4	B'
±0.04**	10.0	B"

*Nearshore currents refer to the cells adjacent to the coast. Other currents are calculated from geostrophy and continuity.

**Currents are along direction of increasing (i) from April to September and along direction of decreasing (i) from October to March.

†Refers to removal by eddy diffusion in all cells, assuming no net advection in the entire area.

††See Figure C-4.

a nearshore current of ±0.04 m/sec, compared with 4.5 months for the combined outfall discharger, indicating that the seasonal nature of the surface run-off, and the spatial changes in the input distribution, have a marginal effect on the residence time. This conclusion is also supported by the 4.0-month residence time obtained for the line source indicated in Table C-1. The corresponding concentration distribution is shown in Figure C-7.

The net motion of the California Current down the coast of California may advect materials discharged above Point Conception into the Southern California Bight. The concentration distributions for inputs in this region are, in the present model, quite sensitive to the assumption used for the nearshore current velocity. If a discharge of 100 mgd from San Francisco Bay is assumed, the predicted dilutions in the vicinity of Santa Catalina Island are 1.75×10^5, 1.72×10^6, and 4.15×10^5 for nearshore currents of +0.04, -0.04, and ±0.04 m/sec respectively. For the nearshore current of ±0.04 m/sec, the concentration of a conservative substance, discharged from San Francisco Bay, in the Southern California Bight is about two orders of magnitude less than the average for direct sewered outfall discharges into the Bight (Figure C-8). If the San Francisco Bay discharge is raised to the same volume rate of discharge as in the Bight, the concentration ratio is reduced to about one order of magnitude.

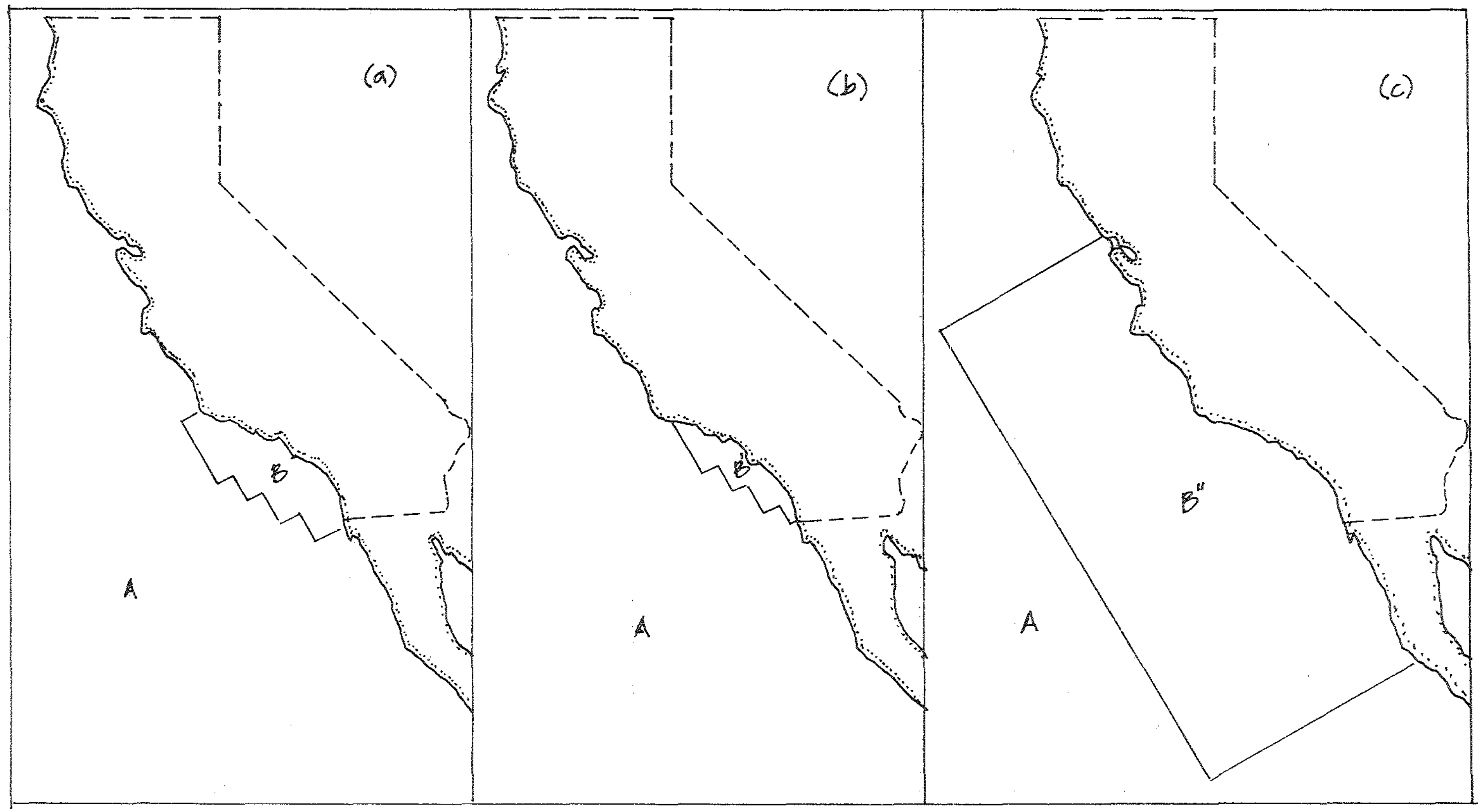

Figure C-4. Definition of Residence Time Areas.

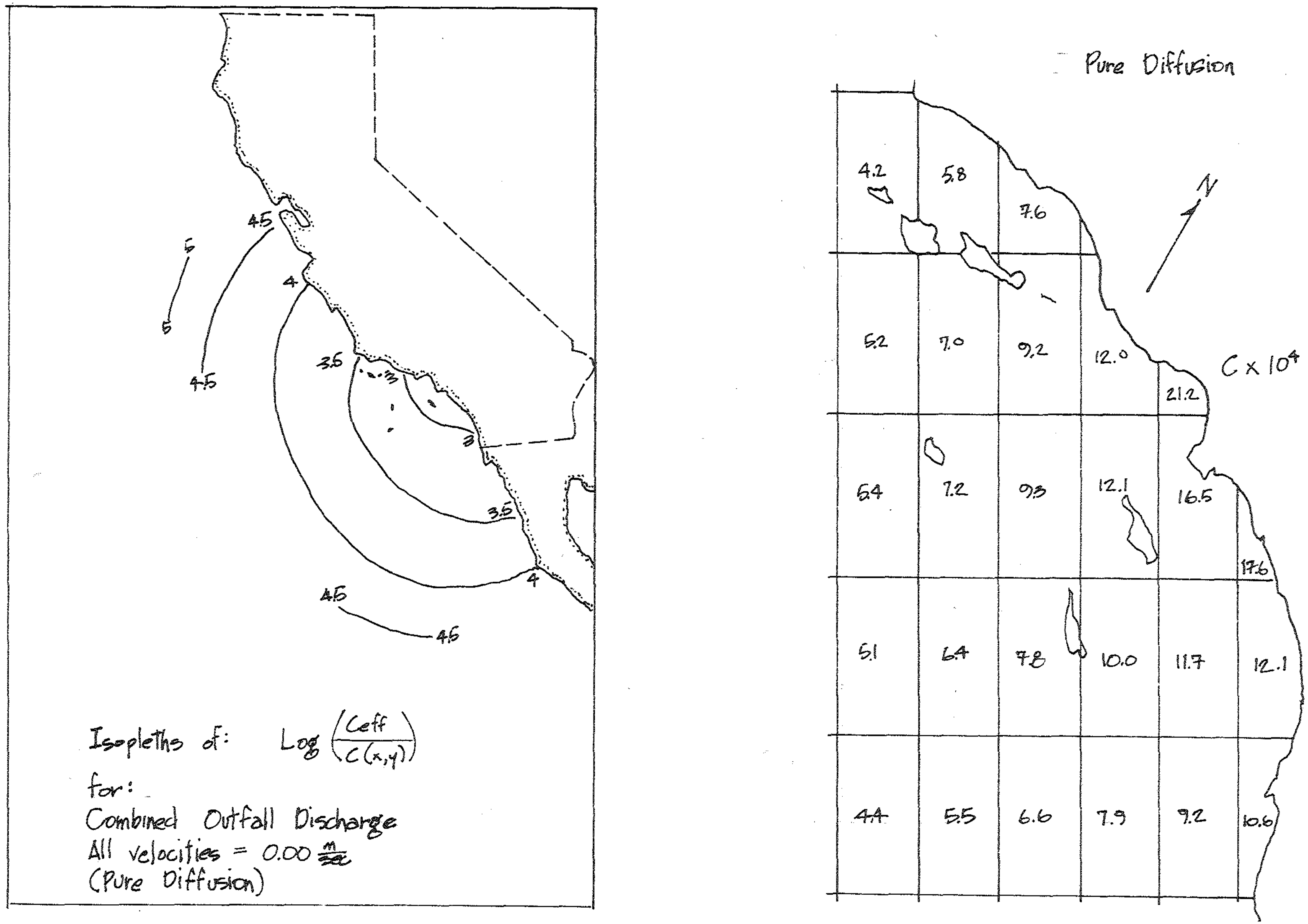

Figure C-5. Dilution Isopleths for Combined Outfalls--Pure Diffusion Example.

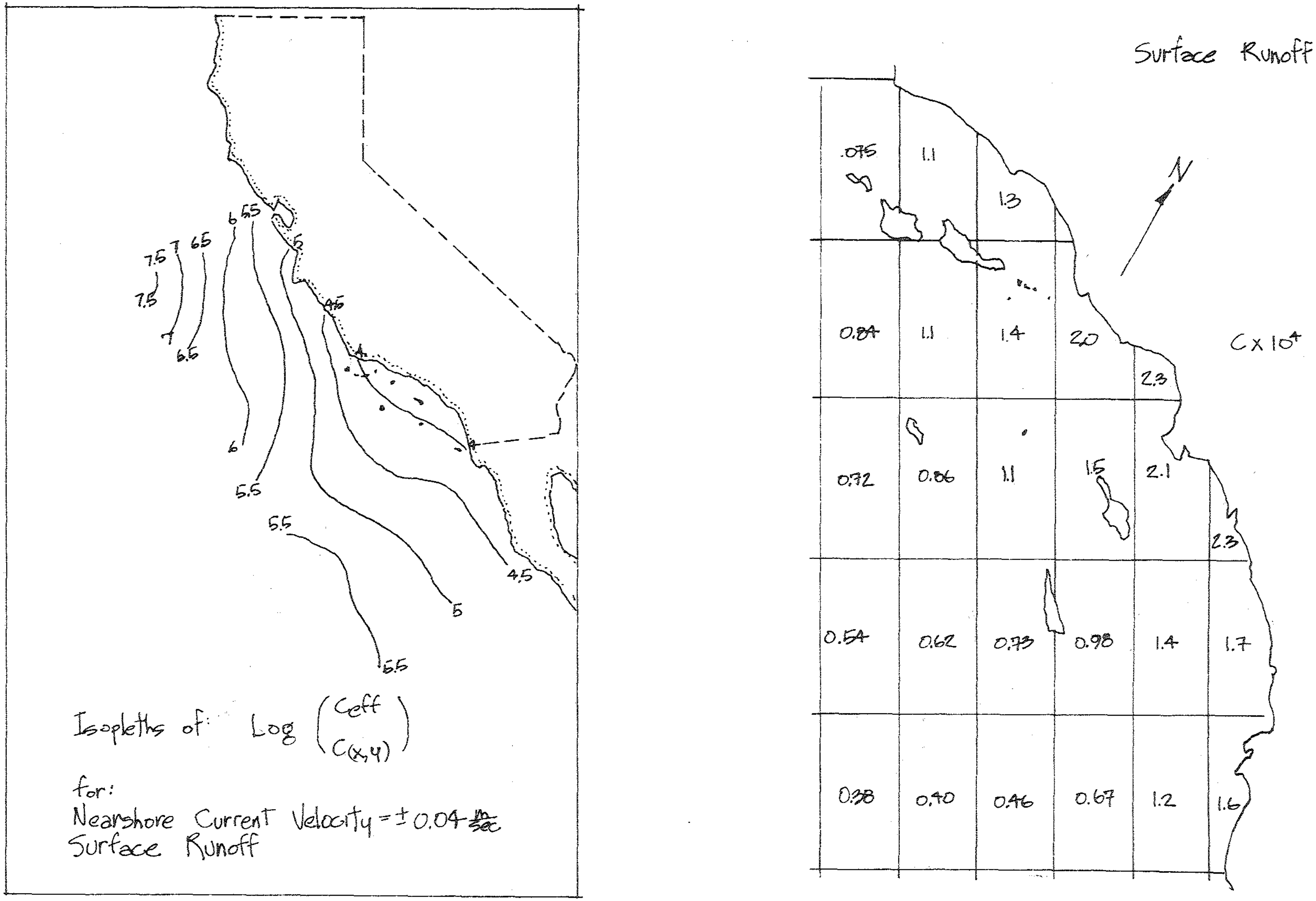

Figure C-6. Dilution Isopleths for Surface Runoff.

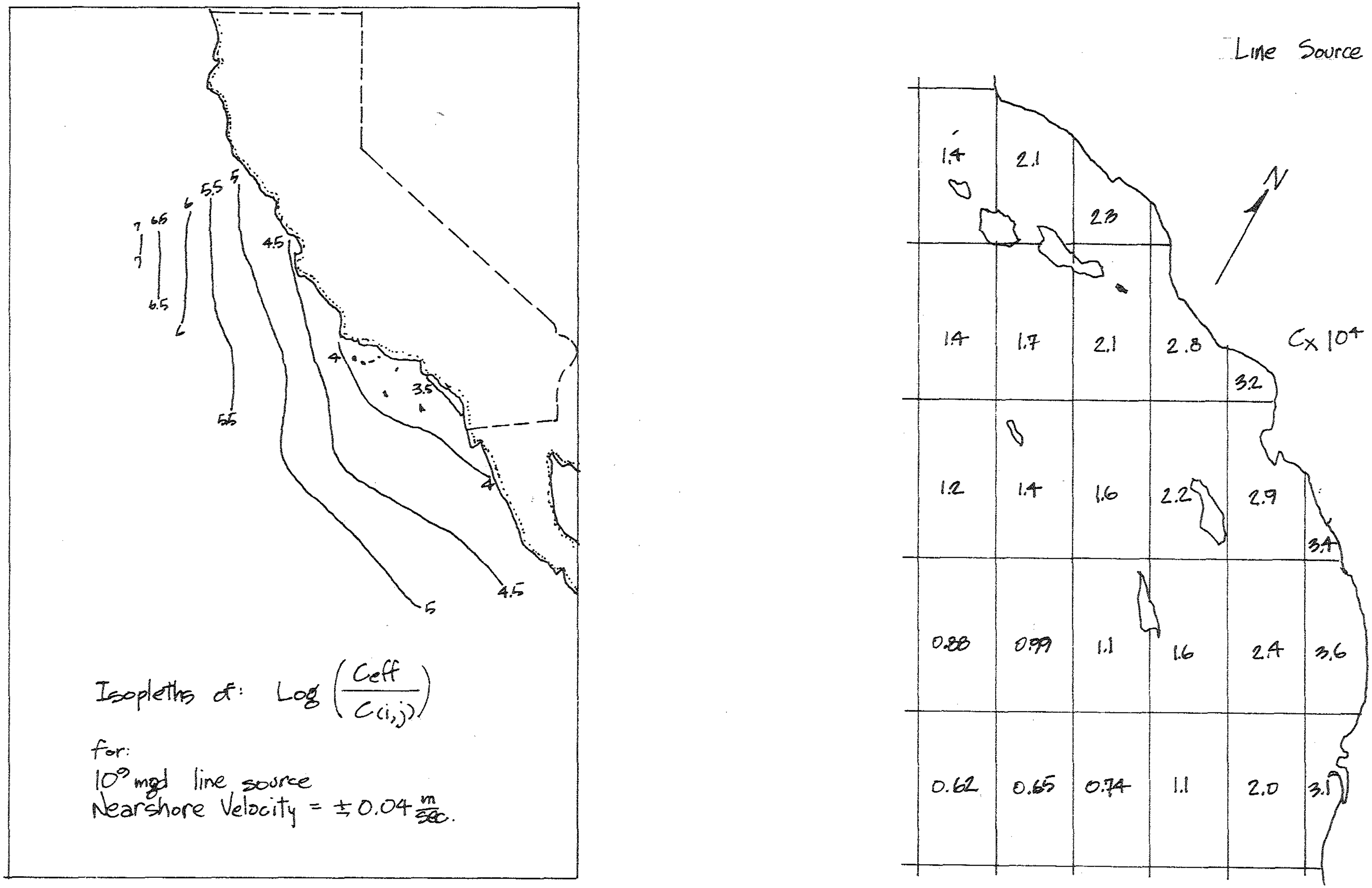

Figure C-7. Dilution Isopleths for a Line Source Along the Southern California Coast.

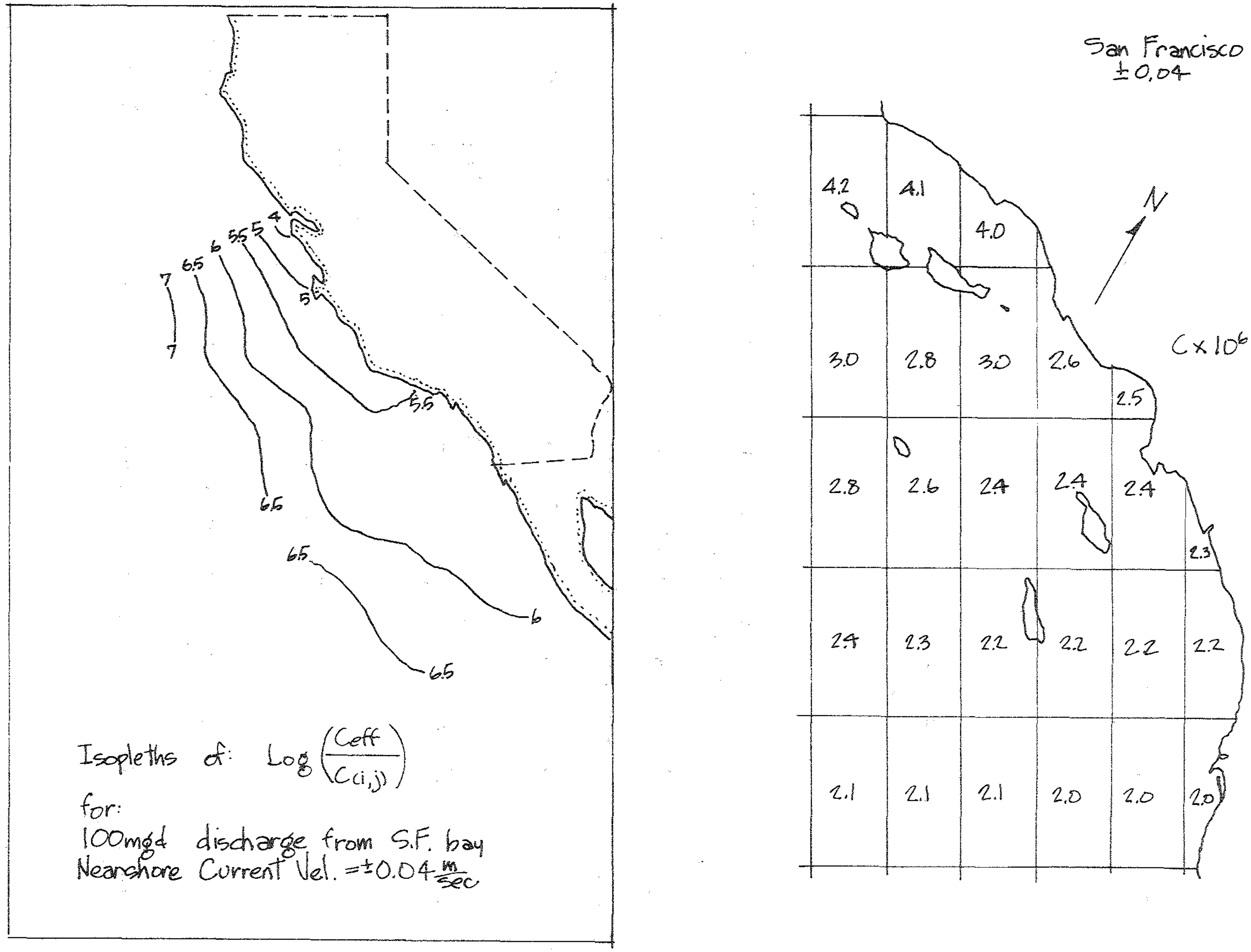

Figure C-8. Dilution Isopleths for San Francisco Input.

C.8 VERTICAL DIFFUSION

In this model, a constant cell depth has been used; hence, these concentrations represent approximations to the average concentration in the cell rather than the average concentration within the wastefield in that cell. To first order, the two are related by

$$C_w(i,j) - C(i,j)\,\frac{l_z}{l_w(i,j)} \tag{18}$$

and

$$V_w(i,j) = V(i,j)\,\frac{l_w(i,j)}{l_z}\,, \tag{19}$$

where

$C_w(i,j)$, $C(i,j)$ = the wastefield and average concentrations in cell (i,j), respectively,

$V_w(i,j)$, $V(i,j)$ = the wastefield and cell volumes, and

$l_w(i,j)$, l_z = the wastefield thickness and cell depth.

The rate of change in the concentration in cell (i,j) can then be written

$$\frac{\partial}{\partial t}\left[C_w(i,j)\cdot \ell_w(i,j)\right] = \Sigma a\,\frac{1}{t_a}\left[C_w^a \cdot \frac{l_w(a)}{l_z} - C_w(i,j)\cdot\frac{l_w(i,j)}{l_w}\right]$$

$$+\,\frac{S(i,J)\cdot l_w(i,j)}{V_w(i,j)\cdot l_z} - \lambda C_w(i,j)\cdot\frac{l_w(i,j)}{l_z}\,, \tag{20}$$

where S(i,j) = is the mass rate (or molar) of input into cell (i,j) and the sum is over the adjacent cells.

If the wastefield thickness does not change appreciably from one cell to an adjacent cell, then

$$l_w(a) \approx l_w(i,j)$$

and Equation 20 becomes

$$\frac{\partial C_w(i,j)}{\partial t} + \frac{C_w(i,j)}{l_w(i,j)} \frac{\partial l_w(i,j)}{\partial t} = \Sigma a \frac{1}{t_a} (C_w^a - C_w(i,j) + \frac{S(i,j)}{V_w(i,j)} - \lambda C_w(i,j) \tag{21}$$

or

$$\frac{\partial C_w(i,j)}{\partial t} \approx \Sigma a \frac{1}{t_a} (C_w^a - C_w(i,j)) + \frac{S(i,j)}{V_w(i,j)} - \lambda C_w(i,j), \tag{22}$$

since it can be shown that

$$\left| \frac{\partial \ln[C_w(i,j)]}{\partial t} \right| >> \left| \frac{\partial \ln[l_w(i,j)]}{\partial t} \right| . \tag{23}$$

Equation 22 would also have been obtained if the original formulation had been based on a grid of cells whose thickness had been chosen to correspond to the wastefield thickness; hence, there is a direct transformation between the two distributions if the inequality (Equation 23) is satisfied.

We have assumed that the characteristic thickness of the wastefield is given by:

$$\sigma_w^2(t) = \sigma_w^2(0) + K_z t \quad , \tag{24}$$

where $\sigma_w(t)$ = characteristic thickness at time t and K_z = vertical diffusivity.

The wastefield thickness in cell (i,j) can then be determined if the elapsed time to reach cell (i,j) after discharge is known. In general, this will not be a discrete value, instead there will be a distribution of elapsed times. In principal, this distribution could be obtained by combining the results of a series of limited duration inputs (say 1 month duration) over the time required for the model to come to "steady-state." This approach was not felt to be warranted because of the large number of simplifying approximations already contained in the model.

In order to obtain a rough estimate of the distribution of elapsed times, we have made the rather gross assumption that the quasi-steady-state solutions represent true steady state solutions, so that the concentrations are independent of time. In that case,

$$C(i,j) = C(x,y) \quad \text{and} \quad \partial C(i,j)/\partial t = 0.$$

If the substance is now allowed to decay according to

$$\frac{\partial C^*(i,j)}{\partial t} = -\lambda C^*(i,j),$$

where λ = decay constant and $C^*(i,j)$ = new concentration in cell (i,j), the new concentration, $C^*(i,j)$, can be expressed in terms of the old concentrations $C(i,j)$ by

$$C^*(i,j) = C(i,j)e^{-\lambda t},$$

since the total derivative, $\partial C^*/\delta t$, can be separated into the two parts, $\vec{\nabla} C^*$ and $\partial C^*/\delta t$. Applying this method to the combined outfall input with a nearshore current of ±0.4 m/sec gives the elapsed time distribution shown in Figure C-9. Figure C-10 shows the new dilution distribution for the combined outfall discharges and may be compared with Figure C-3.

C.9 MODEL TESTING

The assumptions and simplifications introduced into the model can limit the validity of the model simulations, hence it is highly desirable that the model predictions be compared with actual observations.

The relatively high dilutions that might be expected on the basis of the model predictions indicate that there may be major problems in experimentally testing the model due to detectability limits of the apparatus and masking by natural fluctuations. For example, an STD recorder can measure changes in salinities to about 10^{-2} parts per thousand. As municipal wastewaters have salinities on the order of 1-2 parts per thousand, dilutions of approximately 3.3×10^3 could, in principle, be observed. This would correspond to a distance of approximately 25 miles offshore in the Los Angeles area (see Figure C-10). In practice, natural fluctuations and other experimental difficulties limit the range of wastefield detection by an STD recorder to a few miles from the outfall.

In order to obtain some comparison between the model simulations and reality, we have attempted to relate the concentrations of trace materials in intertidal molluscs (Chapter 8) to the concentrations predicted by the model for outfall discharges, surface runoff, and an input from a line source. Because the mass emission rates for most of the unsewered inputs are relatively uncertain, or unknown, the comparison has been made on the basis of the relative changes predicted by the model over the sampling area rather than on the absolute concentrations. The results for DDE, lead, and cadmium are shown in Figures C-11, C-12, and C-13 respectively. Each point represents a sampling area and corresponds to two numbers on the figure. The ordinate is the experimentally measured concentration of the trace material in the digestive glands of the mollusc (expressed as ppm on a dry weight basis) and the abscissa is the predicted concentration for the area in which the sample was obtained. The range on the abscissa has been normalized to cover the range of values from 0 to 1 since the absolute values are uncertain. If an exact correlation

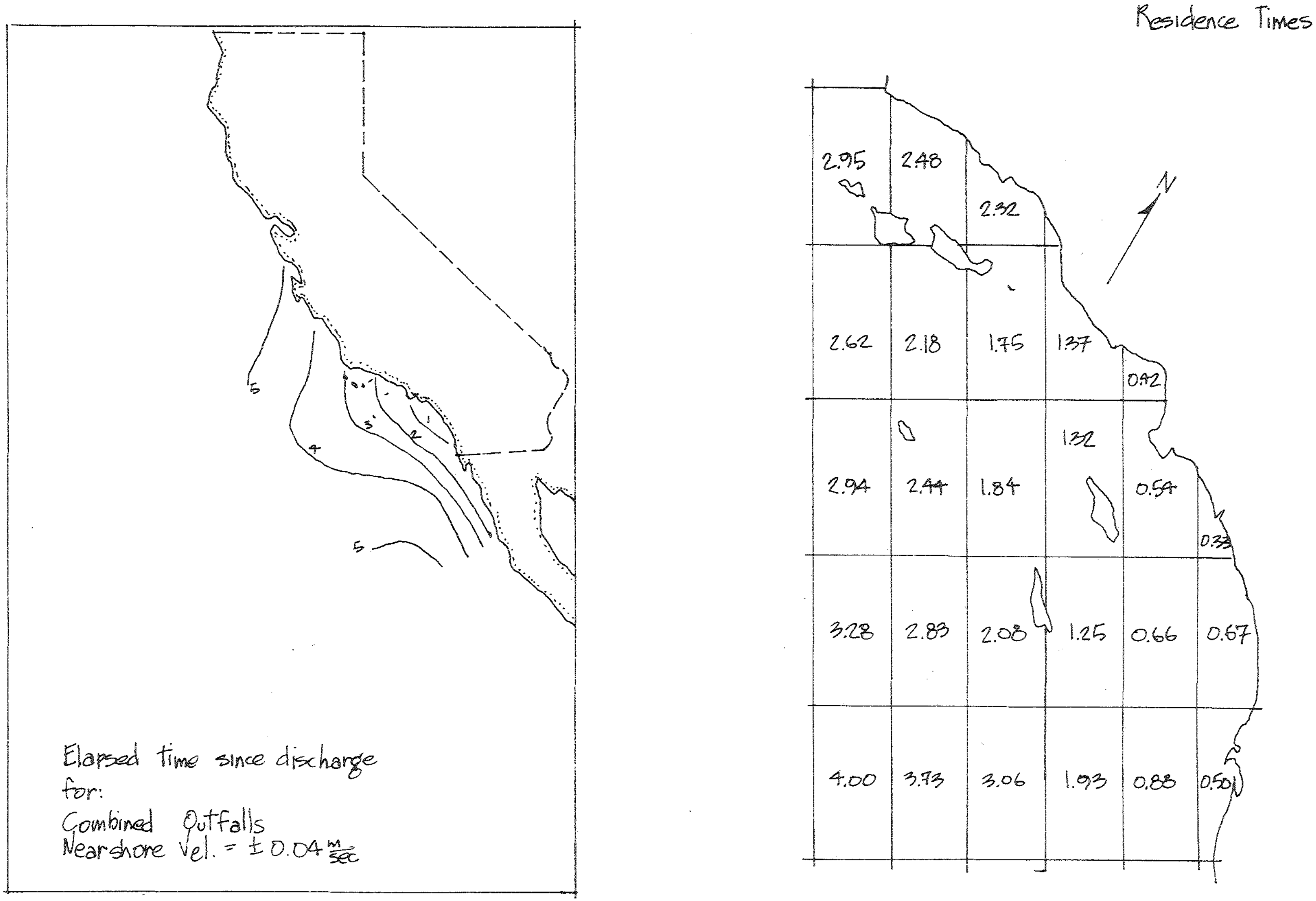

Figure C-9. Elapsed Times for Outfall Discharges from Decay Approximation.

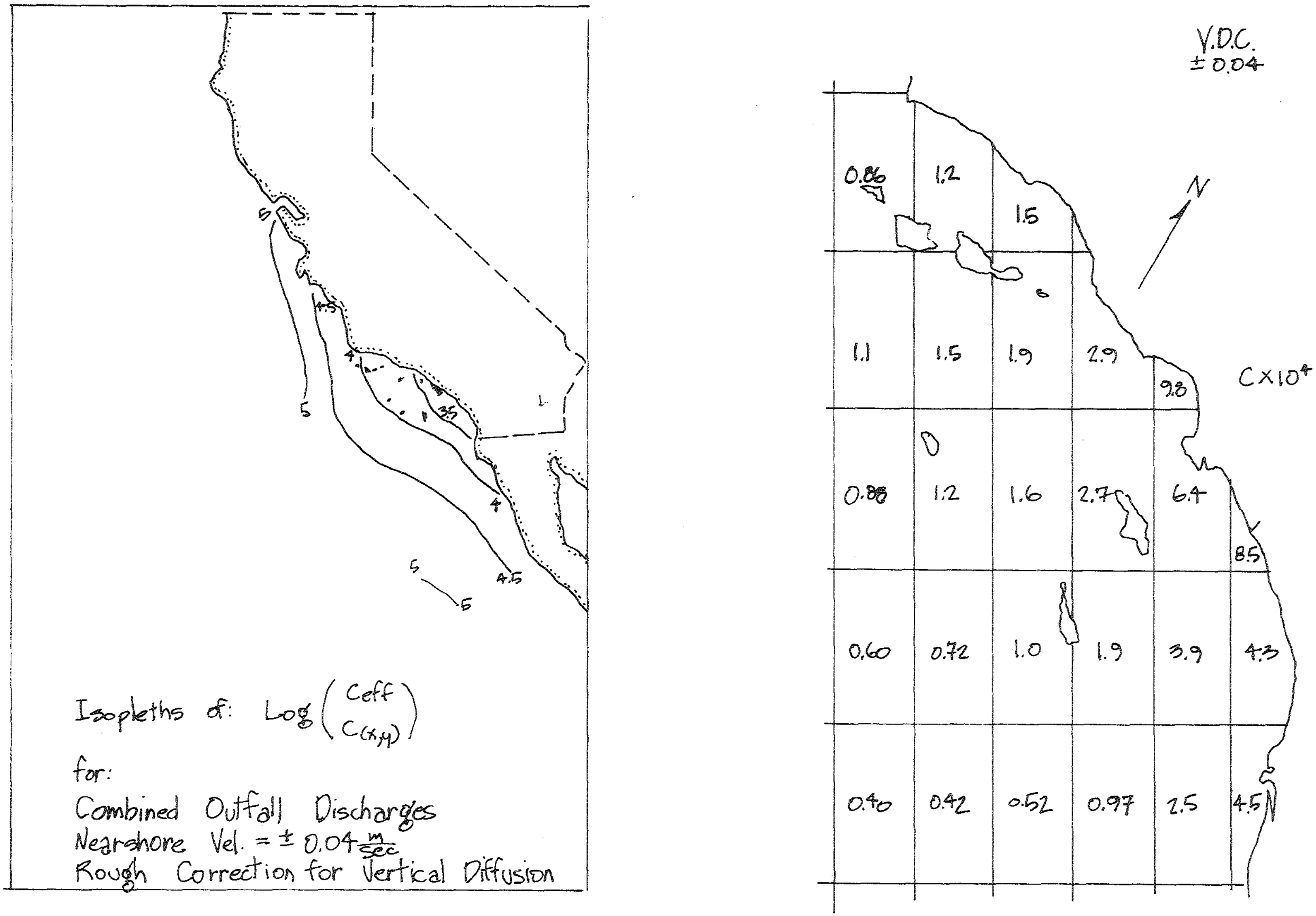

Figure C-10. Dilution Isopleths for Combined Outfall Discharges with Vertical Diffusion Approximation.

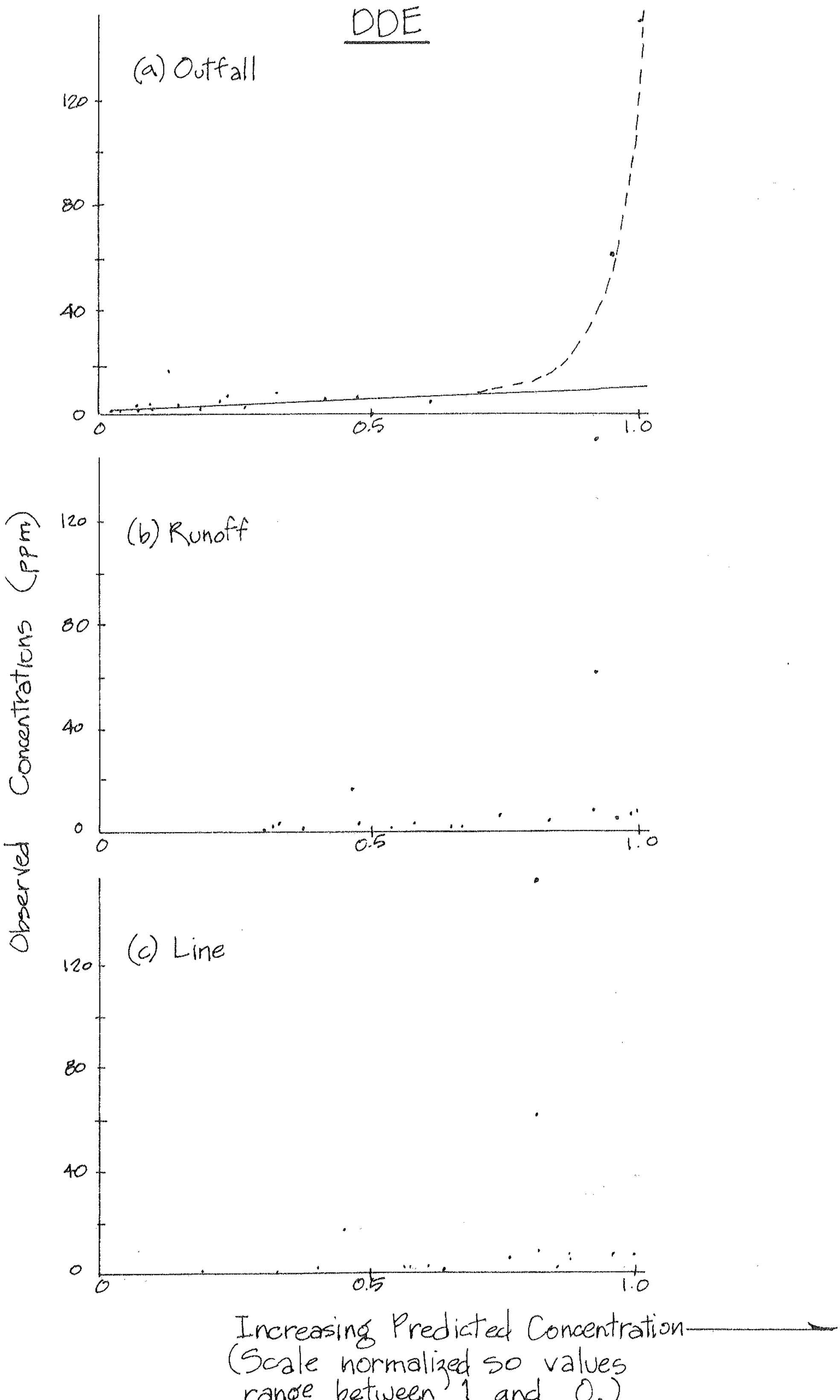

Figure C-11. DDE Correlation Plots

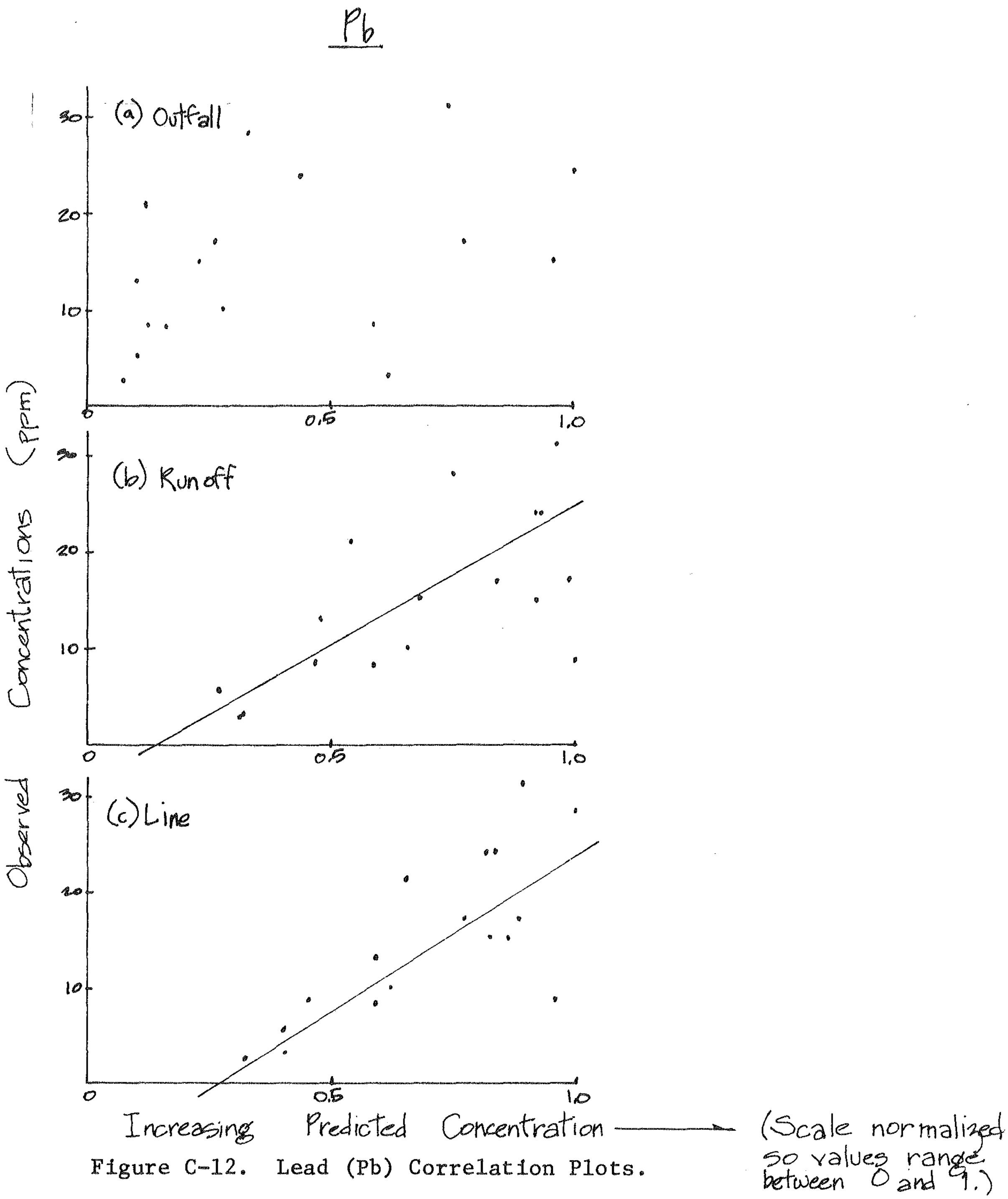

Figure C-12. Lead (Pb) Correlation Plots.

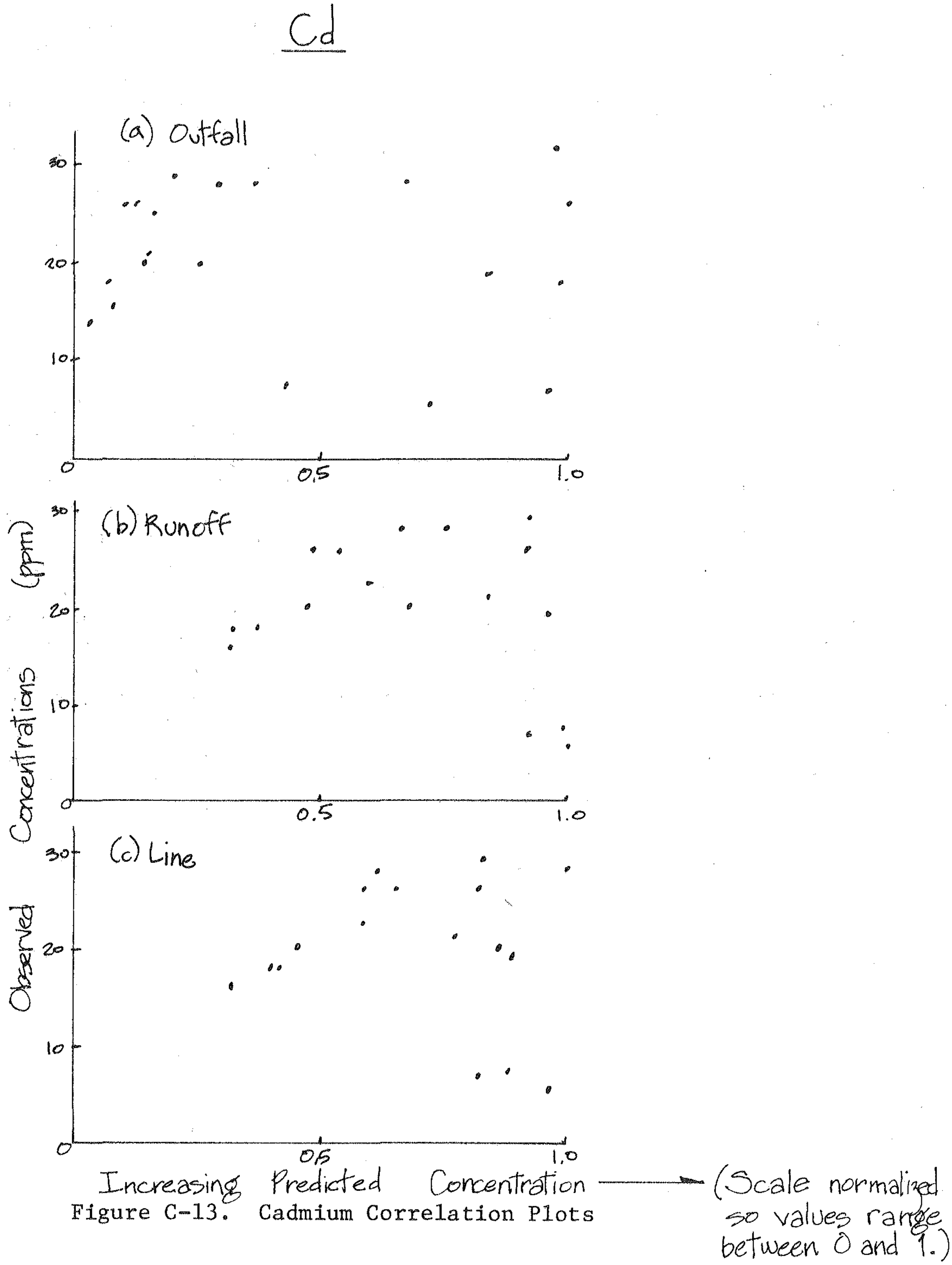

Figure C-13. Cadmium Correlation Plots

existed between the observed and predicted concentrations, the locus of points would fall along a straight line whose intercept on the ordinate would be the mollusc concentration in the input-free ambient waters.

Figure C-11 (for DDE) indicates that there is little, if any, correlation between the observed DDE concentration distributions and those predicted by the model for surface runoff or a line source. There does appear to be a general trend to have higher observed values with increasing predicted values for the outfall discharges although the trend is distinctly non-linear at the higher concentrations.[4] This enhancement in the observed concentrations could result from a variety of defects in using this method to test the model. For example, the intertidal molluscs are samplers of surface water concentrations, while the model predictions are for the concentrations in the subsurface wastefield. Chlorinated hydrocarbons such as DDE are readily dissolved in fatty materials, hence they may be associated with materials in the effluent that float to the surface waters after discharge. The prevailing onshore winds in this area (Appendix B) would then tend to sweep a thin layer of surface water into the intertidal zone, enhancing the observed concentrations in this region.

A comparison of the predicted and observed lead distributions is shown in Figure C-12. There appears to be little correlation between the two distributions when the source is the combined outfall discharges. In contrast, a correlation is evident in the case of line source input, and approximately 50% of the variance in the observed concentrations can be accounted for by this model prediction. This type of source could be associated with aerial fallout of lead introduced into the atmosphere by traffic along the near coastal highways. Some indication of a correlation can be seen in the figure for input from surface runoff. However, preliminary estimates of the mass emission rates indicate that the surface runoff input is at least an order of magnitude less than than from outfall discharges; hence, the apparent correlation with runoff is probably a result of the similarity of this distribution with that produced by a line source. It might be noted here that the negative intercept of the correlation line for the line source probably has no physical meaning. Inclusion of vertical diffusion effects[5] tends to decrease the slope of the line and could change the sign of the intercept.

Figure C-13 indicates that there is no apparent correlation between the observed cadmium distributions and those predicted for any of the three types of input.

C.10 SUMMARY AND CONCLUSIONS

A relatively simple model of the distribution of conservative substances in the Southern California Bight has been developed using the data from the CalCOFI series to estimate the offshore circulation. For nearshore mean transport velocities on the order of 0.04 m/sec, the corresponding residence time for the effluent from the combined discharges of the five major sewered wastewater outfalls in the Bight is in the range of 4 to 4-1/2 months. This residence time is sensitive to the average currents in the first 20 miles

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4. The outfall inputs are weighted by the relative mass emission rates for each outfall. For DDE, nearly all the input was from the Whites Point outfall.
5. This has been done approximately for the outfall distribution.

offshore and changes by about ±50% for nearshore mean transport velocities of 0.00 and 0.08 m/sec; hence, better estimates of the nearshore currents at the depth of the wastefield will be required if accurate estimates of residence times in the Bight are desired. The average dilution of the effluent in the Bight is estimated to be about 5,000:1, ranging from about 1,000:1 in the general region near the outfall to 10,000:1 or more at the outer islands.

At the present time, the model has not been tested by direct comparison of predicted and observed concentrations in the ocean waters, partly because of the experimental difficulties in obtaining significant measurements at such large dilutions. Comparison of the observed concentrations of three trace materials--DDE, Pb, and Cd--in intertidal mussels with the relative changes in the predicted concentrations gave inconclusive results, possibly because the mussels essentially sample the surface waters and the wastefield is generally submerged. Some correlation in the predicted Pb concentrations for a line source and the measured values was observed, suggesting that airborne input of lead may be a significant factor.

Estimates of the concentrations of conservative materials in the Bight as the result of inputs in the San Francisco Bay area indicate that, for a discharge of 4.4 cu m/sec (100 mgd), there is a dilution in the range of 10 to 100 times greater than for the outfall discharges into the Bight.

C.11 REFERENCES

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Appendix D

TRACE METAL CONCENTRATIONS IN SEDIMENTS AROUND MAJOR SOUTHERN CALIFORNIA OUTFALLS

During 1970-72, SCCWRP conducted studies to determine the distribution of metals in the sediments around the major municipal wastewater outfalls in southern California. Tables D-1, D-3, and D-5 through D-7 give the concentrations of 10 metals in the surface layer (0-1 cm) of sediments cored off the five major outfalls. Tables D-2 and D-4 give the concentrations of the same metals in vertical profiles from cores collected off Palos Verdes and in Santa Monica Bay. The tables are discussed in Chapter 6.

Table D-1

CONCENTRATIONS (mg/dry kg) OF METALS IN THE SURFACE LAYER (0-1 cm) OF SEDIMENTS CORED OFF WHITES POINT

Station	Core Type and Date	Metal									
		Silver	Cadmium	Cobalt*	Chromium	Copper	Iron	Manganese	Nickel*	Lead	Zinc
B_1		1.4	65	8.8	860	550	29000	260	45	350	1800
C_1		3.8	79	10	660	340	29000	290	33	240	930
D_1		4.0	25	9.4	500	240	26000	310	29	170	590
E_1		1.4	11	9.5	190	110	23000	320	40	99	290
F_1		3.3	12	7.9	280	110	24000	310	21	110	310
B_2		4.3	32	9.8	490	300	29000	280	32	210	520
N_2		4.7	14	7.2	370	180	26000	300	24	110	520
B_3		3.0	13	6.1	210	140	23000	410	20	90	380
N_3		1.7	2.8	4.5	130	60	21000	260	14	25	180
B_4	Phleger	1.1	2.6	4.9	72	31	11000	340	11	15	100
N_4	Cores:	1.4	1.4	6.1	47	19	14000	120	10	9.4	79
B_5	Collected	2.6	24	5.8	390	230	30000	310	28	170	860
C_5	May, 1970	2.0	16	5.6	280	170	29000	330	30	91	560
D_5		3.1	9.8	9.4	230	160	30000	310	25	40	380
E_5		0.55	1.5	7.4	100	73	26000	250	16	36	160
F_5		0.60	0.63	5.0	43	23	21000	160	11	22	89
B_6		5.7	32	7.6	400	220	31000	330	31	160	770
C_6		3.6	18	10	240	150	37000	370	25	94	420
B_7		2.3	30	8.9	280	190	36000	330	26	110	500
C_7		3.0	13	9.7	160	110	37000	340	25	59	260
B_8		3.0	17	11	210	140	36000	360	24	80	370
C_8		2.5	15	9.4	170	140	31000	340	20	61	310
B18	Box Cores:	7.6	10	4.4	290	160		380	12	120	410
B19	Collected	19	53	6.9	950	640		290	26	470	2100
B20	July, 1971	21	68	7.2	1000	660		320	36	460	2400
B21		19	57	5.2	1000	670		340	30	490	2400

*See Text

Table D-2
CONCENTRATIONS (mg/dry kg) OF METALS IN VERTICAL PROFILES
FROM BOX CORES TAKEN OFF WHITES POINT DURING JULY, 1971

Station and Depth	Metal								
	Silver	Cadmium	Cobalt*	Chromium	Copper	Manganese	Nickel**	Lead	Zinc
B18: 0 cm	7.6	10	4.4	290	160	380	12	120	410
2	5.3	7.8	4.6	230	120	400	10	93	300
4	5.2	6.6	4.2	190	100	420	11	81	270
6	3.5	3.4	3.1	120	57	410	9.7	-	160
8	2.7	1.5	4.0	100	41	430	8.3	44	140
10	2.3	1.7	4.5	85	38	420	7.8	33	110
12	2.0	1.2	4.1	77	39	420	8.1	27	95
14	2.2	0.44	5.6	63	30	420	6.9	31	84
B19: 0 cm	19	53	6.9	950	640	290	26	470	2,100
2	15	46	4.6	750	500	260	22	400	1,600
4	-	-	3.9	-	-	-	26	410	-
6	19	60	7.0	770	550	350	29	430	1,600
8	18	48	7.9	610	460	370	30	390	1,200
10	18	48	8.7	590	460	400	29	430	1,200
12	18	48	8.5	600	430	410	26	410	1,100
14	9.5	24	7.0	270	240	400	18	210	690
16	6.7	12	6.2	230	140	480	14	140	410
18	3.9	5.3	6.4	150	94	480	11	86	260
20	2.4	1.2	5.8	84	46	490	9.7	62	140
22	2.4	1.3	5.0	79	45	480	10	22	140
24	2.2	0.79	5.8	71	47	480	11	17	120
26	-	-	5.5	-	-	-	9.0	15	-
28	1.5	0.51	5.8	78	45	510	8.9	18	110
30	1.9	0.70	5.9	63	39	480	9.2	15	100
32	1.7	0.41	5.3	64	40	500	9.6	9.8	94
34	2.0	0.21	7.4	63	43	520	10	14	96
B20: 0 cm	21	68	7.2	990	660	320	36	460	2,400
2	23	76	7.7	950	670	360	37	480	2,300
4	23	73	7.7	1,000	740	340	37	470	2,400
6	23	76	9.2	790	620	400	37	460	1,900

*These values are an approximation ±50%.
**These values are an approximation ±30%.

Table D-2 (Continued)

Station and Depth	Metal								
	Silver	Cadmium	Cobalt*	Chromium	Copper	Manganese	Nickel**	Lead	Zinc
B20: 8 cm	22	71	9.3	690	540	420	34	420	1,700
10	18	45	8.4	520	390	460	26	290	1,200
12	11	18	6.8	290	190	510	16	140	560
14	5.3	8.3	7.3	180	110	500	11	76	330
16	5.7	7.6	7.2	180	110	520	12	78	320
18	2.6	2.4	5.4	140	50	520	8.7	33	160
20	1.8	0.67	5.9	110	35	500	8.2	24	92
B21: 0 cm	19	57	5.2	1,000	670	340	30	490	2,400
2	16	51	4.4	860	570	290	26	360	2,000
4	24	73	5.2	910	660	350	33	420	2,300
6	19	65	5.2	780	520	360	31	360	1,800
10	16	51	6.2	560	470	390	28	320	1,800
12	17	51	6.0	600	450	390	28	320	1,200
14	15	27	6.6	370	240	490	18	210	780
16	42	15	5.6	250	150	510	15	89	500
18	28	4.6	5.3	130	72	510	9.8	51	240
20	2.4	1.6	4.9	83	35	550	9.0	24	130
22	2.4	1.2	4.8	75	38	530	9.4	23	130
24	2.8	0.76	5.7	73	49	510	8.4	16	120
26	1.9	0.33	5.4	72	40	520	8.2	16	100
28	2.5	0.21	5.4	65	34	520	8.2	11	93
30	14	0.19	4.5	60	31	490	8.1	7.0	85
32	14	-	4.5	51	28	500	8.4	7.2	82
34	6.8	-	4.9	36	25	420	8.0	3.0	86
36	5.9	0.41	5.2	57	32	540	8.7	5.1	90

*These values are an approximation ±50%

**These values are an approximation ±30%

Table D-3

CONCENTRATIONS (mg/dry kg) OF METALS IN THE SURFACE LAYER (0-1 cm) OF SEDIMENTS CORED IN SANTA MONICA BAY DURING 1970-71 (ANALYSES BY GALLOWAY).

Station	Core Type and Date	Metal									
		Silver	Cadmium	Cobalt*	Chromium	Copper	Iron	Manganese	Nickel**	Lead	Zinc
1A		5.0	3.6	6.2	140	67	20,000	270	19	35	160
1B		2.0	0.74	6.0	93	21	20,000	240	18	27	68
1C		6.1	1.2	5.2	75	14	18,000	200	15	22	81
2A		4.4	2.4	4.5	140	54	21,000	260	17	31	120
2B		1.8	0.81	3.8	74	21	18,000	200	14	35	70
2C		3.2	0.72	4.5	71	18	18,000	240	16	65	80
3A		4.4	2.7	4.3	140	55	21,000	240	15	31	120
3B		3.1	0.78	3.6	110	34	21,000	200	14	44	90
3C		2.9	0.67	3.5	74	18	13,000	180	13	31	58
4A	Phleger	2.1	1.6	6.7	100	29	24,000	330	19	15	87
4B	Cores:	4.0	1.4	5.9	160	50	29,000	290	20	38	110
4C	Collected	2.4	0.64	4.7	120	27	27,000	250	16	28	76
5A	June, 1970	2.6	1.4	4.6	110	30	17,000	260	26	21	75
5B		3.4	0.19	6.3	140	34	27,000	240	14	32	91
5C		1.5	0.97	6.0	130	36	29,000	350	20	23	99
6A		3.0	1.9	5.0	62	31	14,000	240	9.0	23	100
6B		2.0	1.4	5.2	120	32	34,000	230	21	20	90
6C		1.5	0.35	6.5	110	23	34,000	350	22	14	92
7A		1.6	0.94	7.8	34	16	8,600	130	12	16	71
7B		2.5	0.27	10	86	31	32,000	410	24	44	84
7C		1.2	0.24	5.0	220	14	72,000	110	18	2.9	60
8A		7.6	7.7	8.8	190	72	18,000	320	32	58	150
8B		3.9	1.9	3.0	52	26	7,100	100	9.0	18	58
8C		3.1	1.1	5.9	120	31	26,000	230	20	24	82
B3		61	43	4.9	940	500		230	26	250	960
B6		30	20	4.8	590	260		250	19	100	450
B7		9.8	5.3	3.7	180	120		290	12	36	230
B8	Box Cores:	8.5	3.9	4.1	190	120		300	13	33	220
B9	Collected	1.8	0.59	4.2	81	46		310	12	9.1	140
B10	July, 1971	4.1	1.3	4.2	120	69		290	10	16	160

*These values are an approximation ±50%.
**These values are an approximation ±30%.

Table D-3 (continued)

Station	Core Type and Date	Metal									
		Silver	Cadmium	Cobalt*	Chromium	Copper	Iron	Manganese	Nickel**	Lead	Zinc
B11		2.0	0.95	3.7	100	45		280	10	12	150
B12		2.8	0.55	4.2	110	56		300	14	16	150
B13		8.2	1.4	5.0	180	110		280	13	30	200
B14		8.8	2.3	5.0	180	120		300	14	30	210
B17		1.4	0.31	3.1	220	18		130	1.6	3.0	100
SMC		2.4	2.6		67	30		400	20	8.0	110

*These values are an approximation ±50%.
**These values are an approximation ±30%

Table D-4
CONCENTRATIONS (mg/dry kg) OF METALS IN VERTICAL PROFILES FROM BOX CORES TAKEN IN SANTA MONICA BAY DURING JULY 1971.

Station and Depth	Metal								
	Silver	Cadmium	Cobalt*	Chromium	Copper	Manganese	Nickel**	Lead	Zinc
B3: 0 cm	61	43	4.9	940	500	230	26	250	960
2	59	46	6.3	1,000	530	240	27	270	960
4	57	43	6.3	920	510	240	27	230	920
6	67	58	6.2	1,200	620	240	32	310	1,000
8	68	59	6.6	1,100	590	230	35	300	1,200
10	67	70	5.8	1,100	610	220	37	290	1,300
12	67	58	5.2	1,100	560	210	30	250	1,100
14	72	63	5.9	1,100	530	220	32	260	-
16	79	67	6.2	1,100	600	230	33	270	1,400
18	83	67	4.4	1,000	600	220	31	280	1,400
20	85	67	5.7	1,000	600	220	32	290	1,500
22	79	69	6.2	1,100	600	220	32	290	1,600
24	83	68	6.1	1,000	580	250	32	280	1,500
26	82	67	4.8	1,000	550	230	28	280	1,500
28	73	67	4.2	930	490	240	26	240	1,200
B6: 0 cm	30	20	4.8	590	260	250	19	100	450
2	33	23	4.5	610	280	250	19	100	500
4	33	25	5.1	630	290	260	21	110	560
6	33	23	3.8	520	260	250	19	93	550
8	32	22	3.6	490	240	260	17	92	410
10	28	20	3.8	510	200	260	15	93	460
12	-	-	-	-	-	-	-	-	89
14	16	11	4.8	280	160	270	14	49	260
18	9.3	6.8	4.3	210	94	270	12	43	180
22	2.9	1.2	3.5	110	44	280	10	11	120
26	1.4	0.36	3.4	92	36	270	10	5.1	70
30	0.93	0.35	3.4	87	29	280	8	-	77
34	0.94	0.71	3.4	78	33	270	10	-	78
B8: 0 cm	8.5	3.9	4.2	190	120	300	13	33	220

*These values are approximations ±50%.
**These values are approximations ±30%.

Table D-4 (continued)

Station and Depth	Metal								
	Silver	Cadmium	Cobalt*	Chromium	Copper	Manganese	Nickel**	Lead	Zinc
B8: 5 cm	8.0	3.7	4.9	180	110	310	14	25	220
10	1.8	0.54	5.1	70	37	310	11	8.9	130
15	1.4	-	3.4	62	32	290	10	2.5	120
20	0.91	0.17	3.4	62	28	310	11	0.82	110
25	0.91	0.25	4.2	62	28	300	10	0.82	110
SMC: 0 cm	2.4	2.6		67	30	400	20	8.0	110
3	2.2	1.5		64	27	450	21	13	110
5	1.7	1.3		58	25	390	21	8.3	100
9	1.9	1.2		58	25	410	18	7.6	110
13	1.1	0.92		57	24	390	20	3.9	100
20	1.4	15		58	23	380	20	4.0	97
34	1.1	2.3		59	24	360	18	6.1	98
49	1.8	14		58	25	410	20	5.6	100
79	1.6	1.2		55	23	410	18	3.3	97
99	1.8	4.8		67	34	470	20	10	100

*These values are approximations ±50%.
**These values are approximations ±30%.

Table D-5
CONCENTRATIONS (mg/dry kg) OF METALS IN THE SURFACE LAYER (0-1 cm)
OF SEDIMENTS CORED OFF THE ORANGE COUNTY OUTFALL SYSTEM.

Station	Core Type and Date	Metal							
		Silver	Cadmium	Chromium	Copper	Manganese	Nickel*	Lead	Zinc
1		1.7	1.1	42	14	390	7.6	13	80
2		1.8	0.92	52	21	470	14	220	110
3		2.5	0.73	49	27	400	15	7.5	100
4	Box Cores:	1.5	0.28	52	21	430	15	6.1	110
5	Collected	1.8	0.84	52	26	400	13	9.1	110
6	October, 1970	1.5	0.43	41	15	420	10	9.4	78
7	Outside	1.8	3.0	34	14	360	8.6	8.5	73
8	10 Fthms	1.5	0.30	33	14	380	8.4	11	71
9	Line	1.5	0.38	24	12	300	6.6	13	57
15		1.6	1.1	38	25	440	13	22	96
16		1.9	3.7	33	14	320	8.3	11	81
17		2.2	7.6	68	55	450	24	29	150
18		1.9	0.95	64	33	420	16	12	120
N4	Hand Cores:	1.7	0.16	30	12	440	8.7	21	63
N3	Collected	2.5	5.6	43	28	430	9.4	37	93
N2	March, 1971	2.7	1.7	47	37	410	10	47	100
N1	10 Fthms	2.8	5.4	35	31	380	9.0	40	92
S1	Line	3.4	4.0	50	37	520	12	62	130
S2		2.8	3.2	52	43	480	11	57	110
S3		2.7	1.4	48	29	350	10	37	91
S4		2.9	1.0	36	33	470	12	31	120
S5		--	0.50	22	12	430	6.8	15	56
S1	Hand Cores: Col-	2.4	0.30	32	14			25	55
S2	lected May, 1971	2.7	1.5	50	30			37	120
S3	10 Fthms Line	2.6	0.67	46	26			42	86
1	Box Cores: Collect-	1.7	0.21	42	15		8.7	12	71
2	ed Sept. 1971 (cont.)	1.5	0.15	58	17		11	6.5	79

*These values are approximations ±30%.

Table D-5 (continued)

Station	Core Type and Date	Metal							
		Silver	Cadmium	Chromium	Copper	Manganese	Nickel*	Lead	Zinc
6	Outside 10-fathom Line	1.5	0.45	44	14		10	11	75
7		1.7	0.38	39	16		8.2	22	80
8		1.7	0.30	41	16		8.0	15	74
9		1.7	0.23	37	15		7.6	16	63
15		2.3	0.61	47	30		11	22	96
16		1.4	0.23	31	17		7.7	12	60
17		2.6	0.23	57	46		16	23	130

*These values are approximations ±30%.

Table D-6
CONCENTRATIONS (mg/dry kg) OF METALS IN THE SURFACE LAYER (0-1 cm) OF SEDIMENTS FROM PHLEGER CORES COLLECTED OFF POINT LOMA DURING NOVEMBER-DECEMBER 1970.

Station	Metal								
	Silver	Cadmium	Chromium	Copper	Iron	Manganese	Lead	Zinc	Mercury
A2	2.4	0.33	40	16	27,000	280	10	53	0.09
A3	-	-	-	-	-	-	-	-	0.06
A4	-	-	-	-	-	-	-	-	0.11
A5	0.88	0.43	40	20	28,000	240	11	59	0.16
A13	-	-	-	-	-	-	-	-	0.15
A14	-	-	-	-	-	-	-	-	0.11
B1	-	-	-	-	-	-	-	-	0.02
B3	-	-	-	-	-	-	-	-	0.05
Y1B	1.4	0.92	46	36	25,000	250	24	83	-
Y2B	0.57	0.47	50	19	30,000	300	11	65	0.14
Y3B	0.74	0.41	38	17	26,000	250	10	55	0.11
Harbor	0.94	0.79	140	-	33,000	220	35	-	-

Table D-7
CONCENTRATIONS (mg/dry kg) OF METALS IN THE SURFACE LAYER (0-1 cm) OF SEDIMENTS FROM BOX CORES COLLECTED OFF THE OXNARD SEWAGE OUTFALL DURING AUGUST 1971.

Station	Metal						
	Silver	Cadmium	Chromium	Copper	Lead	Zinc	Mercury
55	-	-	-	-	-	-	0.02
56	-	-	-	-	-	-	0.02
58	1.6	0.35	33	14	20	50	0.04
59	1.2	0.17	35	13	12	37	0.03
61	-	-	-	-	-	-	0.02
62	-	-	-	-	-	-	0.10
63	-	-	-	-	-	-	0.05
64	-	-	-	-	-	-	0.04
65	-	-	-	-	-	-	0.03
66	-	0.27	39	16	19	49	0.03
67	-	-	-	-	-	-	0.05
68	-	-	-	-	-	-	0.06
70	1.9	0.25	70	30	11	76	0.09

Appendix E

PHYTOPLANKTON RESPONSE MODEL

(Appendix E, a detailed discussion of the SCCWRP phytoplankton response model described in Chapter 9, is available upon request.)

ABBREVIATIONS

BOD	biochemical oxygen demand
chlor-a	chlorophyll a
CN	cyanide
COD	chemical oxygen demand
D_g	Gleason species richness index
H'	unscaled Shannon-Weaver species diversity index
H'_s	scaled Shannon-Weaver species diversity index
HEM	hexane extractable material
JWPCP	Joint Water Pollution Control Plant (County Sanitation Districts of Los Angeles County)
LC_{50}	lethal concentration, 50 percent (the concentration causing lethal effects in 50 percent of the test organisms in the specified time period)
MBAS	methylene blue active substance
mgd	million gallons per day
mL	milliliter
MPN	most probable number (coliform organisms)
PFU	plaque-forming units
ppb	parts per billion (micrograms per liter)
ppm	parts per million (milligrams per liter)
San.Dist.	sanitation district(s)
SAS	standard asymmetry statistic
SD_s	scaled standard deviation species diversity index

S.E.	standard error
S.L.	standard length
STD	salinity and temperature with depth
S-W	Shannon-Weaver

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