QUANTITATIVE RESPONSES OF DEMERSAL FISH AND BENTHIC INVERTEBRATE COMMUNITIES TO COASTAL MUNICIPAL WASTEWATER DISCHARGES

Volume 1. Final Report

by

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FORWORD

The final report on the research performed for the EPA under Grant R801152 by the Coastal Water Research Project consists of two volumes:
The body of the report is contained in Volume 1, and appendices are presented in Volume 2.

ABSTRACT

The results of a three-year field-oriented study of the responses of demersal fish and benthic invertebrates to submarine open coastal municipal wastewater discharges are summarized. The work involved collaborative studies with public agencies conducting their own biological monitoring programs as well as completion of a number of specific research tasks, most of which were undertaken to understand sampling gear and to develop new approaches for evaluating complex biological and physical data associated with the benthos.

The results of the study indicate that about 3 percent of the coastal shelf benthos present to a depth of 200 meters is obviously affected by the discharges. The major responses are (1) a stimulation of some populations of molluscs, polychaetes, shrimp, and benthic fishes, (2) a general depression in species variety and diversity, especially among echinoderms and crustaceans, and (3) at the site of the largest discharge (that of Los Angeles County), a fin erosion disease in benthic fish. These effects generally occur in elliptically shaped bottom areas that are roughly centered near the diffusers of the outfalls but skewed by prevailing alongshore currents at each site. Off Los Angeles County, the area clearly marked by wastewater discharge effects is surrounded by a larger bottom area in which animals are responding to factors of unknown origin--possibly flood control measures, municipal wastewater discharges, or some combination of anthropogenic and natural conditions. The major wastewater-related factors affecting the benthos appear to be the nutritive content of the sewage, the reduction in the particle size of the bottom sediments, and in some cases, the production of free hydrogen sulfide. Trace metals and chlorinated hydrocarbons are highly concentrated in marine sediments at several sites; although these substances do not appear to be responsible for the biostimulation in outfall areas, they do seem related to reduced diversity and they are toxic to certain species. Biological recovery from the effects of a discharge (i.e., reduction in the abundance and biomass of infauna and fish at a discharge site) will probably occur more rapidly in shallow water (20 m, 6 to 12 months) than in deeper water (60 m, several to many years).

ACKNOWLEDGMENTS

The work reported in this and other papers, publications and task reports during the past three years would have benn impossible without the collaboration and efforts of many individuals and gencies. We are particularly indebted to the technical staff of the several sanitation districts. Oceanographer Mr. Douglas Hotchkiss, Dr. Irwin Haydock and their staff (County Sanitation Districts of Los Angeles) have filled many gaps in our understanding of coastal biological monitoring problems and how to solve them. We are also indebted to Mr. Bill Conn (Chief Engineer, Point Loma Treatment Plant, San Diego), Mssrs. Bill Garber and Joe Nagano (Hyperion Treatment Plant, City of Los Angeles), Mssrs. Greg Pamson and Michael Hines (County Sanitation Districts of Orange County) and Dr. George Cianko (City of Oxnard). The experience of Skippers Rusty Sheilds and Deacon Reinschmitt was invaluable (Los Angeles County and Los Angeles City, respectively) as well as interaction with Dr. Lewis Shinazi (Los Angeles Regional Water Quality Board).

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A forum for training and rapid dissemination of information and sampling techniques represents an important aspect of this project not indicated in most publications. The quality of biological monitoring in Southern California has improved markedly partly as a result of this continued work.

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CONTENTS

Section I

CONCLUSIONS

Discharge of large volumes of municipal wastewaters (12 to 370 mgd) into the open coastal waters of Southern California through five submerged outfall systems results in an increase in the abundance and biomass of bottom fish and invertebrates and a decrease in the variety of species present. These effects occur in each outfall area over areas ranging from about 1 to nearly 50 sq km.

The major wastewater-related factors affecting the benthos appear to be the nutritive content of the sewage, the reduction in the particle size of the bottom sediments, and, in some cases, the production of free hydrogen sulfide. High concentrations of trace metals and chlorinated hydrocarbons in the sediments near outfalls generally correlate with other sediment conditions such as high BOD and COD, small particle size, and high sulfide concentrations. However, potentially toxic trace contaminants do not appear to be responsible for the biostimulation that occurs at all discharge sites. Trace contaminants do seem related to reduced diversity and do affect certain species (i.e., DDT may be responsible for the nearly complete loss of small crustaceans off Palos Verdes). But species that increase in abundance in response to the nutritive content of a discharge may in themselves -- through predation and competition -- be factors controlling the diversity of the remaining fauna.

The "background" structure of the benthic communities (the structure that would be expected were there no man-related influences) at the depths now being used for most municipal wastewater discharges (60 to 100 meters) is probably characterized by a diverse benthic fauna associated with high densities of the brittle star, *Amphiodia urtica*. Municipal wastewater discharges appear to reduce densities of *A. urtica* (and the diversity of associated species) and to stimulate populations of small tube-dwelling polychaetes and amphipods, as well as ostracods. As the quantity of sewage discharged increases, these organisms are reduced in abundance, and the small clam, *Parvilucina tenuisculpta*, and other associated species increase in abundance: The stimulation of these organisms may result in a five-fold increase in benthic biomass. Finally, the discharge of sludge or sludge-like materials can result in inhibition of *P. tenuisculpta* and stimulation of tolerant polychaetes and a different species of clam.

The background conditions do not represent the present "baseline" conditions at all sites studied (i.e., the conditions that would be expected were there no municipal wastewater discharges). Our data show that, as one approaches Los Angeles County from the north (Ventura County) or the south (San Diego County), benthic marine life increases in biomass and abundance and decreases in diversity. This trend is generally apparent in both bottom fish and benthic invertebrate populations and probably results from a combination of factors, including flood control measures that have reduced the amount of sand entering the ocean and differences in the circulation of waters in various coastal areas.

The implication of this trend is that the ecological response to treatment of wastewater will differ in each region. For example, the benthic community associated with A. urtica may not return to the Palos Verdes shelf or Santa Monica Bay for years, even with cessation of discharge; at other sites, increased treatment of wastewaters may result in the return of this community within a few months.

Rapid recovery from the effects of wastewater discharge may be a desirable criterion for selection of a discharge site in some situations. We found that, at shallow-water discharge sites (to depths of at least 20 m and with flows of up to 180 mgd), biological effects are reversible in a matter of months when discharge is terminated (i.e., termination is accompanied by a rapid dcline in abundance of organisms and an increase in species diversity). Rates of recovery from deeper water discharge are less certain; however, as these areas are slow to show effects when discharge is initiated, the rate of recovery after cessation of discharge would also probably be slow (several to many years). Therefore, in terms of management and control of ecological effects, nearshore shallow-water discharge should not be totally eliminated as a viable alternative to disposal of municipal wastewaters.

Studies of fin erosion disease in Dover sole off Palos Verdes show that the disease is related to wastewater discharge. The components of the discharged waste that result in the development of the disease have not been identified; however, a number of substances, including DDT, PCB, trace elements, and hydrogen sulfide, have been suggested. Despite source control of DDT in 1971, there are still approximately 200 metric tons of the chemical in the Palos Verede sediments. If DDT is a major factor in the disease, additional treatment of the effluent may not lower the prevalence of the disease. The distribution of hydrogen sulfide in the Palos Verdes sediments has decreased since measurements were taken in winter 1973. If sediment hydrogen sulfide levels are a factor, prevalence of the disease should decrease within the next few years. Because the fin erosion disease in the Dover sole appears to be initiated primarily at one site, improvements in treatment at other outfalls would not have a measureable impact on the prevalence of the disease in Southern California Dover sole populations. Continued monitoring and appropriate laboratory tests are required to identify the agents responsible for this disease.

The Dover sole is the only southern California demersal fish consistently affected with epidermal tumors. Initiation of this noninvasive disease does not appear to be enhanced by the discharge of municipal wastes. Prevalence of the disease most probably would not be reduced by projected improvements in wastewater treatment unless such changes affected the survival or recruitment of juvenile Dover sole in the area.

Section II

RECOMMENDATIONS

Discharge of wastewater solids is apparently the most important factor influencing the benthos of Southern California. Solids could be managed using a logic that places a regional or local limit on mass emission rates with the intent of allowing some biostimulation of the benthos (and a commensurate reduction in diversity) in select areas of the coastal shelf (chosen on the basis of appropriate ecological, economic, sociological, and other considerations). We recommend future research aimed at defining the exact nature of the relationship between the amount of solids discharged and benthic productivity.

Discharge of municipal wastewaters into shallow open coastal areas should not be eliminated as an alternative for disposal. Although the biological effects of discharge into these waters are obvious and easily measured, recovery is rapid and controllable. Rates of recovery of the benthos from deepwater discharge are virtually unknown. A study to monitor recovery after termination of deepwater discharge (e.g., 60 m or greater) should be initiated.

A synoptic regional approach to monitoring coastal marine populations is needed to properly assess the effects of municipal wastewaters and to set attainable ecological goals for wastewater management.

Surveys with small otter trawls are moderately informative, provided the gear and procedures used are regionally standardized and region-wide surveys are conducted to provide a basis for interpreting local surveys.

For benthic surveys in open coastal areas, we recommend use of a device that takes a sediment sample 0.1 sq m in surface area to a depth of at least 10 cm. The device should be fitted with screens to avoid pressure waves and to provide access to the surface of the sediment sample obtained. Chain-rigged Van Veen and Smith-McIntyre grabs meet these criteria.

We highly recommend that control and outfall sites be visually inspected in any future surveys. The use of manned submersibles and divers is not required: Remote-control underwater television and movie cameras have proved useful and inexpensive.

Various indices of species diversity can be informative when used together with other measures of biological conditions (calculations of abundance, biomass, and species and site groups). We have previously recommended use of three indices to determine diversity, richness, and evenness. Brillouin and Shannon-Weaver indices seem to be best for indicating effects of municipal wastewater discharges on infaunal diversity.

Several multivariate techniques should be used in the assessment of benthic infaunal survey data. We recommend use of a site and species clustering technique (to define community structure) and some form of principal component or ordination analysis to aid in detecting cause/effect relationships with sediment chemistry data.

SECTION III

INTRODUCTION

Man's understanding of the effects of his activities on natural ecosystems is undergoing radical change. This is especially true for open coastal marine waters which, until recently, were not considered different enough from freshwater and estuarine systems to merit special attention or concern.

With a few notable exceptions, the effects of municipal wastewater discharge on marine life in open coastal waters have not been adequately assessed, although considerable sampling has been undertaken recently in many U.S. coastal areas. There has been a massive nationwide effort to collect as much data as possible, at considerable expense, in the hope that it will reveal correlations between the biota and the distribution of pollutants in the marine environment. In some cases, correlations are found, but cause and effect relationships often remain unproven. In many other cases where no correlations are found, sampling is either prematurely discontinued or overly intensified. Meanwhile, decisions about how to control and manage wastewater effluents are reached on the basis of other factors such as economics, engineering constraints, and laboratory experiments that are difficult to confirm in the field.

The current lack of an adequate understanding of coastal ecological problems stems from several sources: The poor quantitative historical data base on marine life, our meager understanding of how large-scale natural phenomena affect localized environments, and disagreements among scientists concerning the measurement and evaluation of responses of marine populations and communities.

Those responsible for coastal wastewater management and enforcement clearly need improved criteria for measuring and monitoring the health of marine animal and plant communities. The health, diversity and abundance of sea life in receiving waters is obviously subject to the influence of domestic and industrial wastes in various forms. Thus, it is important to be able to determine quickly when these man-made influences become damaging so they can be properly regulated.

Although most deep ocean municipal outfalls in southern California have diffuser systems designed to rapidly dilute wastewaters and thus minimize toxic effects on marine life, scientists do not agree that the effects have been minimal nor localized. Consequently, a special effort was needed to objectively describe the ecological changes that do result from the coastal discharge of municipal wastewaters, and to offer an evaluation of the nature and degree of these responses.

GRANT GOALS

The Environmental Protection Agency awarded a three-year grant to the Southern California Coastal Water Research Project in 1972 for the purpose of examining the qualitative and quantitative responses of benthic and demersal marine life to municipal wastewater discharges located along stretches of the coastal zone of southern California. The major objective of this effort was to identify and evaluate the responses of bottom dwelling-organisms to treated municipal wastewaters. To meet this objective, several corollary investigations had to be conducted to determine what types of responses are appropriate to measure, which methods of data collection are most effective, and how these data can be most efficiently and effectively quantified.

Therefore, the research supported by this grant involved three major phases. First, new mathematical and numerical techniques for evaluating biological data were tested and applied to actual field data. Second, efforts were made to measure and understand the effects of biological sampling devices and procedures on the representativeness of the data obtained. Finally, historical and contemporary field data from demersal fish and benthic infaunal surveys were examined and analyzed to identify trends with space and time and to distinguish the effects of wastewater discharges from other natural or anthropogenic effects. This report represents a fourth and final phase of this work-- summary of the projects undertaken and application of our ideas and theories to an interpretation of conditions in the coastal benthic environment.

Since most municipal waste discharges in southern California enter the ocean via long, deepwater outfalls, the study focused on soft-bottom dwelling organisms in the depth range of 10 to 180 meters. This delineation restricted the collection of field data to sampling by remote devices (benthic trawls, grabs, cameras); hence, the efficiency at which these devices operated was of utmost importance.

The field and laboratory research carried out for this grant was part of a larger program of the Coastal Water Research Project. This continuing research includes investigations on the sources, magnitudes, distribution, fate and effects of potential pollutants. and also studies of the role of currents and other oceanographic conditions in dispersal and distribution of pollutants and marine life. The findings of these research efforts are summarized in annual reports, technical memoranda, and technical scientific papers published by the Project.

REPORT ORGANIZATION

This report summarizes grant research, which has been described in detail in other publications. In Section IV, our studies of gear and analytical methods are briefly described. This section also contains summaries of a series of special field surveys performed under the grant to obtain data not being collected in the surveys of southern California waters that are regularly conducted by local government agencies and universities. Finally, a program to investigate diseases and abnormalities in southern California fish populations is described. Section V contains an evaluation of the relationship between the condition of southern California demersal fish and invertebrates and municipal wastewater discharges. Section VI is a list of publications prepared under the grant.

Supplemental information is presented in the appendices. Background information on the study area and the past research conducted there is given in Appendix A, which also contains descriptions of local wastewater discharges and monitoring programs. Appendix B contains data supporting the evaluation of wastewater effects presented in Section V. Appendices C and D are lists of the fish and invertebrate species observed during the grant studies.

Section IV

STUDIES OF SAMPLING AND ANALYTICAL METHODS AND SPECIAL SURVEYS

Our approach to the problem of assessing the specialized effects of municipal waste discharge on the benthic environment was two-fold: (1) Pipe-oriented; an in-depth analysis of each individual area receiving large quantities of waste discharge was undertaken, and (2) region-wide; assessments were made in terms of Bight-wide phenomena, observed over as large a time scale as possible, in order to isolate major events occurring in the shelf zone in response to both discharge practices and other natural and anthropogenic influences.

Much of the data used in this work was compiled by local sanitation agencies in their regular monitoring programs. However, the biota was not sampled equally during the surveys conducted by separate agencies nor were the data generated by these programs necessarily directly comparable. To be able to integrate these data, several specific tasks were initiated to determine the nature and extent of these inherent differences. Ensuing investigations were directed at (1) Data management and formulation of computer summarization system, (2) determination of the effects of differences in field gear (trawls and grab devices), (3) description of the biota captured by means of techniques not commonly used (hook and line, camera, television), and (4) completion of special surveys to add to the existing data base where necessary.

To achieve a regional interpretation, several additional tasks were required: (1) election of "control" sites (Dana Point was chosen and routinely surveyed for two years), (2) review of historical data to be integrated and compared with recent data where-ever possible, (3) observation of the incidence of diseased or anomalous animals, (4) evaluation of new and potentially useful analytical techniques (community structure analyses: Cluster analysis, recurrent group analysis; and numerical analyses: Factor analysis, regression analysis, diversity formulations, etc.), and (5) observation of natural fluctuations in the environment (eg. invasions of southern species, temperature and dissolved oxygen anomalies, etc.)

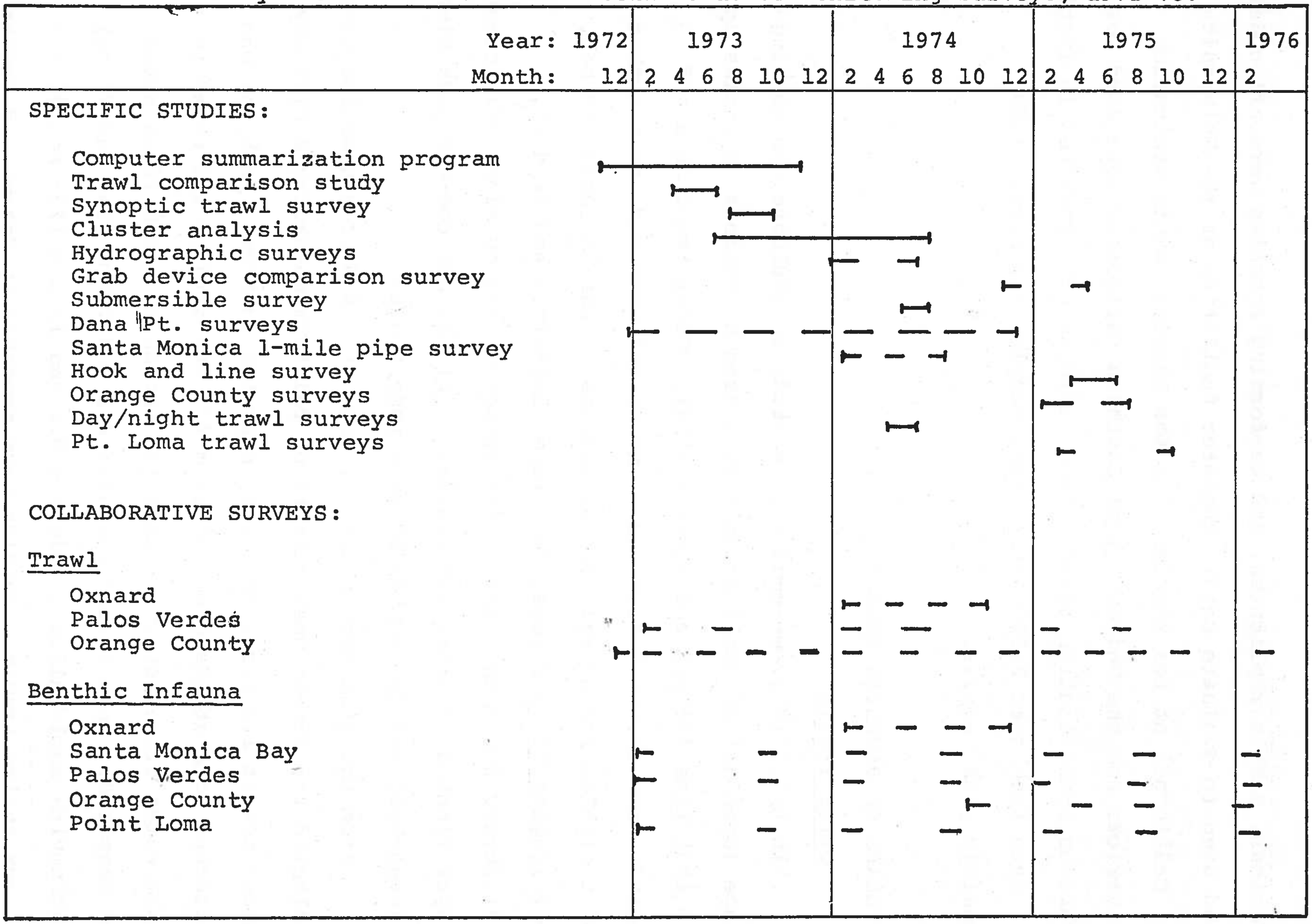
Table 1 summarizes our participation and collaboration in on-going monitoring programs and the occurrences of specific research tasks during the grant period. The sections below describe the individual tasks in more detail.

DATA SUMMARIZATION

A computerized data summarization system was considered essential for analyzing in detail the large number of historical and recent trawl and grab samples. During 1973, we developed a series of computer programs to summarize basic statistics from surveys, with particular emphasis on biomass, abundance, number of species, diversity indices; and for fish, length-frequency distributions and prevalence and size-distributions of diseased and parasitized fishes.

All data was handled through a coded key punch card system, using a five digit code for species. Gear type and variations,

Table 1. Summary of research tasks and collaborative monitoring surveys, 1972-75.



regions, sample replicates, and performing agencies were all coded and used to evaluate data. Computer facilities at the University of California at Los Angeles, the Los Angeles County Sanitation Districts and the University of Southern California were used for various summarization tasks. These efforts have resulted in listings of data from over 2,500 otter trawl samples and nearly 1,500 benthic grab samples.

STUDIES OF SAMPLING METHODS

Otter Trawls

In April 1973, we conducted a study to evaluate the working-gape (opening) of small otter trawls used by various agencies up to that time (Mearns and Stubbs, 1974). Otter trawl nets and boards were obtained from six agencies and compared for a number of variables including: (1) Dimensions of the net body and bag, (2) lengths of head rope, foot rope, leg-lines and bridles, (3) thread types and sizes, (4) number of meshes along all joined edges (including wings and square), (5) bag and cod-end mesh sizes (stretched) and (6) number of head rope floats.

From the nine nets examined, six net and door assemblies were selected for direct measurements of relative spreading efficiency under tow at 1.3 m/sec (2.5 knt) near the surface. Each net was attached to a standard set of 22 m (72 ft) bridles and towed in calm water close astern so that the spread of the bridles could be measured. Nets tested included 4.8 and 7.6 m (16- and 25-ft) Marinovich semi-ballon trawls and 8.2 and 12.2 m (27- and 40-ft) Wilcox shrimp trawls. Results were reported by Mearns and Stubbs

(1974) and summarized in Table 2.

In general, there was a three-fold variation in the spread of the trawl boards (2.7 to 7.9 m) and in cod-end mesh (1.2 to 3.8 cm, including cod-end liners) and otter boards surface areas (0.19 to 0.45 sq m) and a ten-fold variation in leg line lengths (0.91 to 9.3 m). A direct relationship between working-gape and fish catches was suggested (Mearns and Stubbs, 1974).

Following these tests, Mr. Willis constructed several 7.6 m head rope length nets which incorporated some of the best features of the existing gear types. A number of agencies have converted to this gear which has a working gape nearly identical to the Marinovich 7.6 m nets (i.e., 4.9 to 5.2 m; Mearns, unpublished data) but is more heavily constructed for trawling in open coastal waters.

This and related field work is also detailed in a Task Report (EPA) on the use of otter trawls in coastal fish surveys (Allen and Mearns, 1975).

Benthic Sampling Devices

In December 1974 and March 1975, the Coastal Water Research Project, the University of Southern California and the Environmental Protection Agency conducted two cruises in Santa Monica Bay to compare the physical and biological performances of seven sampling devices. The devices included a large box corer (1/16 m^2), a Smith-McIntyre grab (0.1 m^2), two Van Veen grabs (0.1 m^2, chain rigged and non-chain rigged), a Shipek grab (0.04 m^2), a Ponar grab (0.03 m^2) and an Orange Peel grab (0.053 m^2).

Table 2. Spread of 72-ft bridles at 3 ft from cable and calculated spread of trawl boards for eight nets used in southern California trawl surveys.*

Agency	Net Size and Make	Head-rope Length (ft)	Bridle Spread (in)	Calculated Board Spread (ft)
Los Angeles Co. San. Dist.	40 ft Wilcox	40	13	26
	25 ft Wilcox	27	12	24
Hyperion	25 ft Wilcox	27	4.5	9
MBC, Inc.	25 ft Marin-ovich	25	8	16
	16 ft Marin-ovich	16	7.5	15
Occidental College	25 ft Marin-ovich	25	8	16
Coastal Water Research Project	25 ft Marin-ovich	25	7.5	15
	25 ft Willis**	25	8.5	16.5

*Towing speed: 2.5 knots in 2 to 3 meters of water at Morro Bay, California.

**Towing speed: 2.5 knots near surface of water at Los Angeles Harbor, California, December 1975.

Replicate samples (5 or 10) were taken with each device at each of three stations ranging in depth from 20 to 200 m under normal and rough sea conditions. Single samples were taken in sludge deposits. All samples were screened through one or several mesh sizes and the organisms were sorted and identified for most samples. Vertical cores were taken, sectioned, and analyzed for depth distribution of benthos.

Physical performance criteria (depth of sample, wash out, surface disturbance) indicated that the Box corer, the Van Veen # 2 samplers and the Smith-McIntyre grab performed well at sea. Of these, the chain-rigged Van Veen was judged best for overall use in shelf waters sampled by small vessels (Table 3).

The results of these studies are being reported by Word (1976, in preparation). In general, most (90%) of the infauna were found in the upper 10 cm of sediment. At the sludge site animals were found distributed through the upper 20 cm. Microcrustaceans were restricted to the upper 2 cm, molluscs and polychaetes to the upper 5 cm. Screen mesh of 0.5 mm retained significantly greater numbers of small individuals compared to 1.0 mm mesh, but 0.7 mm mesh was no more effective than 1 mm. Relative to Box corer results, three devices underestimated abundance by as much as a factor of 10 while two slightly overestimated abundance.

We concluded that the abundance of some (e.g., pelecypods) but not all taxa from historical surveys might be directly comparable to those in present surveys. Devices which consistently sample to 10 cm or deeper, an area of about 0.1 m^2, and which minimize pressure waves in advance of contact were considered acceptable for coastal benthic surveys.

Table 3. Operating characteristics of seven grab sampling devices now in use in southern California benthic surveys.

Sampling Device	Maximum Surface Area (sq m)	Surface Disturbance (avg. %)	Wash-out Code Number*	Attempts Successful/ Total	Mean Penetration Depth (cm)
Silty sand, 13 m					
Dec 74					
Box Corer	0.06	<10	0 - 1	5/5	11 ± 1.8
Shipek	0.04	>50	1	10/10	3.4 ± 0.5
Ponar	0.05	100	2	10/10	**
Van Veen No. 1	0.10	>50	2	5/5	6.5 ± 0.9
Orange-peel	0.10	100	2 - 3	10/13	6.3 ± 1.5
Mar 75					
Van Veen No. 2	0.10	10 - 25	0 - 1	5/5	4.9 ± 1.6
Smith-McIntyre	0.10	10 - 25	1	5/6	5.7 ± 0.6
Shipek	0.04	>50	1	5/5	2.2 ± 0.5
Clayey-silt, 280 m					
Dec 74					
Box Corer	0.06	0÷	0 - 1	5/5	34.8 ± 6.2
Shipek	0.04	50	0 - 1	10/15	11.0 ± 1.3
Ponar	0.05	100	0	10/13	**
Van Veen No. 1	0.10	5 - 10	0 - 1	5/5	22.0 ± 3.9
Orange-peel	0.10	25	0 - 1	10/21	15.4 ± 1.8
Mar 75					
Van Veen No. 2	0.10	0 - 25	0	5/5	12 ± 2.8
Smith-McIntyre	0.10	0 - 25	0	5/8	13.6 ± 2.0
Shipek	0.04	50	1	1/5	5.0

*Leakage after sampler is out of the water (qualitative evaluation):
0 = None; 1 = Slight; 2 = Moderate; 3 = Extensive.
**Cannot be determined as the sampler cannot be opened from the top.

Alternate Methods for sampling Fish and Microfauna

Several techniques in addition to trawls and grabs were used to sample demersal fishes and invertebrates during the study period.

Hook-and-line surveys. Hook-and-line sampling of marine organisms in Santa Monica Bay was conducted by Jon B. Isaacs during April and May 1975 (Allen *et al.*, 1975). The purpose of this survey was to examine large predatory fishes which avoid capture by trawl nets, and compare frequency of disease incidence (particularly fin erosion which may affect swimming ability) with trawl catches.

Two methods of hook-and-line sampling were utilized. A 100-hook setline was laid across the bottom to catch the species within the vertical range of the trawl that might avoid the net. In addition, schools of fish were located by sonar in the general vicinity of the trawl stations and fished with rod and reel to collect species that dwell in the water column above the vertical range of the trawl or are highly clumped and therefore might be frequently missed by the trawl. Three transects were sampled, each including stations at four depths (20, 60, 100, and 190 m) corresponding to previously trawled sites (Figure 1). Additional hook and line sampling was also done near discharge pipes and at deep rocky sites to identify species living in these areas that cannot be trawled.

Photography from a Deep Submersible. To gain a better understanding of the fish and invertebrate fauna directly associated with outfall structures, we collaborated with Mr. Harry Pecorelli (Aqua

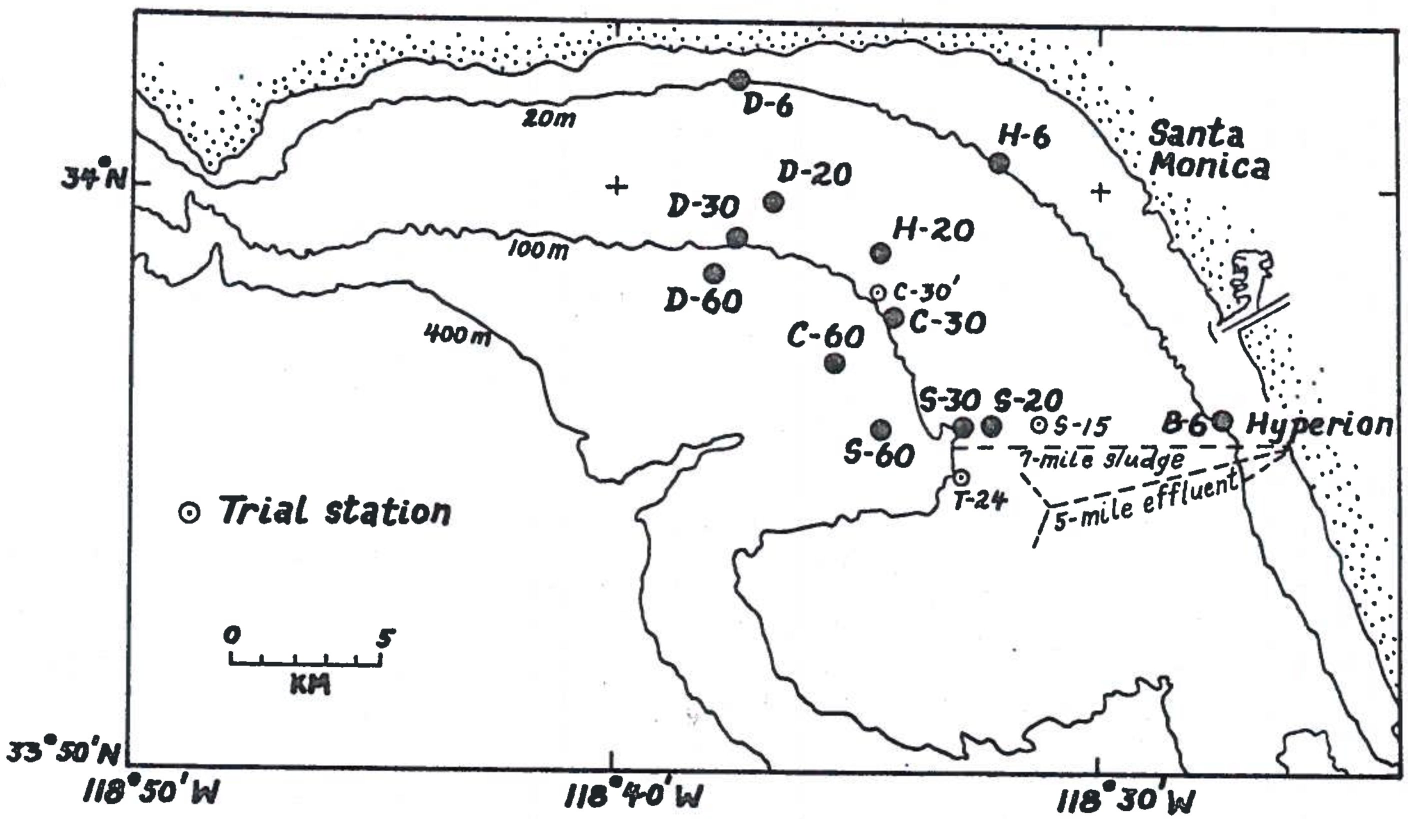


Figure 1. Stations sampled, hook-and-line survey, Santa Monica Bay, March to May 1975.

Contractors and Oceanographers, Inc.) and the Hyperion Treatment Plant in a submersible dive survey of the Hyperion outfalls in June and July 1974 (Allen et al., in press). Photographs were taken at seven stations in three depth zones along the 5-mile and 7-mile pipes--at a shallow station (10 to 30 m) on each pipe, at a middepth station (40 to 50 m) on each pipe, and at three deep stations, one on each of the two diffuser legs (60 m) of the 5-mile pipe and one (60 to 100 m) on the 7-mile pipe (Figure 2). Shallow stations were photographed by scuba divers and middepth and deep stations were photographed from a two-man submersible. Almost 400 color photographs of marine life living on and around the pipe were taken, and species distribution patterns were determined. All photographs were carefully examined by a team of fish and invertebrate biologists and species lists prepared for each station and transect.

Videotape Observations of the Bottom and of Otter Trawls. Underwater television equipment designed to operate at depths to 350 m and to present high quality pictures at low light levels was used to record benthic marine life at several sites and otter trawls during towing. A sled-mounted Jaymar 1000 camera was connected to RG-54 coaxial cable and to a Shibaden monitor with a real-time resolution of 600 lines. Taping was done using a Shibaden 1100 half inch video recorder, which reduces the resolution to 300 lines.

Bottom sled tows were made at all outfall sites (Oxnard, Santa Monica Bay, Palos Verdes, Orange County and Point Loma) and the tapes observed for sediment type and consistency, exposed

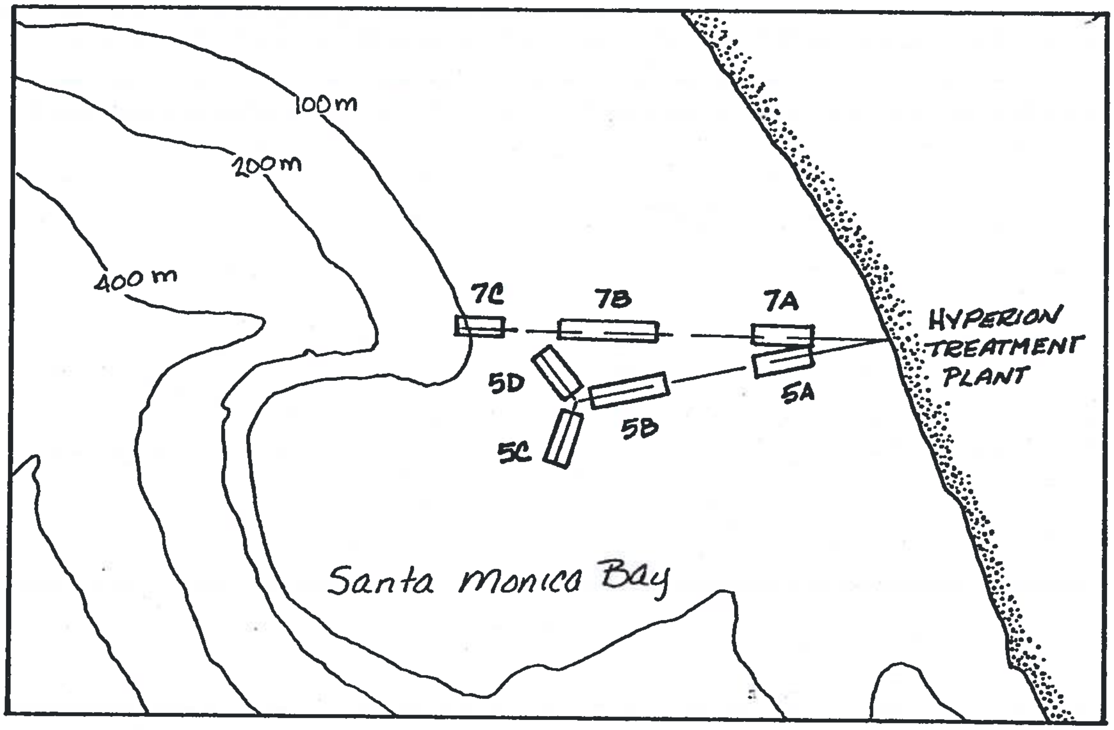


Figure 2 . Regions along the Hyperion 7-mile and 5-mile discharge pipes photographed by two-man submarine and scuba diver, June and July 1974.

rocks and stones that might indicate depth of deposits and dominant observable organisms.

The camera was also attached to the headrope of several otter trawls and video recordings made of the mouth and foot rope area to observe avoidance and capture characteristics of fish and invertebrates. These tests were made in clear water at Catalina Island during the summer and fall of 1974.

Baited Cine Camera. In November and December 1973 we deployed a baited movie camera off the Palos Verdes Peninsula at 10 sites ranging from 75 to 1000 ft to film organisms that might be attracted to bait, but which were rarely observed by other methods.

The camera equipment was developed for use in deep water at the Scripps Institution of Oceanography by Professor John D. Isaacs and Richard Shutts and generously loaned to the Project. The camera used was described in SCCWRP (1973b). The self-contained camera, light, and bait package was lowered to the bottom and at regular intervals (30 minutes) the lights went on, and the camera photographed the water around the bait for a short period (15 seconds). After 24 hours, the entire system was retrieved. The films from each of nine successful drops were examined for species identification, abundance, behavior patterns, sediment type, presence of water column particulates, and water movement. Each "scene" (10 or 15 second exposure of film) was examined in detail by stopping or reversing the film as needed. During the camera drops, we also conducted trammel-net, trawl, and hydrographic surveys in cooperation with the Sanitation Districts' staff.

The preliminary results from the films were previously reported (SCCWRP, 1973b and 1974).

SPECIAL SURVEYS

Two-Year Trawl Survey Away from Major Discharges

December 1974 marked the completion of a 2-year quarterly trawl survey at nine stations off the coastal region between Laguna Beach and Dana Point, California (Mearns, 1975). The purpose of this survey was to obtain information on the abundance, diversity, and health of demersal fish and invertebrate populations at a coastal site away from the direct influence of large wastewater discharge sites of Los Angeles and Orange Counties yet similar enough to represent a reasonable control site.

These surveys were conducted aboard the FURY II by Coastal Water Project personnel, with the assistance of staff members of the Orange County Department of Education. Cruises were conducted quarterly during 1973 and 1974. Nine stations, covering three transects at three depths (Figure 3), were sampled using a 7.62 m Marinovich otter trawl towed for 10 minutes (1.3 m/sec), with a net opening of 5 m, the net covered an area of about 3,860 sq m (0.95 acres).

Fishes and invertebrates were sorted aboard ship, and fishes were weighed, identified, counted, and examined for parasites and signs of disease. After each tow, water samples taken at each station were measured for temperature, clarity, dissolved oxygen content, and, in some cases, pH. The results indicated a region of moderate diversity but low abundance and low occurrence of

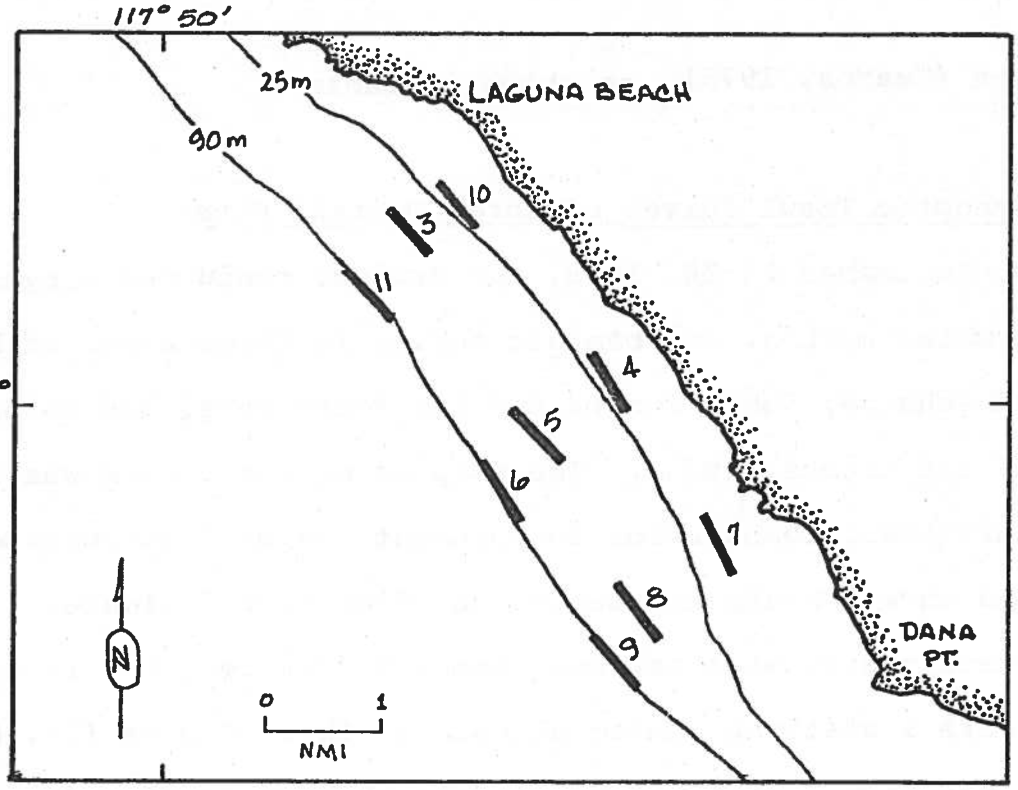


Figure 3. Map of nine standardized stations sampled during cruises conducted in 1973-74.

Table 4. Summary of fish catch statistics for eight quarterly trawl surveys off the Dana Point/Laguna Beach region.

	Sampling Dates 1973				1974				Total or Overall Average
	9 Feb	8 May	8 Aug	15 Nov	14 Feb	14 May	23 Aug	12 Dec	
No. of Stations	9	7	8	9	9	8	9	9	68
Total No. of Fish	858	2,575	3,216	1,714	1,310	2,619	343	411	12,696
Catch per haul									
Mean	95	368	402	190	146	241	38	46	187
Median	83	163	418	145	158	180	31	38	
No./ha	246	954	1,043	492	378	625	99	119	494
No. of Species									
Total per survey	34	40	50	40	33	42	24	21	75
Mean per haul	10.9	14.9	20.8	13.6	10.4	15.4	5.8	5.3	10.9
Mean Diversities									
Brillouin, H	1.54	1.76	1.96	1.60	1.27	1.89	0.99	0.82	1.48
Scaled, H(s)	0.59	0.65	0.64	0.59	0.50	0.66	0.46	0.47	0.55
Biomass									
Kg/haul	3.31	12.01	13.84	8.06	4.78	13.05	1.56	1.79	7.3
kg/ha*	8.18	31.2	36.0	21.0	12.4	33.9	4.06	4.34	18.9

*Kg/ha x 0.89 = lb/acre

diseases (Mearns, 1975), as shown in Table 4.

Synoptic Trawl Survey of Three Outfall Sites

On September 24-26, 1973, the Project conducted a synoptic trawl, water column, and benthic survey in three areas of heaviest waste discharge; Santa Monica and San Pedro Bays, and Palos Verdes (Mearns and Greene, 1974). The purpose of the cruise was to use one gear-vessel combination to document regional differences in fish and invertebrate abundances and disease prevalence.

Twenty-seven stations were sampled (Figure 4.) In each region there were 9 stations, three at each of three depths (26, 61, and 141 m) and each region was sampled in the course of a day. One otter trawl sample was taken at each station. All tows were made with the same 7.62 m (head rope length) Marinovich otter trawl, described above.

All tows were 10 minutes in duration (time on bottom) along bottom contours at a speed of 1.3 to 1.5 m/sec. The fishes and invertebrates from each collection were identified, counted, and measured onboard ship (invertebrates that we could not readily identify were preserved in formalin and examined again in the Coastal Water Project laboratory). Fish and identified invertebrates were weighed by species to the nearest 0.1 kg.

Following retrieval of each tow, we returned to the midpoint of the trawl transect and took water samples at the surface, at mid-depth, and within several meters of the bottom. Measurements of dissolved oxygen and salinity were performed; temperature profiles were recorded from bathythermograph traces. A secchi disk

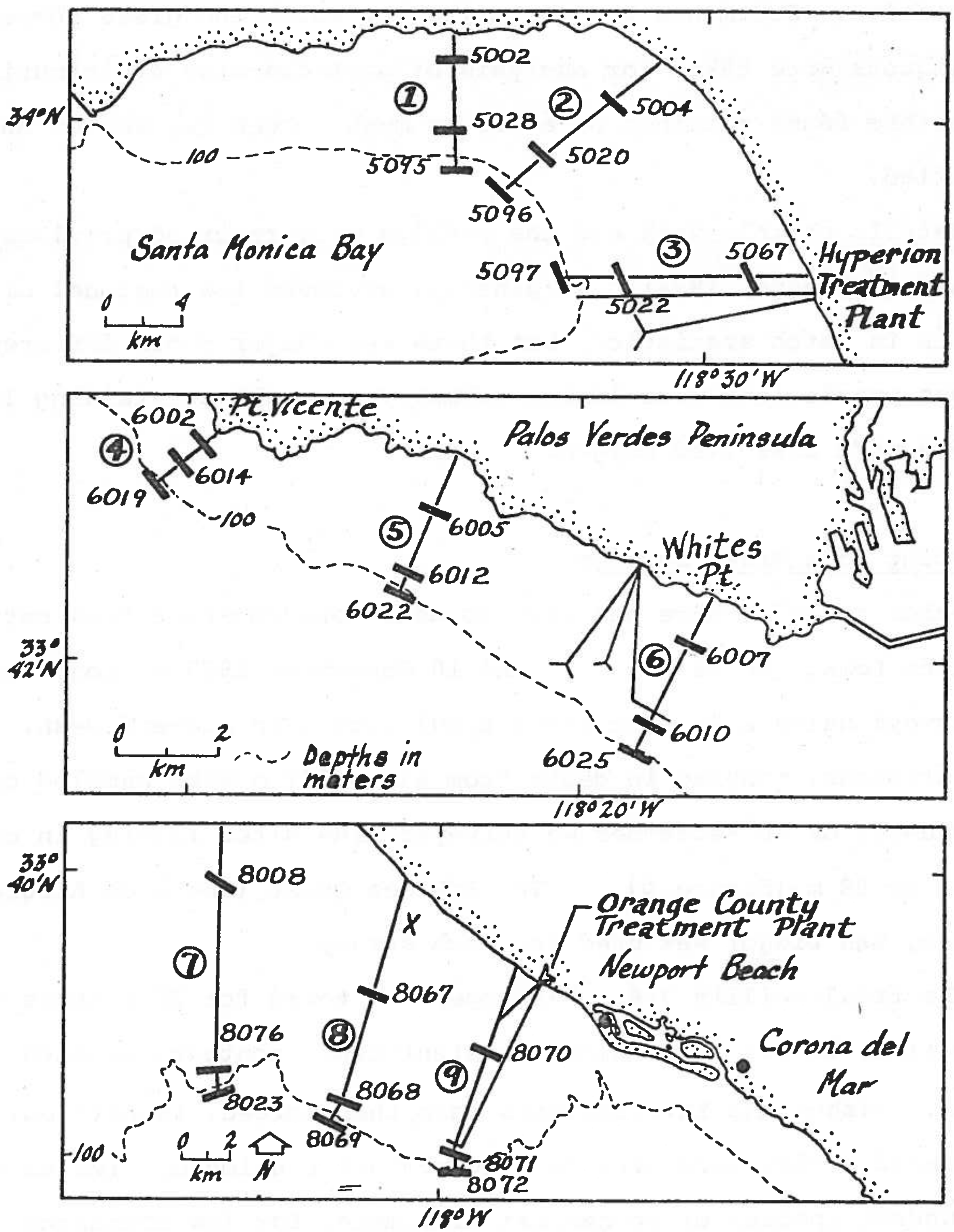


Figure 4. Transects and stations for trawl and hydrographic samples, synoptic survey, September 1973.

was used to determine depth of transparency of the surface layer.

A Shipek grab was used to sample benthic surface sediments at each station. Sediments were described by color and gross composition, and aliquots were taken for analysis of particle-size distribution. The benthic fauna retained on a 0.5 mm mesh screen was sorted and identified.

Details of this work and the results were reported previously (Mearns and Greene, 1974). In general, we found few regional differences in catch statistics, but there were major depth differences; numerous populations were living in water naturally containing less than 5.0 mg/l dissolved oxygen.

Point Loma Trawl Surveys

Prior to 1975 there had been no nearshore demersal fish surveys off Point Loma. On 12 February and 10 September 1975 we conducted two surveys using a 25 foot otter trawl with ½ in cod-end mesh. Eight stations, ranging in depth from 61 to 137 m were sampled on 12 February; on 10 September we surveyed nine sites ranging in depth from 33 to 88 m (Figure 5). The R/V Sea Quest (Lockheed Aircraft Services, San Diego) was used for each survey.

The trawl (Willis 7.6 m headrope) was towed for 10 minutes (on bottom time) at 1.3 m/sec along constant depth contours at each station. Fishes and invertebrates were then sorted, identified, and counted. Fish were measured (to nearest centimeter size class for abundant species or to nearest millimeter for low abundance species) and weighed by species. All fish were examined for deformities, parasites, and signs of disease (fin erosion and tumors).

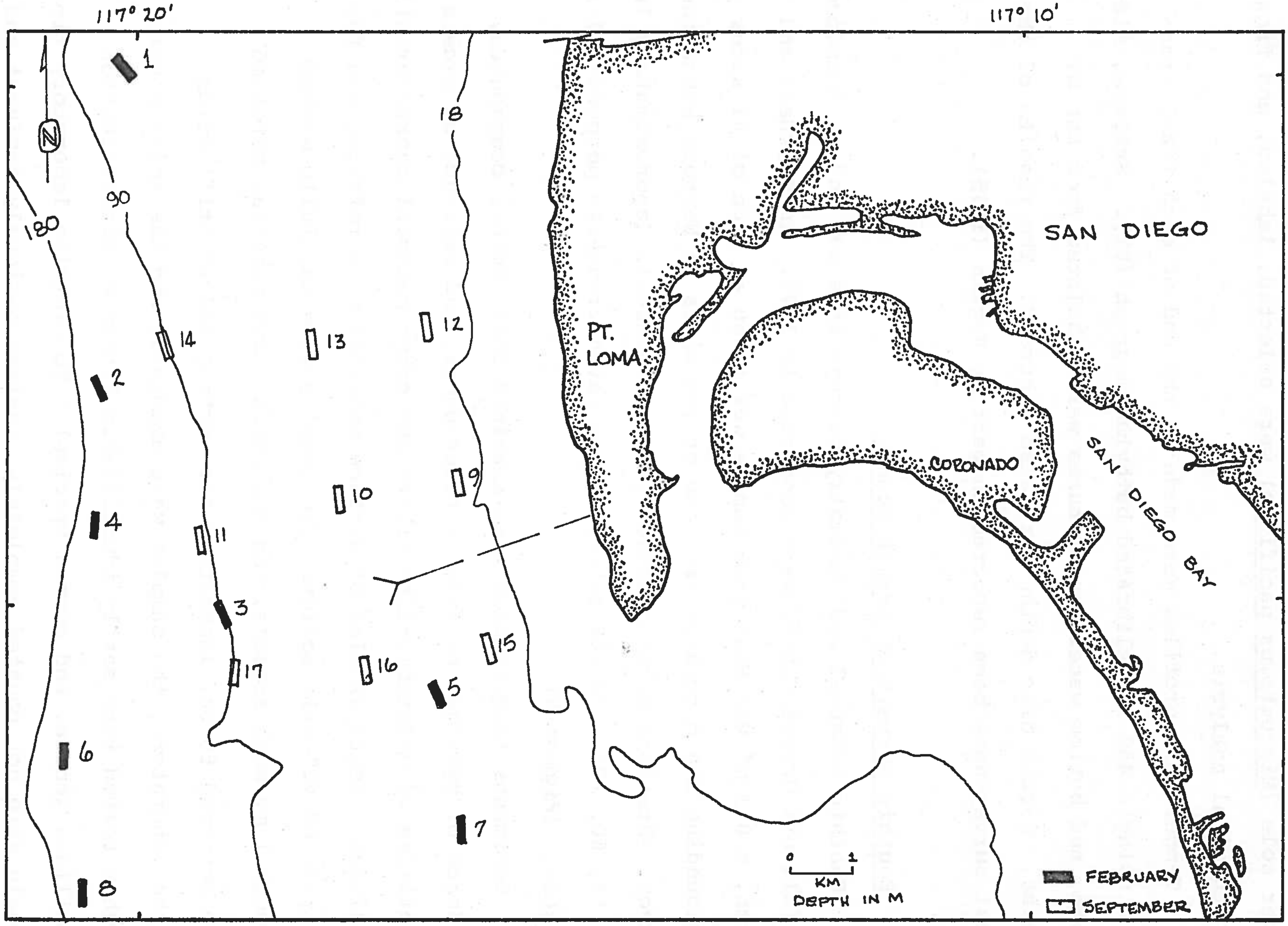


Figure 5. Location of trawl stations surveyed off Pt. Loma during February and September 1975.

Dover sole (Microstomus pacificus) were selected, labeled, and frozen for chemical analysis.

Temperature profiles were made at the end of each trawl transect using a 450 ft calibrated bathythermograph (BT). Surface, mid-depth, and bottom water temperatures were tabulated from the BT graphs. Secchi disc depths were also recorded. The results of the first survey have been reported in part by Voglin (1975).

Benthic Surveys at Orange County

Benthic infaunal and chemistry surveys at a new and an abandoned outfall off Orange County were conducted in 1975. In February and March, a 0.1 m^2 Van Veen grab sample was taken at each of 41 sites surrounding the discharge area and at six sites in Newport Submarine Canyon. Stations were arranged by depth intervals (approximately 16, 30, 50, 60, 100, and 200 meters) along seven transects perpendicular to shore (Figure 6).

Sediments from samples were examined for: Color, coarseness, evidence of hydrogen sulfide or other odors, and presence of excess quantities of vegetable-like fibers and other material characteristic of sludge. Small samples of surface material were refrigerated for analysis of volatile solids. The samples were carefully washed through 1 mm mesh screens, and the animals and material retained were returned to our laboratory for sorting and identification. In the laboratory, the samples were examined, and the animals were roughly sorted into easily identifiable levels of classification (families, genera, and common species). To minimize laboratory time, animals were not counted completely, instead obviously dominant and

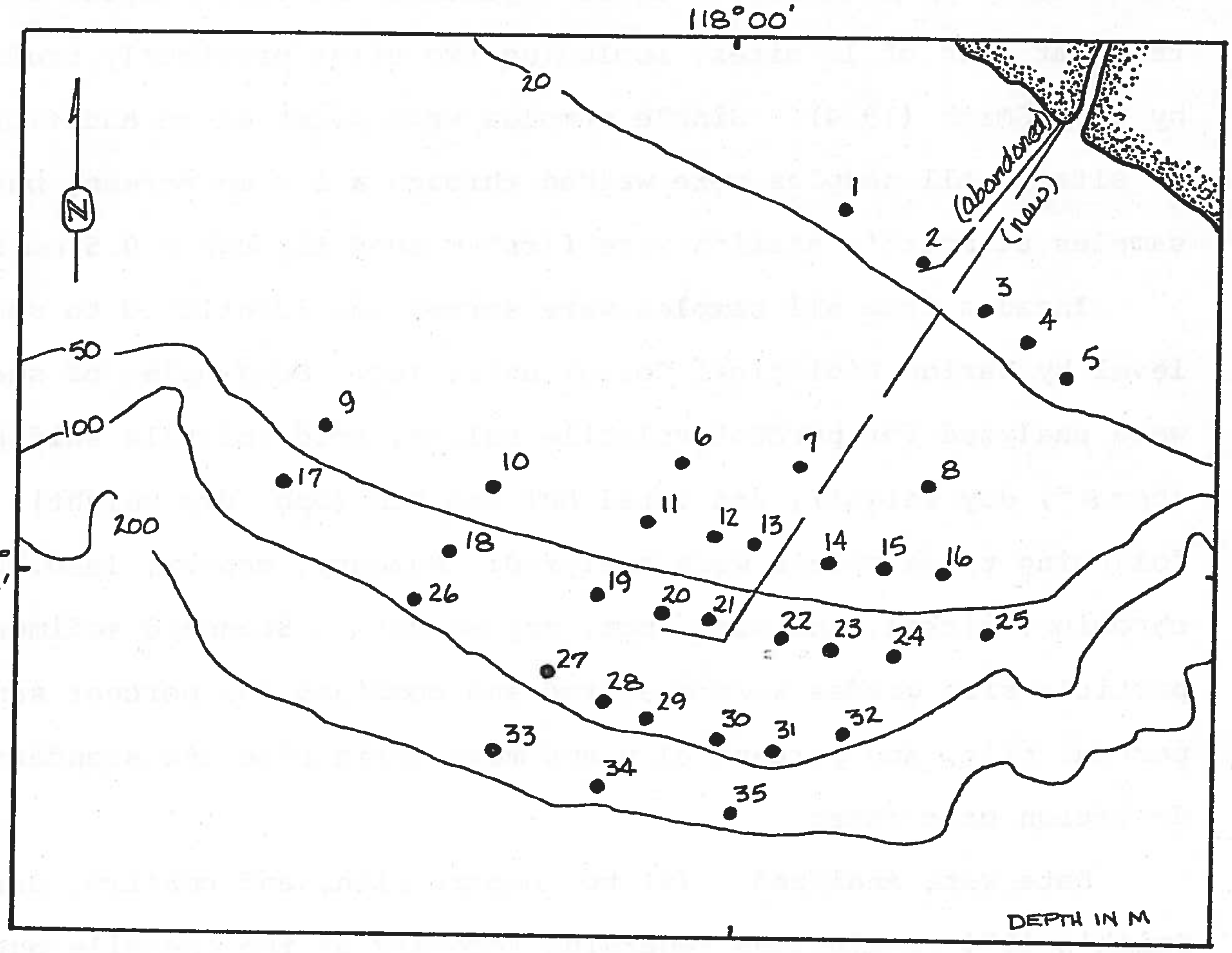


Figure 6. Location of benthic stations sampled in February and March 1975 near the abandoned and new outfalls off Orange County (Stations 3 and 22 were sampled by G. Smith, 1970-72).

abundant species were noted.

The results of this survey (Mearns and Greene, 1975) were used to plan and conduct a second quantitative survey in July 1975 (Greene, in preparation). Three replicate Van Veen samples were taken at each of 19 sites, including two sites previously studied by Gary Smith (1974). Single samples were taken at an additional 18 sites. All samples were washed through a 1.0 mm screen, but samples at Smith's station were first washed through a 0.5 mm screen.

Infauna from all samples were sorted and identified to species level by Marine Biological Consultants, Inc. Subsamples of sediment were analyzed for percent volatile solids, acid volatile sulfides (ppm $S^{=}$, dry weight), and total DDT and PCB (ppb, dry weight). The following trace metals were analyzed: Mercury, copper, lead, cadmium, chromium, nickel, and zinc (ppm, dry weight). Standard sediment particle size grades were measured and combined for percent sand, percent silt, and percent clay and mean grain size and standard deviation calculated.

Data were analyzed (1) to compare with, and confirm, Gary Smith's 1974 conclusions regarding recovery at the one-mile outfall site abandoned in 1971 and observed effects at the new outfall sites and (2) to determine the geographical extent of the presently affected area and its relation to specific pollutants.

In addition to plotting and examining data on benthic biomass diversity, and abundance, we also conducted site and species cluster and applied other multivariate techniques to determine quantitative relationships between biological indicators and contaminants.

Hydrographic Surveys of Santa Monica Bay and Basin

Earlier data suggested that bottom water quality of mainland shelf regions was a direct function of events occurring in the nearshore basins. In January and June 1974, we conducted two cruises to confirm this.

Hydrographic samples were taken on three transects covering nine stations (Figure 7). Bottom depths ranged from 100 to 900 m. The transects were sampled aboard the R/V Van Tuna (Occidental College) on 14 and 15 January and again on 6 and 7 June 1974. Two additional stations (Stations 10 and 11 on Figure A-2) were sampled on 15 January.

At each station, temperature, dissolved oxygen, salinity, clarity, and coliform counts were measured at the surface, at 20 m, and at every 200 m thereafter to the bottom; pH was measured as time permitted. Nansen bottles with reversing thermometers were used to collect subsurface water samples and to determine the *in situ* temperatures of deep waters. A bathythermograph was lowered at each station to record temperature and thermocline profiles. Dissolved oxygen content was measured using the Winkler azide-modification titration method. We obtained salinity values with a Beckman induction salinometer and recorded pH with a Corning pH meter (Model 10). The clarity of the surface water layer was determined with a standard Secchi disk.

Staff from the Hyperion Treatment Plant analyzed Nansen water samples for total and fecal coliform bacteria counts (most probable number, or MPN) according to media culturing methods using lactose

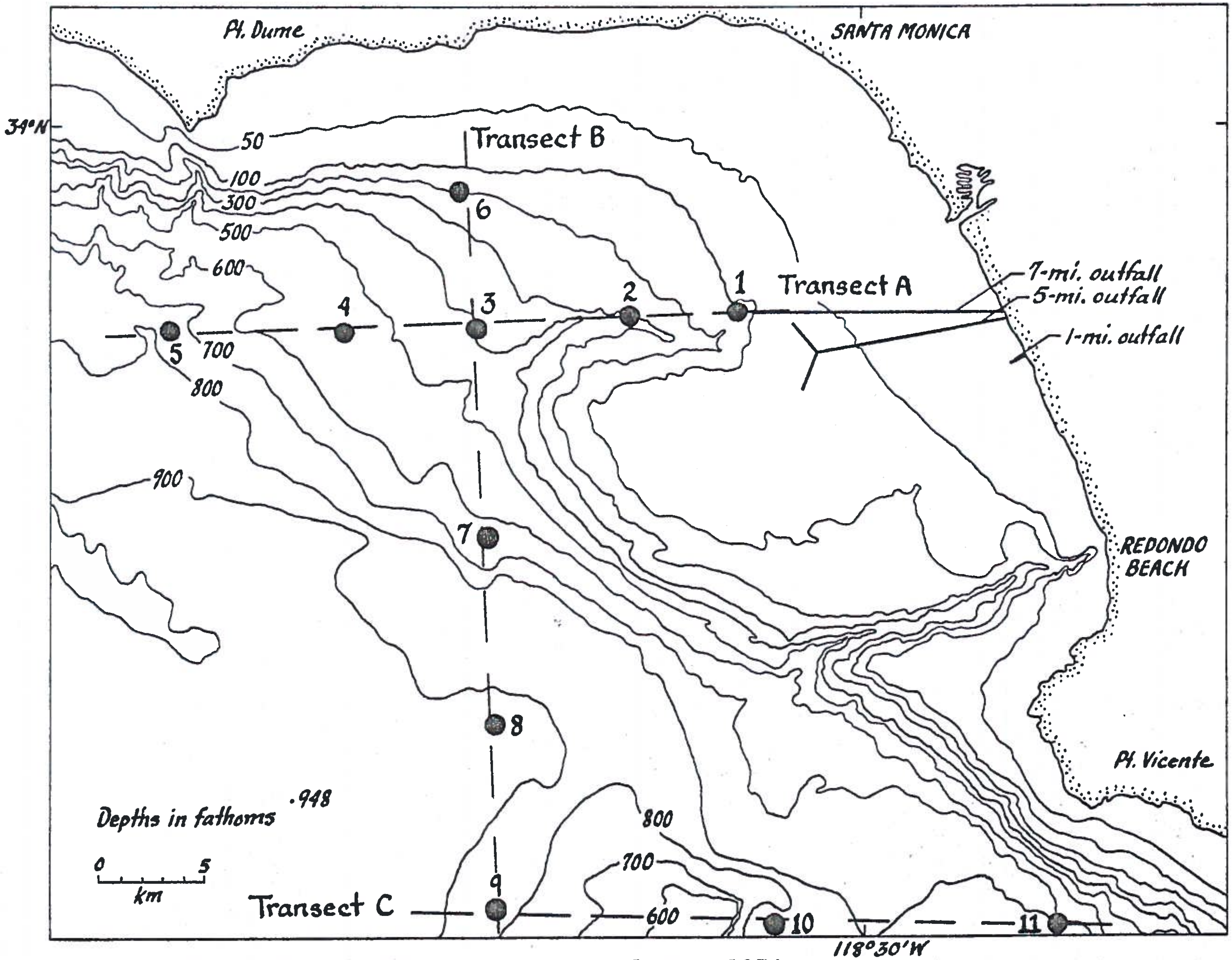


Figure 7. Hydrographic stations, January and June 1974.

broth and brilliant green lactose bile broth for confirmation (Standard Methods 1971). In addition, on 6 June, water samples collected with a sterile Zobell sampler and sediment samples obtained with a Shipek grab were analyzed for total and fecal coliforms, streptococci, marine and freshwater aerobic and anaerobic bacteria, fungi, and specific pathogens. This work was performed under the direction of Dr. Juhee Kim of California State University at Long Beach.

Details and results of this study have been reported (Mearns and Word, 1974).

EVALUATION OF ANALYTICAL METHODS

Species and Site Cluster Analyses

Several techniques for clustering various similarity and dissimilarity indices for species and samples were tested and employed during the study period.

We previously reported on the application of recurrent species group analysis (i.e., Fager 1957 and 1963) to demersal fish, demonstrating highly significant associations of species (i.e., communities). While the associations were distinctly depth-oriented, they did "breakdown" near several outfall sites (Mearns 1974).

This approach to the study of communities was extended to the infauna through the application of site and species clustering techniques applied by Stephenson. Data from the 87 station grid off Palos Verdes (1971) was coded, key punched and Bray-

Curtis dissimilarity indices subjected to a hierarchical classification (Stephenson et al., 1975). The results revealed sites that were clearly impacted by the Whites Point discharges and showed the relation of the outfall communities to more distant sites.

In 1974 we focused attention on the benthic fauna from the second, third, and fourth 40-station semi-annual surveys conducted off Palos Verdes (August 1972, January-February 1973, and August-September 1973). The Bray-Curtis dissimilarity index was applied to data from each survey, and the sites sorted and clustered as before (Greene and Sarason, 1974). These analyses resulted in patterns that reflected apparent seasonal changes in indicator species and groups, but also confirmed that single samples frequently were representative of the replicates.

Results from the summer 1973 survey were then compared with sediment physical and chemical data (percent organic nitrogen, vegetative matter, sediment texture, hydrogen sulfide, DDT and mercury) by inspection and by generating site clusters based on the abiotic data (Greene and Sarason, 1974). This work revealed a moderately satisfying relation between contaminants and groups of biological indicators.

Other Multivariate Techniques

The work summarized above was followed by complimentary use of multivariate techniques which viewed groups of biological and chemical samples as a continuum rather than as discrete groups or clusters. Gower's Principal Coordinate Analysis, a type of ordination procedure, was applied to the summer 1973 benthic data from Palos Verdes, and focus was placed on sites at the 60 m depth (most influenced by the outfalls). The analysis generated two major biological axes that accounted for nearly 78 percent of the variability in the data and regression analysis confirmed that depth, hydrogen sulfide, DDT and nitrogen were the most important abiotic factors affecting the fauna along the 60 m depth contour. Mercury and other metals appeared to be of secondary importance (Greene and Smith, 1975; Smith and Greene, in press).

With additional modifications, these techniques were applied to data from the previously described Orange County survey.

<u>Sensitivity of Diversity Indices</u>

Seven of the numerous diversity indices devised by ecologists were compared for their utility in describing the effects of waste-water discharge on marine benthos. Data from the summer 1973 Palos Verdes benthic surveys (40 station grid described above) were used to calculate a variety of indices including: Gleason's (richness), Brillouin's, Shannon's (Margalef), Simpson's, standard deviation, and scaled Shannon's. The resulting figures were then compared to one another and to sediment chemistry data by multiple regression techniques. The results indicated that the Brillouin and Shannon indices (measures of species richness and evenness combined) were most useful in deliniating outfall related effects (Greene 1974). Independent correlations showed that Brillouin indices were nearly identical in numerical values to Shannon-Weaver indices.

STUDIES OF HEALTH AND CONDITION OF DEMERSAL FISH

Participation in numerous trawl sampling cruises and extensive use of the data summarization programs resulted in a major synopsis of the abundance, distribution and changes in diseased and abnormal fish populations (Task Report to the EPA, Sherwood and Mearns, 1975). Data were examined from surveys of demersal fish communities taken between August 1969 and November 1975, and throughout the coastal area from Port Hueneme to Point Loma including several offshore islands. The data base included approximately 280,000 samples of fishes, comprising 151 species, which were examined for prevalence of fin erosion, skin tumors, color anomalies, structural deformities, and attached external parasites. Particular emphasis was placed on examining data according to length or age classes to allow more discrete identification of relations to life history stages.

This work was accompanied by a variety of field and laboratory experiments (sponsored in part by the Coastal Water Project) to test hypotheses concerning the cause of one disease (fin erosion) shown to be directly related to waste discharge. The evaluation involved histopathological assays (Sherwood and Bendele, 1974 and 1975), microbiological assays (Sherwood and Kim, 1975), analyses of chlorinated hydrocarbons and metals in diseased and normal fish (McDermott and Sherwood, 1975a and 1975b), laboratory exposure of fish to contaminated sediments (Sherwood, 1975) and relations between age, weight, growth and disease from field surveys (Mearns and Harris, 1975 and in press).

Section V

EVALUATION OF EFFECTS OF WASTEWATERS ON BOTTOM FISH AND INVERTEBRATES.

During the grant period (1973-75) we analyzed and examined data from approximately 4,600 trawl and bottom grab samples taken between 1912 and 1975 by 11 agencies. Samples were taken over a depth range of 2 to 567 m in a geographic area ranging from Pt. Arguello, California, to Cedros Island, Baja California, and including four of the eight southern California offshore islands. In the field, we actually participated in over 40 trawl survey cruises and 12 benthic infaunal sampling surveys. In addition, we conducted a number of our own independent underwater television surveys at each major discharge site and other intermediate localities between Oxnard and Point Loma, California (including Santa Catalina and San Clemente islands).

In Appendix B of this report (Conditions of the Benthic and Demersal Fauna), we have presented a review of recent biological and sediment chemistry surveys at each of the five major minicipal discharge sites and a review of regional and historic trends and changes in infauna and bottom fish populations. We believe the most striking features of these data include:

(a) A pattern of increased biomass and abundance and decreased diversity of infauna associated with each outfall studied,

(b) A pattern of very depressed infaunal diversity and moderate abundance associated with deposits of sludge or sludge-like material at two of the five sites studied,

(c) A probable relationship between the size of bottom areas affected and the amount of wastewater and wastewater constituents discharged,

(d) Rapid recovery from effects upon termination of shallow water discharge (Orange County) and possible response to source control and treatment at the JWPCP plant,

(e) Occurrence of a possible large-scale gradient of increasing benthic invertebrate and bottom fish biomass and abundance and decreasing diversity approaching the Los Angeles coastal area from the north and south,

(f) Association of one fish disease syndrome (fin erosion in Dover sole) with municipal discharge off Palos Verdes, but lack of direct association of other diseases (such as tumors in flatfish) with any wastewater discharge.

Below we attempt to evaluate some of these data in terms of ecological significance and management of the municipal wastewaters discharged into open coastal waters.

ECOLOGICAL EFFECTS DIRECTLY ATTRIBUTABLE TO MUNICIPAL WASTEWATER DISCHARGES

Size of Regions Affected

A portion of the benthic infauna within each of the five outfall survey areas has been shown to be clearly influenced by municipal waste discharges. Subtle effects include shifts of a few dominant species of tubiculous crustaceans and polychaetes with no major changes in number of species (additions or losses). One, possibly two, of the 19 sites within the 27 sq km (4.6 x 6.0 km) grid at Oxnard demonstrated such effects (MBC, Inc., 1975); we judge the area so affected might be as large as 1 sq km (250 acres) and possibly as small as 0.3 or 0.4 sq km (75 - 100 acres). Flow into this area has been about 13 to 15 mgd, from Oxnard and Port Hueneme outfalls, with an annual input of 2,300 metric tons of total suspended solids. Most (19 of 23) coastal discharge sites discharge considerable lower volumes at approximately the same depth ranges (5 to 20 meters, SCCWRP, 1973) and would be expected to produce similar and even smaller areas of biological response.

In contrast, four sites, Santa Monica Bay, Palos Verdes shelf, San Pedro shelf and Point Loma shelf, receive considerably larger municipal inputs, accounting for over 90 per cent of the municipal wastewater discharged into mainland shelf waters.

The most obvious regions demonstrating responses in the benthos are Santa Monica Bay and the Palos Verdes shelf, receiving 346 and 345 mgd flow, and 132,000 and 86,000 metric tons per year total suspended solids (dry weight), respectively. One major response at these sites is a 20 to 50 percent reduction in numbers of species, dominated by a few species of molluscs and polychaetes; moderately high density, abundance, and biomass; and major depressions in echinoderm and crustacean abundance and diversity. These conditions seem to characterize two regions influenced by deposits of vegetative matter and sludge-like particles: A 2 sq km area adjacent to the Hyperion sludge-line (11.2 km offshore) in

Santa Monica Bay (100 to 120 m deep) and roughly 10 to 15 sq km area on the Palos Verdes shelf extending northwest of the outfalls. To the best of our knowledge these two regions, totaling 12 to 17 sq km, are the only such areas now so affected on the mainland shelf (representing 0.33 to 0.46 per cent of the southern California mainland shelf, i.e., 3,639 sq km).

Moderate or intermediate effects of wastewaters include conditions of high biomass and abundance, and moderate to low levels of diversity and richness, of the infauna. We estimate that about 30 sq km of the Palos Verdes shelf (excluding the 10 to 15 sq km noted above), 40 to 50 sq km of the Santa Monica Bay shelf, 3 to 5 sq km of the Orange County shelf and 3 to 5 sq km of the Point Loma shelf are so affected. These figures amount to somewhere between 75 and 90 sq km or about 2.1 to 2.5 per cent of the southern California mainland shelf. Such conditions are found surrounding the two "sludge-affected" areas (described above) at Palos Verdes and Santa Monica Bay, and probably represent the total present response of the benthos at Orange County.

Considering the many other small coastal outfall sites and including all three types of responses just described, the total area obviously showing benthic responses to municipal wastewater discharges might approach 100 to 110 sq km, or 2.8 to 3.0 percent of the mainland shelf. However, such a calculation obviously underemphasizes the local significance of each area affected. For example, considering all three types of effects, some 49 per cent of the Santa Monica Bay shelf (52 of 106 sq km) and 72 per cent of the Palos Verdes shelf (65 of 90 sq km) have obviously shown benthic responses to the respective discharges.

Standing Crop of the Benthos as a Response

Among the five discharge sites studied, there is at least a two order of magnitude difference in benthic biomass, ranging from an average of about 10 g/m^2 at Oxnard to over 400 g/m^2 on the Palos Verdes shelf (mean survey values from recent surveys); differences among individual stations range over three orders of magnitude. These trends are depicted in Figure 8, together with estimates of background biomass (from control sites at each survey grid).

These ranges are striking. When compared with the values of any or all wastewater components, a direct relationship with benthic biomass is apparent. It seems obvious, however, that potentially toxic materials such as DDT, trace metals, cyanide, phenols or detergents can be excluded from the factors contributing to increased benthic biomass unless they are of sufficient toxicity to eliminate predators of the benthic infauna (such as bottom fish and larger epibenthic invertebrates). The trawl studies suggest that bottom fish are certainly no less abundant at discharge sites than away from them and that infaunal feeding fishes are more abundant near the outfalls than away. It appears, then, that the infauna is responding through increased abundance and growth of some species, directly or indirectly to the nutrient input from the wastewaters.

In terms of wastewater management, an ideal relationship would be one that relates total benthic productivity (i.e., metric tons per year) directly with input rates (to the bottom) of the limiting

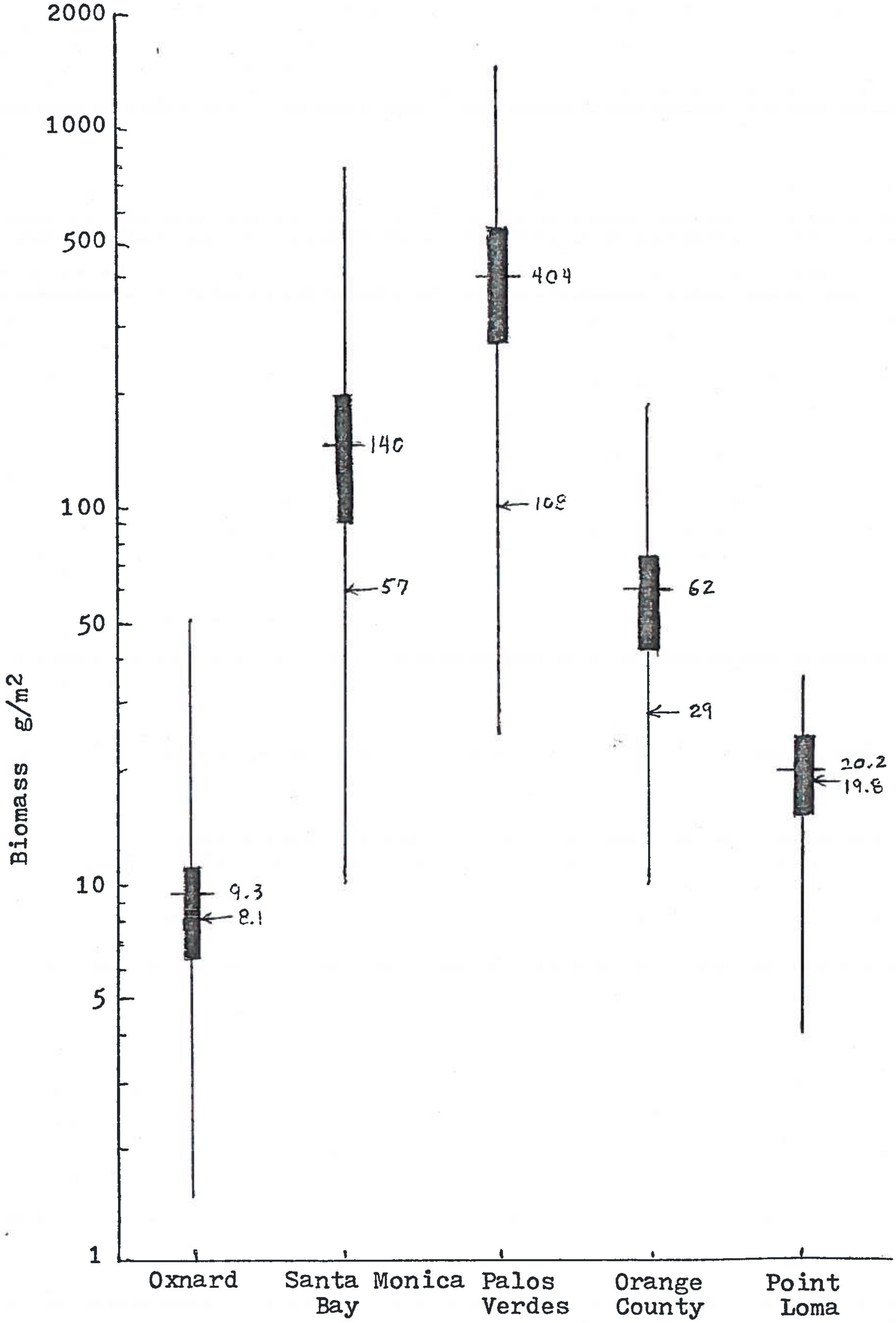


Figure 8 . Comparison of benthic biomass measurements from five municipal discharge sites. Means, $\pm$ 2 S.E. and ranges given. All data from summer, 1975 except Palos Verdes (January, 1975). Estimate of background biomass noted with arrow.

component (i.e., mass emission of organic nitrogen, metric tons per year). However, without some measure of predation, mortality and natality of the infauna, it is nearly impossible to estimate production. Likewise, without a concise measure of fallout rates of organic material on the bottom, it is nearly impossible to estimate input rates into the benthic microflora and macrofauna (such a study is in progress).

Despite these and other ecologically important limitations, it is still useful to speculate about what kind of a relationship might exist between biomass of a coastal infauna and input of some sewage component. One approach is shown in Table 5 and Figure 9, in which the standing crop of benthos in metric tons was estimated for each outfall site and compared to discharge of total suspended solids (part of which we assume to fall out over the affected fauna). To derive the benthic standing crop, we estimated a level of background biomass (g/m^2), and subtracted this estimate from biomass values characteristic of zones of enhancement (in sq km) associated with each discharge. The product of these two numbers yielded estimates of standing crops ranging from 17 metric tons over an area of 1 sq km at Oxnard to nearly 12,000 metric tons over an area of 30 sq km on the Palos Verdes shelf (Table 5). When plotted together, these calculations provided an intriguing direct log-log relation between total suspended solids discharge (metric tons dry weight per year) and standing crop (Figure 9): Between the limits of 1,000 and 100,000 metric tons dry weight total solids (per year), the response appears linear after log transformation (the relationship does not hold at lower levels of solids dis-

Table 5 . Comparison of benthic infaunal standing crops and solids discharged at five wastewater discharge sites.

SITE	BENTHIC BIOMASS, grams/m^2 Background[1]	Outfall[2] Average	Difference	Estim. Area (km^2) Affected	Standing Crop Metric Tons Wet Wt.	Solids Discharge (Annual) Metric Tons Dry Wt.
OXNARD	8	25	17	1	17	2,340
SANTA MONICA BAY	57	182	125	45	5,625	86,600
PALOS VERDES	108	500	392	30	11,760	132,000
ORANGE COUNTY	29	120	91	5	455	25,200
POINT LOMA	20	50	30	5	150	19,800

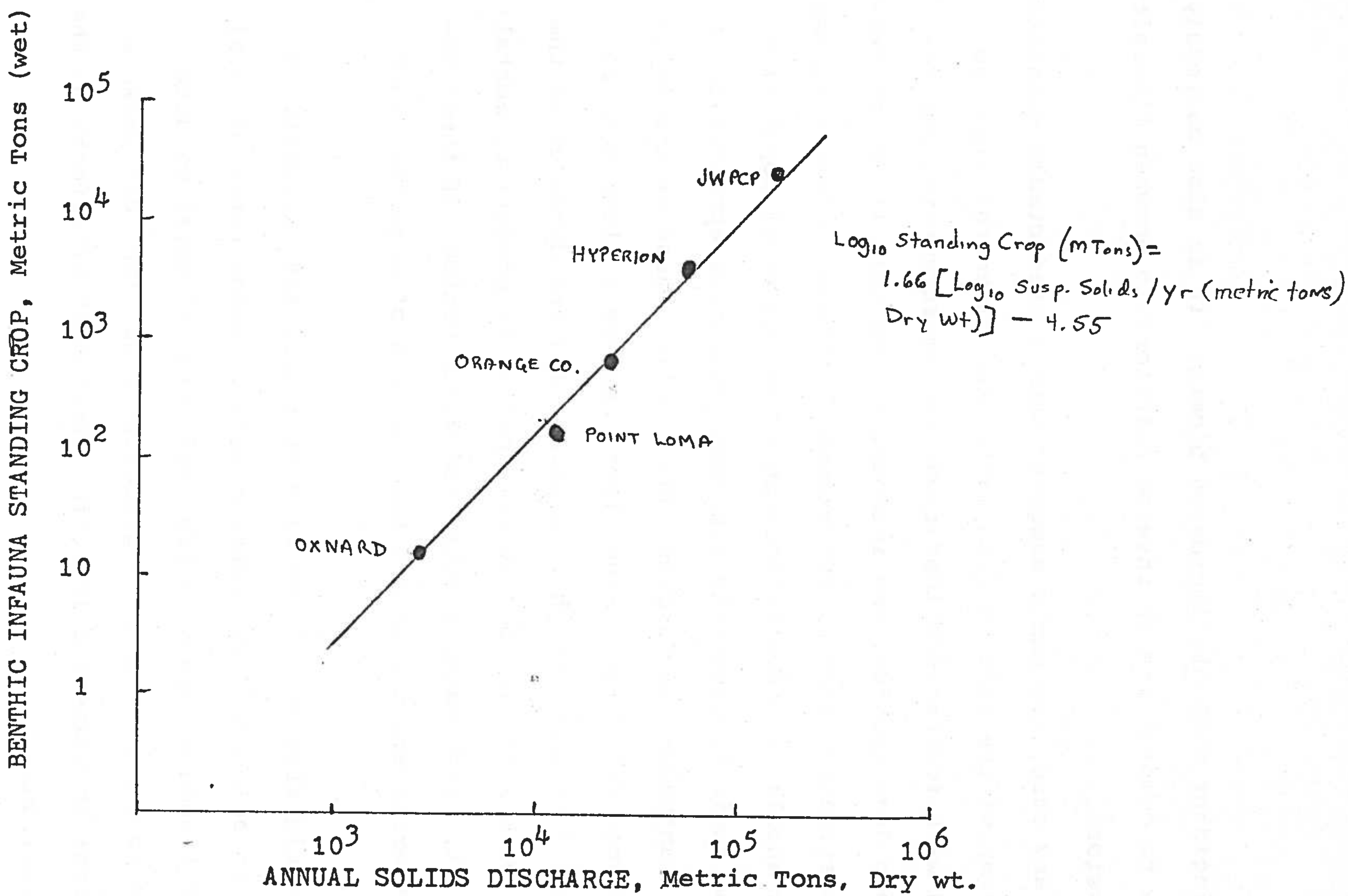


Figure 9 . Estimated relationship between solids discharge and benthic infaunal biomass (standing crops) at five municipal discharge sites.

charge).

Coincident with the increased biomass, it is also obviously possible to demonstrate an inverse relationship between diversity and emissions.

In any case, the curve suggests that a predictable quantitative enhancement of the infauna from wastewater discharge might be realized with further considerations and measurements. The relationship does provide some interesting new guidelines for examining wastewater effects. For example, perhaps benthic sampling programs should be directed towards measuring total population sizes and their fluctuations (through additional application of resource management techniques) and relating these estimates to to wastewater discharges. Also, there appears a clear need to understand more about trophic relationships and dynamics of the infauna, with inclusion of new information on predation, mortality, recruitment, birth rate, growth, and distribution of input nutrient material among soft and hard tissues of organisms such as clams.

We would also expect the size of areas, and intensity of effects, to be reduced by reducing mass emission rates of total solids. Although a more detailed evaluation of existing data is needed to generate precise guidelines, we might use present observations to suggest a logic for management of effects on the benthic environment.

The logic we recommend is one that places a regional or local limit on mass emission rates (not concentrations) of total solids to allow some biostimulation (and depression in diversity) within a specified surface area of the coastal shelf. For example, a desired goal might be to allow maximum achievable biostimulation at a discharge site with no region or zones of depressed abundance and biomass within or without the area of enhancement.

This might generally be achieved in southern California by keeping the mass emission rates of total solids at a given site below the level now represented by the Hyperion inputs, i.e., about 86,600 metric tons (dry weight) per year (the JWPCP plant has exceeded this by about 46,000 metric tons per year).

One might further wish to keep the area so affected to only a few sqare kilometers (e.g., 3 to 5 sq km, as at Orange County, where about 25,000 metric tons per year of total solids are discharged). Alternatively one may further wish to place a limit on the total area of coastal shelf to be affected. For example, to limit effects of obvious biostimulation and depression of diversity to a total area of 20 sq km, it would be necessary to apply a total regional limit on solids mass emissions of about 40,000 to 45,000 metric tons per year, to be proportioned among dischargers according to which coastal areas are more or less acceptable for disposal. We caution, however, that the present data may not adequately reflect conditions and areas affected by small discharges; it is possible that a threshold for effect occurs at some lower level of solids mass emission.

Rates of Response and Recovery

As a result of studies in Santa Monica Bay (Carlisle, 1969) and off Orange County (G. Smith, 1974 and Greene, 1976) it seems clear that both the benthic infauna and bottom fish communities responded quickly to cessation of discharge (both primary and secondary treated) through 20 m (shallow water) outfalls. Within three months of discharge termination at Orange County, infaunal abundance had dropped to 10 percent its discharge level: this was accompanied by 95 percent decrease in sediment sulfides, a 75 percent decrease in sediment organic carbon (G. Smith, 1974), and a 50 percent decrease in sediment metals (SCCWRP, 1973). These decreases have apparently continued; all values in July 1975 were even lower than previously reported. Diversity was the only parameters showing an increase (about 15 percent). Changes in the fish fauna were less dramatic. Although scattered with seasonal variability, long-term catch statistics for the white croaker (*Genyonemus lineatus*) indicates it is no longer an abundant and dominant species at the outfall, and incidence of tail erosion disease in this species has been markedly reduced. The total number of fish present is also about one-half that previously present. Although fish diversity and number of species of Orange County have increased by aout 10 percent, fish abundance, diversity and number of species showed no definitive increase or decrease in response to termination of discharge of solids, and later, secondary effluent through the Hyperion 1-mile outfall (20 m) in Santa Monica Bay during the period 1957-62. Observers did note a decrease in party-boats and commercial anchovy fishing in the area following discharge termination.

These observations suggest that chronic discharge of primary or secondary effluent in shallow open coastal waters (e.g., to a depth of at least 20 m) results in no irreversible effects on the bottom fauna, even after periods of discharge exceeding 10 years. Reversibility, therefore, may be an achievable criterion under conditions of nearshore shallow water discharge in open coastal areas, even for the large discharges (i.e., 180 MGD) involved in these observations. It is most likely that such responses are due to the dynamics of the inshore region itself, where wave action and alongshore sand transport act quickly to overcome years of accumulation of organic material and outfall-induced benthic community structure.

We are as yet less certain about the rates of responses and recovery of the benthos and bottomfish communities to deeper water discharge (60 m or deeper). The trawl studies in Santa Monica Bay seemed to show a trend of increased fish catches at the 60 m deep 5-mile effluent line beginning about a year after full discharge was initiated (1961), but there was no obvious change in number of species or diversity even two-and-one-half years after discharge termination (1963). Catches in 1971 again show no decreases in abundance. At the sludge discharge site, a fall in total catch occurred during the first two years after initiation of sludge discharge, but catches, number of species and fish diversity recovered and showed no significant depression six years later. Fish catches were even higher in the 1970's, but this may be due in part to use of more efficient gear. We believe the low abundances of bottom fish in 1957-59 were a response to the intrusion of warm water.

Increased abundance of bottom fish was also evident at the Orange County deepwater site, becoming obvious about two years after discharge initiation; infaunal feeding flatfish showed the most increase in abundance. Meanwhile, Gary Smith detected increasing abundance and decreasing diversity of the deepwater site infaunal beginning about a year after discharge initiation, but there was no significant increase in carbon or sulfides. By 1975, increased abundance, carbon, sulfides, and decreased diversity were apparent at Smith's site as well as in a region of about 3-5 sq km north west of the diffuser.

These observations suggest that biostimulation of the benthos precedes that of benthic fish and that the appearance of both processes is not readily apparent within the first year after discharge initiation. Full development of a changed benthic and demersal fish fauna may take from two to five years or longer. It is therefore important to continue surveillance of both bottom fish and benthic infauna at the deepwater discharge site off Orange County.

Increases in biomass, abundance and diversity of the infauna off Palos Verdes have occurred since 1973 and appear to be related to a major reduction in the size of a field of free hydrogen sulfides in sediments as well as to a 15 percent reduction in total solids emissions, 60 to 70 percent reduction in settleable solids and thiosulfate emissions and a 70 percent increase in cyanide. There have been no significant changes in levels of DDT, PCB's, metals or nitrogen in the sediments, but a modest decrease in the size of area containing vegetable matter has occurred. Influx and establishment of the echiurid worm, Listriolobus, was noted in 1973, and the population has grown. We do not know whether this organism contributed to aeration of the sediments, but it is a possibility. Again, continued chemical and biological monitoring of this site (including the rocky subtidal and intertidal areas) coupled with accurate information on mass emission rates of solids and industrial wastes should provide a basis for determining which wastewater components are most responsible for ecological changes and most useful for ecological management. The data already suggest that 1) hydrogen sulfide was a factor limiting incorporation of waste solids into benthic productivity, 2) organic input is now the new limiting factor, and 3) with some exceptions (i.e., crustacean diversity and fin erosion diseases), DDT, PCB's and metals are the wastewater-related factors least limiting to the biota studied.

Fin Erosion in Flatfish

It is quite clear that conditions on the Palos Verdes shelf are causing the fin erosion disease in benthic fish. When taken together, our data indicate the disease results from chemical or metabolic disorders rather than from infectious microorganisms. High chlorinated hydrocarbon levels in fish tissues appear to be in some way related to the disorder, yet source control of DDT has not effected a reduction in either tissue levels of DDT or prevalence of the disease. Thus, DDT, PCB or other as yet unmeasured chemicals can not be eliminated as a cause. Since the principal source of these substances to the benthic biota appears to be the persistence of contaminated sediments at Palos Verdes, it is possible that changes in prevalences will reflect changes in treatment only if the measures taken change the biological availability of trace chemicals in the sediments. Reduction of the disease might require action directed toward the sediments themself (i.e., dredging or burying) or simply waiting for natural processes of decay and resuspension.

REGINONAL EFFECTS OF QUESTIONABLE ORIGIN

Large-Scale Benthic Gradients

Benthic samples taken from the "control" sites of the outfall survey grids (at a given depth and season) were not at all similar in terms of biomass, densities or diversity of the infauna. The arrows in Figure 9 reflect these differences for biomass and suggest a large-scale pattern of decreasing infaunal diversity extending from the Los Angeles coastal areas to the north and south.

While additional sampling is required to confirm such a trend, it is tempting to speculate on its implications for wastewater management. First, natural background condition defined by Orange County, San Diego or Oxnard (i.e., biomass 5 to 40 g/m^2, Shannon or Brillouin diversity 3.0 or above, Gleason index 15 or greater) may be unachievable in the Los Angeles area if the natural background conditions for this region are less diversity and more abundance of organisms. If this is not the case, and if the large dischargers are the major cause of the high biomass and low diversity observed, then appropriate treatment (such as complete removal of settleable and suspended solids) can be expected to result in a decline in benthic standing crop well beyond the limits of areas presently defined as "affected". We are not at all certain whether either choice is available, but it would certainly be worth the effort to further define the boundary conditions of these trends.

A second implication concerns the cause of such patterns. It is certainly likely that the discharge of municipal sewage into sub-thermocline waters off Los Angeles County for nearly 20 years is a factor contributing to stimulation of the benthos over a large portion of the coastal zone. But other natural and anthropogenic influences may be equally important. A noteable anthropogenic factor might be the flood control projects, undertaken in the 1930's and 1940's after several periods of intense flooding in the Los Angeles Basin. Dams and lined channels prevent silt and sand flow, but may continue to allow discharge of very fine particulate matter in disproportionate quantities, possibly contributing to a regional decrease in mean particle size of local marine sediments (and therefore substantially changing the infauna).

Alternatively, this portion of the coast may be under the influence of unknown natural physical, chemical, or biological processes not generally important in regions to the north or south.

Skin Tumors in Dover Sole

During the past two years, our investigations have indicated that tumor-bearing Dover sole can be collected anywhere in the Southern California Bight as well as off central Baja California (to the south) and Pt. Arguello (to the north). The disease is histologically homologous to similar disorders in pleuronectid flatfish populations in central and northern California, off Oregon, Washington, British Columbia and in the Gulf of Alaska and Bering Sea, Alaska. Furthermore, there is no indication that the prevalence of the disease within a year class of fish is any higher near outfalls than away from them while there is considerable evidence pointing toward an epizootic cause related to the early life history of pleuronectid flatfishes. Curiously, flatfish of the Atlantic coast are not affected, even in areas of heavy waste discharge.

For these reasons, we anticipate that no amount of wastewater treatment will reduce the incidence of this disease in future year classes of Dover sole. Treatment may change incidence in all age groups as a whole, however, if the survival of post-larval fishes is reduced or increased by changing the availability of food organisms in the benthos (e.g., small clams, polychaetes and crustaceans).

The cause for the disease will not be confirmed without a broader study of the biology and population dynamics of affected and unaffected populations and of histological similarities and differences among affected fishes.

Comments on Regional Fisheries

In reviewing fisheries data it is interesting to find that most of the sport and commercial landings in the Southern California Bight come from regions of heaviest waste discharge. As shown in Figures 10 a and b sites of heaviest commercial and sportfishing in 1972 have included Santa Monica Bay south through San Pedro Bay as well as several distant sites.

This observation is not presented with the intent to imply a direct relationship with sewage discharge but rather to point out that the removal of fish from coastal waters has been considerably higher in these areas and that fishing could be another regionally important impact on coastal ecology. For example, if sufficiently intense, such harvesting could affect the structure of marine communities by changing predation rates or influencing competition (among resident and migratory fish) for food (small forage fish and invertebrates).

In any case, fishing itself should not be excluded from the factors possibly contributing to regional differences in coastal marine communities.

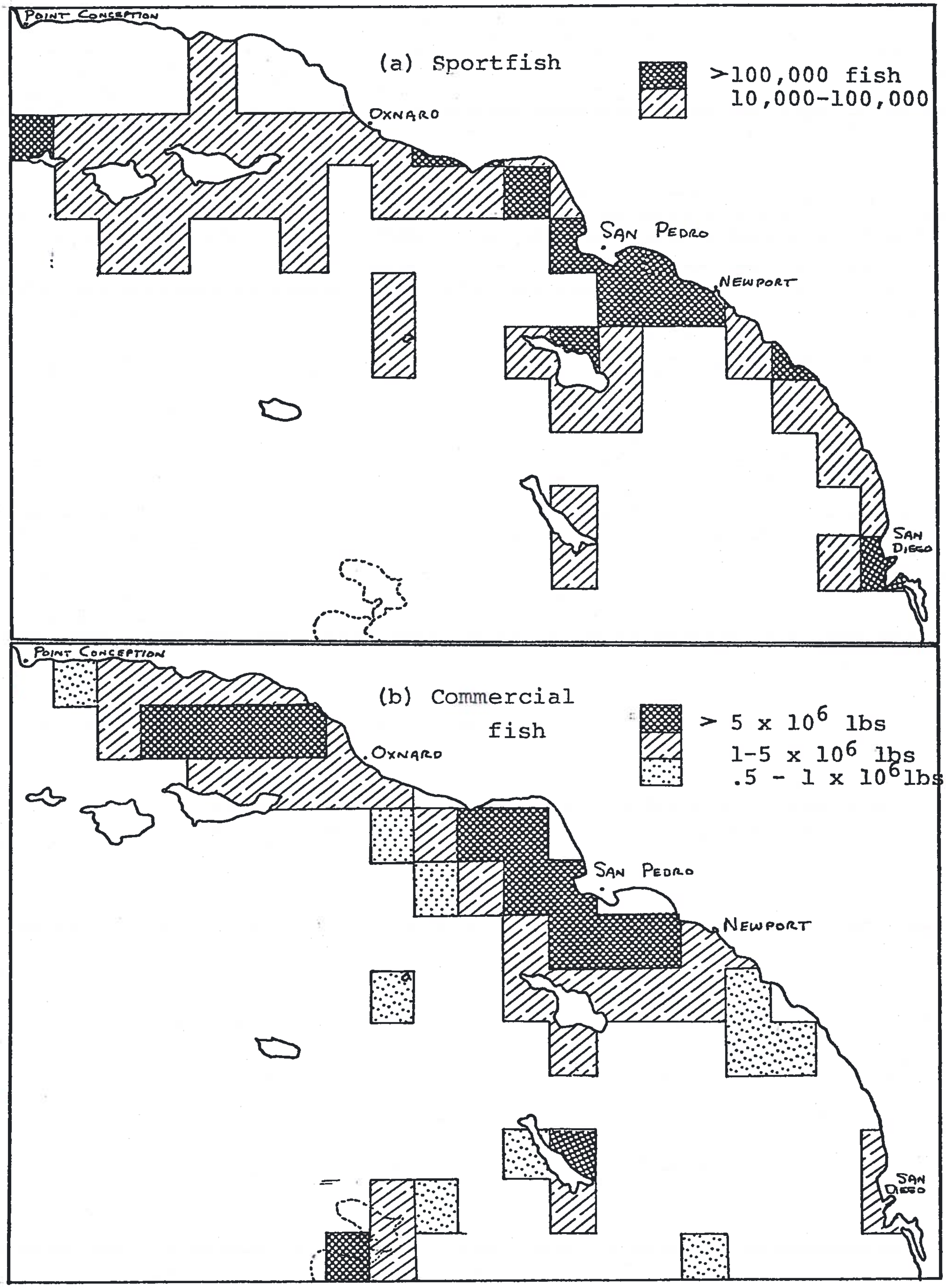


Figure 10 . Sites of (a) sportfish and (b) commercial fish landings in southern California. Calif. Dept. of Fish and Game, 1972 data.

Section VI

PUBLICATIONS

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Papers Published

1974 Mearns, A.J. and M.J. Sherwood. Environmental aspects of fin erosion and tumors in southern California Dover sole. Trans. Amer. Fish. Soc. 103(4):799-810

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