INVESTIGATIONS OF THE TERMINAL ISLAND TREATMENT PLANT EFFLUENT AND FISH PROCESSING WASTES IN OUTER LOS ANGELES HARBOR, 1981-1982

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MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA PART 19

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A Report for the City of Los Angeles,
Department of Public Works

by

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Cover: Reverse color satelite imagery of cold water upwelling (red), west of Santa Monica Bay (left) and southwest of San Pedro Bay off Palos Verdes Peninsula; (Center) Santa Catalina Island. (Courtesy of Gary Kleppel, Ph.D.)

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INTRODUCTION

The City of Los Angeles, in conjunction with their application for a new five year permit to discharge effluent from the Terminal Island Treatment Plant (TITP) in outer Los Angeles Harbor, sought information on several aspects related to present and future environmental management of those wastes. These included evaluating the existing biological health of the harbor, and determining whether a change in treating and managing fish processing waste effluents would return the harbor to a more enhanced biological condition while giving assurance that projected effluent mixtures would not be toxic.

Background

The history of regulatory efforts to clean up the harbor precedes federal legislation by several decades. However, it was after the federal enforcement legislation was passed in the 1960s and early 1970s that a dramatic improvement in water quality occurred. Between 1971 and 1972 there was great improvement in the harbor benthos, as determined by the number of species and numbers of individuals per square meter, and by other survey methods (Soule and Oguri, 1976; 1979; 1980). At that time three fish processors were operating two outfalls for pre-screened wastes and TITP released primary treated effluent in the outer harbor. There were numerous direct dischargers of sanitary and industrial wastes to the harbor.

Control of industrial waste effluents, oil field brine disposal, dockside sewage, bilge and hold pumping and other dumping practices helped to make the harbor the richest soft-bottom inshore habitat in southern

California in 1973-74. At that time there was a zone of reduced benthic quality in and around Fish Harbor (Station A04, Figure *i*) and at the immediate site of the TITP outfall and two cannery waste outfalls (Station A07), particularly when the fall wetfish (anchovy) processing production peaked during natural phenomena such as warm water turnover, Santa Ana winds or red tide episodes.

In 1975, the EPA required installation of pre-treatment of fish processing wastes by dissolved air flotation (DAF) or similar equipment, which virtually eliminated anoxic episodes in the vicinity of the outfalls, but appeared to result in a reduction in total productivity of the outer harbor. While it is difficult to determine direct cause and effect, with the multiplicity of events that influence the harbor, the long-term trends have been consistent with changes in the nutrient flow to the harbor.

In 1977, conversion of TITP from primary to secondary treatment apparently impacted marine organisms to varying degrees, depending on distance from the outfall and location in relation to the major outer harbor circulation gyre, resulting in a declining trend in numbers of most types of marine organisms in the outer harbor.

In 1977-78, fish processing waste lines were hooked into the TITP system for secondary treatment between October 1977 and January 1978 and the cannery outfalls shut off except for non-process flows. The following six months was a period of adjustments and malfunctions at TITP, after which operations were relatively stable. As predicted, however, the intermittent nature of cannery operations and the high salinities have created periods when TITP exceeded NPDES permit levels for biochemical oxygen demand (BOD), or suspended solids (SS).

The total productivity of the harbor never returned to levels found in 1972-75; 1973 was the peak year. The total number of benthic species remained at approximately 1972 levels, in spite of the massive expenditures of funds made to convert from primary to secondary treatment and treatment of cannery wastes.

Comparison of other parameters between 1971 and 1978 led to the following evaluations of changes concomitant with changes in waste management practices (Soule and Oguri, 1979; 1980).

In 1971-78 there were the following changes;

1) Four-fold decrease in total phytoplankton;

2) Decrease in total zooplankton numbers and shift in the zooplankton population;

3) Four-fold decrease in numbers of benthic organisms per square meter of bottom sediments and a decrease in species to about 1972 levels;

4) Four-fold decrease in total fish numbers, but 50 to 100-fold decrease in anchovy in the harbor as compared with a slight increase in anchovy outside the harbor;

5) A 25 percent decrease in numbers of meroplankton species and numbers, and a shift in composition to the less nutritious (per unit of feeding effort) amphipods;

6) A 2.5 fold decrease in marine-associated birds, but a greater decrease in the California gull, the species which created concern over reduced habitat at Mono Lake, California;

7) A 30-fold decrease in marine microheterotrophs (microbials) on which the harbor detrital food web is based.

8) There was improvement in the immediate area of the outfalls in the shallowest water up to 25 ft (8m) where levels of benthic organisms returned to the peak numbers recorded in 1973; in exchange, total production regressed in most of the outer harbor.

The 1977-78 harbor-wide investigations included complete biological surveys of microheterotrophs (microbials), phytoplankton productivity, zooplankton, benthic organisms, meroplankton (fouling) organisms, fish and marine-associated birds. In addition, sediment grain size and chemical pollutant burden were determined, and physical water quality and nutrients were measured (Soule and Oguri, 1979; 1980). Results of multivariate statistical analysis and food web structure information were reported, bioassay/toxicity studies were performed and an ecological simulation model of the harbor receiving waters was presented.

- o It was concluded on the basis of the long-term records and on 1977-78 investigations, that the harbor was greatly enhanced when liquid cannery waste was being discharged to it after screening or other pretreatment, but without undergoing secondary treatment at TITP.
- o It was also concluded that the harbor was still enhanced, but less so, when only secondary treated effluent was released, as compared with coastal areas near the harbor.
- o Based on the long-term results, Harbors Environmental Projects concluded that an effluent system in which some liquid fish wastes would be released to the harbor directly, mixed with the larger volume of secondary treated TITP waste, would be most beneficial for the ecological health of the marine receiving waters.

In 1981, the TITP outfall was relocated in deeper water to the south of its original site, to the east of Fish Harbor seaward of a landfill created by dredging the main channel. There have been intermittent TITP problems with meeting the existing National Pollution Discharge Elimination System (NPDES) permit requirements for biochemical oxygen demand (BOD) loading and suspended solids (SS) which have been partially attributed to the intermittent nature of fish processing and consequent fluctuation in quantity of waste, in loadings and in salinity.

Although from a biological standpoint higher cannery loadings are beneficially assimilated by the harbor, are non-toxic, and result in a more productive environment so long as receiving water dissolved oxygen remains adequate, changes in permit conditions are not easily gained from the Environmental Protection Agency. Federal policy for more than a decade has been that all disposal to the marine environment is harmful, regardless of the ecosystems supported by biodegradable, non-toxic nutrient wastes. This legalistic approach ignores the natural detrital input of rivers or of upwelling, and the productivity of estuarine and coastal environments. Waste effluents that are not toxic at receiving water dilutions have been shown to support substantial fish populations. The National Advisory Committee on Oceans and Atmosphere (NACOA) Report (1981) criticized the federal policy of rejecting the ocean disposal alternative without consideration of site characteristics and other available alternatives.

1981-1982 STUDIES

In view of the results of the earlier field and laboratory studies, as well as the ecological modeling efforts (Soule and Oguri 1980; Kremer and Kremer, 1980), and because of the problems in effluent management associated with the NPDES effluent permit conditions, the City of Los Angeles wished to reexamine the concept of returning some or all of the liquid cannery waste to the harbor, mixed with secondary treated TITP wastes.

The City has applied for a new five year NPDES permit for TITP, to be obtained from the California Regional Water Quality Control Board (RWQCB), with the approval of the California WQCB, and the Environmental Protection Agency. (EPA), Region IX. This three-part study requested by the City from Harbors Environmental Projects considers the following:

Part I. Evaluation by means of computer modeling studies, of whether the harbor could theoretically assimilate the additional BOD loadings if pre-treated cannery wastes were to be released without secondary treatment, but mixed with secondary treated TITP effluent. This study required computer manipulations, field ground truth measurements and laboratory testing.

Part II. Evaluation of the biological "health" of the harbor. Benthic sampling was selected as the parameter most appropriate for a limited survey of receiving waters, following relocation of the TITP outfall to the south of landfill that was being created over the previous locations of cannery and TITP outfalls. Dredging was in progress during the benthic surveys in December 1981 and March 1982, and parameters such as populations of fish, phytoplankton and zooplankton would have been much more affected by suspended sediments and turbidity in the water column. Benthic stations were selected which were considered to be outside the dredging and filling area, although some effects of resettlement of suspended sediments may have been encountered at one or two of those stations.

Part III. Evaluation by means of toxicity, bioaccumulation and growth tests, of the quality of the present effluent and that of various mixtures representing proposed effluent if some portion of non-secondary treated cannery wastes were introduced into the TITP waste stream. The 96 hour toxicity tests were followed by 24 day exposure tests to permit uptake, if any, to occur. Measurements were also made to determine whether the solutions tested provided for sustenance and growth during the test period, as evidence of enhancement by the effluent mixtures.

Results of the three part investigations are summarized in the following pages and discussed in detail in the body of the report.

SUMMARY, PART I
INVESTIGATIONS OF TERMINAL ISLAND TREATMENT PLANT EFFLUENT,
ECOLOGICAL SIMULATION MODEL

The purpose of these investigations was to evaluate by means of computer model studies whether Los Angeles-Long Beach Harbors could theoretically assimilate waste loadings with varied levels of biochemical oxygen demand (BOD), such as mixtures of pre-treated cannery waste and secondary treated urban wastes.

The model used in this work was a slightly modified version of an earlier ecological simulation model of outer Los Angeles-Long Beach Harbors (Kremer and Kremer, 1980). The simulation model predicted levels of phytoplankton biomass, biochemical oxygen demand (BOD), dissolved oxygen and dissolved inorganic nitrogen. The major known fluxes of oxygen and inorganic nitrogen were included in the formulation of the model.

Field sampling of oxygen, BOD, and nutrients was conducted on two dates to validate that the model results were reasonable for the harbor with its newly filled configuration. Results of model runs were also compared with 1978 field data. Computer simulation runs included not only conditions for these two specific dates, but also "average" conditions, patterns, and various combinations of wastes and loadings.

- If results of the simulation model are assumed to be completely accurate, direct discharge without treatment by TITP of even 10 MGD of cannery effluent (total process plus non-process water), would be expected to have little or no effect on the plankton, nutrient chemistry and dissolved oxygen.
- According to the model with 10 MGD of cannery discharge (process and

non-process water), the BOD would be expected to increase about 0.2 mg O_2 l^{-1} and the average dissolved oxygen level would drop about 0.5 ppm from conditions without any cannery discharge. Under normal conditions these small changes would not represent an oxygen stress to the receiving waters. Nutrients and BOD associated with the cannery effluent would be anticipated to be quickly assimilated.

It is important to make this conclusion cautiously and tentatively, however. Although a state-of-the-art circulation-model and well-established nutrient formulations were used in the studies, the model is quite simplified compared to nature, and not all possibilities are included in the model formulations. The size of the computational grids is large (650m on a side) so that small-scale horizontal gradients are not detectable. The model is two dimentional (depth averaged) so the effects of stratified conditions are minimized. In addition, a direct effect of changing wind conditions on the circulation of harbor waters was not included. Because of these and other unknown factors, not included in the simulation model, it would be desirable to encourage appropriate environmental monitoring if direct discharge of cannery effluent is permitted.

SUMMARY, PART II
EVALUATION OF THE OUTER HARBOR BENTHOS

Benthic populations tend to be more stable than those of fish, zooplankton or phytoplankton, since they are directly dependent upon the characteristics of the bottom sediments and water column in the immediate vicinity. While many harbor benthic species have motile or planktonic larvae, adults generally are more or less sessile and lack capabilities for escaping environmental insults, should they occur.

Therefore, as part of investigations for a new NPDES permit application, benthic organisms were selected for evaluation of the biological "health" of harbor waters which receive effluent from the City of Los Angeles Terminal Island Treatment Plant (TITP).

Harbors Environmental Projects at the University of Southern California has a computer data bank with records of benthic organisms in TITP receiving waters dating from 1971 and thus has been able to document environmental changes which have occurred under changing methods waste of treatment and water pollution control enforcement.

Ten stations were sampled for benthic organisms in December 1981 and March 1982, using the Reinecke box corer, which covers $1/16m^2$ of surface to depths up to 0.5m. Samples were taken for grain size analysis, and sediments were then rinsed through 0.5mm screens. Organisms were preserved with formalin-seawater. In the laboratory samples were rinsed, transferred to 70 percent ethanol and identified to the lowest feasible taxa.

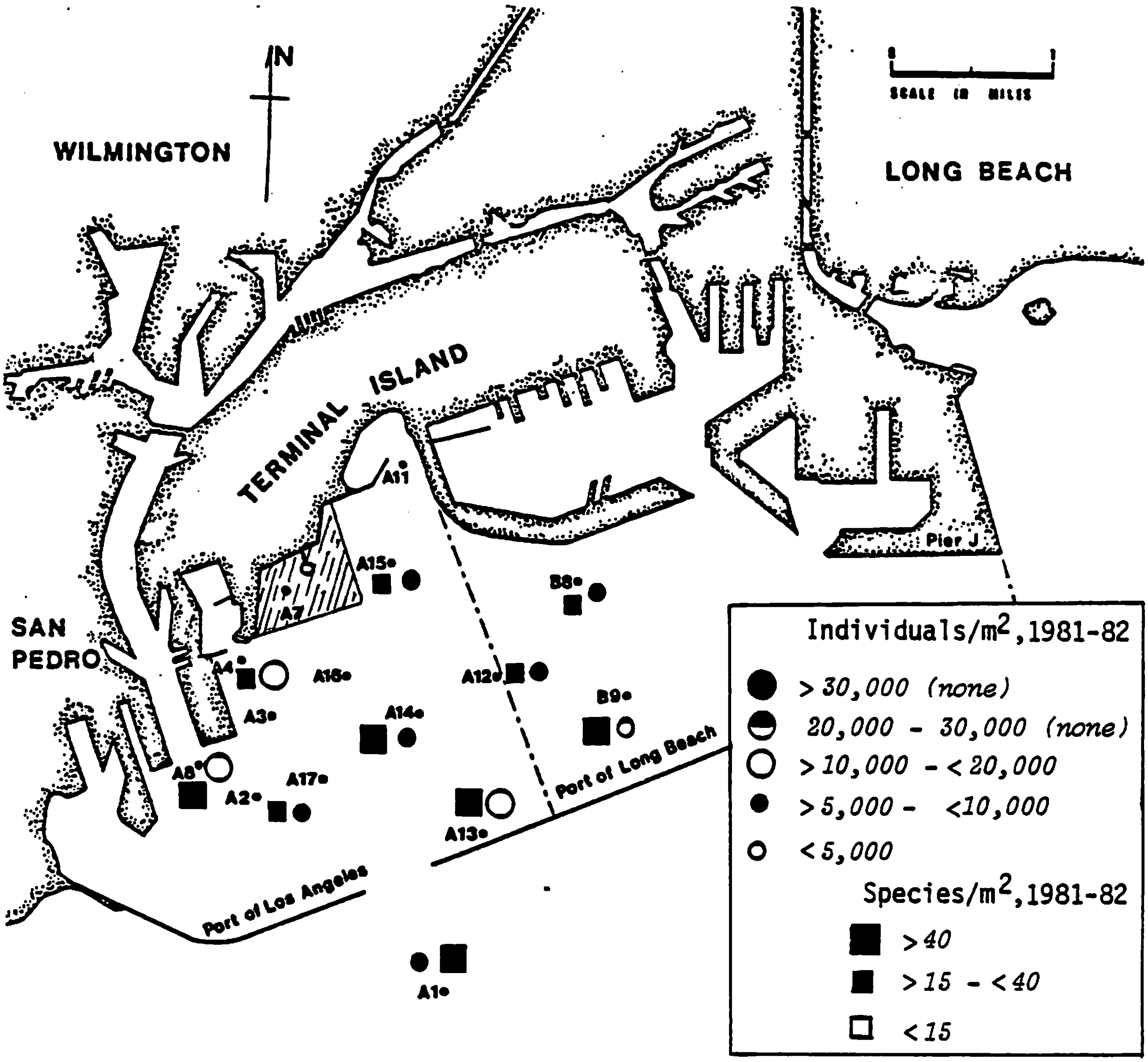
- o Grain size measurements in 1981-82 indicated that no more than a minor change in sediment characteristics had occurred at two stations selected for sampling, except for an increase in percentage of sand at stations A08 and B08 above 1978 levels.
- o The benthic results indicated that benthic diversity has remained at about 1972 levels since 1978, after peaking in 1977. Total productivity based on numbers of individuals per square meter has apparently remained below 1972 levels since 1975 as calculated by annual averages for the outer harbor stations sampled.

Figure *i* shows the general benthic results for the stations and compares the data with that for 1973-74 and 1978, in symbols used in the 1978 TITP study (Soule and Oguri, 1980). Individual stations showed considerable variation between 1971-72 and 1981-82. Certainly localized episodes such as TITP plant upsets, exceeding of assimilation capacity by canneries in earlier years, oil spills and other industrial waste paractices have affected receiving waters and benthic populations. Natural phenomena such as warm water years and cooler water years, upwelling, rainfall, storms and reversal in direction of currents may affect benthic organisms. However the majority of the harbor species are probably tolerant of most of these phenomena; such events will more likely affect the incidence and numbers of species which form minor components of the harbor biota.

Large numbers of unidentified juvenile amphipod species and a single polychaete genus comprised over 30 percent of the fauna at the sea buoy (A01) outside the Los Angeles harbor entrance, which may have biased the species diversity calculations and overall rankings of species. This may be, in part, indictive of stimulation due to turbidity from deposition of a new surface from dredging activities but it may also be the result of coastal storms and seasonal phenomena. Notwithstanding the extremes noted in seasonal and annual variation at single stations, the data represented in Figure *i* clearly shows that the harbor has declined in benthic productivity by an order of magnitude or more since 1974.

o Examination of temperature and rainfall data for 1971 to 1983 provide no clear indication of patterns linked with benthic productivity in the harbor. The decline since 1973-74 occurred during both cool and warm years, as well as both wet and dry years. The timing of temperature changes and rainfall may be critical but there is insufficient information on life histories of biota to determine this as being responsible for harbor-wide, long-term trends.

- In spite of the decline in benthic production since 1973, limited data from offshore of the harbor, (Soule and Oguri, 1982) and along the Palos Verdes and Santa Monica coasts (SCCWRP, 1977) show that the harbor is more productive, and can be considered as bioenhanced on the basis of benthic populations.
- The harbor probably would be enhanced further as a nursery ground for larval and juvenile fish, by reintroducing a managed level of non-secondary treated fish processing wastes in conjunction with secondary treated TITP effluent. Such fish feed primarily on nutrients, suspended particulates, living bacteria and other microheterotrophs and phytoplankton. Many of them thrive in turbid waters, which offer some protection from predators as well as necessary density of food, since most are weak swimmers at best.
- The harbor would probably be enhanced further as a habitat for young and adult fish, and for marine associated birds if the proposed mixture were reintroduced, because it would support more benthic organisms per square meter on which omnivores and benthos feeders depend.
- Management and monitoring programs would be essential to determine that depletion of dissolved oxygen did not occur if the assimilation capacity were exceeded, or that excess oil and grease were not released, which might foul hard substrata in the harbor. The effects on the biota could easily be tested by releasing a known quantity of cannery wastes directly and conducting a biological survey to determine the resultant changes.



	1973-74		change, 1974-78	1978		change, 1978-81	1981-82		change, 1974-82
A 1	■	•	-	■	◦	+	■	•	o
A2A	■	●	-	■	◦	-	▪	•	-
A 4	□	◦	+	▪	•	+	▪	○	+
A 7	▪	○	o	▪	○				
A 8	■	◒	-	■	•	+	■	○	-
A11	■	●	-	▪	•				
A12	■	●	-	■	◦	-	▪	•	-
B 8	■	●	-	■	◦	-	▪	•	-
B 9	■	●	-	■	•	-	■	◦	-

Figure *i*. Numbers of Benthic Individuals and Numbers of Species Per m^2 in Outer Los Angeles Harbor in December 1981 and March 1982, Compared to 1973-1974 and 1978 Survey Data.

SUMMARY, PART III
BIOASSAY, BIOACCUMULATION AND BIOENHANCEMENT INVESTIGATIONS

The bioassay program was designed to address the effects of proposed mixtures of TITP secondary treated waste and non-secondary treated cannery waste on organisms representative of those in the harbor. Procedures were therefore set up to utilize concentrations of waste diluted in seawater that were similar to those expected to occur in the harbor as a result of mixing the effluents. Standard testing of the effect of 100 percent waste is routinely done at the City of Los Angeles Hyperion Laboratory and a repetition of tests at such high concentrations would be not only redundant but also less germaine than the tests centering on lower concentrations of 0.01 percent to 10 percent.

Three phases were established for these tests. Acute toxicity, if any, was determined by exposure of four species of test organisms to the waste mixture in seawater for a period of four days. Biostimulation or enhancement was determined by considering the change in weight during a 24 day period on mussels exposed to the waste mixture. Bioaccumulation of metals and chlorinated hydrocarbons by both mussels and fish during a 24 day exposure to the waste was determined by chemical analyses of organisms exposed to the waste compared to analyses of organisms held for the same period in clean seawater.

- o No acute toxicity could be demonstrated since mortalities even at the highest concentration of the waste material, were not significantly greater than in the controls.
- o There was also no consistent significant finding that any of the pollutants for which analyses were performed occurred in greater

concentration in the test organisms than in the controls. Depuration was apparent in some instances. Analyses were performed for cadmium, chromium, copper, mercury, lead, zinc, nickel, silver and arsenic, as well as for pesticides, PCB and chlorinated hydrocarbons.

- There were consistent and significant increases in weight in organisms exposed to the waste mixtures as compared to the control groups.
- The test results strongly indicate that there would be no significant mortality in the biota at waste concentrations which were selected to bracket the concentrations expected from the proposed operational discharge. No significant bioaccumulation of the pollutants tested would be expected in the organisms exposed to the waste.
- Larger populations of organisms should result from the mixed discharge since the material could serve as a food resource to support the larger populations, but the diversity and composition would not be expected to change appreciably, based on the historical data.

In the following pages, the regulatory aspects of the bioenhancement concept are reviewed, excerpted from Soule and Oguri (1979). The bioenhancement concept is crucial to the proposed solution for waste management problems in the harbor.

ENHANCEMENT OF THE HARBOR
RECEIVING WATERS

INTRODUCTION

The release of sewage effluent into embayments is controlled by the State of California, as well as by federal legislation, and California specifies certain qualifications in addition to the federal requirements. The following discussion of these factors is excerpted from Marine Studies of San Pedro Bay California (Soule and Oguri, 1979):

> In the years since the passage of the National Environmental Policy Act (NEPA), the National Pollutant Discharge Elimination System (NPDES), and the 1972 revisions to the Federal Water Pollution Control Act (FWPCA), the emphasis has shifted from chemical, physical and biological standards for receiving water quality to the more easily regulated standards for effluent discharges. Apparently the basic impetus, in addition to ease and uniformity of enforcement, was that some particular number, or set of numbers, could be selected as standards that would guarantee good water quality, nationwide.
>
> The Environmental Protection Agency (EPA) delegated to the states the authority to enforce national water quality standards and to develop policies that serve to implement control. Thus the California Resources Agency created the State Water Resources Control Board and the several Regional Water Quality Control Boards (RWQCB).
>
> In May 1974 the policy document, under which Los Angeles Harbor is regulated, was created.
>
> Bays and Estuaries Policy
>
> In the document Water Quality Control Policy for the Enclosed Bays and Estuaries of California (May 1974), the following excerpts are germane to the concept of bioenhancement:
>
> > The Introduction (p. 1) of the above document states that the purpose of the policy is ... "to prevent water quality degradation and to protect the beneficial uses of enclosed bays and estuaries."
> >
> > In Chapter 1, Item A (p.2) states that it is the policy of the State Board that discharge of municipal wastewaters and industrial process waters ... "shall be phased out" ... (except) "when the Regional Board finds that the wastewater in question ... *would enhance the quality of receiving waters above that which would occur in the absence of the discharge* "[3] (author's italics).

Footnote 3 (p. 11) provides for 96 hour bioassay tests of undiluted effluent such that the effluent would produce not less than 90 percent survival, 50 percent of the time, and not less than 70 percent survival, 10 percent of the time. The footnote continues by indicating that these requirements by themselves *do not constitute evidence* "that the discharge satisfies the criteria of enhancing the quality of the receiving waters above that which occur in the absence of the discharge."

This constitutes the principal difficulty of the document; namely, that no definition of enhancement is provided.

Chapter I, Item B, 1c (p. 3) states that "Monitoring requirements shall be established to evaluate any effects on water quality, particularly changes in species diversity and abundance ..."

This clearly suggests a *biological* evaluation of water quality.

Chapter IV, Item C (p. 9) states that "The Clean Water Grants Program shall require that the environmental impact report for any existing or proposed wastewater discharge ... shall evaluate *whether or not the discharge would enhance the quality of receiving waters above that which would occur in the absence of the discharge"* (author's italics).

Again, no definition of enhancement is given.

Definition for the City of Arcata

In October 1974, Bill B. Dendy (then Executive Officer of the State Water Resources Control Board) wrote a memorandum to David C. Joseph, Executive Officer of the North Coast RWQCB with the subject titled: Definition of "Enhancement" for the City of Arcata (California). Mr. Robert A. Storey, City Manager of Arcata, had requested a definition of the term "enhancement" along with specific criteria for demonstrating that a particular effluent would meet the definition.

Mr. Dendy's letter has been widely circulated in California in an attempt to define the policy, but to date little progress has been made in qualifying any effluent under this "definition." Mr. Dendy's letter is quoted as follows:

> "Before discussing these items, I should point out that the rationale for the establishment of the enhancement concept was provided to State Board members prior to their adoption of the policy. This rationale is to be found in pages 5-6 of Appendix A to the Bays and Estuaries Policy.
>
> "My understanding of the term enhancement as it appears in the Bays and Estuaries Policy includes: (1) full uninterrupted protection of all beneficial uses which could be made of the receiving water body in the absence of all point source waste discharges *along with* (2) a demonstration by the applicant that the discharge, through the creation of new beneficial uses or a fuller realization, enhances water

quality for those beneficial uses which could be made of the receiving water in the absence of all point source waste discharges. In short, the Bays and Estuaries Policy requires that a discharge not only provide full protection of beneficial uses which the receiving water body is capable of supporting but also yield a positive water quality benefit.

"In view of the Regional Board's detailed knowledge of particular waste discharges, it was our opinion that it would be the appropriate agency to develop specific criteria which would guarantee full protection of beneficial uses. In approaching this task you may wish to consult EPA's Water Quality Criteria, the State Board's Ocean Plan and the Health & Safety Code which identify waste constituent limits which are appropriate to the problem of protecting the beneficial uses of saline waters. In addition, Footnote 3 of the Policy provides additional guidance with respect to minimum toxicity control and effluent quality guarantees.

"While I believe that your staff could develop effluent limits which reflect what is necessary to protect beneficial uses, I also believe that it is the responsibility of the City of Arcata to provide a convincing demonstration that an identifiable water quality benefit would be realized through the continuation of in-bay disposal.

"I would suggest that as a means of resolving the Arcata issue you request the City to submit a report containing the following information:

a. Identification of those beneficial uses which they contend would be enhanced by the continuation of in-bay disposal;

b. Identification of those effluent characteristics (physical, chemical or biological) which would have a direct bearing on the beneficial uses identified in 2.a. above;

c. Information supporting the contention that receiving water conditions would not be optimum for supporting beneficial uses in the absence of all point discharges, and receiving water conditions the applicant contends would be enhanced by the effluent;

d. Proposed specific effluent characteristics which the discharger believes would enhance receiving water conditions;

e. A description of treatment facilities and cost thereof which would meet conditions identified in item 2.d.;

f. A description of alternatives and costs thereof, which would not involve in-bay disposal (items (e) and (f) would be coordinated with Division of Water Quality).

"I would then suggest that a public hearing be noticed indicating that the information provided by the applicant is on file at the Regional Board for review by interested parties. The purpose of the hearing would be to determine whether in-bay disposal should be allowed to continue based on the following considerations:

1. That there is a beneficial use which could be created or enhanced.

2. That the effluent limits proposed by the applicant would optimize conditions for the realization of the beneficial uses identified in item 1.

3. That continuation of in-bay disposal would not compromise any beneficial uses which could be made of the receiving water in the absence of any point source waste discharge.

4. That the benefits derived from a project meeting conditions one through three above, are commensurate with the incremental costs, if any, of such a project over and above alternatives which did not involve in-bay disposal.

"I believe the requirements of the Bays and Estuaries Policy would be satisfied only if these four conditions were upheld."

It should be noted that Dendy's statement appears to go beyond Footnote 3 in the Policy, which requires bioassay survival test on a *percentage* basis, whereas he stipulates "uninterrupted protection." This has in some quarters been interpreted to negate the percent survival tests, and to mean *continuous* enhancement.

Along with enforcement of percentages of time for effluents to meet standards, it seems desirable that, in semi-enclosed bays and harbors, some averaging conditions should be allowed over space. This would permit overall enhancement conditions to be evaluated, even if conditions were not as good at the point source, as would be the case at the point of discharge of fresh water into a fully marine environment.

If the general trend of the Arcata letter is followed, it becomes necessary to define two different terms; beneficial uses and enhancement.

Beneficial Uses of Harbor Waters

The application of the term "beneficial uses" has frequently been based only on human orientations; *e.g.*, the uses of harbors for commerce, transportation and industry, or recreational fisheries, body contact sports or boating.

In the Los Angeles-Long Beach Harbors, which are political jurisdictions that divide one body of water into two ports, the emphasis of the beneficial uses has changed in some ten years to reflect the concern for living marine resources as such, as well as for human activities.

An example of this sequence can be seen in documents dating from 1969 to 1978, described below.

In May 1969 the Los Angeles RWQCB listed in a review document the nine main uses of harbor waters at that time, as follows:

A. Shipping	D. Recreation	G. Cooling water
B. Anchorage	E. Fishing	H. Air washing
C. Waste disposal	F. Dry docks	I. Food handling

The document noted that the Board had enunciated the following major beneficial uses of harbor waters to be protected:

Outer Harbor Area

Shipping
Yacht anchorage
Bait fishing
Bathing, recreation and sport fishing

No mention of natural biological environment was made, except as pertains to resources for man.

In July 1972 the State WRCB adopted Resolution No. 72-45 entitled "Water Quality Control Plan for Ocean Waters of California." It gave the beneficial uses of ocean waters in general to include ... "industrial water supply, recreation, esthetic enjoyment, navigation, and preservation and *enhancement of fish, wildlife, and other marine resources or preserves* (author's italics). It further stated (Chapter IID) that "marine communities, including vertebrate, invertebrate, and plant species, shall not be degraded."

Coupled with the Bays and Estuaries Policy of May 1974, referred to previously, this is representative of the State position on beneficial uses and protection of ocean waters in general, and harbor water in particular.

In June 1978 the Port of Long Beach was the first in the State to have a Final Master Plan accepted by the California Coastal Commission. In the section on goals and objectives the first item is as follows:

> "1. The Port will seek to protect, maintain, *enhance* and restore the overall quality of the coastal environment, its natural as well as man-made resources ...
>
> ...--Preserve existing fish nursery areas and indigenous water habitats.
>
> --Maintain significant natural habitats which exist in the Port."

Enhancement and Bioenhancement

Enhancement is the improvement of some particular parameter or set of parameters according to the value system of a participant or observer.

Bioenhancement refers to a more specific set of parameters, namely to diverse organisms and their habitats. The term bioenhancement is sometimes applied according to the immediate perspectives or values of humans, such as fisheries resources for food or recreation. However, in the context of environmental quality, it should be applied as though organisms also had intrinsic values not dependent upon human value systems.

Because enhancement is the more general term, it can be applied to parameters valued by humans that are almost mutually exclusive to the intrinsic biological system. For example, completely clear water may be esthetically pleasing to seashore visitors and boaters. However, to plants and animals completely "clean," clear water represents an environment devoid of food.

Enhancement of water quality is viewed by regulatory and enforcement agencies as achievement of a given set of numerical values of such parameters as dissolved oxygen, pH, temperature, transparency and absence of chemicals or bacteria. Such "enhancement" may lose site of the fact that protection of diverse organisms is one of the basic reasons for environmental quality legislation in the first place.

The major humanistic objectives of esthetically pleasing, potable, swimmable fresh water may possibly be achieved only by having chlorinated water, reduced in nutrient content. Under these conditions, such as occur in some rivers and lakes, human value criteria are applied which make a positive choice for the needs of people for safe drinking water as opposed to organisms or habitat. The intrinsic biological values are secondary or are selected against. It therefore seems apparent that enhancement of water quality could occur while enhancement of biological quality, or bioenhancement, is being degraded or eliminated. Thus it is essential to develop criteria by which true biological enhancement can be defined.

Criteria for Evaluating Biological Enhancement

In May 1978, a California legislator requested suggestions for text that might be added to the California Bays and Estuaries Policy to define and evaluate bioenhancement. The following statement was submitted by the present principal investigator as a suggestion for further discussion and development:

> "The criteria for evaluation of enhancement shall include, but not necessarily be limited to: species diversity, and/or the presence of species with commercial and/or recreational value, and/or the presence of rare, endangered or threatened species, and/or the presence of living biomass, above that which would occur in the absence of the discharge."

Additions to the above criteria could well include species richness, presence and interaction of essential food web species, ecological diversity, or population dynamics measurements. *It should be recognized that no single criterion shall be considered sufficient to qualify as bioenhancement, but a combination of two or more might be utilized.* There are cogent reasons for not accepting one criterion alone. The inherent complexity of biological systems leaves each parameter, or the methods for measuring it, open to criticism. Also the systems are subject to development of new criteria, or new quantification techniques.

The utilization of at least two criteria would provide some assurance that the drawbacks of any given method of evaluation did not bias the conclusions unduly. The consensus of the scientists consulted by the present investigators was that bioenhancement can be defined by criteria that are quantifiable, although the biological measurements are less precise than those of physical and chemical systems.

DISCUSSION

The two sorts of bioenhancement referred to previously -- that which benefits man and that which benefits the biota with intrinsic value -- deserve further discussion. By developing criteria for evaluation it should become possible to designate the biological quality of specific areas or effluents. Quantifying biological organisms is generally not difficult, but evaluating species or communities quantitatively is far more difficult and subject to controversy than is quantifying and evaluating physical parameters. It must be remembered, however, that selection of regulatory levels for physical parameters is not an end in itself but represents an attempt to protect biological systems supported by the physical conditions.

Human Values and Intrinsic Values. Societal values for the marine biological environment are generally represented by commercially valuable species, primarily those that are prized for food, or by environments that are esthetically pleasing, such as the biologically diverse seashore.

Man tends also to value predator species at the top consumer level of the food energy cycle that actually compete with man for food; these species include whales, dolphins and sea lions as well as pelicans and other birds. It is only in relatively recent years that a portion of society has voiced the principle that worms or algae have sufficient intrinsic environmental value to deserve protection from environmental insult or outright destruction

The commercially valuable species are readily recognized, but understanding the species, community and habitat on which the commercial species depend is difficult at best and oftentimes impossible. Illustrative of this are the difficulties in developing the federally mandated Fishery Management Plans (FMP). In order to develop harvest quotas, the sustainable yields have to be calculated from knowledge of reproductive cycles, habitats and ranges and food requirements. Yet very little information could be found for some commercial species. The conservative approach to protection and enhancement thus must be that all species in a habitat may be important to some commercial crop and should therefore be valued. At this point the commercial interests merge with the intrinsic valuation of all species, but for different reasons.

Species Diversity. Several species diversity indices have been developed over the years; the Shannon-Wiener is perhaps one of the most widely used. One problem with the species diversity criterion is that diversity might be low because of man-made abuses of an area, or it might be low due to the limitations of the natural habitat. For example, where estuarine flow is intermittent, as it is in Los Angeles where rainfall is limited to a few major winter storms, the salinity changes are too rapid and too severe to be tolerated by anything except hardy, euryhaline species. Storm flow in some regions may be so strong that most plankton and nekton are carried to sea. Recolonization occurs regularly, but diversity may be very low in relation to biomass because only opportunistic species will be present shortly after the storm season. Yet there is evidence that such changes create better estuarine conditions than would stable conditions which allow a few species to dominate a community permanently. The literature is extensive on the relative merits of various methods for measuring diversity. Total numbers of species alone are often as revealing as complex calculations, however.

Presence of Species with Commercial or Recreational Value. It is easy to identify areas where commercial or recreational fisheries exist. Not so easily identified are areas that serve as spawning grounds, as juvenile nurseries, or as sources of food chain organisms essential to the large predator species of fish or shellfish. Often these elements are unknown, poorly known, or ignored.

Of particular importance is the support of the phytoplankton crops, which are the primary producers of energy (food) for so many of the marine consumer and predator organisms. Bacteria and protistans are also essential to food webs as food sources for certain invertebrates (filter feeders), and as primary agents of nutrient recycling. Yet the public, incorrectly, associates bacteria almost exclusively with terrestrial disease.

Rare, Endangered or Threatened Species. Just as is the case with the easily identified commercial species, the rare and endangered species have largely been recognized. However, the needs of the latter species may be even less well known than the food chain and habitat requirements of commercial species. Threatened species may not be recognized as such when they are a few steps from the endangered or rare classification. The turning point may be when a population decreases until it is too scattered to breed *en masse*, even though substantial numbers of animals still exist. So many factors are unknown, that it is essential to give close attention to those factors which can be identified as to species and populations.

A case in point is the Northern Anchovy, which has declined drastically off southern California since 1975. Is the decline due to a change in eastern Pacific water temperatures; is it due to intensive commercial fishing in a few areas, which separated the large breeding populations; or is it due to a reduction in terrestrial nutrient flows which have in turn reduced phytoplankton and zooplankton densities in inshore waters, densities on which the tiny larvae depend? Or is it due to a combination of these or other, unidentified factors?

A parenthetical question may be asked as to why nutrients of terrigenous origin that are digested aerobically and anaerobically in deep canyons in the ocean and then brought to the surface by upwelling are considered "good," while the same kinds of nutrients delivered from outfalls are considered "bad." At the present time very costly experiments are simulating upwelling offshore by pumping nutrients up from deep canyons to nourish transplanted kelp beds off the southern California coast, for potential methane production when harvested. Yet non-toxic nutrient wastes are being regarded as hazardous to the environment and subjected to expensive secondary waste treatment requiring land disposal of sludge.

Biomass. Biomass is a valuable, quick indicator of the presence and quantity of life in a given locality, but since the measurement gives no hint of the quality of living material, size of individual organisms or identifiable ecological role, the criterion taken alone is not a good one. In stressed environments it has long been recognized that large numbers or weights of one or a few species that are extremely tolerant, opportunistic or rapid reproducers, may be present. The lack of diversity is considered to be a fault -- unless, of course, that biomass happens to represent clams or oyster beds!

Richness. While the usual species diversity indices consider both numbers of species and numbers of individuals, richness emphasizes numbers of species. Habitat diversity is generally essential to species diversity because of the variety of microenvironments it provides. Thus, for example, a silty-bottomed estuary with unconsolidated sediments eliminates many invertebrates that require solid substrate or cannot tolerate turbid, silty water. Such a soft bottom is, however, ideal for filter-feeding worms and the flatfish that feed on them. Also, measurement of habitat diversity according to species diversity might suggest to some that rocky shore intertidal habitats were the best and that soft-bottomed bays and estuaries should therefore be considered undesirable.

Evenness. In some instances, species diversity may be high, but only one or a few species may provide a very large percentage of the individuals. This is considered to be less desirable than a more even distribution of numbers among the species or among the higher taxa present. While some of these points may seem obvious, it should be clear that there are several criteria that can be selected to evaluate for determination of biological enhancement.

RELEVANCE

The above excerpt from Soule and Oguri (1979) remains relevant to examination of the role of waste effluents in Los Angeles-Long Beach Harbors, and to the investigations reported in the preceeding sections, for 1981-1982.

I

EVALUATION OF ALTERNATIVE FORMULATIONS AND EFFLUENT SIMULATIONS IN AN ECOLOGICAL MODEL OF LOS ANGELES HARBOR RECEIVING WATERS

by

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INTRODUCTION

Objective

The main goal of this study was to investigate, by use of an existing computer simulation model of the harbor, the ecological consequences of diverting fish cannery wastes from secondary waste treatment in the Terminal Island Treatment Plant (TITP) to a co-mingled direct discharge into Los Angeles Harbor of pre-treated cannery waste and secondary treated urban wastes. In order to meet this objective it was necessary to develop a modified version of the model which would produce results that were consistent with the results of data from a limited field sampling program (presented as Appendix A, following this section) and other relevant historical field data. This model was then used to simulate the following:

a) average present conditions (The Standard Run);

b) conditions for specific dates, using actual field data;

c) conditions for seasonal extremes; and

d) a variety of scenarios for direct discharge by the canners.

Background

Prior to the construction of secondary treatment facilities at TITP, process and non-process wastes from the canneries were discharged directly into outer Los Angeles Harbor in an area near the TITP primary treatment outfall. The oxygen dynamics associated with this effluent were the subject of a preliminary model study which was limited to the region within 800 meters of the cannery discharge (P. Kremer, 1978). For the past few years, however, the cannery processing wastes have been subjected to secondary treatment along with urban wastes at TITP, which has served to oxidize the wastes and lower the BOD (biochemical oxygen demand) associated with the discharge.

With the conversion of TITP to secondary treatment, a more comprehensive computer simulation model was developed for the harbor receiving waters (Kremer and Kremer, 1980). This model consisted of 300 computation grids, each 650 m on a side, representing the Los Angeles-Long Beach Harbor (Fig. 1). A harbor configuration representing the Phase 1 Landfill, which has not been constructed, was obtained by omitting three grids. Appropriate velocity coefficients for tidal mixing for both the filled and unfilled configurations were based on a hydrodynamic model for tidal circulation in the harbor (Chiang, 1979).

Formulations used in the 1980 ecological model included the major processes thought to be the most important in the planktonic system. The standing crop of phytoplankton was a function of light, nutrients, zooplankton grazing, and circulation. Nutrient levels were controlled by effluent loading, phytoplankton uptake, regeneration of ammonium by the benthos, and circulation. The oxygen dynamics were based on the earlier model of oxygen (P. Kremer, 1978) and included the effects of effluent loading, phytoplankton production, air-water diffusion, benthic respiration, and circulation (advection). The results of the 1980 model focused primarily on projections for phytoplankton and inorganic nutrients; oxygen was a minor consideration therein because secondary treated effluent (with low BOD) was used as input for the effluent discharge.

PRESENT STUDY

Previously, the ecological simulation model of Los Angeles Harbor had been compared with existing field data only in a general way. No attempt was made to validate the model further relative to field samples, and make appropriate modifications to "tune" the model to reality. Therefore, field sampling on two dates was included as part of this study to provide ground truth data on dissolved oxygen, phytoplankton standing stock, and nutrients. Measurements were also made of values for 5-day BOD and the assocated oxidation rate. Field and laboratory results are presented and discussed in Appendix A, at the end of this section (Tables and Figures have the prefix "A") rather than interspersed with the figures showing the results of the model runs. This organization was chosen for two reasons;

1) to avoid a potential confusion between field and model results;
2) to avoid, because of the very limited scope of the field program, undue emphasis on these two particular dates.

In evaluating the results of the model other relevant historical data have been considered as well and are discussed.

Since a detailed description of the ecological simulation model already exists (Kremer and Kremer, 1980), the original formulations will not be included here as well. A few modifications of the original model, however were made as a part of the study. The original model results predicted very high standing stocks of phytoplankton and correspondingly low levels of inorganic nitrogen. Although the phytoplankton standing stocks were estimated to be two to four times higher than typical averages for the harbor during 1976-1978 (Soule and Oguri, 1979), these results were assumed to represent the potential extremes which might be achieved during bloom conditions (Soule and Oguri, 1980).

The following modifications were made to the formulations to bring the predictions of the model more in line with field observations:

Maximum Growth Rate

Studies of phytoplankton production in the Harbor (Allan Hancock Foundation, 1976; Soule and Oguri, 1976; 1979; 1980) had always been conducted in incubators under conditions using modified methods of Steeman-Neilsen (1952), where light was limiting to productivity and growth. Thus, these results underestimate the maximum in situ rates, although they may have been close to water column averages. The model originally used a formulation for the maximum growth rate of phytoplankton (in the absence of light or nutrient limitation), based on the work of Eppley (1972), and coupled with light and nutrient limitation terms. In modifying the model for the present study this rate was cut to 50 percent for all temperatures. Although a somewhat arbitrary choice, the revised growth coefficients produces levels of phytoplankton which were substantially reduced and more comparable to field observations. The reasons are not clear why the growth rate of phytoplankton should be lower in the harbor relative to measurements of Eppley (1972). Sewage has been found to inhibit carbon and nutrient uptake (MacIsaac et al., 1979), but the simulated concentration in all our model grids were below the experimentally measured threshold.

Benthic Grazing

Benthic grazing was originally omitted from the model, although oxygen consumption and ammonium regeneration by the benthos were included, based on available literature values. In the present model modification, benthic grazing was included. The formulation was based on a filtration rate equivalent to 3 clams per square meter, derived from a variety of published sources (cited in Kremer and Nixon, 1978).

The effect of benthic grazing was not as dramatic as the decreased maximum growth rate, but it helped contribute to a lower standing stock for phytoplankton.

Benthic Oxygen Consumption

Data on benthic oxygen consumption has never been published on undisturbed sediments with intact fauna in the Los Angeles Harbor. Values used in the original model were based on unpublished measurements for Colorado Lagoon near Alamitos Bay in Long Beach and a variety of published data (cited in Kremer 1978, Table 3). Since the oxygen predictions of the original model were chronically low relative to measured values, the rate of benthic oxygen respiration was reduced to 50 percent of the original value. The coefficient for ammonium regeneration was left unchanged.

Biochemical Oxygen Demand (BOD) Oxidation Rate

The BOD oxidation rate was calculated, based on the results of laboratory measurements of the BOD over time at both 15 and 20°C. In this study, the oxidation rate averaged 0.36 per day (d^{-1}) (BOD time series data are given in Appendix A) as compared with 0.48 per day (d^{-1}) from earlier results (Kremer, 1978). In general the water samples from the present study had very low 5-day BOD values (< 2 mg/l) so the oxidation rates derived from the samples were used only for model simulations for similar conditions. For all runs simulating the direct discharge of cannery wastes and comparison baseline conditions, the value of 0.48 per day was used because it was derived from waters with a higher BOD loading when direct discharge was occurring, and it is more appropriate for the projected conditions.

Effluent Discharge

Input conditions of the model were updated to reflect the actual average secondary treated TITP effluent composition, including cannery wastes, and flow rate from September 1981 through March 1982 (Tables 1, 2). Loadings of BOD, ammonium, and nitrate plus nitrite were calculated for the two specific sampling dates (8 Dec 1981 and 24 Feb 1982) in addition to the six month TITP averages (Table 3). The high variability in ammonium discharge is obvious when the tabular data are presented graphically (Fig. 2). Nitrate and organic nitrogen were also extremely variable but were only infrequently measured (Table 1). On 8 Dec 1981, TITP was in NPDES compliance for Total Suspended Solids (TSS) at about 9000 lbs da^{-1} and BOD about 4000 lbs da^{-1}. On 24 Feb 1982, TITP was under the permit limit of 12,500 lbs da^{-1} (TSS) at about 11,500 $\pm$ lbs da^{-1} but BOD was about 14,5000 lbs da^{-1}, over the permit limit of 10,000 lbs da^{-1}.

RESULTS AND DISCUSSION

The Modified Standard Run

The conditions of the Standard Run were intended to repesent average conditions in the harbor. Changes in the coefficients from the original model are summarized in Table 4. All other values used in the Modified Standard Run were identical to those of the original Standard Run (Table 3 in Kremer and Kremer, 1980).

Starting from arbitrary and uniform conditions for nutrients and phytoplankton standing crop, the model was run for a simulation time of fourteen days using the modified standard input. The output of this preliminary run was then used as input for all subsequent runs. This procedure was designed to minimize the effect of the initial conditions on the results. All simulations were run for a period of two weeks on the original fourteen day background.

Phytoplankton. In this model, phytoplankton biomass was expressed in terms of the nitrogen content (Fig. 3). For comparison with standing stocks measured as chlorophyll, these numbers should be multiplied by two. The results of the model were comparable to, although slightly higher than, stocks that were actually measured on the sampling dates (Figs. A4, A13), and during the winter and spring of 1977-1978 (Soule and Oguri, 1980, Section IIIA).

Nitrogen. In the Modified Standard Run nitrate values were predicted to range from about 4 ug-at N per liter (l^{-1}) outside the breakwater to more than 7 near the TITP discharge (Fig. 4). These results were slight underestimates of the surface patterns observed in the field on 8 December (Fig. A5) and slight overestimates of values measured on 24 February (Fig. A14). When the total water column is considered, however, (Tables A1, A4) and not just the surface values, the agreement is better. There were complex patterns observed for nitrate from winter-spring 1977-1978 (Soule and Oguri, 1980, Section IIB) which demonstrated roughly comparable results if the influence of the Los Angeles River is ignored.

Ammonium concentrations predicted by the Modified Standard Run of the model (Fig. 5) also predicted an onshore-offshore gradient, which was reflected in one of the sampling dates (Fig. A15). Measured values and model predictions for the outer Los Angeles Harbor were generally above the half saturation constant used in the model (K_s = 2.0 ug-at N l^{-1}), indicating that for these conditions nutrients were not limiting the growth of phytoplankton. The results of the field sampling were quite comparable to the 1977-1978 samples during winter and spring (Soule and Oguri, 1980, Section II).

BOD. In the Modified Standard Run, the addition of BOD in the effluent added only a trivial loading (Fig. 6) to the normal ambient levels. These results are consistent with sampling from 24 February when the BOD levels were nearly uniform throughout the outer harbor except right at the discharge site (Fig. A12). The small but consistent increase in BOD observed on 8 December did not agree with the model, however (Fig. A3). Part of the discrepancy might be due to stratification. Both chlorophyll (Fig. A4) and nitrate (Fig. A5) were appreciably higher in the surface waters in the same region where the higher BOD was observed.

It must be reiterated that the results of the model give vertical averages only, and therefore would not reflect occurrences observed only in the surface waters. In addition, it is important to note that BOD is the result of several complicated chemical and biological processes happening simultaneously. In the model, the amount of BOD measured in the effluent (Tables 2, 3) is simply diluted by the appropriate amount as it is discharged into the receiving waters. But there may be important synergistic biological or physical effects which might occur that alter (either increasing or decreasing) the BOD slightly from this predicted value.

Oxygen. The model predicted values of dissolved oxygen about 7 mg l^{-1} (Fig. 7) while measured values were appreciably higher (Fig. A2, A11).

This difference does not appear to be due to stratification since on both sampling dates the oxygen profiles did not generally measure appreciably higher oxygen concentrations in the surface waters (Tables A2, A5; Figs. A9, A18). It is likely that the formulations used to describe the oxygen dynamics in the model are more conservative than the real processes in nature, therefore underestimating the values. This is not considered to be a real weakness since low oxygen episodes are undesirable, and to be safe, model predictions should err on the low side.

Simulations of Specific Dates

Two simulations were run to try to duplicate conditions of the two sampling dates. Day length was adjusted to 10.5 hours (instead of 12 hours from the Standard Run) and the BOD oxidation rate was made 0.36 d^{-1} to correspond to actual field observations (see Appendix A at end of section I). Effluent discharge rates and composition appropriate to these dates were also used (Table 3). Although results for phytoplankton and oxygen were nearly identical for these two runs, interesting differences were seen for nitrate, ammonium, and BOD. The nitrate levels were higher in the 8 December run (Fig. 8a) relative to 24 February (Fig. 8b). These patterns were consistent with the field data (Fig. A5, A14); however the TITP plant was not in NPDES permit compliance for BOD on the February date (Table 1).

Model predictions using date-specific loading for ammonium (Table 3) reflected differences in the loading on the two dates (Fig. 9a, b). These differences, however, were not clearly reflected in the results of the field samples (Figs. A6, A15). Some of the discrepancy between the model predictions and the observed data may be due to the variable concentration of the ammonium in the TITP discharge (Table 1 and Fig. 2). The model used a fixed value for the entire fourteen day simulation, while the actual effluent loading may have been fluctuating more than ten-fold, further complicating an already complex ecological system. In addition, nutrients in runoff water and sources other than sewage effluent and benthic regeneration are not included in the model. Patterns predicated by the model are more likely to represent longer-term averages rather than reflecting the daily fluctuations.

Although small, the model predicted larger BOD increases on 24 February than on 8 December (Fig. 10a, b). These differences are probably less than the resolution of the BOD test procedure and replication of the samples, and are inconsistent with the field data for the dates. As discussed earlier, stratification may have played some role for the observed pattern on 8 December, and the model may handle this variable too simplistically.

Seasonal Simulations

As with the original model (Kremer and Kremer, 1980), the modified model was run to simulate conditions of temperature and light for winter and summer (Table 5). Effluent loading remained equivalent to the standard run, although the exact discharge for each time block had to be altered slightly because of differences in day length. Phytoplankton standing stocks (Fig. 11a, b) were predicted to be much lower in the winter relative to the summer. This pattern was not consistently observed in historical data.

Nitrate levels were predicted to be virtually identical for the two seasons (Fig. 12a, b), while ammonium values were much lower in the summer than in the winter (Fig. 13a, b). The seasonal differences for the two forms of nitrogen is linked directly to the preferential uptake of ammonium by phytoplankton (MacIsaac and Dugdale, 1969). Comparison with historical data for inorganic nitrogen was complicated by the difficulties with the secondary treatement at TITP during 1978).

Oxygen values predicted by the model had fairly uniform distributions for the outer harbor. In the winter, oxygen levels were about 7.5 mg $O_2 l^{-1}$ while in the summer the values were around 6.9 $O_2 l^{-1}$. Part of this difference would be due to the influence of temperature on the levels for oxygen saturation. In addition, oxygen consumption by the benthos is greater at high temperature. Data from 1977-1978 winter and summer did not demonstrate a similar trend (Soule and Oguri 1980, Section 11). If anything, oxygen values in the summer were higher than winter ones, perhaps due to production by phytoplankton.

Direct Discharge of Cannery Effluent

In order to be able to assess fairly the effect of direct discharge of the cannery effluent, it was necessary to establish baseline discharge data for the TITP in the absence of cannery loading. During the period 25 April to 3 May 1982 the Star-Kist Cannery was not discharging waste to TITP and the flow was reduced through 10 May, but Pan Pacific was discharging. Values for flow rate and composition were calculated from TITP records for this period (Table 6). Differences with the six month average (Table 3) were as follows:

1) the flow rate was about 4-5 MGD lower;
2) BOD levels for the last 10 days without cannery discharge were only slightly more than half the six month average;
3) ammonium levels (based on measurements for three days) were about

two thirds the concentration for the six month average;

4) the single nitrate measurement for this period was nearly double the six month average.

There was also reduced loading of organic nitrogen, reported as Kjeldahl nitrogen (based on a single measurement and not listed in Tables 3 or 6).

Results of a model simulation using these "baseline" estimates for TITP effluent were generally very similar to the results of the Standard Run. Predicted levels for phytoplankton and oxygen were identical and ammonium was within 10 percent. Only the nitrate and BOD results showed any appreciable difference (Fig. 14). The low level of BOD contributed by TITP was reduced further by 50 percent (Fig. 14b), while nitrate increased 10-30 percent (Fig. 14a). Flow rate and BOD are monitored daily by Star-Kist for effluent from their two plants and reported monthly to the City of Los Angeles. For the period July 1981 - June 1982 the combined average daily discharge was 1.7 MGD with an average level of BOD of about 1000 mg l^{-1}. This included only the so-called "process" water. If the canneries were to discharge their wastes directly into the harbor, the effluent would be a combination of process and non-process water. The flow rate of this discharge has been calculated to be about 6 MGD with a 5-day BOD level of about 400 mg l^{-1} for Star-Kist and Pan Pacific combined (personal commumication J. Naumann). The nitrogen content of the cannery wastes has not been measured routinely.

As part of earlier studies when canneries were discharging directly into the Harbor, the ammonium concentration of the effluent was measured by Harbors Environmental Projects to be about 500 ug-at l^{-1} while there were only low levels of nitrate (data part of survey reported by Soule and Oguri, 1979, Section I). This value for ammonium was used for a series of runs evaluating a range of cannery discharge rates (Table 6). Nitrate loading was assumed to be trivial.

In general, the cannery effluent had only a small effect on the predictions of the model, so the discussion of the results will be confined to a maximum loading of 10 MGD. Neither phytoplankton standing stock, nor nitrate, showed any appreciable change. There was a predicted increase in the ammonium concentration (Fig. 15) due to increased loading from the canneries, but the levels were only slightly greater than the results of the standard run (Fig. 5). As a result of slightly increased levels of BOD (Fig. 16) the oxygen levels were prediced to be slightly lower but only by a few tenths of a mg l^{-1} (Fig. 17a, b). One run attempted to simulate a "worst case" situation, where cannery effluent was not discharged continuously, but came out during the daytime only, while the precessors were operating. In this case, the increased daytime rate equivalent to a 14 hour discharge of 10 MGD about doubled the predicted BOD concentration near the discharge, but this still resulted in a fairly small change in oxygen (Fig. 17c).

CONCLUSIONS AND INTERPRETATIONS

If the results of the simulation model were assumed to be completely accurate, direct discharge of even 10 MGD cannery effluent would be expected to have little or no effect on the plankton, nutrient chemistry, or dissolved oxygen. The nutrients and BOD would be quickly assimilated by the receiving waters producing no dramatic changes.

There are, however, major limitations of this ecological model which need to be considered:

a) The size of the grid is large, 650 m on a side, so small-scale horizontal gradients are not detectable.

b) The elements of the model are depth-averaged so periods of stratification cannot be treated precisely, and surface events may be underestimated. BOD loading, which would be predicted to be trivial according to the model, might result in increased oxygen stress during stratified conditions. Stratification commonly occurs during summer months when surface waters are warmer, and therefore lighter than the underlying water. Because of these stratified conditions, phytoplankton standing stocks can be increased in the surface water, increasing the demand for nutrients in this layer. If the supply of nutrients is greater to the surface waters than at depth (for example by an effluent with decreased salinity), then neither light nor nutrients would limit phytoplankton in the way currently treated by the model.

c) The mixing model does not include the effect of wind, which has been demontrated to have a rapid and dramatic effect on the distribution of nutrients in the surface waters (Oguri et al., 1975; Dugdale, personal communication). The interaction of wind with circulation is something that might be treated empirically in a future modification of the circulation model, if the model were ever applied in a real management sense. Under the prevailing southwest winds, mixing would be enhanced in the normal outer harbor gyre (Soule and Oguri, 1978, Section II); under occasional "Santa Ana" conditions, strong winds from the north or east cause the gyre to be disrupted, with a possible alternation in mixing.

d) Advection is critical to the dispersal rates and patterns. The physics drives the biological system according to the substances dissolved and suspended in the water column. Although the circulation model was derived from a state-of-the-art physical mixing model (Chiang 1979), it was developed based on theoretical principals and is untested in the field. The general circulation pattern seems reasonable when compared with available results from hydraulic models (McAnally, 1975; Soule and Oguri, 1980; see also Kremer and Kremer 1980, for further references) and field data (Soule and Oguri, 1972; Robinson and Porath, 1974). Specific field verification of the circulation model is lacking, however.

e) The pathways and dynamics of organic effluent are not well understood for the harbor receiving waters. The model treats this organic matter simplistically as "BOD" and emphasizes the oxygen uptake associated with its breakdown.

In spite of these limitations, the model is derived from the best available data and uses well accepted formulations for the plankton, nutrient, and oxygen dynamics. The results of these simulations indicate that the harbor receiving waters can accommodate the direct discharge of cannery effluent at the 1981-1982 operating level along with the TITP discharge at the same site without seriously affecting the average level of oxygen in the harbor. Due to the limitations of the model, these results necessarily can only be considered as indicative that the harbor can assimilate direct cannery discharge, but the results are not absolute. If the cannery discharge is redirected from the TITP, it would still be advisable to have appropriate environmental monitoring to check periodically that low oxygen episodes do not occur.

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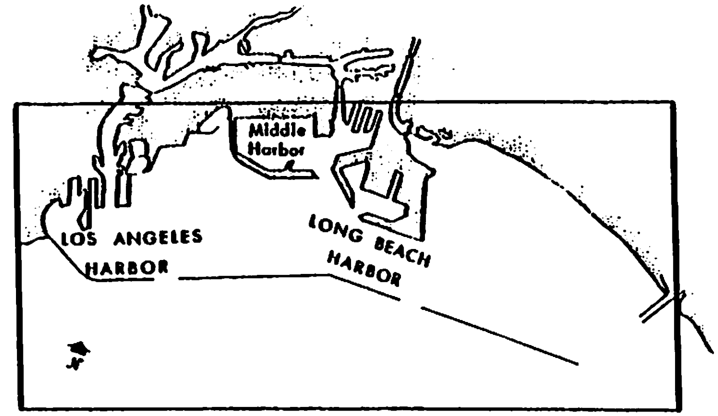
Figure 1. Map depicting the 300 spatial grids used in the model to represent the Los Angeles-Long Beach Harbors and adjacent offshore waters. Each grid square is 650 m on a side and the average depth in feet at mean lower low water (USGS Chart #5148) is designated for each. Dashed grids indicate the location of the Phase I fill.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14				33.0				12.0		26.6	45.2	46.4		60.0	46.1
13				33.0			16.0	17.3		37.3	45.4	45.1	47.9	49.5	
12				33.0		12.3	19.9	22.5	23.0				60.0		52.2
11				33.0		20.4	25.0	22.8	29.1	44.7	37.5	41.6	51.2		54.9
10		8.3	37.0	33.0	18.6	26.9	30.4	32.1	33.3	48.4	50.4	47.7	59.6	54.1	46.8
9		28.5	44.0	41.8	36.6	37.8	39.8	38.7	40.5	46.8	55.4	69.3	70.5	65.1	58.4
8			42.4	42.3	41.8	43.2	42.7	44.6	46.8	46.9	49.8	60.4	61.8	62.4	63.3
7	36.9	39.8				46.0									
6	71.2	62.4	57.0	57.9	56.1	50.1	51.4	55.9	56.3	53.2	52.1	52.7	53.5	52.8	52.7
5	98.0	77.6	75.9	71.2	61.1	58.6	59.9	61.9	63.1	60.4	58.3	57.7	57.8	56.4	56.7
4	109.	89.4	87.5	84.0	73.9	77.3	65.6	64.1	71.0	71.2	69.8	64.6	61.8	63.5	58.3
3	108.	92.0	90.8	85.4	81.2	79.8	70.5	68.0	75.9	77.8	75.2	73.0	69.8	66.6	67.0
2	113.	99.0	92.5	85.4	83.4	81.0	74.2	70.7	74.8	77.7	78.4	77.7	73.7	72.7	70.0
1	114.	95.3	81.6	84.5	82.4	77.4	76.8	74.0	78.0	77.7	78.2	78.8	76.0	74.0	72.9

	16	17	18	19	20	21	22	23	24	25	26	27	28	29
14														
13			43.8	25.8	22.4									
12			37.6	34.8	30.5	20.7	22.7							
11	48.7		42.3	34.3	33.3	26.8	26.5	23.3	21.0					
10			46.8	39.0	37.4	31.2	29.9	26.7	23.3	18.8				
9	47.0	47.0	49.7	43.9	43.4	35.5	33.6	28.9	26.8	21.2	16.5			
8	53.1	50.8	54.5	47.0	47.0	40.6	37.3	32.8	35.6	23.6	19.0	12.0		
7	55.8	54.7	57.0	50.8	51.6	44.4	41.2	37.2	35.6	28.0	23.6	15.6	15.0	
6		60.0		54.0	53.0	50.0	45.2	41.3	40.0	34.4	28.0	23.0		
5	57.2	58.8	57.0			52.0	49.4	42.5	44.3	37.5	34.3	28.0	16.0	10.0
4	61.2	60.4	58.7	58.6	57.8				49.0	42.8	39.5	34.0	22.7	16.0
3	65.8	63.9	61.7	61.0	60.4	56.6	55.6	51.5		41.0	42.0	38.3	29.2	24.4
2	69.7	68.3	65.8	64.3	63.4	62.2	58.5	55.0	50.0	49.0	48.5	41.7	39.0	30.8
1	72.4	72.3	69.8	67.6	66.5	65.3	66.5	59.0	55.0	52.3	50.5	48.5	44.0	35.5

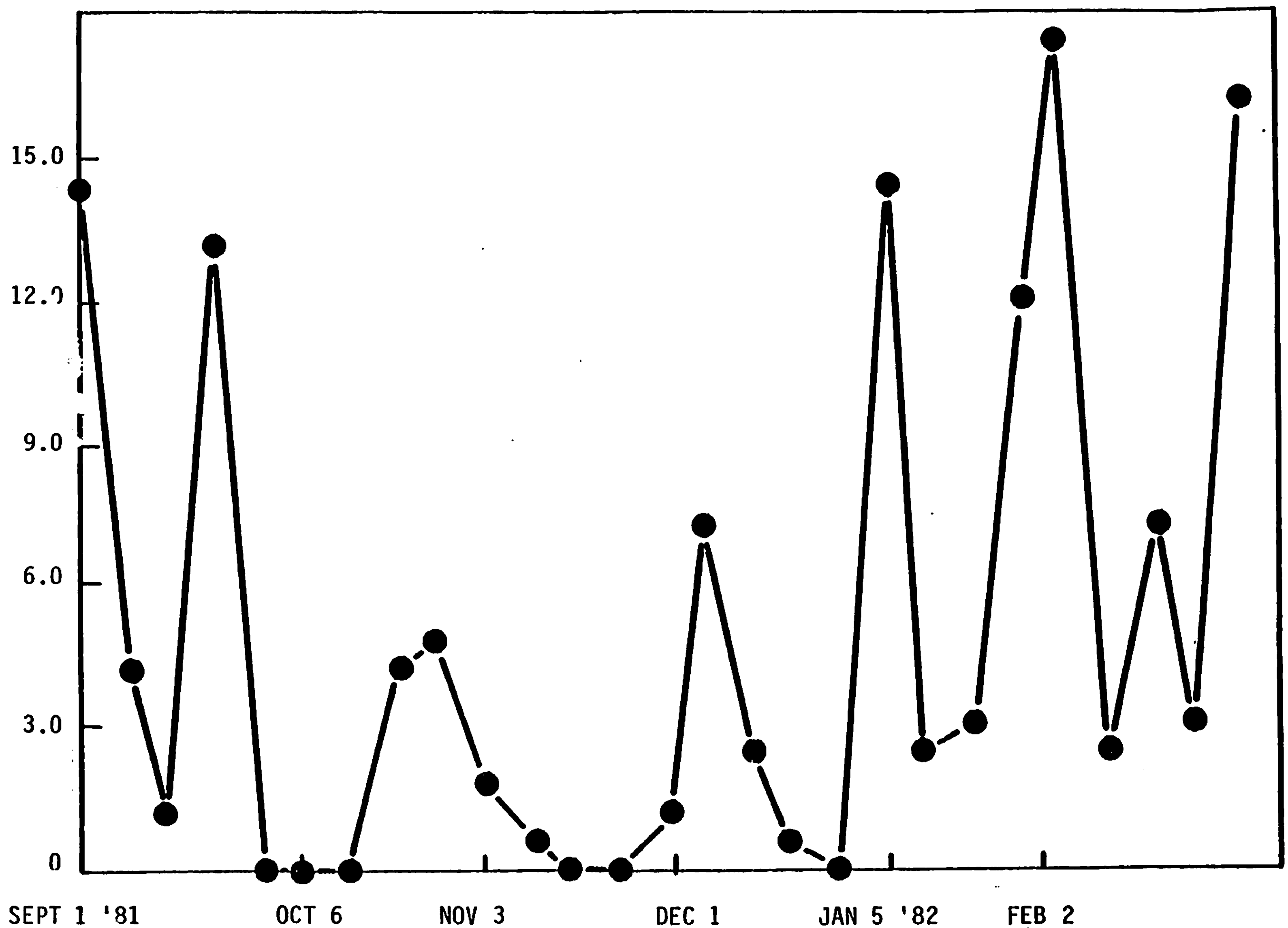


Figure 2. The Ammonium Concentration ($mg\ N\ l^{-1}$) in the TITP Effluent Varied Dramatically Through Time

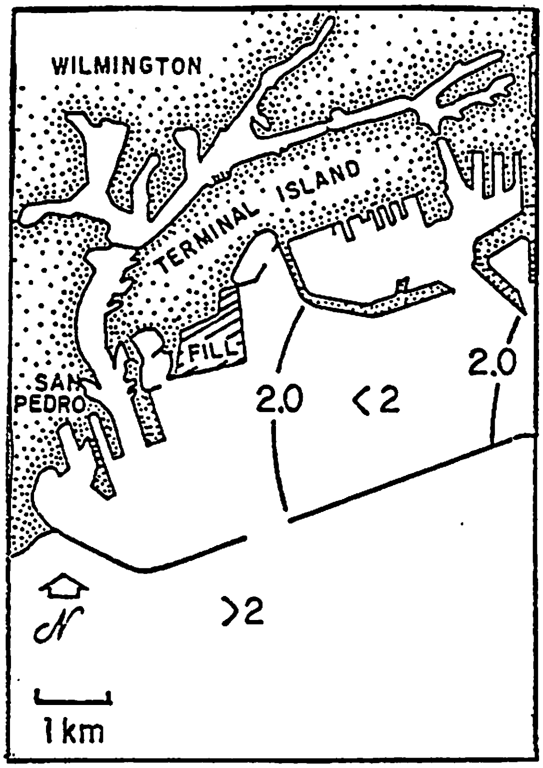


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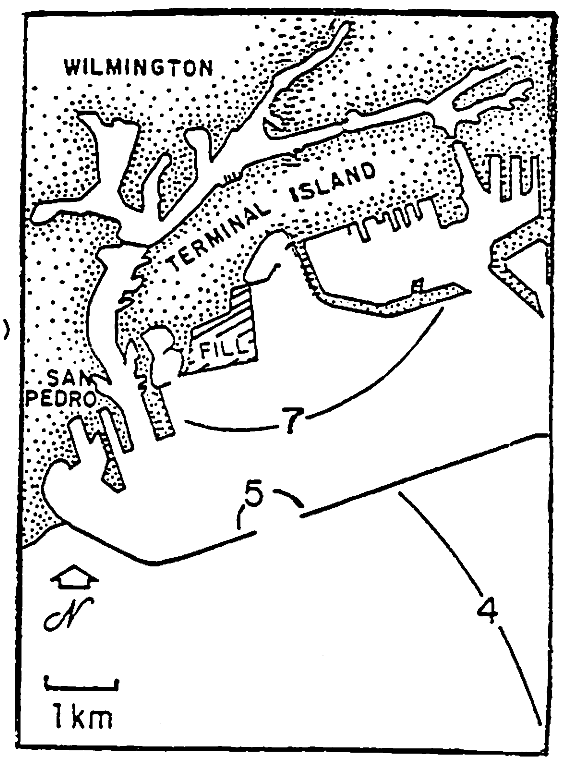
FIGURE 3. THE RESULTS OF THE MODIFIED STANDARD RUN OF THE MODEL EXPRESSED PHYTOPLANKTON STANDING STOCKS IN NITROGEN UNITS (μg-$at\ N\ l^{-1}$).

RIGHT:

FIGURE 4. THE NITRATE LEVELS (μg-$at\ N\ l^{-1}$) OF THE STANDARD RUN OF THE MODEL PREDICTED DECREASING CONCENTRATIONS OFFSHORE FROM THE TITP DISCHARGE SITE.



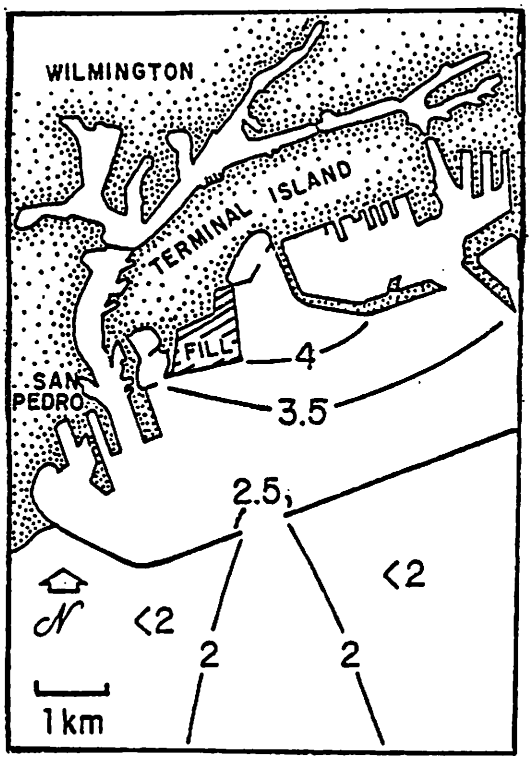


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FIGURE 5. THE AMMONIUM CONCENTRATIONS (μg-$at\ N\ l^{-1}$) PREDICTED BY THE STANDARD RUN OF THE MODEL GENERALLY PARALLELED THE NITRATE PATTERNS.

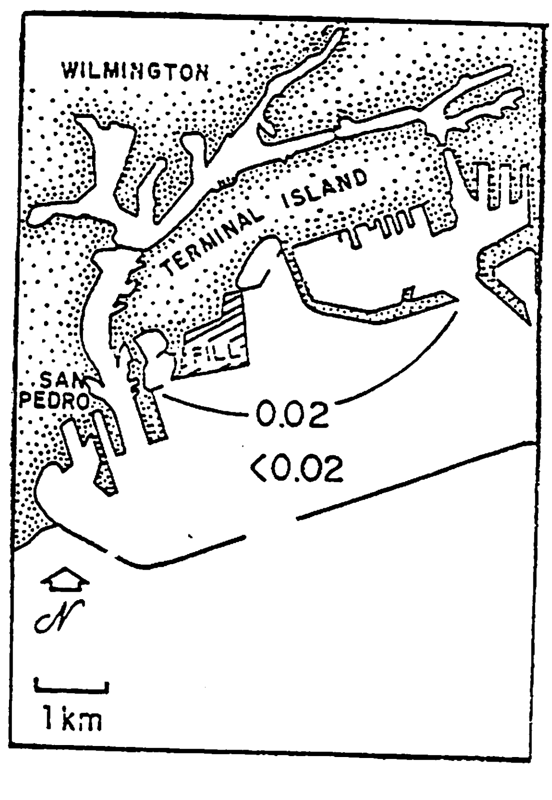

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FIGURE 6. ONLY VERY SMALL INCREASES IN THE BOD ($mg\ O_2\ l^{-1}$) WERE PREDICTED BY THE STANDARD RUN OF THE MODEL.

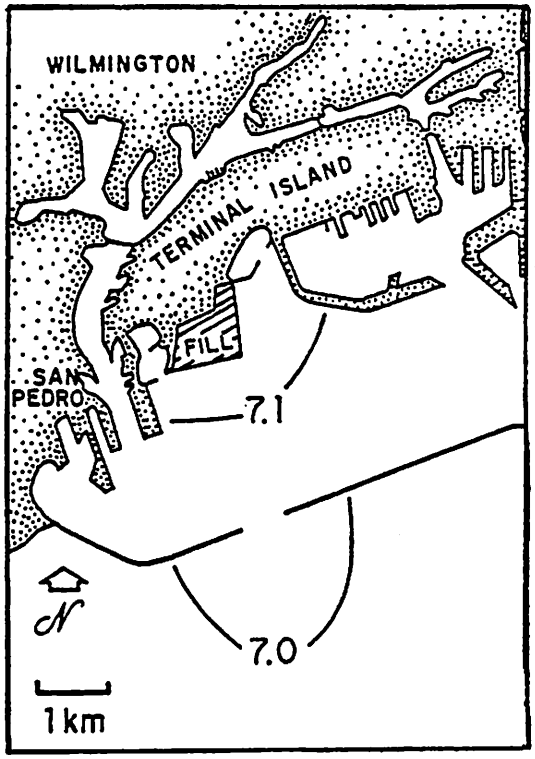


FIGURE 7. THE OXYGEN CONCENTRATION ($mg\ O_2\ l^{-1}$) PREDICTED BY THE STANDARD RUN WAS NEARLY UNIFORM FOR THE OUTER LOS ANGELES HARBOR.

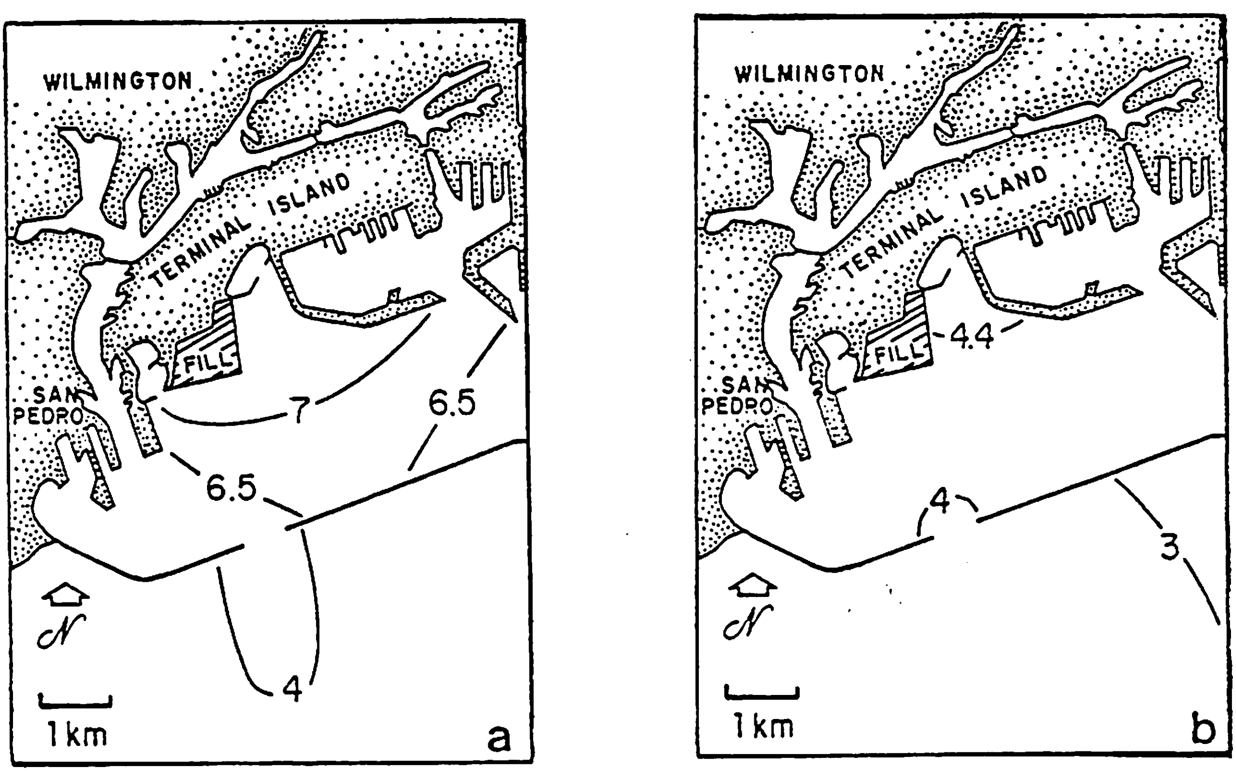


FIGURE 8. PREDICTED CONCENTRATIONS OF NITRATE ($\mu g\text{-}at\ N\ l^{-1}$) FOR 8 DEC. (A) AND 24 FEB. (B) REFLECT DIFFERENCES IN THE NUTRIENT LOADING AND ARE CONSISTENT WITH THE SAMPLING RESULTS FOR THESE DATES.

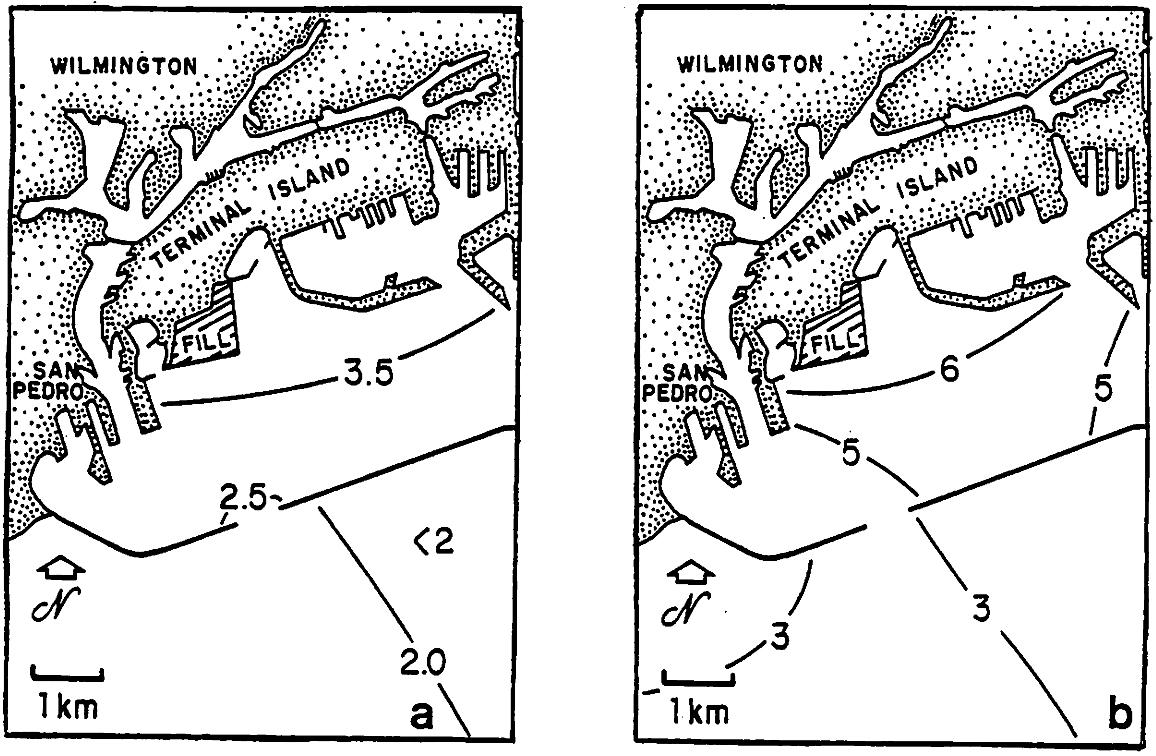


FIGURE 9. PREDICTED CONCENTRATIONS OF AMMONIUM (µg-at N l^{-1}) FOR 8 DEC. (a) AND 24 FEB. (b) REFLECT DIFFERENCES IN THE NUTRIENT LOADING, BUT DO NOT REPLICATE RESULTS OF FIELD SAMPLING.

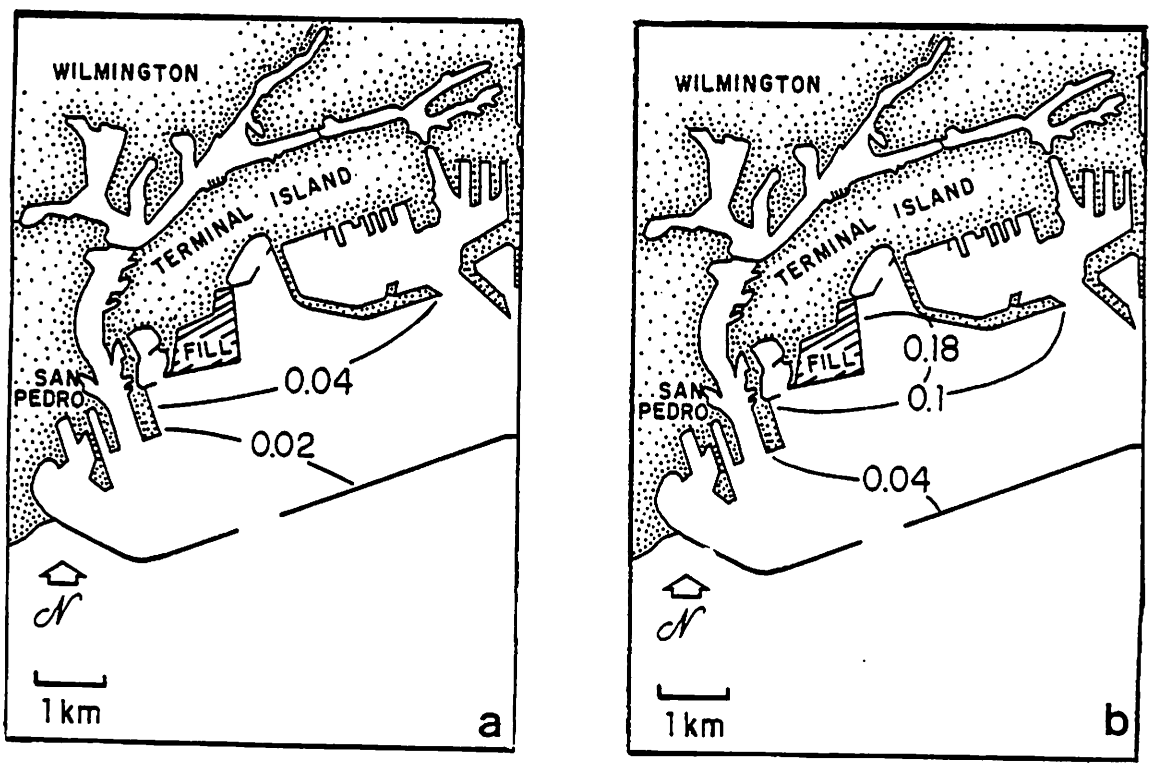


FIGURE 10. PREDICTED INCREASES IN BOD (O_2 l^{-1}) FOR 8 DEC. (a) AND 24 FEB. (b) REFLECT DIFFERENCES IN NUTRIENT LOADING, WHICH ARE NOT DEMONSTRATED IN THE FIELD DATA.

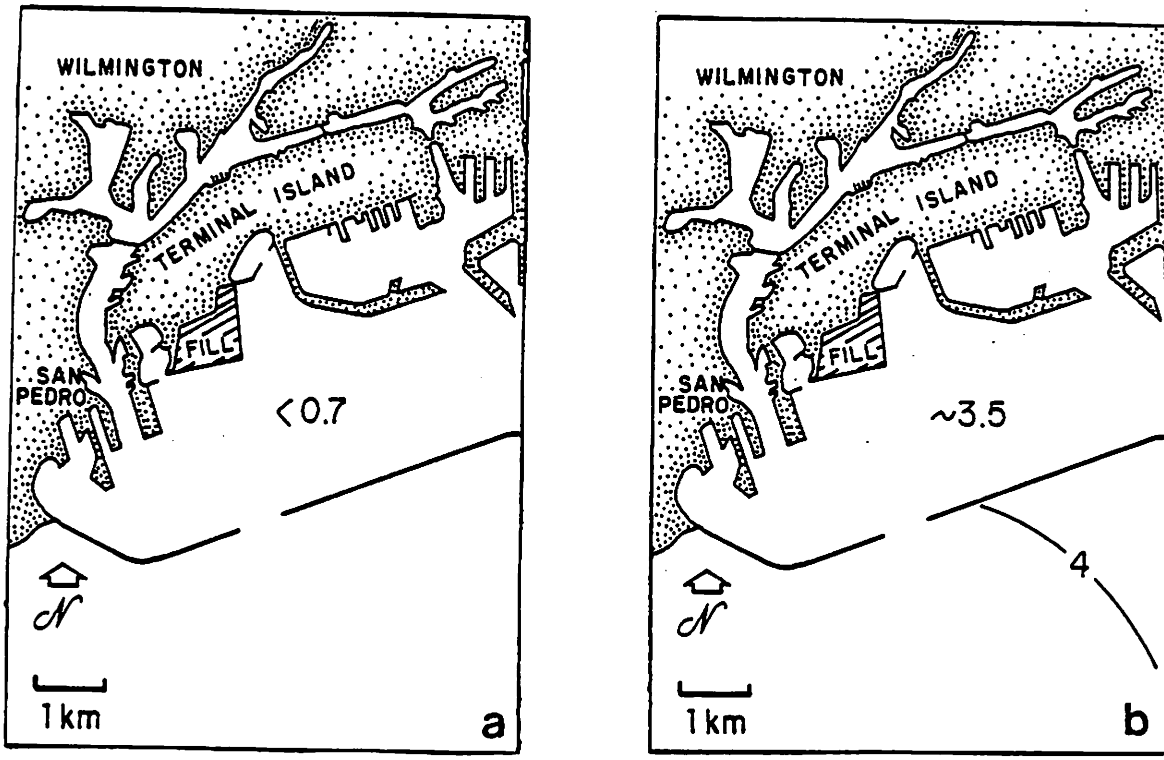


FIGURE 11. SIMULATIONS FOR WINTER CONDITIONS (a) PREDICTED MUCH LOWER PHYTOPLANKTON STANDING STOCKS (μg-at N l^{-1}) THAN FOR SUMMER CONDITIONS (b).

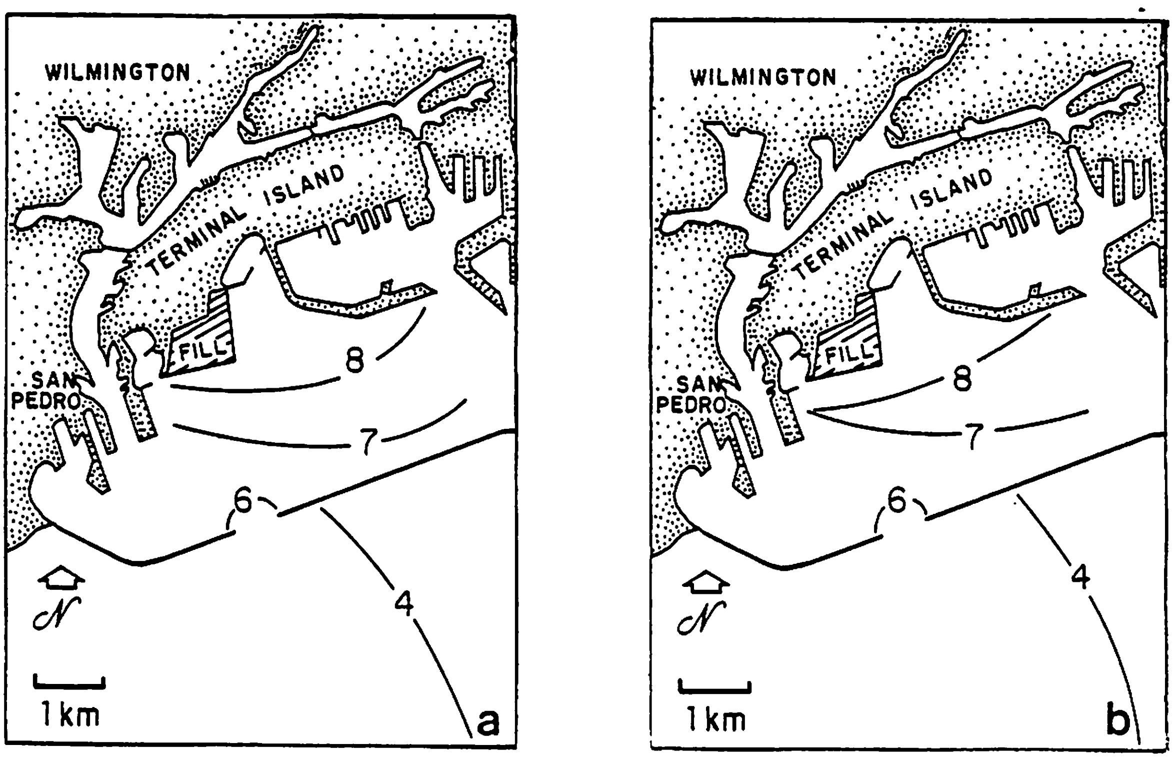


FIGURE 12. NITRATE CONCENTRATIONS (μg-at N l^{-1}) WERE PREDICTED TO BE VIRTUALLY IDENTICAL FOR THE WINTER (a) AND SUMMER (b).

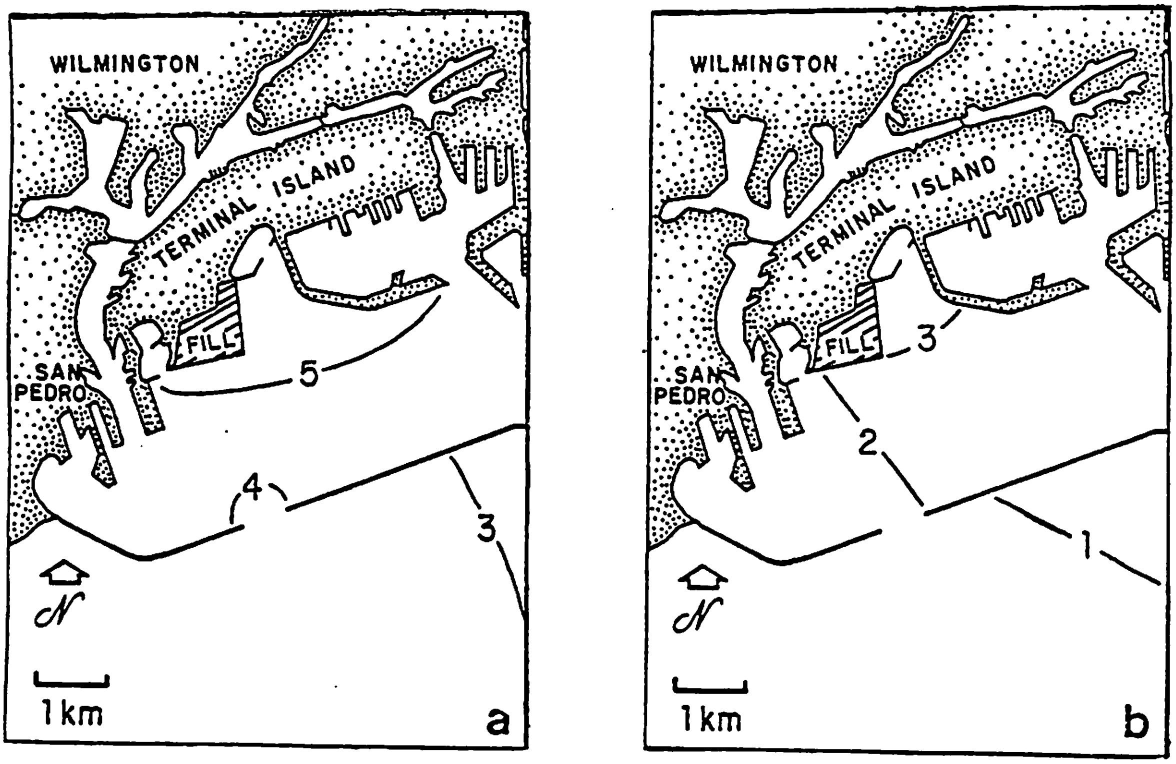


FIGURE 13. AMMONIUM CONCENTRATIONS (μg-$at\ N\ l^{-1}$) WERE PREDICTED TO BE HIGHER IN THE WINTER (a) THAN IN THE SUMMER (b).

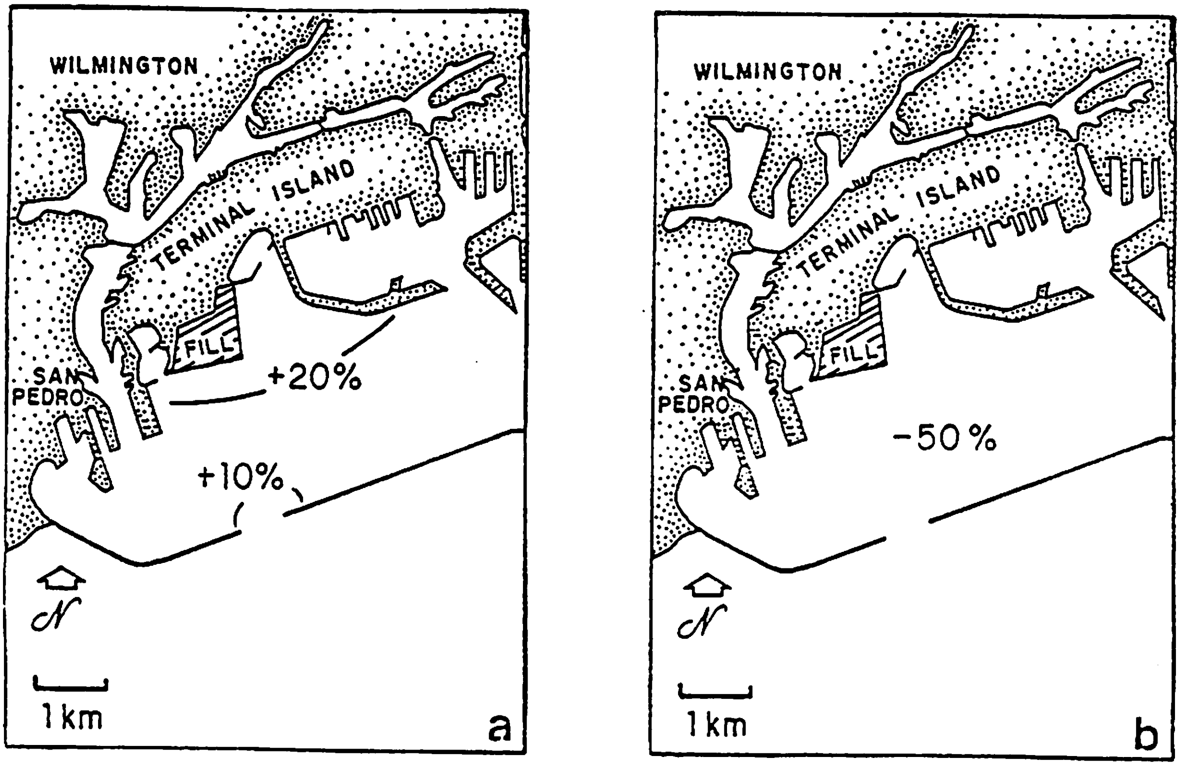


FIGURE 14. COMPARISON PLOTS OF NITRATE AND BOD AS PERCENTAGE CHANGE IN "BASELINE" TITP EFFLUENT LOADING (IN ABSENCE OF CANNERY EFFLUENT) RELATIVE TO RESULTS OF STANDARD RUN. RESULTS FROM THE BASELINE SIMULATIONS SHOWED INCREASED NITRATE CONCENTRATIONS OF 10-30% (a) WHILE BOD LEVELS WERE DECREASED 50% (b)

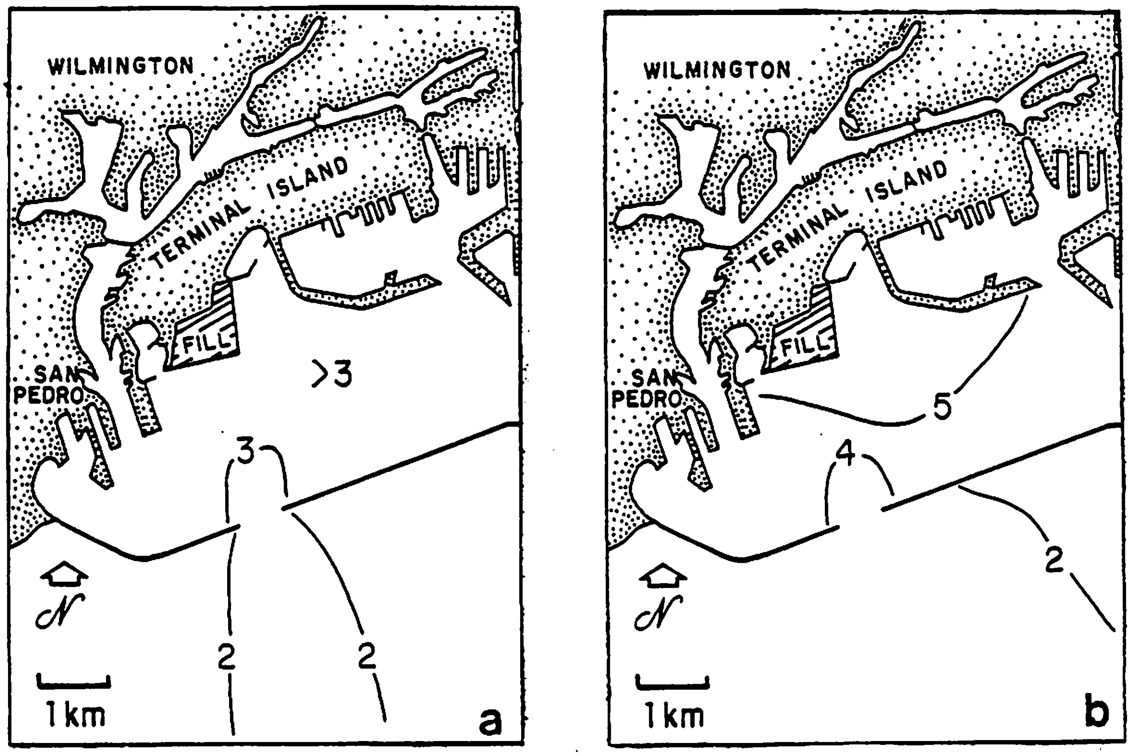


FIGURE 15. SIMULATIONS PREDICTED THAT DIRECT CANNERY DISCHARGE OF 10 MGD EFFLUENT (b) WOULD BE EXPECTED TO RESULT IN HIGHER LEVELS OF AMMONIUM (μg-$at\ N\ l^{-1}$) RELATIVE TO BASELINE TITP DISCHARGE WITH NO CANNERY EFFLUENT (a).

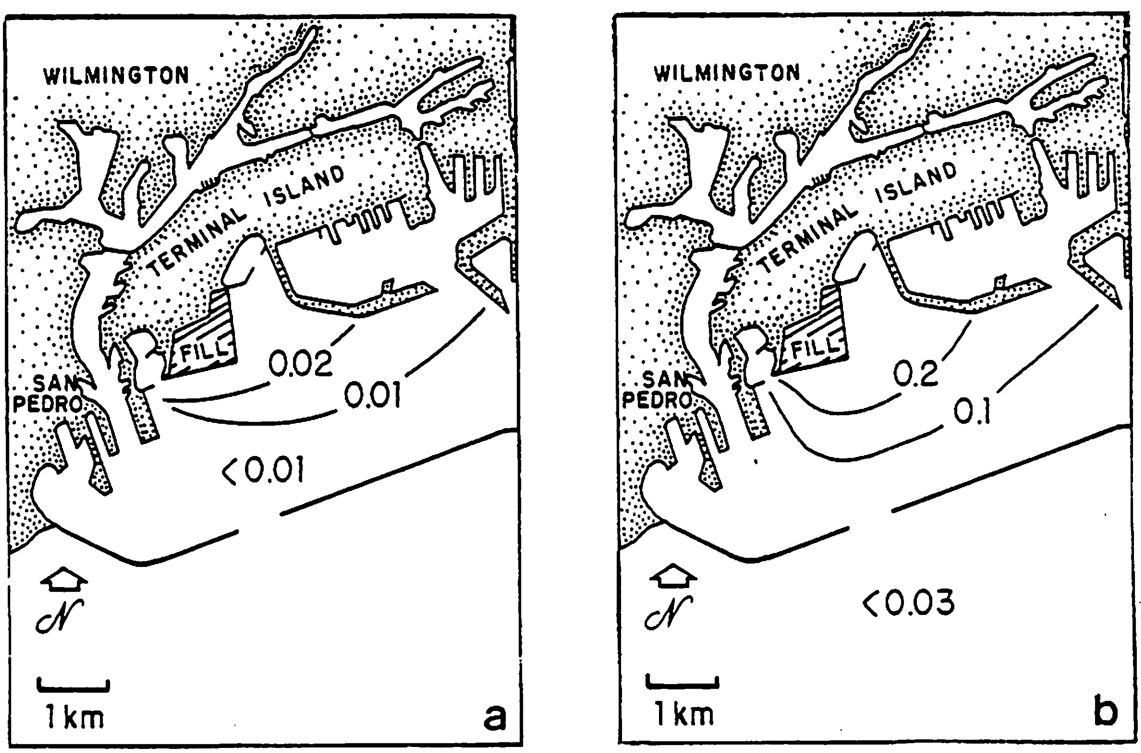


FIGURE 16. MODEL SIMULATIONS PREDICTED SLIGHTLY INCREASED 5-d BOD LEVELS ($mg\ O_2\ l^{-1}$) IN THE HARBOR WITH 10 MDG CANNERY EFFLUENT (b) RELATIVE TO BASELINE TITP (a).

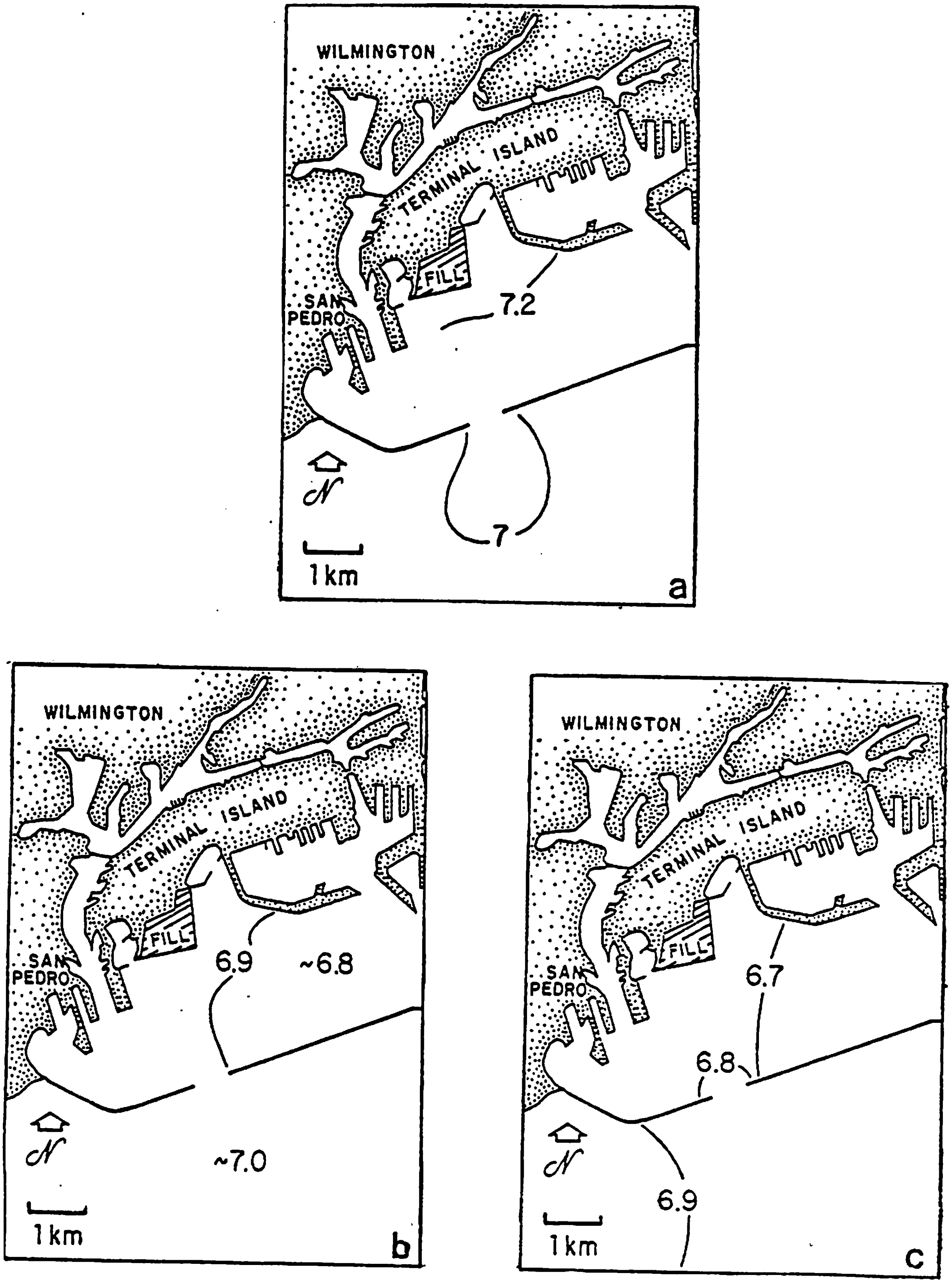


FIGURE 17. OXYGEN CONCENTRATIONS ($mg\ l^{-1}$) WERE PREDICTED TO BE DEPRESSED SLIGHTLY WITH DIRECT DISCHARGE OF CANNERY WASTE (b,c,)(a) RELATIVE TO THE BASELINE TITP

TABLE 1. TITP EFFLUENT NUTRIENT COMPOSITION DERIVED FROM MONTHLY REPORTS, SEPTEMBER 1981 TO MARCH 1982

A. NITROGEN

DATE	[NH4]	[NO3]	[NO2]	[Org N]
		(mg N/l)		
1 SEP 81	14.7	----	----	----
8 SEP 81	4.5	25.0	1.1	3.0
15 SEP 81	1.2	----	----	----
22 SEP 81	13.3	----	----	----
29 SEP 81	0.3	----	----	----
6 OCT 81	0.0	18.4	< 0.1	7.6
13 OCT 81	0.0	----	----	----
20 OCT 81	4.2	----	----	----
27 OCT 81	4.7	----	----	----
3 NOV 81	1.8	27.6	0.2	3.3
10 NOV 81	0.5	----	----	----
17 NOV 81	0.0	----	----	----
24 NOV 81	0.0	----	----	----
1 DEC 81	1.3	----	----	----
2 DEC 81	7.4	10.9	3.9	10.4
8 DEC 81	2.7	----	----	----
15 DEC 81	0.4	----	----	----
22 DEC 81	0.0	----	----	----
5 JAN 82	14.4	0.1	1.3	19.9
12 JAN 82	2.2	----	----	----
19 JAN 82	3.0	----	----	----
26 JAN 82	12.0	----	----	----
2 FEB 82	17.7	----	----	----
3 FEB 82	2.7	7.0	1.4	5.4
9 FEB 82	7.2	----	----	----
16 FEB 82	3.3	----	----	----
23 FEB 82	16.5	----	----	----
3 MAR 82	0.6	7.8	2.3	2.2
9 MAR 82	2.0	----	----	----
16 MAR 82	0.8	----	----	----
23 MAR 82	4.0	----	----	----
30 MAR 82	3.0	----	----	----

Table 2. TITP Effluent Monthly Means for Biochemical Oxygen Demand and Flow Rate, September 1981 to March 1982.

	BOD Effluent (mg/l)			FLOW Effluent (MGD)		
MONTH	Max	Min	Mean	Max	Min	Mean
September 1981	21	3	10	24.6	11.3	19.9
October 1981	25	13.9	19.8	52	4	17
November 1981	38	6	12	25.5	11.9	20
December 1981	41	7	16	21.8	14.6	17.9
January 1982	69	10	26	23.6	16.2	19.4
February 1982	102	16	47	19.6	15.4	17.4
March 1982	53	6	19	23.3	15.5	19

Table 3. TITP Discharge. Six-Month Average for September 1981 through March 1982. Compared with Field Sample Data.

Effluent Discharge		6-Mo. Average	Field Sample Data 8 Dec 1981	24 Feb 1982
Composition:				
BOD (mg l^{-1})		21.4	25	97
Nutrients (ug-at N l^{-1})**				
Ammonia	average	326	193	1178
	range	0-1200		
Nitrate + Nitrite	average	985	778*	71*
	range	7-1970		
Loading:				
Discharge Rate (MGD)		18.7	21.8	18.4
BOD (g O_2 min^{-1})		1050	1440	4,710
Nutrient (mg-at N min^{-1})**				
Ammonia		16,000	11,000	47,000
Nitrate + Nitrite		48,000	45,000	3,400

* Values approximated due to infrequent measurements

** 1 ug-at N = 0.014 mg,N

Table 4. New Input Values for the Modified Standard Run.

Parameter		Value	
Sewage Effluent:			
Ammonium: (N)	Morning	2.1×10^4	mg-at N per min
	Midday	2.56×10^4	
	Afternoon	2.1×10^4	
	Night	9.6×10^3	
Nitrate: (N)	Morning	6.24×10^4	mg-at N per min
	Midday	7.68×10^4	
	Afternoon	6.24×10^4	
	Night	2.88×10^4	
BOD: (O_2)	Morning	1.37×10^3	g O_2 per min
	Midday	1.61×10^3	
	Afternoon	1.37×10^3	
	Night	6.30×10^3	
Benthic Oxygen consumption		1.2 g O_2 per m^2 per day	
Phytoplankton maximum growth rate		0.85 per day	
Benthic grazing		15 l per m^2 per hour	

Table 5. Seasonal Differences Were Simulated by Changing Values of Some of the Input Parameters.

Parameter	Winter	Summer
Photoperiod, h	9	15
Temperature, °C	12	20
Phytoplankton maximum growth rate, per day	0.67	1.09
Ratio of incident radiation to optimum light:		
Morning	0.5	1.5
Midday	1.0	3.0
Afternoon	0.5	1.5

Table 6. Composition and Loading for Baseline TITP Discharge and a Range of Values for Cannery Effluent.

Composition

Effluent Discharge	TITP Baseline (without cannery)	Cannery Waste Only
BOD (mg O_2 l^{-1}) 15 days	21	400
Last 10 days	12	
Nutrients (ug-at N l^{-1})		
Ammonium (av. of 3 dates)	228	500
Nitrate (single date)	1857	

Loading

	TITP Baseline	Cannery Waste Only		
		Low	Average	High
Discharge Rate (MGD)	15.7	2	5	10
BOD (g min^{-1})	490	2,100	5,200	10,000
Nutrients (mg-at N min^{-1})				
Ammonium	9,300	2,600	6,500	13,000
Nitrate	75,000			

APPENDIX A
FIELD AND LABORATORY RESULTS

INTRODUCTION

In an attempt to provide some ground truth measurements for the ecological simulation model, sixteen stations were sampled on two dates for dissolved oxygen, chlorophyll, 5-day BOD, and nutrients (nitrate, ammonium, phosphate, silicate). The station locations are shown in Fig. A1. Stations which were the same as those sampled in previous studies by the Harbors Environmental Projects retained the former label (Prefix A and B); new stations were numbered 0-5. Station "0" was right at the TITP effluent "boil", and four additional stations (1, 2, 3, A16) marked the perimeters of the grid in the model into which the effluent is discharged.

Surface water samples were collected by bucket, and samples were collected at 1 m off the bottom with a water bottle. Vertical profiles of oxygen were made using a polarigraphic oxygen electrode mounted in a MARTEK sensor. Calibrations of these readings were made using Winkler titrations (Strickland and Parsons, 1972). All values for surface oxygen and BOD (biochemical oxygen demand) were made by titration. Bottles for BOD determinations were kept in the dark at 15 and 20C. Chlorophyll was measured by extracted fluorescence (Holm-Hansen et al., 1965) and inorganic nutrients were measured on an auto-analyzer using methods adapted from Strickland and Parsons (1972).

Tables A1 and A4 summarize the sampling results for 8 December 1981 and 24 February 1982 respectively. Figures A2 to A8, and A11 to A17 show the surface measurements on the two dates for oxygen, 5-d BOD, chlorophyll, and nutrients.

Surface Oxygen

On both dates the oxygen concentration near the surface exceeded 7.5 mg $O_2 l^{-1}$ for most of the harbor. On 24 February the oxygen concentration (Fig. A11) was quite constant for the entire harbor (ranging from 7.7 - 8.1 mg $O_2 l^{-1}$). On 8 December (Fig. A2) there was a band inshore with slightly lower oxygen (7.1 - 7.5 mg $O_2 l^{-1}$).

In general these results were comparable to measurements during winter 1977-78 (Soule and Oguri, 1980, Sec. 11B) but did not demonstrate the depressed oxygen values near the outfall obvious in the earlier data. It should be pointed out however, that the site of the discharge has changed as a result of the landfill, and is now in deeper water (8 m).

During the two sampling dates for this study there was no general pattern of stratification of oxygen, and the values were fairly uniform with depth (Tables A2, A5; Figs. A9, A18). Although not reported specifically, temperature was about 15°C and uniform with depth for both dates.

Surface 5-day Biochemical Oxygen Demand

On both dates the 5-d BOD exceeded 2 mg $O_2 l^{-1}$ only immediately at the "boil" station (Fig. A3 and A12). For most stations the 5-d BOD measurements were less than 1.0 mg $O_2 l^{-1}$. These results are in contrast to earlier measurements (Kremer, 1978) in the area, before cannery effluent was required to be routed through the Terminal Island Treatment Plant TITP was converted to secondary treatment. Water collected in 1976-77 within 1000 m of the discharge sites had 5-d BOD levels greater than 3 mg l^{-1} and a few greater than 6 mg l^{-1}. Stations further away had values less than 2 mg l^{-1}.

Chlorophyll

On both dates the chlorophyll averaged around 2.5 µg l^{-1} for both surface and bottom (Tables A1 and A4 - Figs. A4 and A13). On 8 December the region to the southwest of the outfall showed a greater chlorophyll concentration (>4 µg l^{-1}) than the region immediately east (<2 µg l^{-1}).

Nitrate

For both dates there was a clear onshore-offshore gradient for nitrate (NO_2 + NO_3) (Figs. A5 and A14) with the highest values (>15 µg-at l^{-1} at the surface) in the vicinity of the TITP discharge. On 8 December there were also vertical differences with increased nitrate at the surface (Table A1). On 24 February increased nitrate at the surface was only obvious from the stations immediately surrounding the discharge site (Table A4).

Ammonium

There were generally higher ammonium levels (>5 µg-at l^{-1}) near the landfill on 8 December, and to the west of the TITP effluent boil (Fig. A6). This area of higher ammonium generally correlated with increased nitrate, phosphate, silicate, BOD, and lower oxygen (Figures A2 to A5, A7 to A8). On this date there was no obvious stratification of ammonium. On 24 February there was a general onshore-offshore gradient and greatly increased concentrations of ammonium in the vicinity of the TITP discharge, although the boil itself was not measured (Figure A15). For these stations near the boil there were also higher levels of ammonium at the surface relative to the bottom (Table A4). Records indicate that TITP was over NPDES permit limits for BOD in the effluent, on that date.

Phosphate and Silicate

Both phosphate and silicate also reflected higher values in the region near the boil (Figs. A7, A8, A16 A17), and there was evidence of increased levels of these nutrients in the surface waters (Tables A1, A4). Results for these sampling dates were comparable to measurements from winter-spring 1977-78 (Soule and Oguri, 1980, Sec. IIB).

Time-Series BOD

The biochemical oxygen demand (BOD) was measured through time for several days of incubation at 15 and 20°C for water from nine stations on each sampling date (Tables A3, A6). Representative results are shown in (Figs. A10, A19). The results from the two temperatures were very similar, confirming the findings of earlier studies (Kremer, 1978).

The value of the BOD oxidation rate (rate of BOD oxidation per unit time) was calculated using the slope of the linear regression of the logarithmic transformation of the BOD data with time. In order for this approach to be valid, the time series data needs to have a hyperbolic shape so there is a clear "ultimate" BOD. Most of the data met this requirement, but some of the time series were closer to linear (e.g., boil station on both dates, Figs. A10, A19). The BOD oxidation coefficients ("K") calculated from these data (excluding Station "0" on February 24) are summarized below:

Date	Temperature C	K hr^{-1}
8 December 1982	15	0.018 ± .007 (S.D.)
	20	0.021 ± .012
24 February 1982	15	0.015 ± .004
	20	0.015 ± .004

Although slightly lower, these results are consistent with the previous determinations of 0.02 hr^{-1} (Kremer 1978).

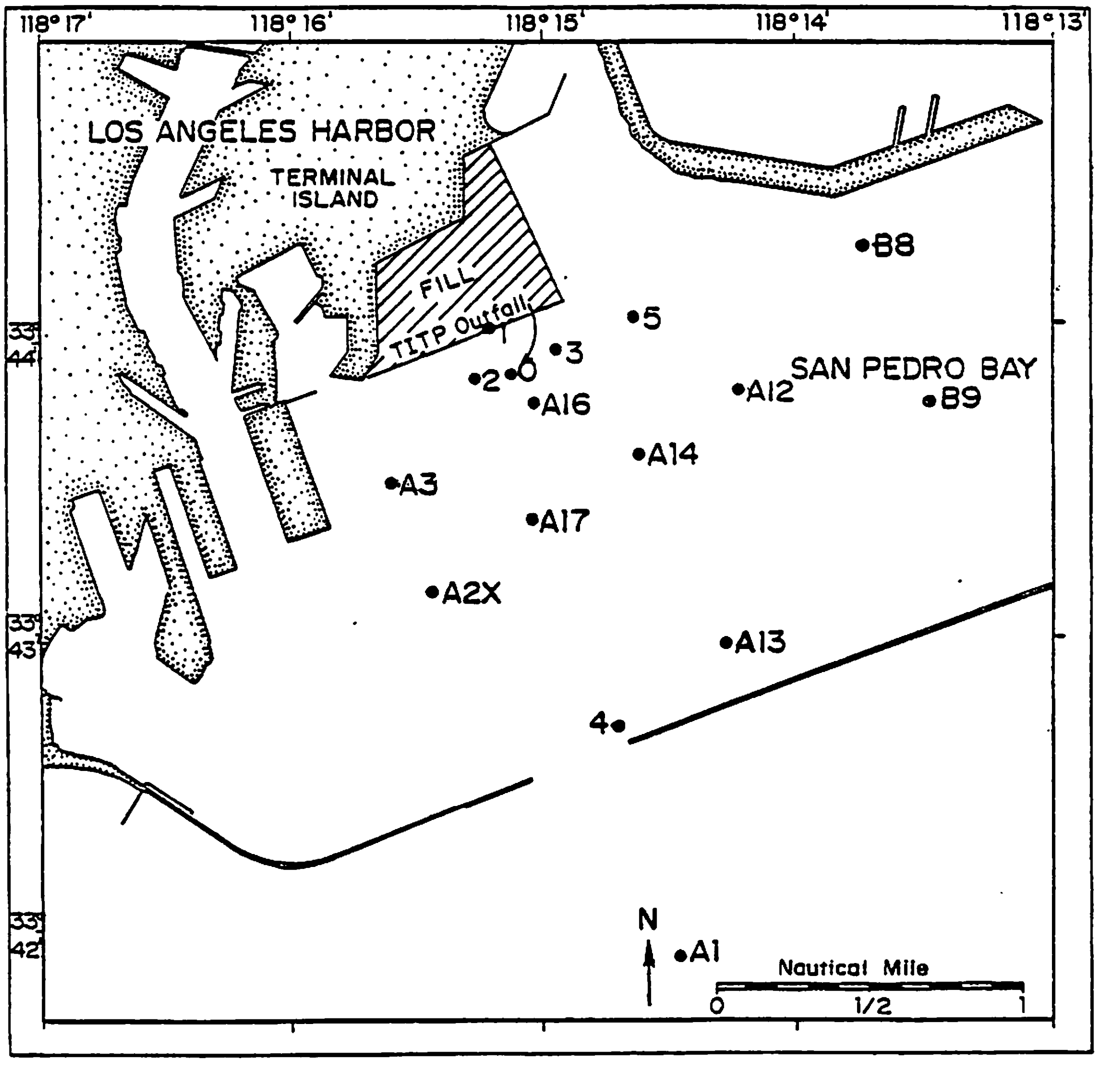


FIGURE A1. STATION LOCATIONS FOR FIELD SAMPLING 8 DECEMBER 1981 - 24 FEBRUARY 1982.

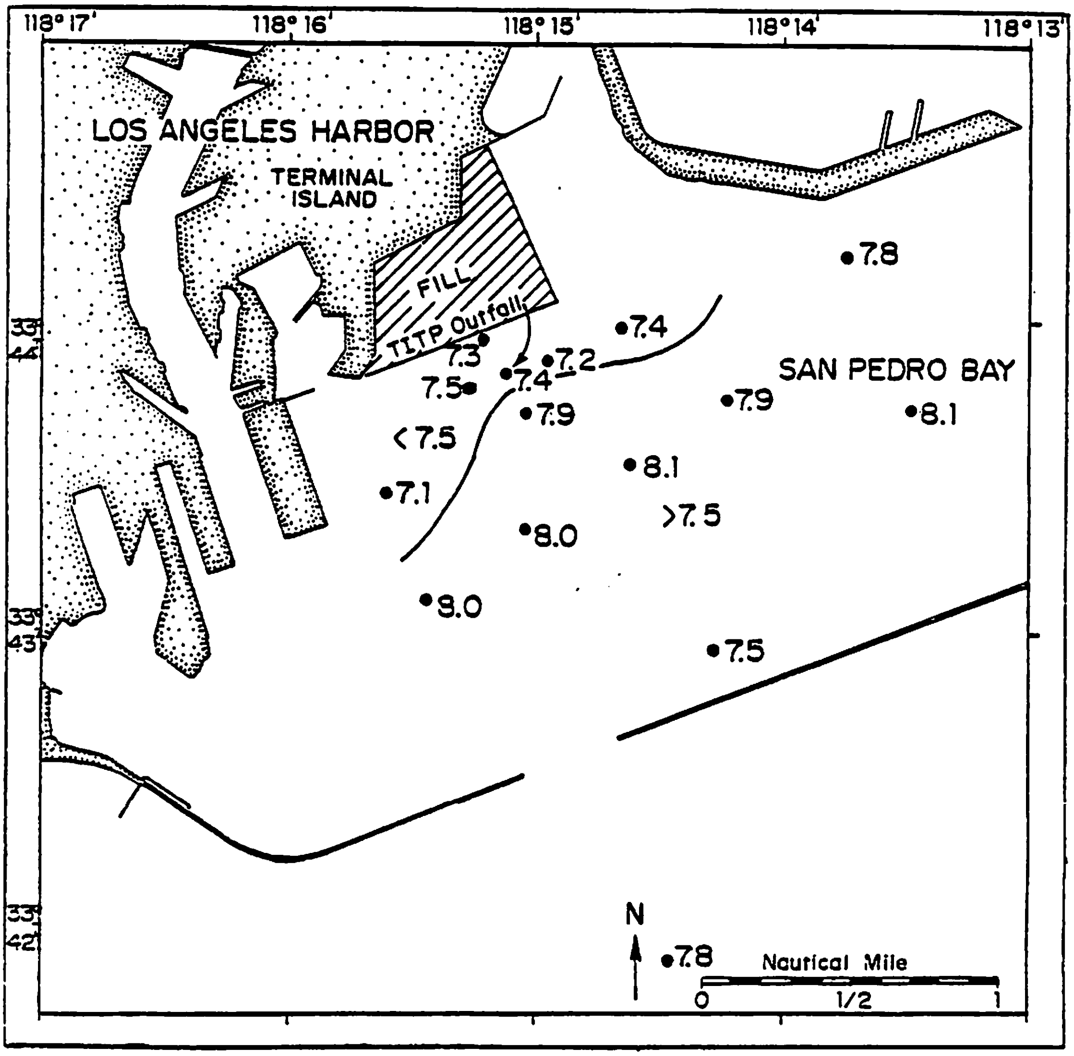


FIGURE A2. SURFACE DISSOLVED OXYGEN, mg O_2 l^{-1}, 8 DECEMBER 1981.

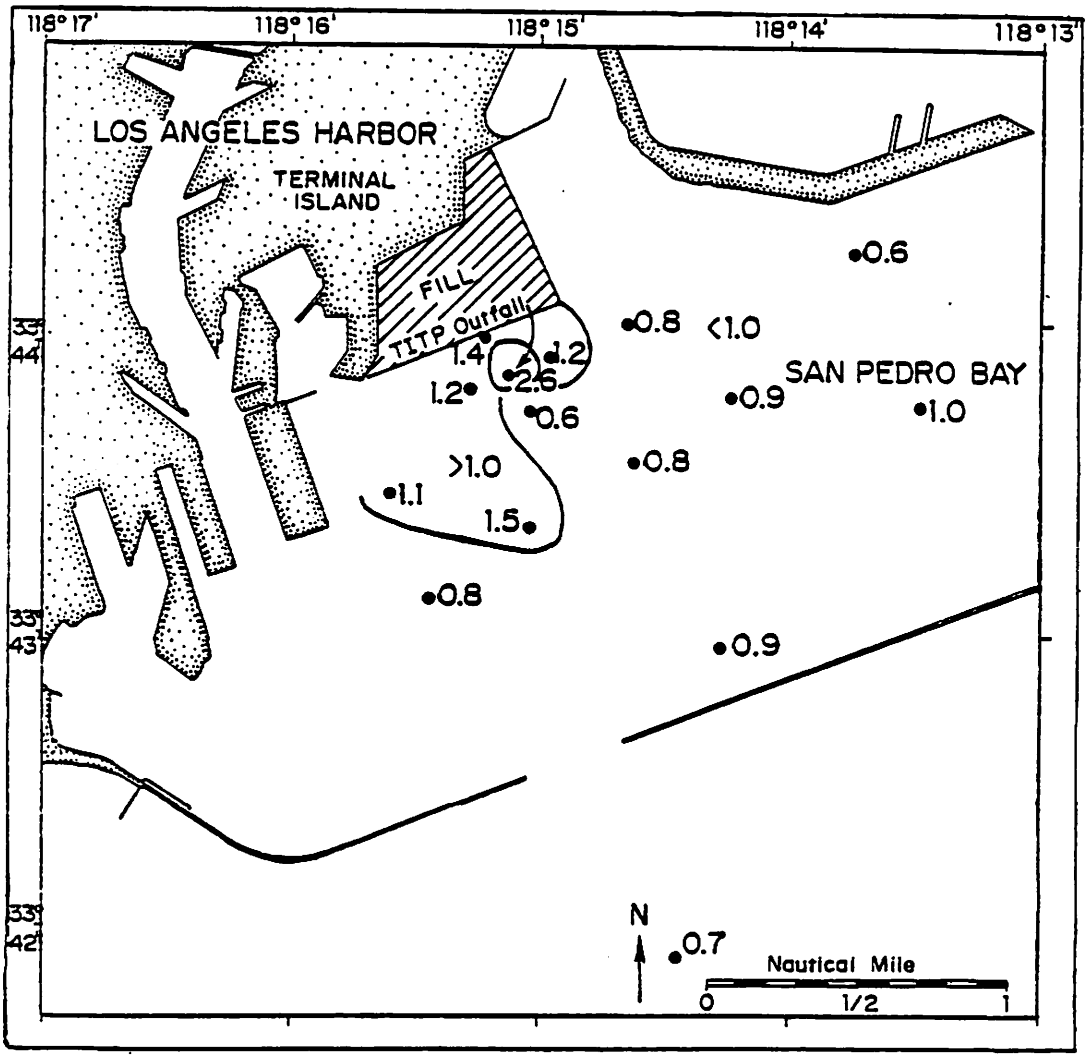


FIGURE A3. SURFACE 5-DAY BOD MEASUREMENTS, mg O_2 l^{-1}, 8 DECEMBER 1981.

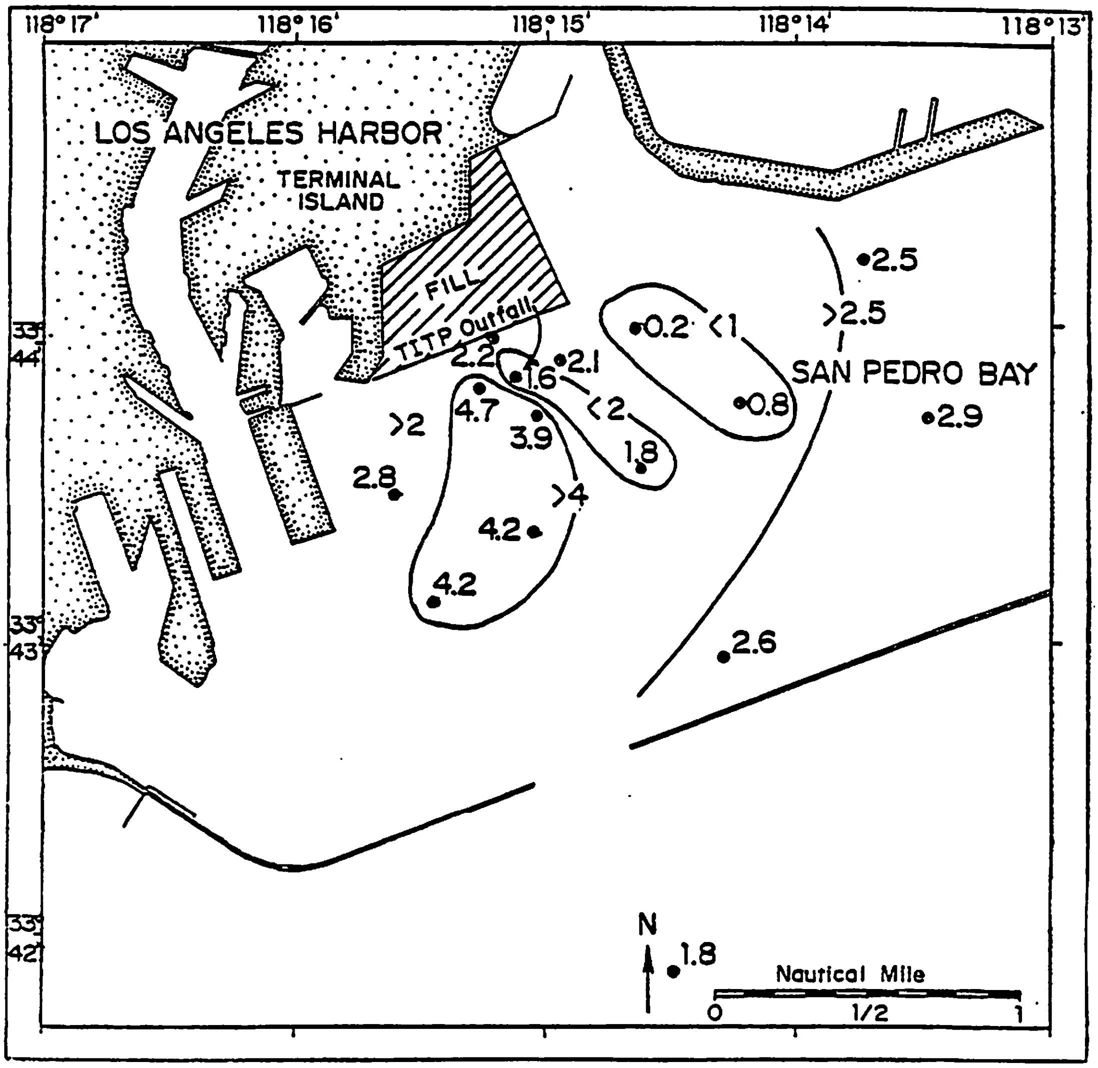


FIGURE A4. SURFACE CHLOROPHYLL (a), µg l^{-1}, 8 DECEMBER 1981.

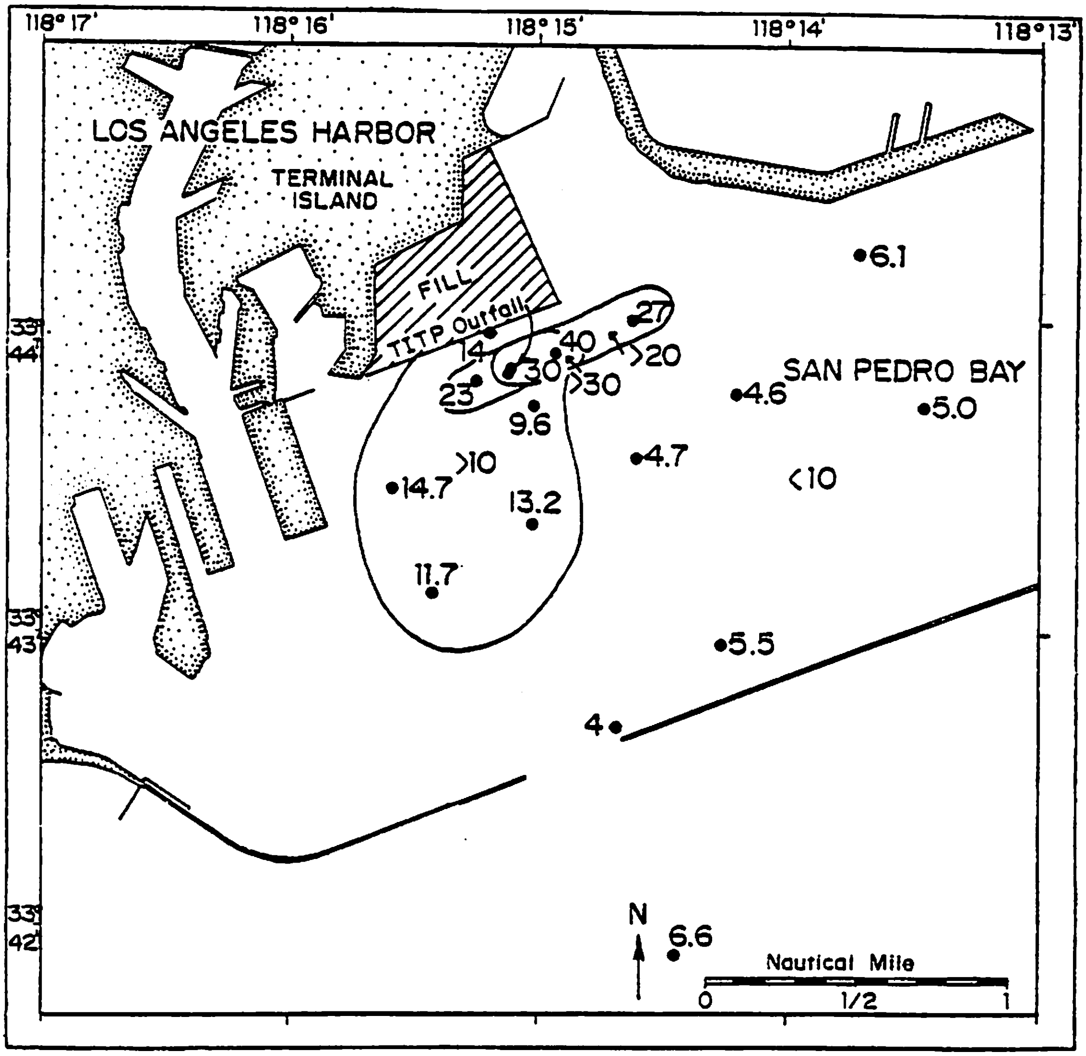


FIGURE A5. SURFACE NITRATE PLUS NITRITE, μg-at $N\ l^{-1}$, 8 DECEMBER 1981.

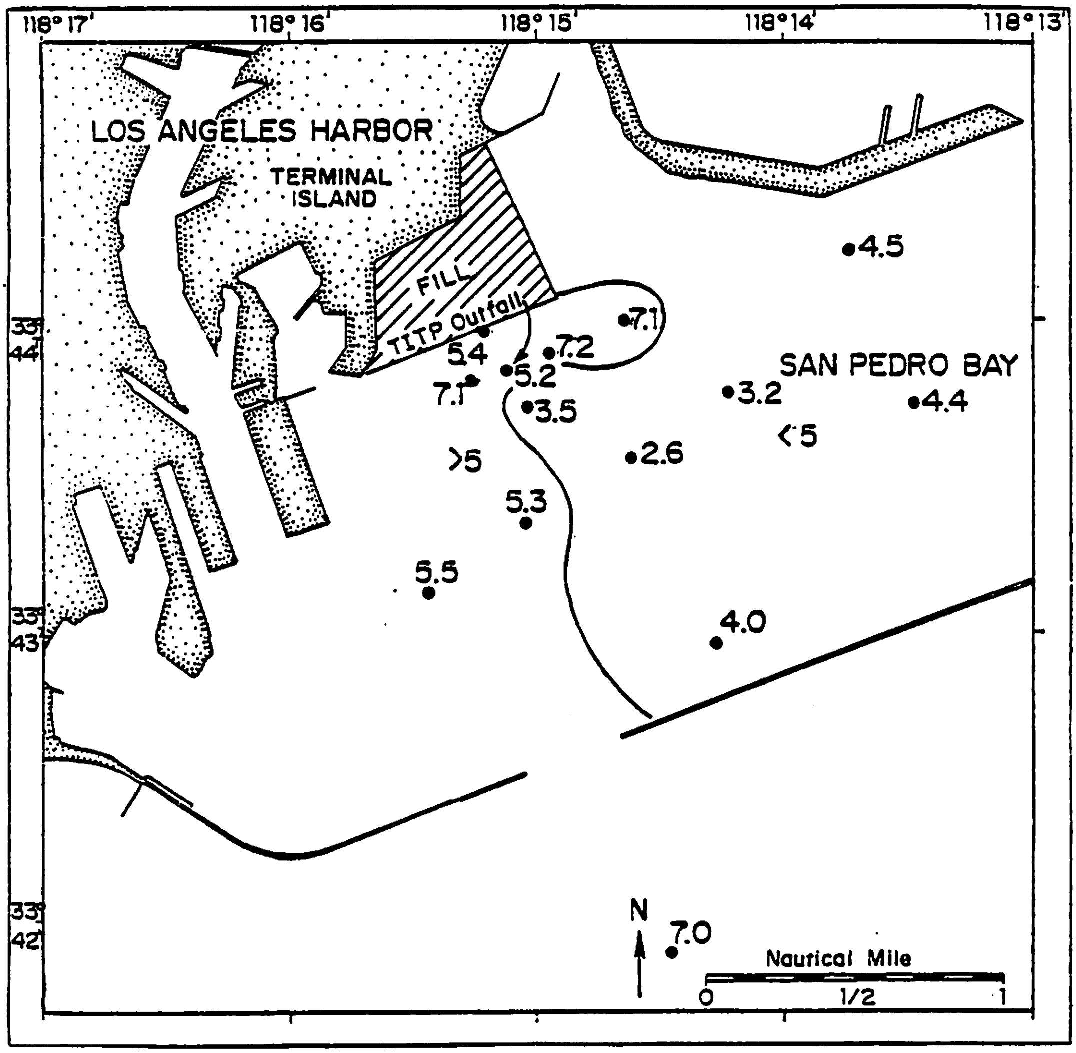


FIGURE A6. SURFACE AMMONIUM, µg-at N l^{-1}, 8 DECEMBER 1981.

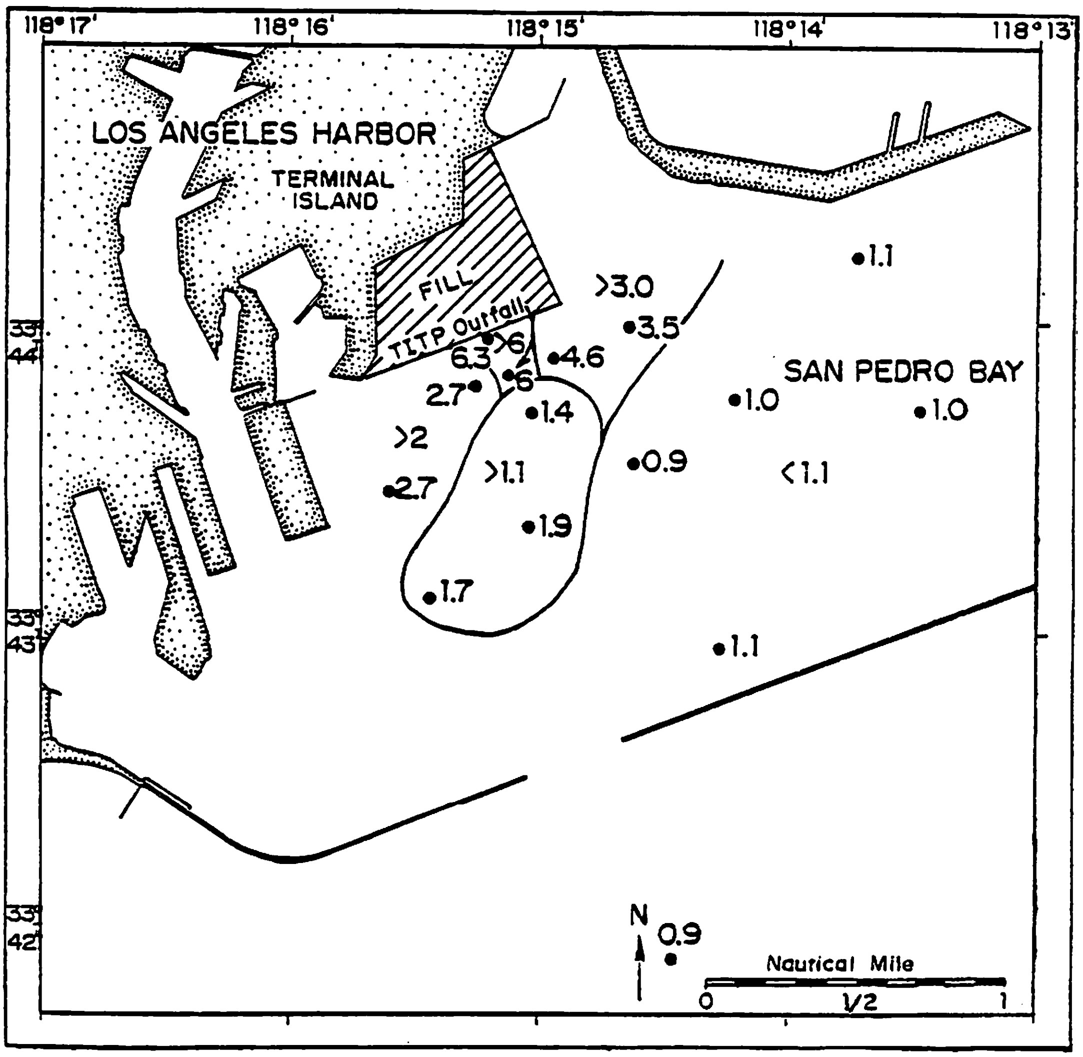
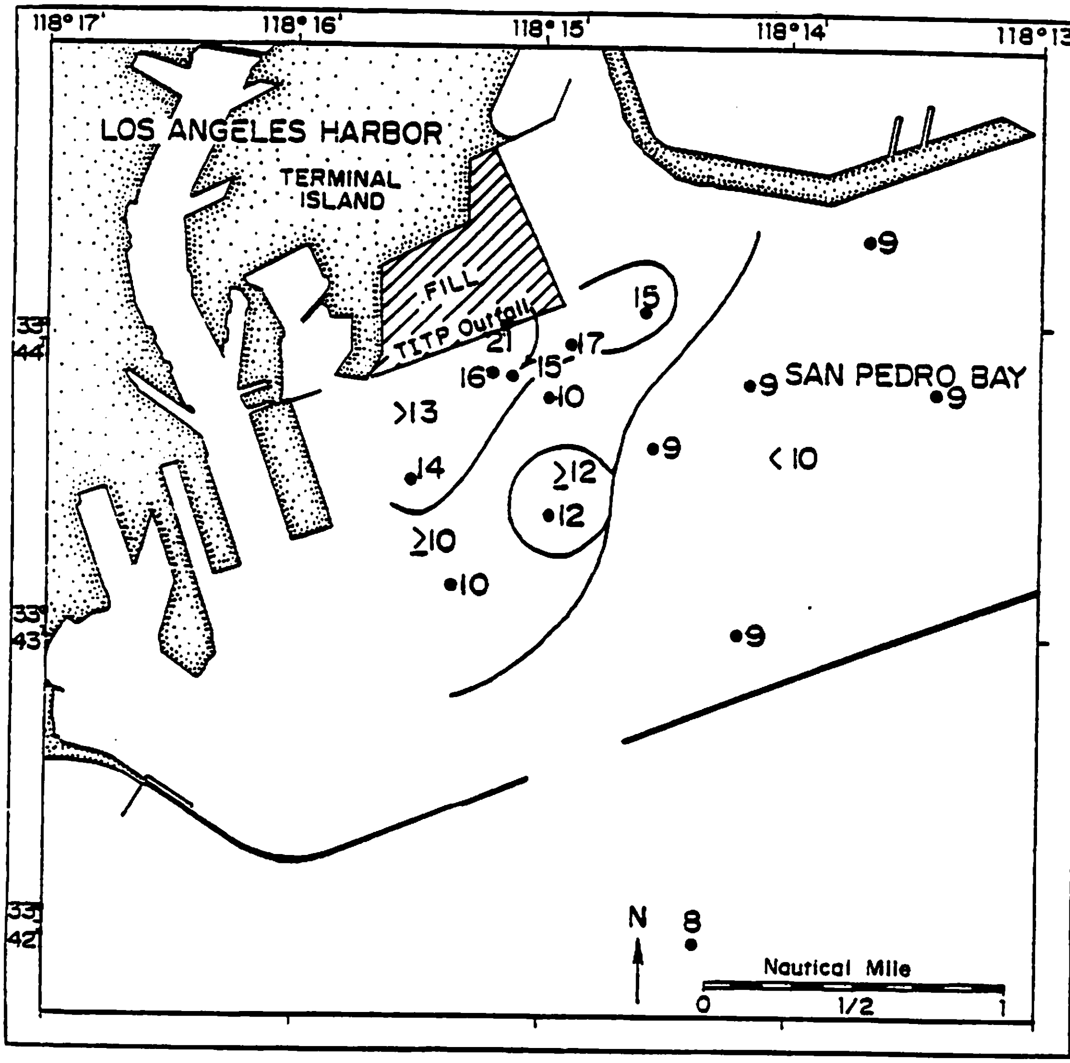


FIGURE A7. SURFACE PHOSPHATE, μg-at P l^{-1}, 8 DECEMBER 1981.



F'GURE A8. SURFACE SILICATE, μg-at Si l^{-1}, 8 DECEMBER 1981.

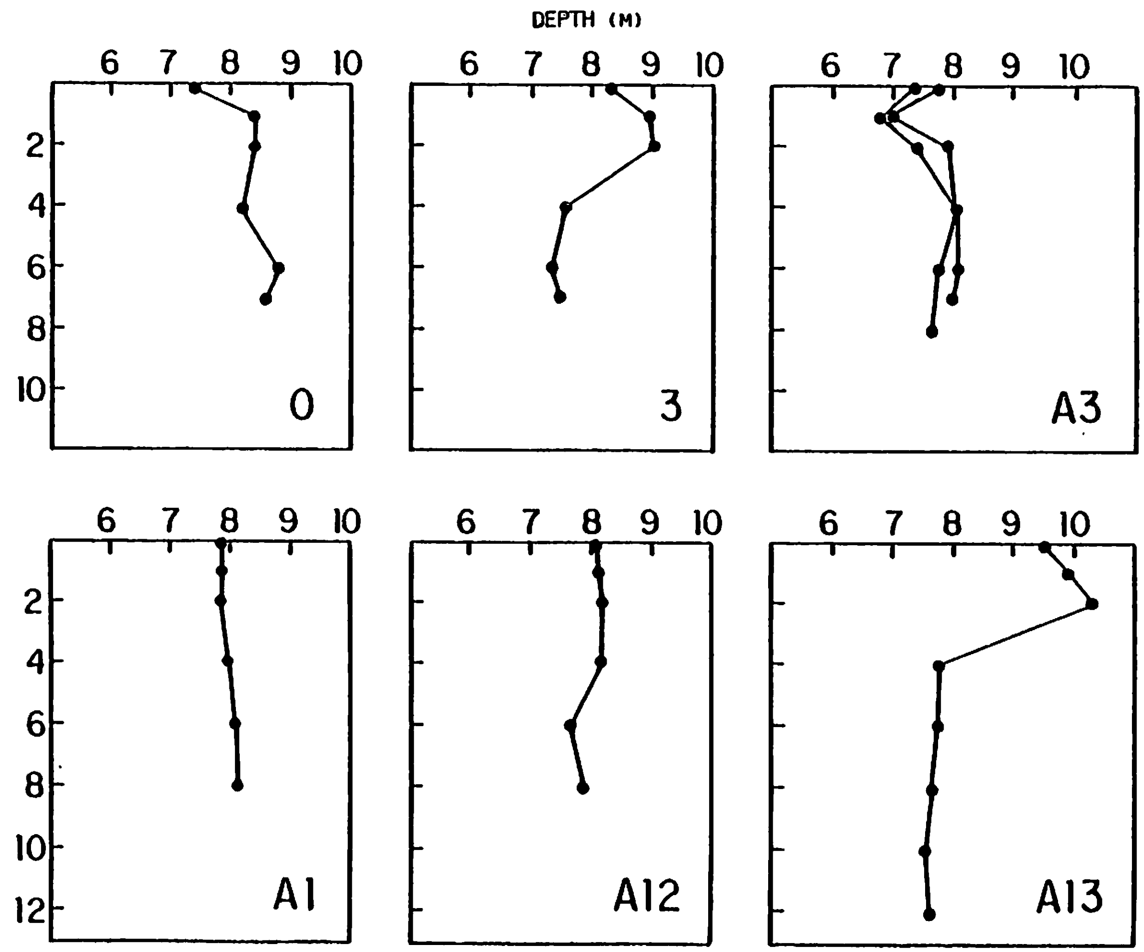


FIGURE A9. REPRESENTATIVE OXYGEN PROFILES FOR 8 DECEMBER 1981. (mg O_2 l^{-1})

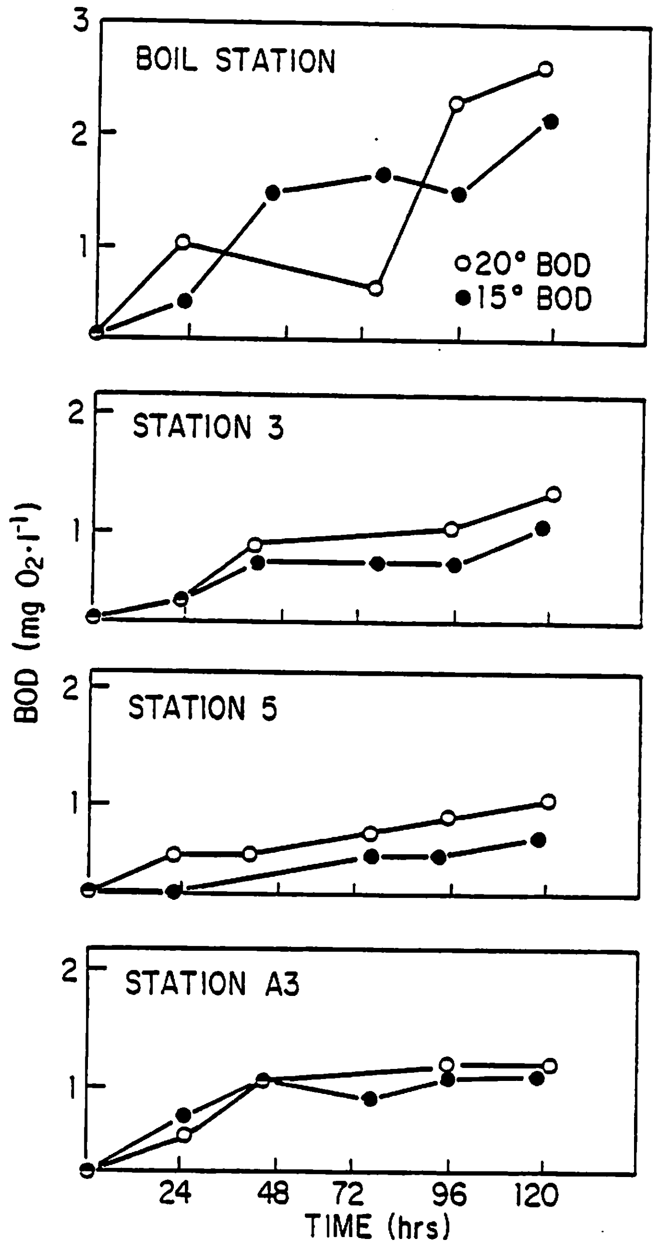


FIGURE A10. REPRESENTATIVE MEASUREMENTS OF BOD THROUGH TIME FOR SELECTED STATIONS FROM 8 DECEMBER 1981.

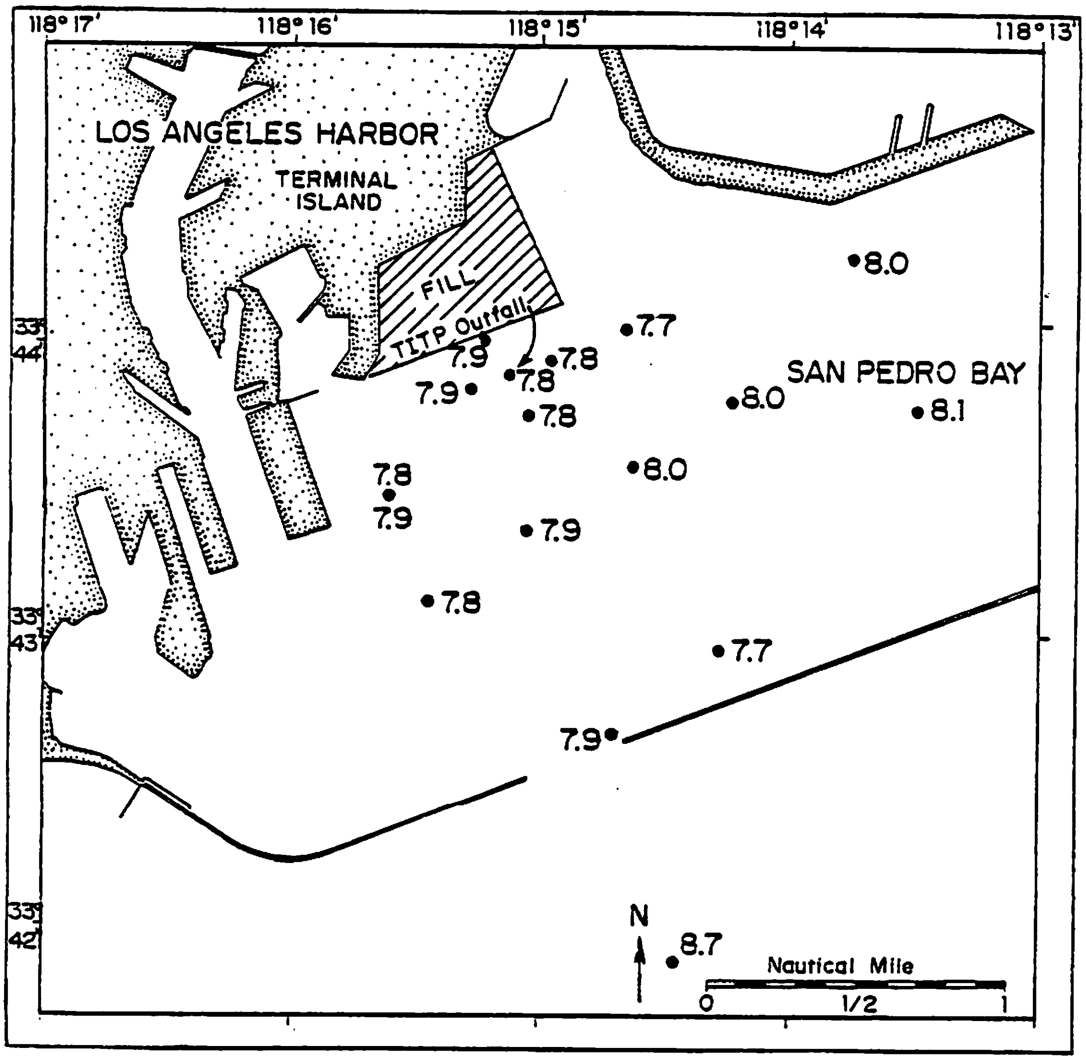


FIGURE A11. SURFACE DISSOLVED OXYGEN, $mg\ O_2\ l^{-1}$, 24 FEBRUARY 1982.

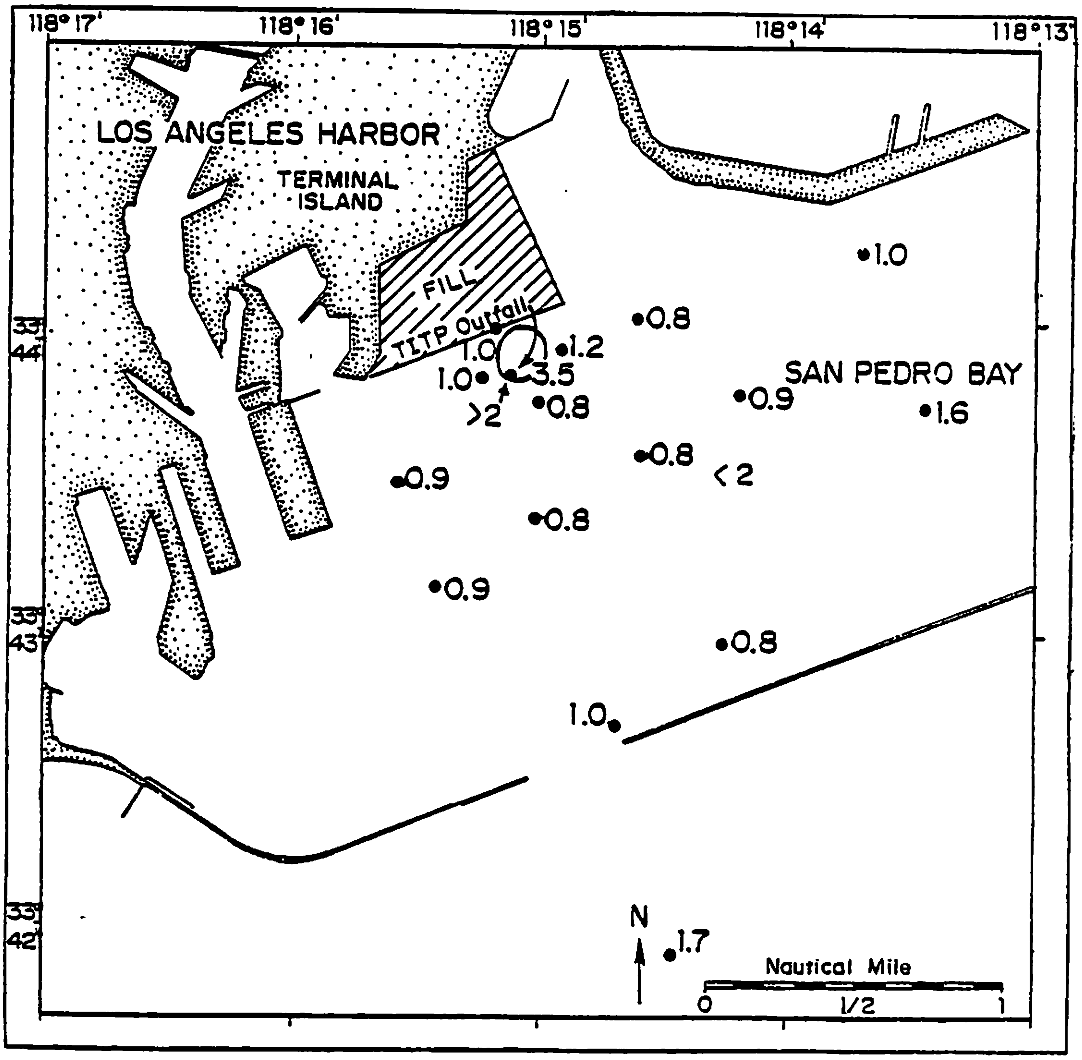


FIGURE A12. SURFACE 5-DAY BOD MEASUREMENTS mg O_2 l^{-1}, 24 FEBRUARY 1982.

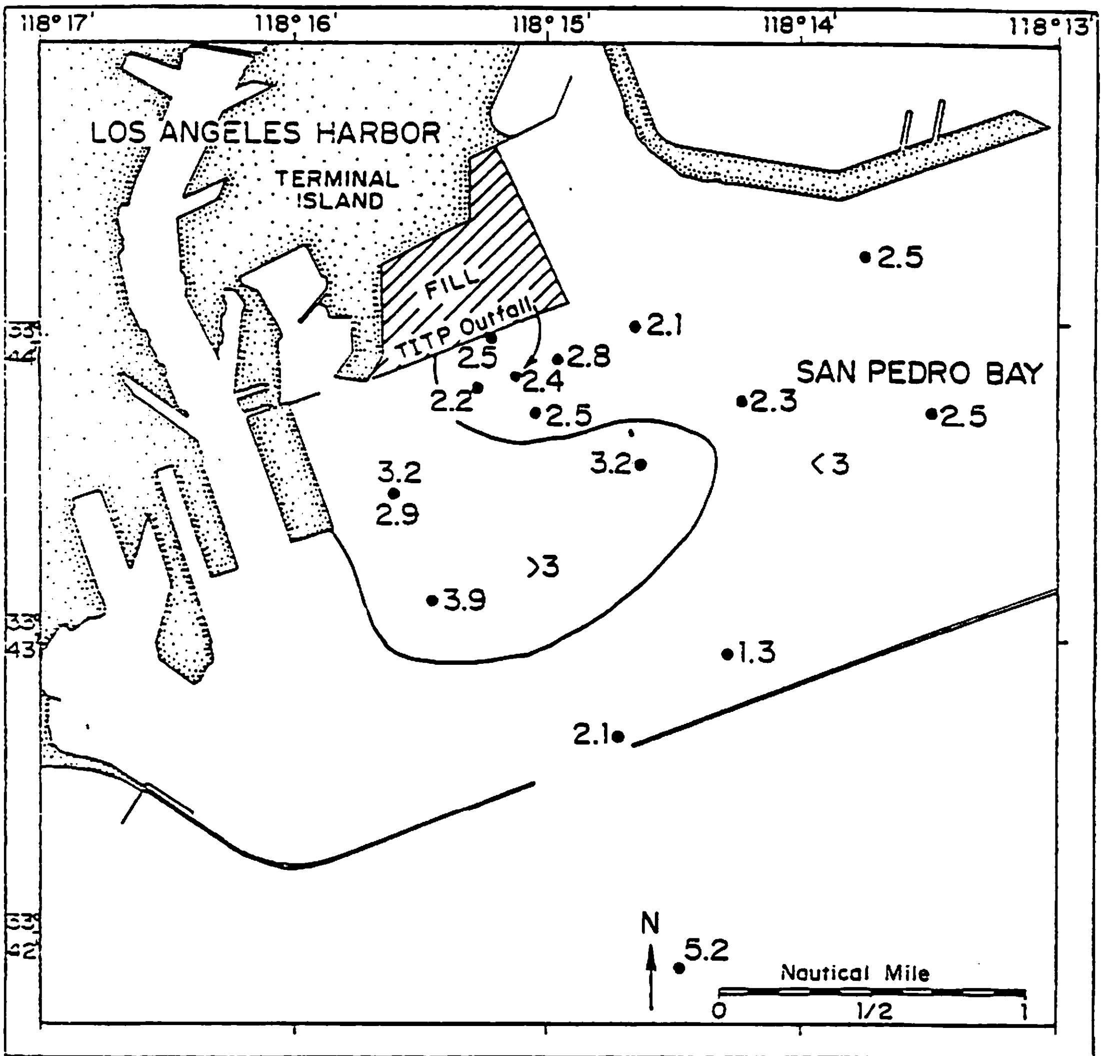


FIGURE A13. SURFACE CHLOROPHYLL A, $mg\ l^{-1}$, 24 FEBRUARY 1982.

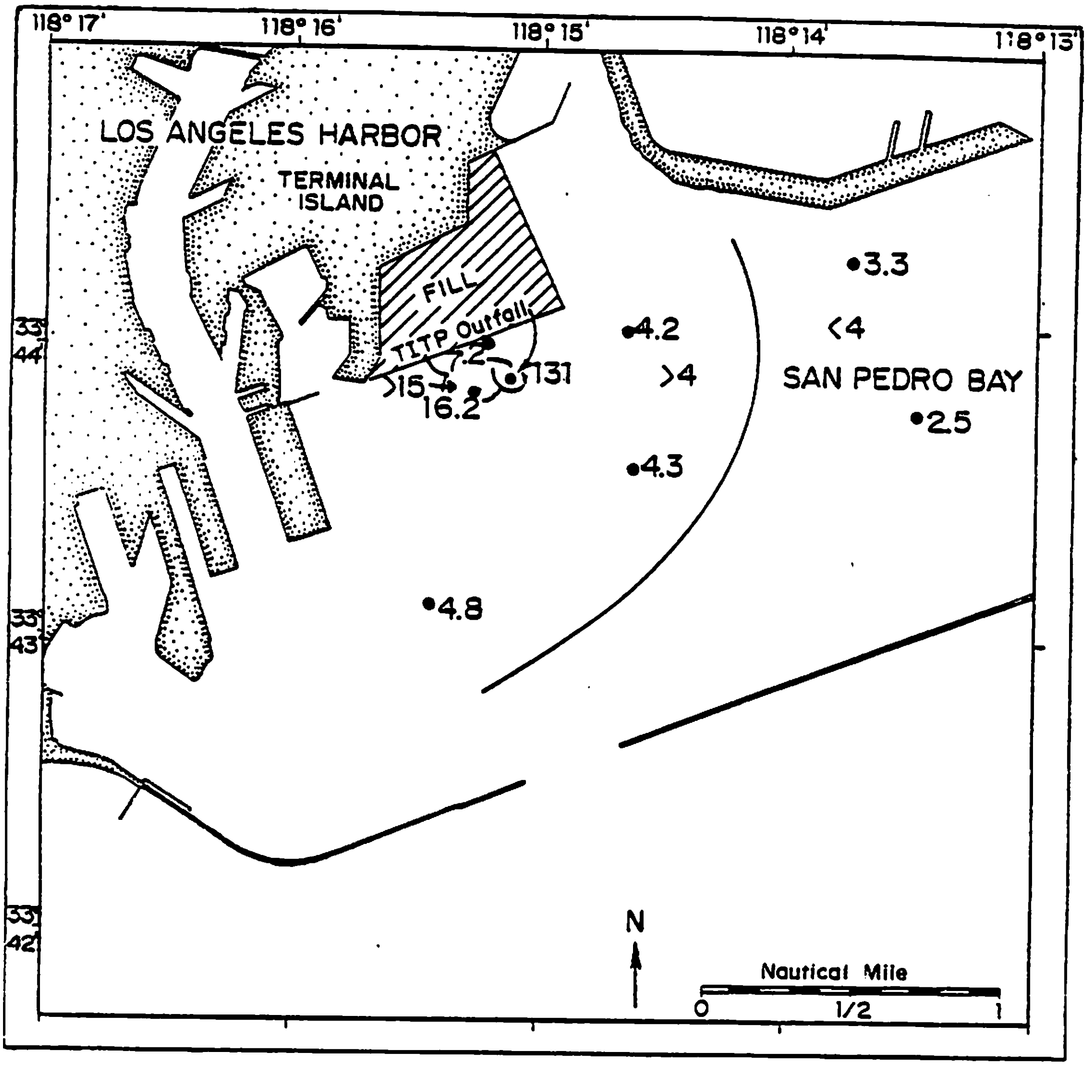


FIGURE A14. SURFACE NITRATE PLUS NITRITE, μg-at $N\ l^{-1}$, 24 FEBRUARY 19[illegible].

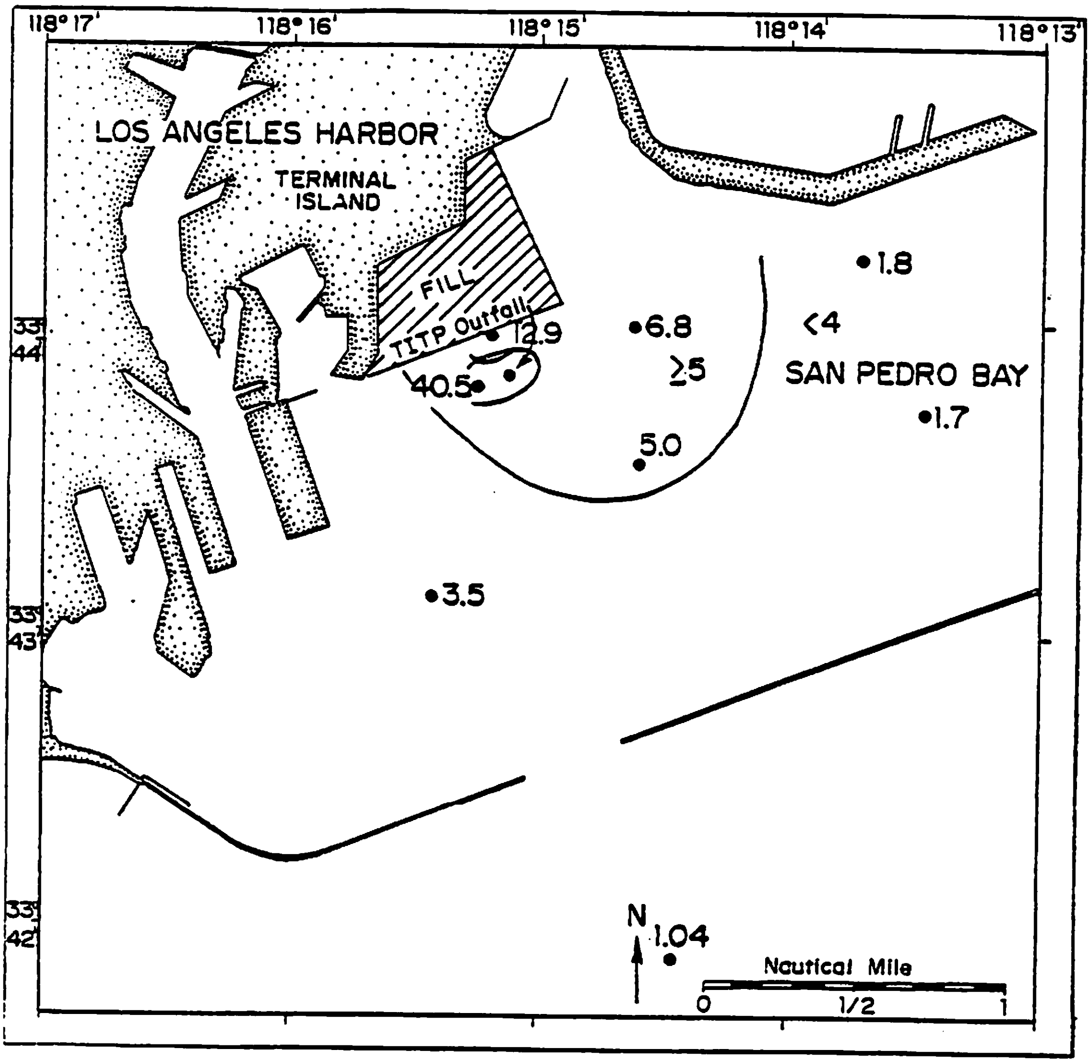


FIGURE A15. SURFACE AMMONIUM, μg-at N l^{-1}, 24 F—RUARY 1982.

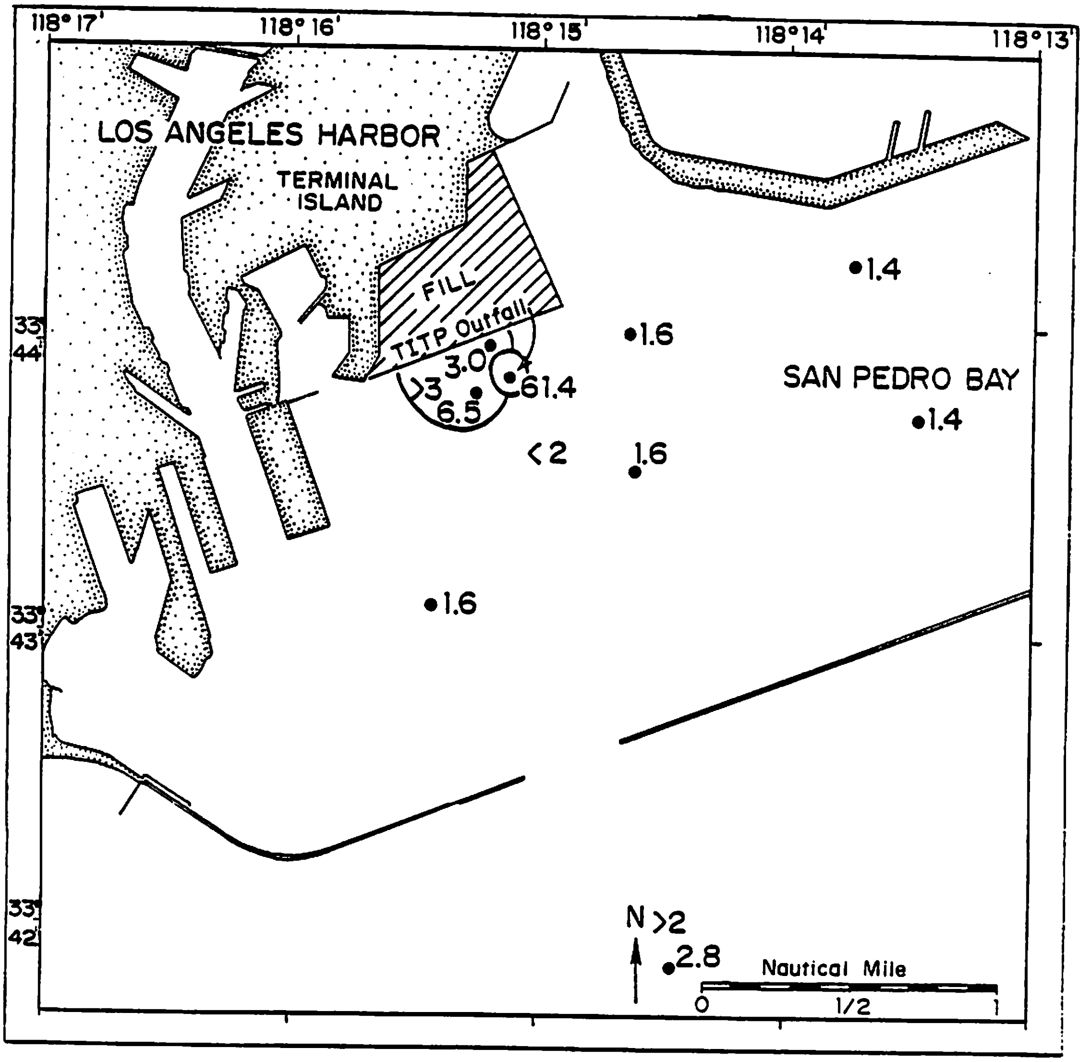


FIGURE A16. SURFACE PHOSPHATE, µg-at P l^{-1}, 24 FEBRUARY 1982

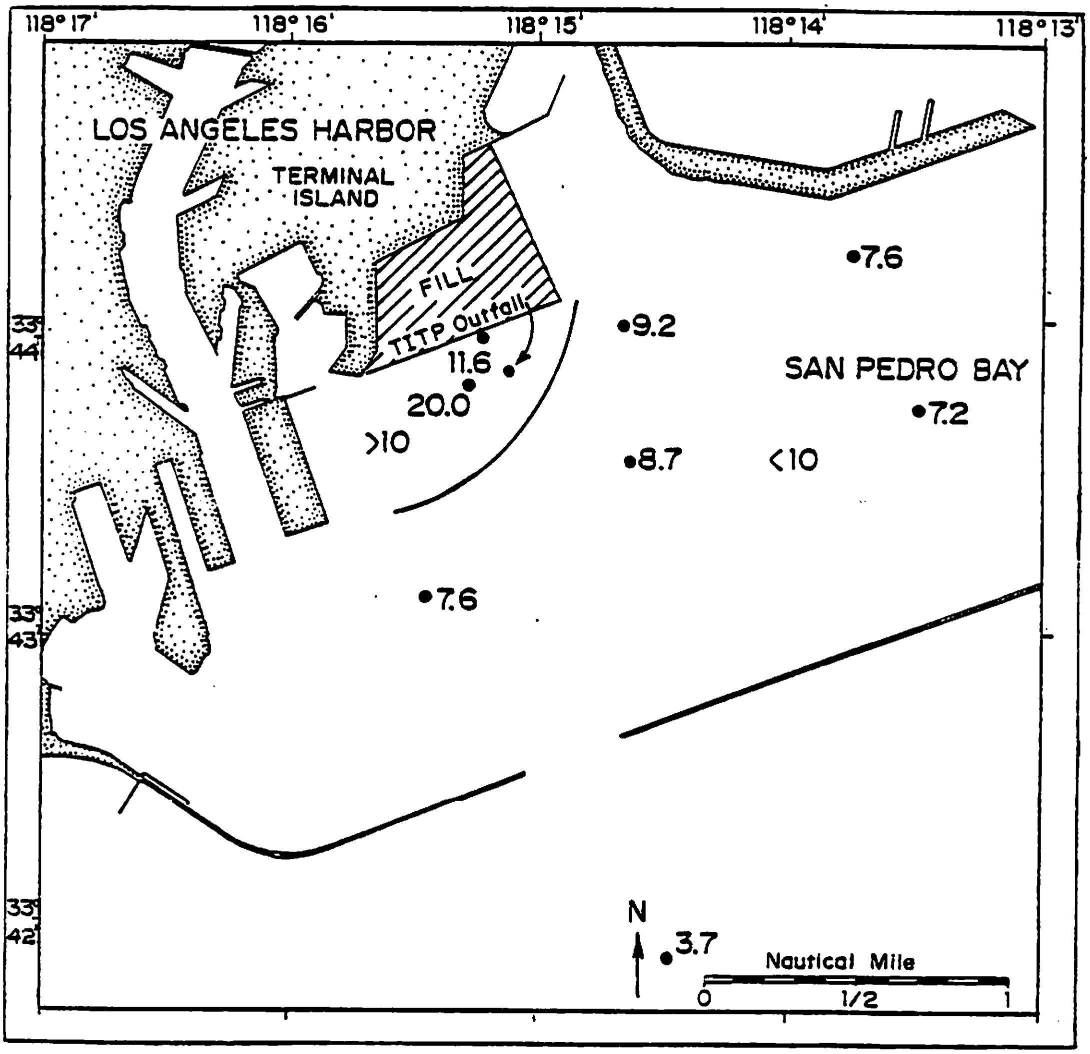


FIGURE A17. SURFACE SILICATE, $\mu g\text{-}at\ Si\ l^{-1}$, 24 FEBRUARY 1982.

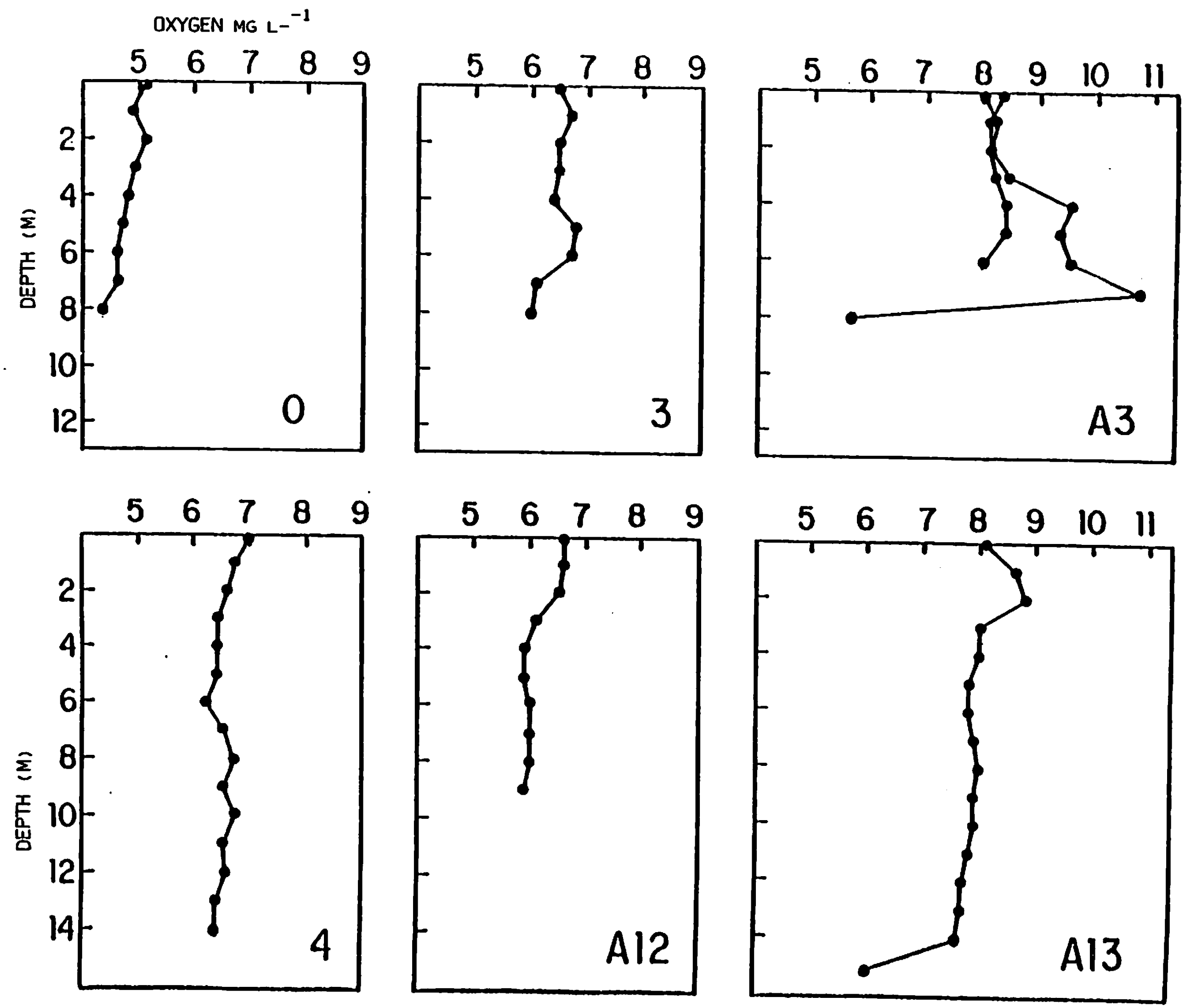


FIGURE A18. REPRESENTATIVE OXYGEN PROFILES FOR 24 FEBRUARY 1982. (mg O_2 l^{-1})

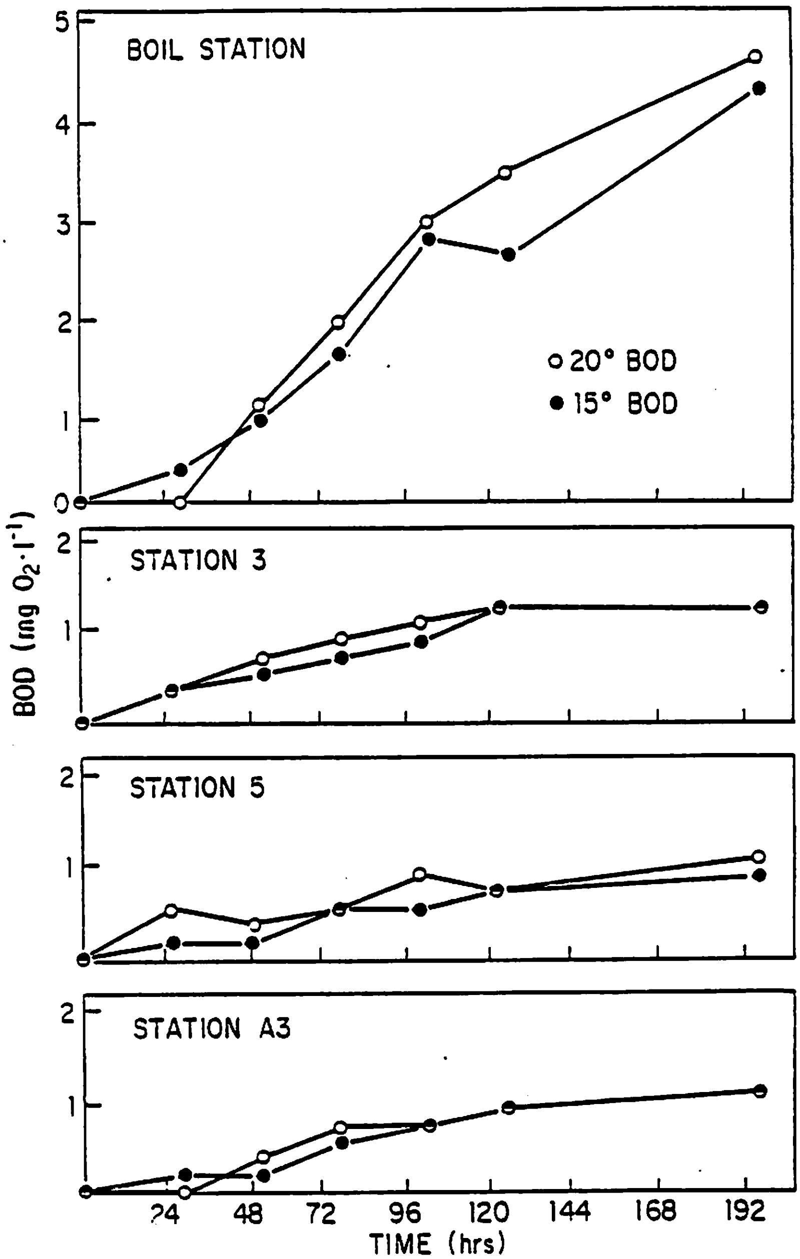


FIGURE A19. REPRESENTATIVE MEASUREMENTS OF BOD THROUGH TIME FOR SELECTED STATIONS FROM 24 FEBRUARY 1982.

TABLE A1. 8 DECEMBER 1981, HARBOR DATA SUMMARY OF WATER QUALITY AND NUTRIENTS

Station #	Surface Oxygen mg 02/1	5 Day BOD mg 02/1	Chl A ug/1 Surface	Chl A ug/1 Bottom	NO2+ NO3 ug-at/1 Surface	NO2+ NO3 ug-at/1 Bottom
0	7.36	2.59	1.59	2.28	30.3	24.5
1	7.27	1.35	2.18	1.59	14.3	11.4
2	7.53	1.19	4.67	2.38	22.7	7.6
3	7.23	1.22	2.12	1.92	39.9	7.0
4	----	----	------	------	----	----
5	7.41	0.80	0.17	0.15	26.6	5.4
A1	7.80	0.66	1.83	0.84	6.6	2.9
A2x	7.99	0.84	4.24	2.98	11.7	5.2
A3	6.86	1.08	2.78	1.79	14.7	6.8
A12	7.85	0.86	0.79	2.98	4.6	4.0
A13	7.53	0.89	2.63	1.83	5.5	3.9
A14	8.07	0.83	1.79	3.57	4.7	4.4
A16	7.87	0.60	3.91	3.08	9.6	5.9
A17	8.10	1.60	4.17	2.53	13.2	5.3
B8	7.82	0.58	2.54	3.18	6.1	4.7
B9	8.07	1.01	2.98	3.71	5.0	4.0

STATION	NH 4 ug-at/1 Surface	NH 4 ug-at/1 Bottom	PO 4 ug-at/1 Surface	PO 4 ug-at/1 Bottom	Si 04 ug-at/1 Surface	Si 04 ug-at/1 Bottom
0	5.2	6.5	6.0	3.2	14.9	11.6
1	5.4	6.5	6.3	1.7	21.2	11.4
2	7.1	5.5	2.7	1.3	15.6	10.4
3	7.2	5.3	4.6	1.4	17.4	9.0
4	----	----	----	----	----	----
5	7.1	5.7	3.5	1.1	15.0	8.4
A1	7.0	2.7	0.9	0.7	8.0	6.8
A2x	5.5	5.5	1.7	1.1	10.0	8.8
A3	----	7.9	2.7	1.7	13.7	8.6
A12	3.2	3.5	1.0	1.0	9.3	9.2
A13	4.0	3.7	1.1	0.9	8.8	8.1
A14	2.6	2.6	0.9	1.0	9.2	8.8
A16	3.5	3.6	1.4	1.0	10.5	9.1
A17	5.3	3.3	1.9	1.1	11.7	8.6
B8	4.5	4.5	1.1	1.1	9.3	10.2
B9	4.4	3.9	1.0	1.0	8.9	9.2

Water Temperature = 15 Deg C

Low Tide 13:12 hrs PST -0.1 m
High Tide 06:23 hrs PST 1.9 m
Tidal Amplitude 2.0 m

TABLE A2. 8 DECEMBER 1981, HARBOR OXYGEN PROFILE DATA

	STATION					
DEPTH (M)	0	1	2	3	5	A1
0	7.44	7.65	8.93	8.30	8.89	7.84
1	8.42	7.63	9.07	8.94	9.19	7.85
2	8.42	7.88	9.34	9.01	9.91	7.83
3	----	----	----	----	----	----
4	8.23	7.73	9.45	7.54	10.39	7.96
5	----	7.74	----	----	----	----
6	8.76	----	7.72	7.32	11.18	8.09
7	8.56	----	----	7.49	----	----
8	----	----	----	----	11.02	8.09
9	----	----	----	----	7.43	----
10	----	----	----	----	----	8.17

	STATION					
DEPTH (M)	A2x	A3	A3-2	A12	A13	A14
0	9.48	7.34	7.77	8.01	9.51	8.32
1	8.76	6.75	6.95	8.11	9.92	8.54
2	8.84	7.39	7.90	8.17	10.29	8.71
3	----	----	----	----	----	----
4	7.80	8.02	8.02	8.16	7.79	8.67
5	----	----	----	----	----	----
6	7.63	8.02	7.75	8.13	7.75	8.59
7	----	7.98	----	----	----	----
8	7.63	----	7.39	7.63	7.63	8.50
9	----	----	----	----	----	----
10	7.57	----	----	7.82	7.54	8.29
11	----	----	----	----	----	----
12	----	----	----	----	7.61	----
13	----	----	----	----	----	----
14	----	----	----	----	7.51	----
15	----	----	----	----	----	----
16	----	----	----	----	7.38	----
17	----	----	----	----	----	----
18	----	----	----	----	7.35	----
19	----	----	----	----	----	----
20	----	----	----	----	7.34	----
21	----	----	----	----	7.28	----

TABLE A2 (CONT'D)

DEPTH	A16	A17	STATION B8	B9
0	9.56	9.52	9.06	9.71
1	10.25	10.15	9.64	10.44
2	11.14	10.81	10.38	11.40
3	----	----	----	----
4	9.38	11.46	10.89	13.25
5	----	----	----	----
6	9.20	12.25	10.85	14.97
7	----	----	----	----
8	7.54	10.69	10.44	16.72
9	----	----	----	----
10	----	----	10.60	18.37
11	----	----	7.38	----
12	----	----	----	18.83
13	----	----	----	----
14	----	----	----	19.38
15	----	----	----	----
16	----	----	----	20.82
17	----	----	----	----
18	----	----	----	18.93
19	----	----	----	----
20	----	----	----	19.52
21	----	----	----	8.28

TABLE A3. MEASUREMENTS OF BIOCHEMICAL OXYGEN DEMAND (BOD) OVER TIME FOR WATER COLLECTED 8 DECEMBER 1981 AND INCUBATED AT TWO DIFFERENT TEMPERATURES.

STATION							
	ELAPSED TIME (hrs)	0.0	25.7	45.0	75.0	95.0	120.0
0	BOD 15 deg C	0.0	0.3	1.3	1.5	1.4	2.1
	BOD 20 deg C	0.0	0.8	1.4	0.5	2.3	2.6
	ELAPSED TIME (hrs)	0.0	24.0	45.0	75.0	95.0	95.0
1	BOD 15 deg C	0.0	0.5	0.6	0.5	0.7	1.0
	BOD 20 deg C	0.0	0.2	0.8	0.7	1.0	1.4
	ELAPSED TIME (hrs)	0.0	24.0	45.0	74.0	95.0	120.0
2	BOD 15 deg C	0.0	0.2	1.7	0.6	0.9	0.8
	BOD 20 deg C	0.0	0.7	1.0	0.8	1.0	1.2
	ELAPSED TIME (hrs)	0.0	24.0	45.0	74.0	95.0	121.0
3	BOD 15 deg C	0.0	0.1	0.5	0.5	0.6	0.9
	BOD 20 deg C	0.0	0.3	0.7	0.6	0.8	1.2
	ELAPSED TIME (hrs)	0.0	24.0	44.0	74.0	94.0	120.0
5	BOD 15 deg C	0.0	0.1	-0.3	0.3	0.4	0.6
	BOD 20 deg C	0.0	0.4	0.4	0.5	0.7	0.8
	ELAPSED TIME (hrs)	0.0	25.0	46.0	75.0	95.0	121.0
A3	BOD 15 deg C	0.0	0.5	0.8	0.7	0.8	0.9
	BOD 20 deg C	0.0	0.4	0.9	---	1.0	1.1
	ELAPSED TIME (hrs)	0.0	23.0	44.0	73.0	94.0	119.0
A14	BOD 15 deg C	0.0	0.2	0.8	0.5	0.7	0.9
	BOD 20 deg C	0.0	0.6	0.8	0.7	1.3	0.8
	ELAPSED TIME (hrs)	0.0	23.0	41.0	71.0	91.0	116.0
A16	BOD 15 deg C	0.0	0.3	0.8	0.4	0.6	0.6
	BOD 20 deg C	0.0	0.3	0.5	0.7	0.9	0.6
	ELAPSED TIME (hrs)	0.0	23.0	44.0	74.0	94.0	119.3
A17	BOD 15 deg C	0.0	0.4	0.5	0.7	0.8	1.1
	BOD 20 deg C	0.0	0.8	0.8	0.8	1.1	1.6

TABLE A4. 24 FEBRUARY 1982, HARBOR DATA SUMMARY OF WATER QUALITY AND NUTRIENTS

Station #	Surface Oxygen mg 02/1	5 Day BOD mg 02/1	Chl A ug/l Surface	Chl A ug/l Bottom	N02+ N03 ug-at/l Surface	N02+ N03 ug-at/l Bottom
0	7.75	3.53	2.35	1.99	130.70	5.25
1	7.91	0.95	2.52	1.99	7.23	4.51
2	7.91	0.96	2.17	2.46	16.23	5.27
3	7.83	1.22	2.82	2.35	----	----
4	7.86	1.01	2.17	2.35	----	----
5	7.73	0.76	2.05	2.23	4.16	4.26
A1	8.72	1.67	5.23	3.93	----	1.15
A2x	7.81	0.91	3.88	4.05	4.76	4.55
A3	7.75	0.87	3.17	5.70	----	----
A3-2	7.93	1.01	2.94	2.82	----	----
A12	7.96	0.92	2.29	1.99	----	----
A13	7.70	0.84	1.27	1.70	----	----
A14	7.96	0.72	3.23	2.70	4.26	4.05
A16	7.82	0.77	2.46	3.05	----	----
A17	7.88	0.84	------	-----	----	----
B8	7.97	0.97	2.52	2.05	3.25	3.14
B9	8.08	1.60	2.52	2.17	2.52	3.24

Station #	NH 4 ug-at/l Surface	NH 4 ug-at/l Bottom	PO 4 ug-at/l Surface	PO 4 ug-at/l Bottom	Si 04 ug-at/l Surface	Si 04 ug-at/l Bottom
0	----	4.54	61.40	2.69	----	8.78
1	12.88	4.26	3.01	1.79	11.56	7.74
2	40.50	5.56	6.48	2.57	20.03	8.16
3	----	----	----	----	----	----
4	----	----	----	----	----	----
5	6.75	6.06	1.55	1.57	9.19	9.09
A1	1.04	0.72	2.79	2.23	3.72	4.54
A2x	3.51	3.14	1.57	1.43	7.64	8.05
A3	----	----	----	----	----	----
A3-2	----	----	----	----	----	----
A12	----	----	----	----	----	----
A13	----	----	----	----	----	----
A14	5.02	3.01	1.55	1.37	3.67	7.23
A16	----	----	----	----	----	----
A17	----	----	----	----	----	----
B8	1.77	2.24	1.40	1.45	7.64	8.16
B9	1.69	3.16	1.40	1.45	7.23	9.09

Water Temperature = 15 Deg C

Low Tide	15:53 hrs PST	-0.2 m
High Tide	09:11 hrs PST	1.7 m
Tidal Amplitude		1.9 m

TABLE A5. 24 FEBRUARY 1982, HARBOR OXYGEN PROFILE DATA

	STATION					
DEPTH (M)	0	1	2	3	4	5
0	5.06	6.20	5.82	6.49	7.07	6.40
1	4.91	6.03	5.51	6.69	6.69	6.59
2	5.13	5.92	5.51	6.49	6.59	6.41
3	4.97	6.59	6.02	6.46	6.45	6.37
4	4.81	6.20	5.63	6.43	6.41	6.07
5	4.74	6.16	5.03	6.70	6.41	6.08
6	4.61	----	5.50	6.74	6.17	6.34
7	4.69	----	5.08	6.11	6.47	6.52
8	4.34	----	----	5.99	6.67	6.61
9	----	----	----	----	6.54	6.77
10	----	----	----	----	6.71	6.25
11	----	----	----	----	6.54	----
12	----	----	----	----	6.55	----
13	----	----	----	----	6.38	----
14	----	----	----	----	6.45	----

	STATION					
DEPTH (M)	A1	A2x	A3	A3-2	A12	A13
0	7.75	8.04	8.23	7.98	6.61	8.06
1	7.79	7.97	8.13	8.23	6.59	8.63
2	7.51	7.93	8.13	8.14	6.53	8.80
3	7.84	7.96	8.43	8.24	6.12	7.96
4	7.46	7.97	9.51	8.40	5.85	7.93
5	7.63	7.97	9.31	8.39	5.95	7.82
6	7.79	7.98	9.51	7.94	5.90	7.78
7	7.74	7.96	10.08	----	5.98	7.93
8	7.53	7.79	5.68	----	5.98	7.96
9	7.68	----	----	----	5.98	7.91
10	7.19	----	----	----	5.90	7.90
11	7.47	----	----	----	----	7.76
12	7.47	----	----	----	----	7.69
13	7.42	----	----	----	----	7.70
14	7.37	----	----	----	----	7.58
15	7.35	----	----	----	----	6.00
16	7.47	----	----	----	----	----
17	7.53	----	----	----	----	----
18	7.53	----	----	----	----	----
19	7.58	----	----	----	----	----
20	7.64	----	----	----	----	----

TABLE A5 (CONT'D)

DEPTH	STATION A14	A16	A17	B9
0	8.20	6.02	8.18	8.17
1	7.83	5.54	8.41	8.54
2	7.77	5.10	8.77	8.75
3	7.74	5.32	8.95	9.00
4	7.72	5.34	9.20	8.69
5	7.71	5.29	9.17	8.63
6	7.58	6.03	9.08	9.03
7	7.57	6.11	8.77	8.51
8	7.60	5.97	8.90	8.57
9	7.57	----	----	8.48
10	7.57	----	----	7.73
11	----	----	----	7.73
12	----	----	----	7.67
13	----	----	----	7.17
14	----	----	----	7.02
15	----	----	----	6.96
16	----	----	----	6.95
17	----	----	----	5.89
18	----	----	----	6.98
19	----	----	----	6.93
20	----	----	----	6.98
21	----	----	----	6.85
22	----	----	----	6.76

TABLE A6 MEASUREMENTS OF BIOCHEMICAL OXYGEN DEMAND (BOD) OVER TIME FOR WATER COLLECTED 24 FEBRUARY 1982 AND INCUBATED AT TWO DIFFERENT TEMPERATURES.

STATION								
	ELAPSED TIME (hrs)	0.0	28.0	52.0	75.0	101.0	124.0	197.0
0	BOD 15 deg C	0.0	0.3	0.9	1.5	2.7	2.7	4.3
	BOD 20 deg C	0.0	0.0	1.0	1.9	3.0	3.5	4.6
	ELAPSED TIME (hrs)	0.0	27.0	51.0	75.0	0.0	123.0	196.0
1	BOD 15 deg C	0.0	0.2	0.4	0.6	0.8	0.9	1.1
	BOD 20 deg C	0.0	0.3	0.5	0.7	1.0	1.0	1.3
	ELAPSED TIME (hrs)	0.0	27.0	51.0	75.0	100.0	123.0	196.0
2	BOD 15 deg C	0.0	0.3	0.4	0.6	0.9	1.0	1.4
	BOD 20 deg C	0.0	0.3	0.4	0.7	0.8	1.0	1.3
	ELAPSED TIME (hrs)	0.0	27.0	51.0	74.0	100.0	123.0	196.0
3	BOD 15 deg C	0.0	0.3	0.5	0.7	0.8	1.2	1.3
	BOD 20 deg C	0.0	0.3	0.7	0.9	1.0	1.2	1.3
	ELAPSED TIME (hrs)	0.0	27.0	51.0	74.0	99.0	123.0	196.0
5	BOD 15 deg C	0.0	0.1	0.2	0.6	0.6	0.8	0.9
	BOD 20 deg C	0.0	0.5	0.3	0.5	0.8	0.8	1.0
	ELAPSED TIME (hrs)	0.0	28.0	52.0	76.0	101.0	124.0	197.0
A3	BOD 15 deg C	0.0	0.1	0.2	0.5	0.7	0.9	1.0
	BOD 20 deg C	0.0	0.1	0.3	0.7	0.7	0.9	1.1
	ELAPSED TIME (hrs)	0.0	25.0	49.0	73.0	98.0	121.0	----
A14	BOD 15 deg C	0.0	-0.3	0.0	0.2	0.4	0.7	----
	BOD 20 deg C	0.0	0.0	0.3	0.4	0.7	0.8	----
	ELAPSED TIME (hrs)	0.0	29.0	2.0	75.0	100.0	24.0	197.0
A16	BOD 15 deg C	0.0	0.1	0.3	0.5	0.7	0.7	1.3
	BOD 20 deg C	0.0	0.1	0.4	0.5	0.7	0.8	0.9
	ELAPSED TIME (hrs)	0.0	25.0	49.0	72.0	98.0	121.0	194.0
A17	BOD 15 deg C	0.0	0.1	0.3	0.4	0.5	1.1	1.2
	BOD 20 deg C	0.0	0.2	0.4	0.4	0.7	0.8	1.1

II

EVALUATION OF THE OUTER LOS ANGELES HARBOR BENTHOS IN 1981-1982, COMPARED WITH CONDITIONS FOUND IN 1971-1978 INVESTIGATIONS

by

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EVALUATION OF THE OUTER LOS ANGELES HARBOR BENTHOS IN 1981-1982, COMPARED WITH CONDITIONS FOUND IN 1971-1978 INVESTIGATIONS

INTRODUCTION

Benthic organisms, those living in or on the benthos (bottom), were selected for evaluation of the present biological condition of the harbor because they generally constitute more stable communities than phytoplankton, zooplankton or pelagic fishes. However, within the time frame available for the Terminal Island Treatment Plant (TITP) studies, in the winter of 1981 and spring of 1982, severe perturbations of the environment were taking place due to dredging and filling in outer Los Angeles Harbor. Because the turbidity plume attracted fish from surrounding waters, fish trawls would have been biased, exceeding the variations usually induced by seasonality. Phytoplankton productivity might have been stimulated or inhibited, depending upon changes in nutrients and light penetration due to dredging, while studies of zooplankton assemblages, which normally fluctuate greatly according to tide and season, would have been inconclusive due to the limited collecting period.

One station, A07, nearest the old TITP outfall (Figure 18) for which benthic records exist from 1971-1978, has been eliminated by the fill. The outfall pipe has been extended to the south side of the fill in 26 ft (8 m) of water. Ten stations were selected for sampling, based on available past records, on the spectrum of habitat represented in the outer harbor, and on the very obvious constraints of the dredging equipment operations and the fill site.

Background

In 1971, benthic stations were established by Harbors Environmental Projects (HEP) for the Port of Los Angeles, Pacific Lighting Corp., and the USC Sea Grant program, at seven locations in Los Angeles Harbor extending from the Sea Bouy outside Angeles Gate (A01), north to a position between the TITP outfall and the two fish cannery outfalls (A07). Other stations were added in 1973-74 to create a dredge impact study, for the U. S. Army Corps of Engineers, which extended from Cabrillo Beach on the west to the San Gabriel River on the east (AHF, 1976). The original seven stations were continued until 1978 when the station pattern was again extended to encompass the harbors from Cabrillo Beach on the west to the oil islands east of the Los Angeles River (Figure 18). The 1978 survey for the City of Los Angeles TITP and the Ports of Los Angeles and Long Beach assessed the impacts of discontinuing the separate cannery effluents, which were diverted to TITP, converting TIIP to secondary waste treatment and moving the TITP outfall to its new location (Soule and Oguri, 1979;1980).

The ecology of the Los Angeles-Long Beach Harbors was documented by HEP under various effluent conditions as follows:

1971-1974	Urban, primary treated TITP wastes; screened fish processing wastes; separate outfalls;
1975-1977	Primary treated TITP wastes; dissolved air flotation (DAF) treated fish processing wastes; separate outfalls, land disposal of sludge;
Apr-Oct 1977	Secondary treated TITP wastes; DAF treated cannery wastes;
Oct 1977-Jan 1978	Secondary treated TITP wastes; canneries being hooked up to TITP, one outfall;
Jan-May 1978	Variable quality secondary treated TITP wastes (chlorinated Mar 9 - Aug 30, 1978);
June-Aug 1978	TITP upset; secondary treatment plus activated sludge solids discharged accidentally;

Sept 1978-Jan 1979	Secondary treated TITP;
Dec 1981 and Mar 1982	Secondary treated TITP;

In previous investigations, the harbor studies included physical water quality, nutrient chemistry, microbiology, phytoplankton productivity, zooplankton populations, meroplankton (settling rack fauna), benthic fauna, fish populations and marine-associated birds. Because of constraints imposed on the present study by limited time and limited available funding, as well as the large outer harbor dredge and fill project, it was concluded that the benthic fauna offered the best means of making an abbreviated assessment of the outer Los Angeles Harbor ecology, in conjunction with the City's application for a new NPDES permit for TITP from the State Regional Water Quality Control Board.

Historical Changes

The historical record of the benthos in San Pedro Bay dates from studies of marine fossils reported in geological surveys of the 1850s, and biota recorded from the early 1900s (Kennedy, 1975). Changes in the habitats and the associated biota were discussed by Soule and Oguri (1980). Alterations of the harbor by construction of breakwaters and landfill changed it from open bay, sand bar and estuarine mudflat configurations to channels and relatively calm water, with a benthos composed largely of very fine unconsolidated sediments. Normal, year-round riverine flow from the San Gabriel mountains was interrupted by increased urbanization, paving and channelization of runoff. Diversion of the Los Angeles and San Gabriel Rivers and concretization of their channels permanently altered the production of sand and the depositional patterns in the harbor (AHF, 1976). The nutrient input patterns were also altered by limiting terrigenous flow to the periods of rapid runoff during winter storms. This carries nutrient material out of the harbor and makes the ecosystem more dependent on the relatively uniform flow from urban waste outfalls such as TITP and, formerly, the fish processors.

THE PRESENT INVESTIGATIONS

Methods

The Reinecke box corer, which takes a sample of 1/16 m^2 of surface, was used in the 1973-74 and 1978 HEP investigations for all stations except for the sewer outfall station, A07. That station was in shallow (4-5 m) water and could not be sampled from the large vessel required to operate the box corer, so it was sampled from a smaller vessel by a Campbell grab (similar to a Van Veen grab), which samples a 1/10 m^2. All of the 1981-82 samples were taken by box corer from the R.V. Sea Watch, since the shallow A07 outfall station is now part of the harbor landfill.

The box corer has the advantage that it does not mix the sediments vertically, preserving the surface integrity, and the surface is untouched by metal parts so that sediment samples for chemical and grain size analyses can be taken along with the benthic organism samples. Earlier, HEP made comparative studies with benthic sampling gear and concluded that replicate box cores, which increased the time, effort and cost unduly, were not necessary in the soft-bottom harbor. Extensive replicate tests produced only a slight increase in single species occurrences (and thus in diversity) but did not alter the rankings of the 10 most dominant species. The much smaller and inefficient Shipek grab (1/25 m^2) used by some investigators probably requires replicate sampling. HEP washes box core muds through a 0.5 mm screen on board the vessel and preserves the organisms in a 10% formalin-seawater solution. Specimens are rescreened and drained in the laboratory and transferred to 70% ethanol for identification to the lowest feasible taxon. Following identifications, the data on numbers of species and individuals were calculated on a per m^2 basis, and the Shannon-Weiner Species Diversity Index (H') calculated. Also determined were H'max., Evenness (J^1) and Gleason's Index, as follows:

H' = Shannon-Weiner Index (Diversity)
SWI emphasized the number of individuals.

$$H' = -\Sigma \frac{n_j}{N} \ln \frac{n_j}{N}$$

where n_j = number of individuals in the $_j$th species
N = number of individuals
ln = natural log

J' = Evenness in Sampled Community where:

$$J' = \frac{H'}{\ln S}$$

where: S = total species
ln = natural log

<u>H'max</u> is a diversity index of a hypothetical community, used as a standard, having both the same number of species and individuals as the observed community.

$$H'max - \frac{H'}{J'}$$

Gleason's Index (modified) = Margolef

$$\frac{S - 1}{\ln (N)}$$

where: S = number of species in sample
N = total number individuals in sample
ln = natural log

Benthic samples for organisms and grain size were taken on 16 December 1981 and 26 March 1982 at ten stations (Figure 19). Station A01, outside the harbor, has served since 1971 as a comparison (not a control) for coastal conditions, and nine of the stations selected in the outer harbor represent varying depths, substrates, and distances from outfalls or the entry (Stations A2A, A04, A08, A12, A13, A14, A15, B08 and B09). Efforts were made to avoid stations that appeared to be unduly affected by proximity to dredging or filling, such as A03 and A11, but signs of effects on other stations would not have been surprising.

The Shannon-Weiner Diversity Index, (H') is a widely used measure of environmental quality predicated on assumptions that higher diversity represents a healthier ecosystem. However, the diversity index can misrepresent conditions; for example, if the number of species remained the same, but the number of individuals dropped by an order of magnitude, as occurred in the harbor, it would appear that the environment was improved because diversity was increased. On the other hand, impacts could result in a completely altered species composition even though the numbers remained exactly the same. Because of such deficiencies in the present report, the raw numbers for species and individuals were plotted separately for those data points which were taken in the winter and spring between 1971 and 1982. These plots were then compared with Shannon-Weiner calculations.

RESULTS AND DISCUSSIONS

In the harbor, impacts from storm water runoff, storm wave damage, dredging, industrial spills, illegal disposal, sewage plant malfunctions and other factors can produce large fluctuations in the benthic populations, in addition to the normal fluctuations due to seasonality and temperature. It is that variability which creates an environment for the "opportunistic" species, those having short, year-round reproductive cycles and those that are euryhaline and eurythermal in tolerance.

In spite of the variability, however, results of analysis of the long-term HEP computer data base shown by averaging the annual data, are striking, as is demonstrated in Figure 20. Numbers of species have not changed greatly since 1972-1973, after great improvement over 1971 levels. Numbers of organisms, however, decreased dramatically after 1973 and have remained below 1972 levels, which indicates a tremendous loss of organisms in the food web on which fish and birds depend.

Because the sampling periods in 1981-82 represented the winter and spring seasons, data for the selected stations and those seasons were retrieved for the prior years from the HEP computer, were analyzed for comparison of longer-term trends. Species were also ranked in order of dominance for each station and for the entire area. Some stations have more records than others because of the differences in survey scopes and periods referred to above, as will be noted in the figures and tables.

In spite of the large variations, some trends can be seen in Figures 21 to 25 in which the numbers of species and individuals are plotted. The plots are based on data presented in Tables 7 through 10. Winter data were plotted separately from spring data to improve potential visual comparisons of trends.

Inspection of the plots indicates that, more often than not, the increases in species were accompanied by increases in numbers of individuals. This would tend to suggest that optimal conditions often occur for both species and numbers; an inverse relationship may well represent a shift from the normal state, or perhaps from chronic conditions of environmental stress.

<u>The Sea Buoy and Main Channel, Stations A01 and A2A</u>

The earliest data available on the stations included are from March and December 1971, for stations A01 and A02 (Figure 21), and from March 1971 for station A04 (Figure 22). It seems clear that a rise both in species and numbers followed imposition of the 1969-1970 State and Federal legislative mandates on water quality (Reish et al., 1980). The quantity of pollutants that had flowed out of the Los Angeles Harbor Main Channel in previous years would almost certainly have influenced the environmental conditions at the Sea Buoy (A01) and reduction in pollution would serve to increase numbers of species and individuals at stations A01 and A02/ A2A. The channel marker buoy used as station A02 was relocated somewhat in 1972, causing the new designation of A2A to be assigned.

Peak numbers of species and individuals at all stations are summarized in Table 11. While numbers of both increased dramatically from 1971 to 1972, the 1973-1974 values were the highest paired values. Species increased, with fluctuations, through 1976 and decreased greatly through 1978-79, rebounding considerably in 1981-82. Numbers of individuals decreased by an order of magnitude in 1975-76 in general; A01 recovered to about 25 percent of peak 1972 levels. It seems probable that reduction in fish cannery waste loadings in 1975-76 reduced the nutrient levels reaching the sea buoy, but fluctuations in sea temperatures may also have affected the populations (Figure 28, after Soule and Oguri, 1980).

Numbers of species and individuals at A02-A2A (Figure 21 C,D) rose rapidly between 1971 and 1972, similar to the rise at A01 (Tables 7,11). Numbers of individuals at A2A climbed to as much as five times those at A01 in 1974, and decreased somewhat through 1976, dropping after that. The dredging project may have produced the low 1981-82 levels of species, but the low numbers are similar to 1978 levels. Again, this could be the result of retreating contours of nutrient levels from waste effluents, or of fluctuations in coastal temperatures, or other factors, but the trend lines appear to be downward since peaks in 1974, especially in the spring. Taken independently, A2A data trends would not be conclusive. Station A2A was roughly 2000 meters southwest of the waste outfall area and upwind (upstream) of the wastes, which are carried in the opposite direction, clockwise, in a major harbor gyre (Robinson and Porath, 1976; McAnally, 1975; Soule and Oguri, 1980). The outfall line was extended about 700 m to the southwest in 1981.

Station A08, at the Main Channel and Reservation Point

Station A08 was a similar distance from the outfall, to the west-southwest, at the tip of Reservation point on the Los Angeles Main Channel, but was also closer to shipyard pollutant input. Station A08 experienced a tripling of species and a twenty-fold increase in numbers to 123,000/m^2 in 1972 (Figure 22 A,B). It then experienced decreasing numbers of individuals, especially in 1977, but retained relatively high species counts in 1975-77 (Tables 8,10) until those dropped in 1978; there appears to have been a modest recovery in 1981-82. The shipyard is no longer in operation nearby.

Station A12, Center of the Outer Harbor

Station A12 was about 2000 m southeast of the old outfalls, almost in the vortex of the clockwise gyre. It supported high levels of species and numbers in 1972 through 1975 but crashed in January 1976 (Table 9), when only 11 species and 170 individuals /m^2 were found. This appeared to coincide with a TITP upset. The wintertime trend at Station A12 has otherwise been of relatively stable numbers of species with declining populations; the springtime profiles indicate a more steeply declining slope (Figure 22). The dredging may well have inhibited the population counts in 1982, but counts were also low in 1978, and none have equalled the 1972-75 levels (Table 9).

Deep Water Harbor Stations, B08 and B09

Stations B08 and B09 were about 2700 and 3500 m distant respectively from the old outfall to the east and southeast on the clockwise surface gyre. Stations A2A, A12, B08 and B09 were all in depths charted at 33 to 42 ft (10-13m) and so offer good comparisons with one another. Raw data on species and individuals (Table 10-11), although lacking the 1971 sampling periods, show that there were clear increases in number of species and individuals between 1972 and 1973 in winter, followed by declining numbers of individuals through 1978. Species numbers were more stable at B09 in the winter than at B08. In Figure 23, the slope for both species and individuals at both stations in the spring indicate continuing declines, although the decline in species was more severe at B08. The decline in individuals was about 10-fold. The peak data for these two stations, which were consistently amound the richest in 1973-74, are compared with the winter 1981 - spring 1982 data in Table 11.

Shallow Water Stations A04 and A07

Station A07 was originally located to lie between the fish processing outfalls (Figure 18) and the TITP primary outfall. The fish waste outfalls were relocated in 1964 from Inner Fish Harbor where that small enclosed basin was frequently anoxic and the bottom was covered by several meters of fish scales. Boat hold-water and fish scraps or culls often went into Inner Fish Harbor. Unfortunately, when the cannery outfalls were relocated, from Inner Fish Harbor, they were placed intertidally, and the TITP outfall was in 4-5 m of water, which compromised the potential for dispersion. Had the large harbor gyre not circled past the outfalls area, transporting, oxidizing, mixing and distributing nutrients to the rich benthic community in the outer harbor, the harbor would have been very seriously impacted. After the installation of pre-treatment of cannery wastes by dissolved air flotation (DAF), the nutrient loading of the harbor no longer exceeded assimilation capacity periodically, as evidenced by the lack of large anoxic episodes.

Station A04, at the mouth of Outer Fish Harbor, showed impacts of anoxic episodes within, in 1971 and 1973 (Table 8). Red tide blooms occurred throughout the harbor in 1973 and 1974 (Oguri, 1974; AHF, 1976), as well as in open coastal waters in Southern California, and blooms persisted near the Los Angeles River year around. When blooms were trapped by wind cells in Fish Harbor that basin would quickly become anoxic, killing fish and turning boats black with sulfide fumes. Two boatyards, a machine shop and oil docks also dumped wastes into Fish Harbor prior to enforcement, and cannery wastes were sometimes carried in by tides or when the prevailing winds, usually from the Southwest, switched to the east or northeast (Santa Ana winds). Station A04 recovered in 1972, sagged badly in 1973-74 and peaked in spring, 1977 (Figure 24). Species numbers increased in 1981-82 returning to spring 1972 levels, while 1972-73 represented peak numbers of individuals. Variability is great at Fish Harbor due to the potential for localized environmental insult in the small basins.

Station A07 has, in the past, shown the impacts of the highly organic wastes, possible toxic substances and salinity fluctuations, having supported generally low numbers of species and individuals. It is interesting, however, to note that the peak totals of individuals have been quite close to those at the Sea Buoy, but with episodes of low counts between.

Surprisingly, at the sewer outfalls (A07), the March 1973 sampling showed 23 species and 12,704 individuals; the April 1978 sampling, the last one carried out by HEP, showed 23 species and 12,460 individuals, virtually identical to March 1973, prior to all advanced treatment. This tends to negate the supposed improvements due to installation of secondary treatment, or at least to indicate a wide range of fluctuation in an area of variable affluent composition and run off.

In 1978 after secondary treatment was installed, the population was composed of more than 50 percent Capitella capitata (polychaete worm), plus about 23 percent Caprella equilibra, (crustacean amphipod) whereas there had been only 28 percent Capitella capitata in the March 1973 period. In January 1979, total population had increased greatly at A07, but 86 percent were capitellid worm species. This was not the effect predicted by early advocates of secondary treatment. In periods of stress, the opportunistic Capitella increases in percentage; it was the only species at A04 on occasion, for example. Capitella capitata has been called a pollution indicator but it is typically present in newly exposed sediment habitats or ones with rapid environmental fluctation, since it reproduces year around. It does not compete as well with other species however. The increase in population at A07, at the outfall, was traded off for decreases at most stations sampled in the harbor. Numbers were, however, similar to those found in 1973 at station A07.

Cross-Harbor Transect; A13, A14, A15

Stations A13, A14, and A15 were established for the TITP survey in 1978 (Soule and Oguri, 1979; 1980) and hence have a much shorter record. At A13, near the breakwater, the 1982 survey showed the highest numbers of species and individuals as compared with 1978- 79 data (Figure 25; Table 9).

The highest number of species at A14 was in 1982, but the peak in individuals was in 1979. Station A15 peaked in both species and individuals in April 1978, when counts more than doubled between January and April.

Because the fill operation was so close to A15, it is interesting to note that the polychaete Cossura candida provided 89 percent of the numbers in December 1981, but in March 1982 the polychaete Prionospio pygmaeus composed 87 percent of the biota.

Classifying Harbor Areas

In earlier multivariate analyses of harbor surveys (AHF 1976; Soule and Oguri 1979), depth proved to be a prominent factor. This tends to be overlooked as a factor in the inhibition that was produced at the outfalls when TITP and the two fish processor outfalls entered water of less than 5 meters in depth. There was a zone of inhibition within the 5 m contour, but there was, however, a large zone of enrichment in both species and numbers, particularly near A08 to the west, and B08 and B09 on the east of the outer harbor. Station A08 is on the edge of the deeper main channel and is probably better flushed than B08 and B09, although it could receive more pollutants from the main channel.

Bar graphs of the total numbers of species for all records (N) are shown in Figure 26. The differences are significant in winter, when A04, A07 and A15 are separated from the other stations. Station A07 is separated from A04 and A15 in the spring, and the three in turn are separated from the other stations, with some overlap at A15. Such changes in groups were illustrated by multivariate analysis in Soule and Oguri (1979). The shallower waters are more susceptible to thermal fluctuations than the deeper waters are, but in winter the harbor waters are generally well mixed and not stratified. In other seasons, temperatures declined with depth but thermoclines were absent, or transitory if present.

Bar graphs of differences in numbers of individuals for all records (N) are shown in Figure 16 A, B. Station A2A appeared to be separated from A01, A04, A07, A13 and A14 in winter, but the extreme fluctuations at A08 tend to mask all other trends.

In contrast to winter trends, there was a lack of significant separation in the spring. The similarity, in terms of population counts, between the Sea Buoy, A01, and the outfalls area, A07, was noteworthy.

<u>Comparisons with Other Studies</u>

In spite of the obvious deficiencies in the information provided by diversity calculations, it is relevant to compare such data with those from other studies. Most harbor stations have maintained surprisingly high ranges of diversity in spite of the fluctuations encountered. However, diversity has been on occasion as low as zero at stations A04 and A07 in 1971-74, and 0.05 at A07 in 1976-78, during conversion to secondary waste treatment. Peak diversities of 4.17 and 3.6 occurred at A01 in 1976, and at A08 in 1977, respectively. There was often an increase in diversity in the spring of up to 50 percent more than the low winter values. Figures 29 and 33 show the long-term trends in diversity for the harbor stations surveyed in 1981-82.

SCCWRP Control Survey

In 1977, the Southern California Coastal Water Research Project (SCCWRP 1978; LACySD 1981) sampled 71 coastal benthic stations between Pt. Conception and San Diego to provide a basis for comparing the outfall areas in Santa Monica Bay and off Palos Verdes Peninsula. Diversities ranged from 1.34 to 4.16, the lowest occurring in the southern confluence of Santa Monica Bay with southwestern Palos Verdes Peninsula waters (Figure 29).

For comparison, the ranges and means of numbers of species and individuals for all harbor stations included in the 1981-82 study are tabulated for winter and spring periods between 1973 and 1982 in Table 12. Means for station A01 were also calculated separately and compared with the SCCWRP 1977 survey in Table 10. Mean numbers of both species and individuals were higher at the Sea Buoy A01 than means from the SCCWRP coastal stations. While station A01 is outside the harbor, it is tidally flushed and thus it is strongly influenced by the harbor.

It is significant to note that peak means in the harbor for both species and numbers occurred in 1973-74, following the clean-up and enforcement actions subsequent to Federal and State Legislation (Figure 20). In the spring of 1982, mean numbers of species declined slightly from the winter, as they did in 1978, but mean numbers of individuals rose somewhat, as compared with data from winter 1981. This is somewhat the reverse of normal expectation, for numbers of species present usually increase in the spring.

NOAA Study

In April 1982, HEP made a NOAA - Office of Marine Pollution Assessment survey of seven stations at the 37 m (20 fm) contour south of the harbor some 3 to 4 n mi. The mean number of species there were much higher than the means found in either the harbor or the SCCWRP surveys, at 88, with a peak of 106. The mean number of individuals was only slightly higher in the NOAA survey than in the SCCWRP survey. The lower numbers of individuals, as compared to the high population counts in the harbor, produced high species diversities which ranged from 3.29 to 3.93 in the offshore survey.

Other Harbor Studies

Reish (1982) sampled benthic stations in the outer Los Angeles Harbor Seaplane Base (interior to Station A11 in Figure 18) on 15 December 1981 and 19 March 1982. His station I was the only one near the present study, probably about 200 m to the east of HEP station A15; the latter is closer to the fill. Reish found only 5 species and 260 individuals/m^2, whereas HEP found 15 species and 7900 individuals on 16 December; Reish found 5 species and 230 individuals/m^2 on 19 March and

HEP found 24 species and 9100 individuals/m^2 on 26 March 1982. Such large differences were unexpected, but may have been due to the dredging and filling, which began on 12 March 1981. Dredging impacts can be profound at one place and relatively mild close by. Scouring of the bottom near the entrance of the seaplane basin has been observed in previous years, by HEP, due to winter storms. That area receives the full brunt of wind and surge, as evidenced by vessels that were previously wrecked between Fish Harbor and the Navy mole.

For whatever reason, the number of species at A15 in the HEP December survey was clearly only 20% to 50% of those at other stations, but in the HEP March study (Table 11) the number of species at A15 was only slightly lower than those at most stations and was higher than at A12. The HEP counts in March at A15 were higher than at six other stations, suggesting recolonization. *Cossura candida*, which composed 89% of the population sampled at A15 in December, disappeared completely and was replaced by *Prionospio pygmaeus* (87%) in March 1982. *Cossura* is a subsurface deposit feeder while *P. pygmaeus* is a surface deposit and suspension feeder, perhaps reflecting dredging, or stirring by storms.

The HEP Station A11 (Figure 18) was not sampled as a part of this study, but was closer than A15 to Reish's Station I. The HEP data for sampling between August 1973 and January 1979 were reviewed and the following trends noted. There was a drop from 69 species and 27,760 individuals per m^2 in 1973 to 41 species and 1490 individuals in October 1975. Species numbers rebounded to more than 80 in 1976-77 but populations did not reach 10,000 per m^2. In January 1978, species dropped to 20, with 1152 individuals, but by August 1978 there were 44 species and

14,176 individuals. The last sampling in January 1979 showed 26 species and 3050 individuals per m^2. The Shannon-Weiner Diversity Index has varied between 1.5 and 3.03.

Dominant Benthic Species

In 1978, Cossura candida dominated the outer Los Angeles Harbor in all four seasons sampled (Table 13, from Soule and Oguri 1980), ranging from 22.6% to 37.5% of the benthic fauna, from January through October. Capitella capitata dropped from fourth to twelfth rank in that period, and Tharyx, sp. dropped from second to fourth rank. Mediomastus californiensis (=Capitita ambiseta) increased from 19.49% to 25.07% during 1978, and Prionospio pygmaeus (=Apoprionospio pygmaea) increased from 3.44% to 6.7%, moving up from fifth to third rank. The latter species has frequently been found in small numbers in the harbor, but its numbers fluctuate greatly; it occurred at more HEP stations in November and February-March. It constitutes a larger percentage of the fauna at station A01, outside the harbor.

Cossura candida continued to dominate the harbor in 1981-82 (Table 14) but at lower percentages (21.6-22.6%) in December and March respectively; Mediomastus californiensis was second with 13.2-16.9%, and Prionospio cirrifera was third with 8.7%-15.4%. There was thus an increase in evenness between the 1978 and 1981-82 values among the highest ranking species.

Evenness was higher at Station A01 as compared to the rest of the outer harbor, with the top twelve species composing 61.5% as compared with about 72% for the top 12 species at the ten harbor stations.

Offshore at the 20 fm contour (37 m), in a study of seven stations (Soule and Oguri, 1982), the top 12 species composed only 37.8% of the fauna. It is of interest that Mediomastus californiensis was in second place there (Table 15), as it was in the harbor. Lumbrineris and Tharyx were also present in both the harbor and at the 37 m station.

The Los Angeles City Bureau of Sanitation carried out benthic samples near some of the HEP stations in 1981 (Table 16). In March, June, July August and September an amphipod species Amphideutopus oculatus ranked in first place, with 21% to 28% of the population sampled. In December 1981 (Table 17) that species dropped to third, replaced by Tauberia gracilis, 15%) and Cossura candida (11%), but A. oculatus dominated the City data for the year 1981.

The HEP collections included only single individuals of A. oculatus at A2A and A04 in December 1981. The significance of the high amphipod numbers is unknown, but it is probably a reflection of the dredging operations during that year, which provided new substrata for opportunistic recolonization, and probably, food. Settling rack (meroplankton) data in 1978 showed an increase in amphipods concurrent with the transition to secondary treatment, a different kind of perturbation. Earlier, the return of amphipods to the site of the Sansinena spill signaled the return to a "normal" faunal composition some nine months after the tanker explosion (Soule and Oguri, 1978).

Nutrient Values

A shift from polychaetes to amphipods as dominant species represents up to a 50% drop in nutritional value per unit effort for demersal fish species (Soule and Oguri, 1980, III G), based on caloric content. As stated therein, the gut contents of one white croaker contained 600 polychaete worms identifiable to genus (freshly consumed), each of which could have been supported by $3x10^9$ bacteria. Using the 1974 polychaete count at station A2A, there were 63.3 "fish meals" per m^2 available. Since polychaetes may reproduce every 30 days, replenishment was good. In 1978, there was a 38-fold reduction in bacterial counts, due to secondary treatment of all effluents. There was a 9fold drop in polychaetes from a maximum count of over 60,000/m^2. This reduced the theoretical "fish meals" more than eight fold, to 7.3/m^2. In actuality, there was a four-fold drop in fish per trawl and a 2.5-fold decrease in birds in 1978 (Soule and Oguri, 1980). No harbor-wide fish or bird surveys have been done since 1978. Apparently the reduction in waste loadings reduced the nutrient value of the harbor, although it is still higher than adjacent coastal waters (Table 12). This is extremely important to the enhancement concept of the Bays and Estuaries Policy.

Grain Size and Species

The preponderance of harbor species are suspension feeders (Fauchald and Jumars, 1979; Soule and Oguri, 1980) and thus they thrive in the silty harbor and bay areas. While dredging undoubtedly created siltation and probably temporarily buried certain harbor locations outside the fill area itself, most grain sizes did not change appreciably in 1982 from the means found in 1973-74 (Figure 35, from AHF, 1976). The minor exceptions were at station A08 and B08 (Table 16). At A08, 57.6% fine sand (0.075-0.42 mm), and 39.5% clay and silt (<0.075 mm) were found, while at B08, 51% fine sand was found.

Grain size would influence the species composition, selecting for suspension feeders and surface deposit feeders in or on the finer particle clay-silt substrates. Soule and Oguri (1980) reviewed the feeding guilds to which harbor benthic organisms belong. The herbivore *Acesta catherinae* dominated the offshore 37 m stations (Table 13), where the substrate was primarily fine sand (Table 17) with some algal turf covering it. *Cossura candida* is a subsurface deposit feeder, while *Mediomastus californiensis* is both a surface and subsurface feeder. *Amphideutopus oculatus* is a suspension feeder, which would account for an increase during dredging.

MAN-MADE IMPACTS VERSUS NATURAL VARIABILITY

Questions concerning the relationship of natural environmental variation to the changes observed in the harbor and coastal waters, as compared with changes in man-made environmental effects, are always relevant to evaluation and planning. Single, infrequent surveys, or those which cover only a small sector of the harbor, are totally inadequate for examining such questions. Were it not for the decade of data that Harbors Environmental Projects has available, it would not be possible to document any trends, and that data base is less complete than might be desired.

The variability at individual stations provides considerable analytical "noise", which is probably due to fluctuations within seasons, such as storms, and episodes of environmental insult such as small oil spills or industrial pollution episodes. Harbor biota are generally characterized as temperature-tolerant (eurythermic), and salinity-tolerant (euryhaline); many species reproduce year around or for more than one period annually so that replacement from adjacent populations after such episodes can be rapid.

Temperature and Oceanography

The oceanographic regime of the eastern Pacific and southern California was reviewed by Soule and Oguri (1980). The regime is dominated by the southward-flowing California Current, which brings cold water from the north, and usually passes outside the Channel Islands. A series of small counter-clockwise gyres, probably transitory, circulate into Santa Monica Bay and the San Pedro Channel and Bay. Upwelling of colder water also occurs off Santa Monica Bay, and to a lesser extent at the head of San Pedro Valley, southwest of the harbor. In winter, a northward-flowing undercurrent, the Davidson Countercurrent, flows for one or more months from tropical latitudes northward for varying distances and may surface off San Pedro Bay or Point Conception; in the so-called El Niño years, it may extend into northern California or Oregon and may last for most of the year. It is not unusual for the water off the harbor to be warmer in January, February and March than it is in April.

The El Niño (the Christ child, for Christmastime) events are better known for the devastating effects on Peruvian and Chilean fisheries, when the cold, nutrient-laden Peru Current is diverted offshore, and tropical equatorial counter current waters with low nutrient content, flow south along the coast (O'Brien, 1978; Halpern 1983).

At Los Angeles Harbor, temperatures showed considerable fluctuation during the years that the biota were under study, with relatively short periods of warm and cold water as well as longer term fluctuations, (illustrated in Figure 28).

If the production of harbor biota were strongly related to temperature, one would expect the peak years of 1973 and 1974 to differ from others and the more modest production years of 1972, 1978 and winter of 1981-82 to be similar.

Although 1972-73 was a strong El Niño year in the southern hemisphere, 1972 in Los Angeles Harbor began with the lowest January temperatures of the decade, below 12°C. Instead of a cool water influx in April, temperatures continued to rise through the summer, except for a slight dip in May. January and February were cold months in 1972, 1973, 1974, 1975 and 1976, years of considerable biotic differences. January in the years 1979, 1980 and 1981-82 were warmer, (14-15°C), and 1977, 1978 the warmest. (In 1982-83, not a period within the studies, the warmest water events occurred since 1957-58, according to NMFS, 1983). March of 1975 and 1976 was cold; 1972, 1974 and 1977 had warmer 14-15°C temperatures, while 1973, 1978, 1980, 1981 and 1982 had temperatures above 15°C.

A drop in temperature between March and May when the Davidson Current normally drops off in California apparently provides reproductive signals to many fish and invertebrate species. Return of colder water may bring upwelling and associated nutrients that will stimulate plankton production on which juvenile fish can feed. The poorest years for anchovy commercial catch outside the harbor were 1971-72 and 1978,and the best years were 1973, and 1975 through 1977. The anchovy bait catch inside the harbor peaked in 1973; however,it dropped after 1973, and never recovered. Anchovy larvae and juveniles fed heavily on the fine particulates in cannery wastes and on phytoplankton, and were protected by turbidity from heavy predation. The spring cold period was pronounced in April of 1973, 1974, 1975 and 1977, and less intense in 1980 and 1982. Production peaked in 1973-74 and decreased greatly during subsequent years. The cold period occurred in March in 1976, in May in 1972, and not until July in 1978.

Temperatures have ranged from below 14°C to almost 20°C in June, with 1973 the coldest and 1977 the warmest; the other years in order of ascending temperature from 1973 were 1975, 1980, 1972, 1974, 1978, 1976, 1979, a mixture of good productive years and poor years.

July temperatures show a less extreme range overall, with a range from 15°C to less than 19°C. The lowest July temperatures were in 1972 and 1978, followed by 1975 and 1977, and the warmest were in 1974, 1979, 1973, 1981 and 1976. August temperatures clustered between 17°C and a bit over 18°C, except for a low in 1975 below 15°C, and above 19°C in 1977 and 1979-1981 (in 1982, a peak of 23°C was recorded).

Decreasing temperatures in the fall signal another reproductive period for some species and the return of species that disappear during the hotter period, but a fall die-off of biota also occurs at some point. September was very cold, below 14°C in 1976, but temperatures surged upward in October and remained warm through the winter, into 1977. Moderate cooling in September occurred, in ascending order, in 1975, 1973, 1974 and 1980; cooling also occurred to a lesser extent in 1977, 1979 and 1981. In 1972 and 1978, however, temperatures rose in September. In 1972 the temperatures fell steadily from the September high through December and into 1973, whereas temperatures continued to rise in September 1978 through October, and cooling did not occur until December.

The monthly records are not adequate to determine whether there are short-term episodes of upwelling and incursions of warm water, but other evidence suggests that this is the case. Commercial fishing was excellent off Los Angeles throughout 1981-82 a warm year, but disasterously poor in

1982-83, during the record El Niño event.

According to Los Angeles Harbor Department data, the mean annual surface temperatures at the harbor entrance were as follows:

1971	15.7°C	1977	16.5
1972	15.7	1978	16.8
1973	16.1	1979	16.3
1974	15.1	1980	16.3
1975	15.4	1981	17.4
1976	16.7	1982	17.6

Similarities in temperature between 1972, 1978 and 1981-82 that might account for biotic similarities are difficult to discern. The 1972 and 1978 patterns were quite different in the spring but were similar in June through September, and in December. December of 1981 was much warmer than 1972 or 1978, whereas spring temperatures were intermediate between low 1972 and high 1978 spring temperatures. No March 1982 readings were taken due to rough seas.

Rainfall

A possible association with rainfall has also been suggested since run-off is a nutrient source. The lowest rainfall years during this study were 1971-72 and 1975-76 which were below 7.5 inches in the Los Angeles basin, while 1973-74, 74-75 and 76-77 were near-normal years with 12 to 15 inches); rainfall in 1972-73 was somewhat higher, at about 22 inches. Conversely 1977-78 and 1981-82 were among the wettest years in history. Thus 1971-72 is not comparable in rainfall to 1977-78 or 1981-82, although levels of biota were similar.

Too little is known about the precise effects of timing of short-term fluctuations in temperature or in rainfall, to be unequivocably certain that the biotic trends are related or not. No doubt there are synergistic effects at some level. The water mass changes probably have more influence on species composition of a minor component of the harbor biota as compared to the species composition offshore. Influxes of northern, or southern zooplankton species in small numbers are seen with the changes, and they increase diversity, but they do not remain for long and do not provide a major component of the fauna.

CONCLUSIONS

The outer Los Angeles Harbor improved dramatically in 1971-72 following enforcement of Federal and State legislation to control marine pollution. With the improvement of point-and non-point source control, the secondary production of the outer harbor increased to form the richest soft-bottom marine habitat in southern California. Periodic episodes of overloading the assimilation capacity of the outer harbor led to installation of dissolved air flotation pre-treatment of fish processing wastes, conversion of primary treatment to secondary treatment at the Terminal Island Treatment Plant, and diversion of the fish waste effluents to the treatment plant.

Natural deviations as well as man-made impacts create fluctuations in the numbers of species and individuals present in the harbor. No clear pattern of temperature seems to be directly associated with the peak years of 1973 and 1974, nor with the less productive years. Harbor activities seem to be more related to biotic production.

The strongest trends in the harbor appear to be associated with the more uniform nutrient input of the effluents. Thus the biota are dependent upon those wastes for long-term sustenance, which simulates the normal flow of an estuary and is the basis of a detrital food web (e.g., Soule and Soule, 1981; Jannasch, 1979; Fenchel, 1977; Hylleberg, 1975).

More often than not, increases or decreases in species and individuals are concomitant; an inverse trend in the relationship may be indicative of stress. Following conversion to secondary treatment, there was a drop in mean numbers of species, except at the station nearest the outfall. There, in 1978, the numbers of species and individuals returned to levels that existed in 1973, before any upgrading of treatment. Episodes of low dissolved oxygen or pollutant discharge in 1974-76 substantially decreased production of benthic fauna near the outfalls to the depauperate levels that existed prior to pollution control.

The harbor can be considered enhanced as compared with nearby coastal benthic areas. In spite of the massive dredging project affecting the outer harbor in 1981-82, mean numbers of species remained relatively high (46 to 50) and mean numbers of individuals were almost double those at the SCCWRP (1977) coastal control stations (Table 10) in the Santa Monica Bay-Palos Verdes area.

Diversity is lower in the harbor than offshore, due in part to the limitations of the unconsolidated soft-bottom harbor, and to the greater fluctuations in environmental conditions such as rainfall runoff and temperature changes, as well as to man-made episodes such as waste overloads or spills.

We have concluded that the outer harbor ecosystem would probably benefit from a combination of TITP secondary effluent, mixed with some level of pretreated fish processing effluent which is not subjected to TITP secondary treatment. Both diversity and numbers of benthic individuals were higher, supporting greater numbers of fish and birds, when some fish processing wastes were released directly into the harbor and episodes of anoxia were eliminated by pre-treatment such as dissolved air flotation. This seems to indicate that an ecologically better nutrient input to the harbor can be achieved by judicious mixing of the two types of waste.

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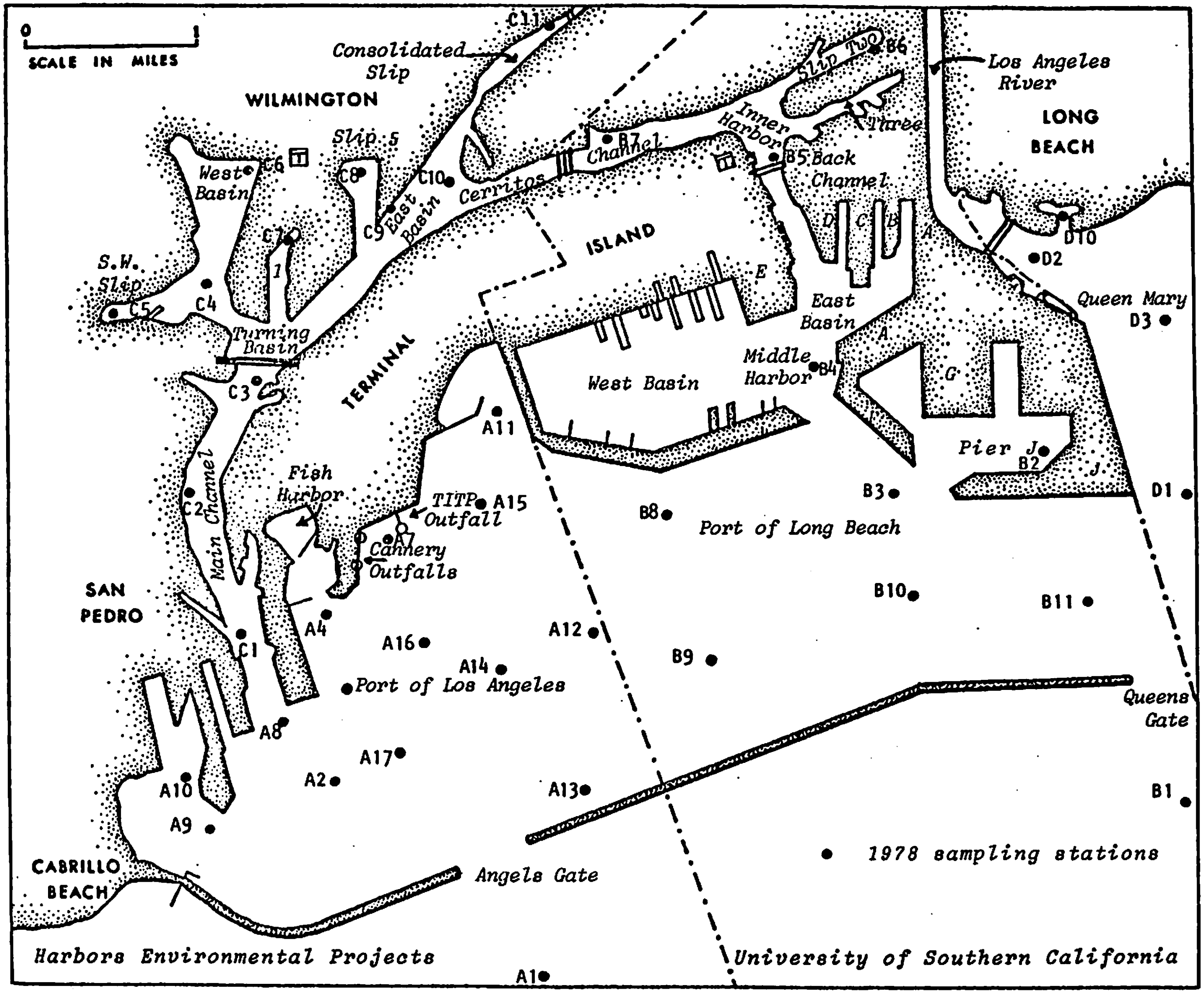


FIGURE 18. LOS ANGELES-LONG BEACH HARBORS 1978 SAMPLING STATIONS.

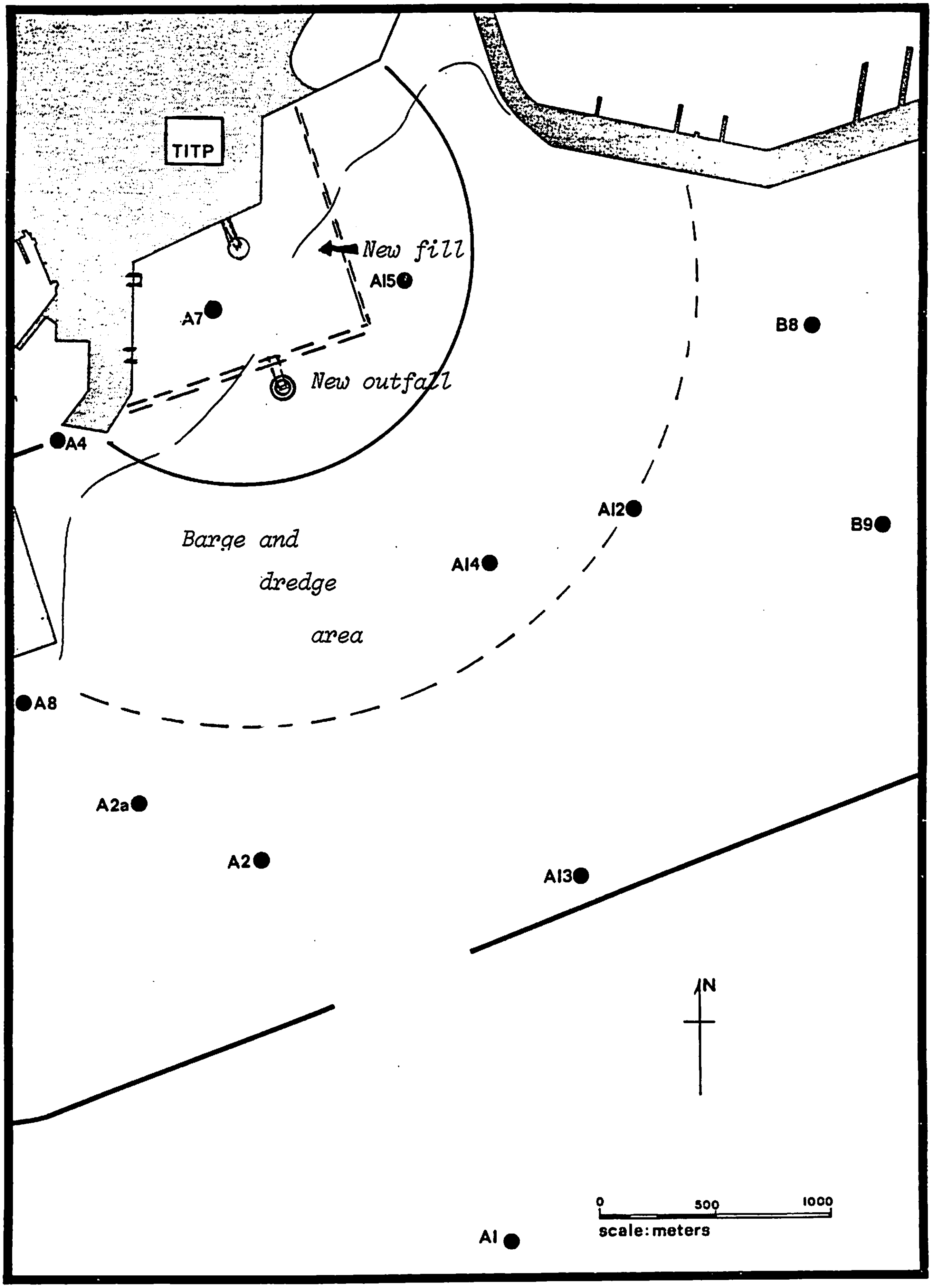


FIGURE 19. HARBORS ENVIRONMENTAL PROJECTS BENTHIC STATIONS SAMPLED 16 DECEMBER 1981 AND 26 MARCH 1982.

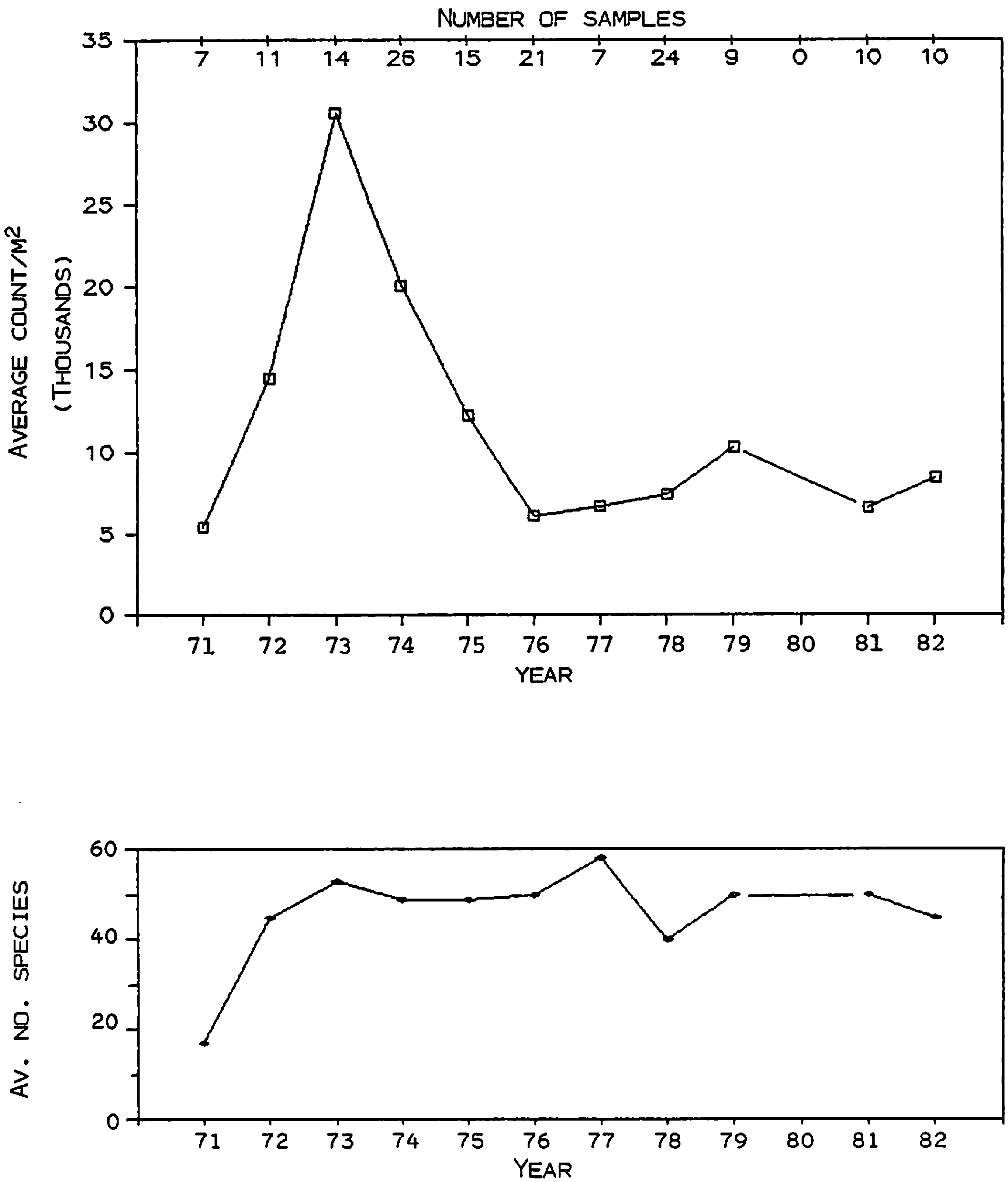


FIGURE 20. AVERAGE NUMBERS OF INDIVIDUALS, IN THOUSANDS PER METER^2 (UPPER GRAPH) AND AVERAGE NUMBERS OF SPECIES PER METER^2 (LOWER GRAPH) BY YEAR.

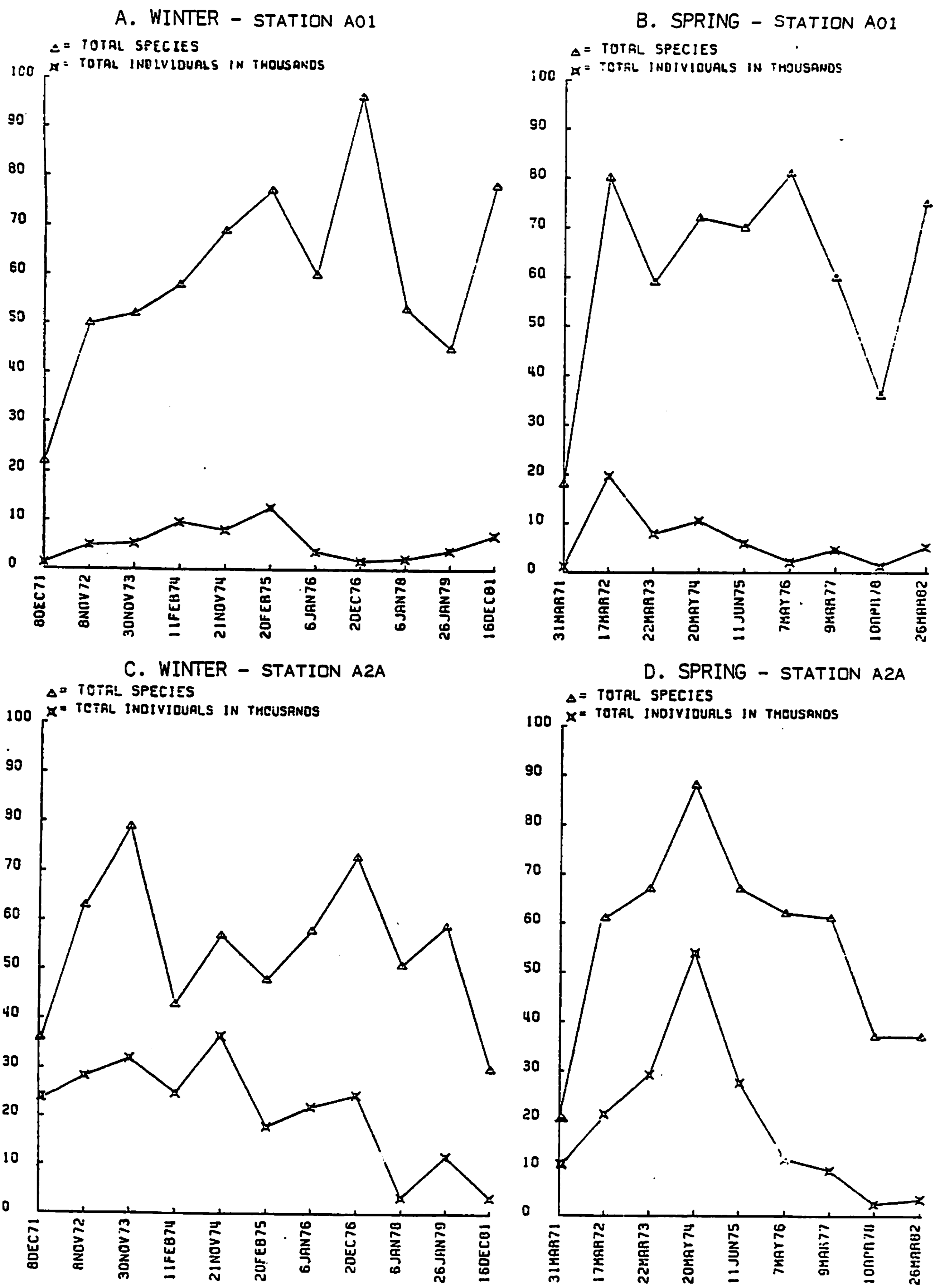


FIGURE 21. TOTAL SPECIES AND TOTAL INDIVIDUALS, WINTER AND SPRING, 1971-1982, AT STATIONS A01 AND A20 (A2A IN 1971) IN PER M2

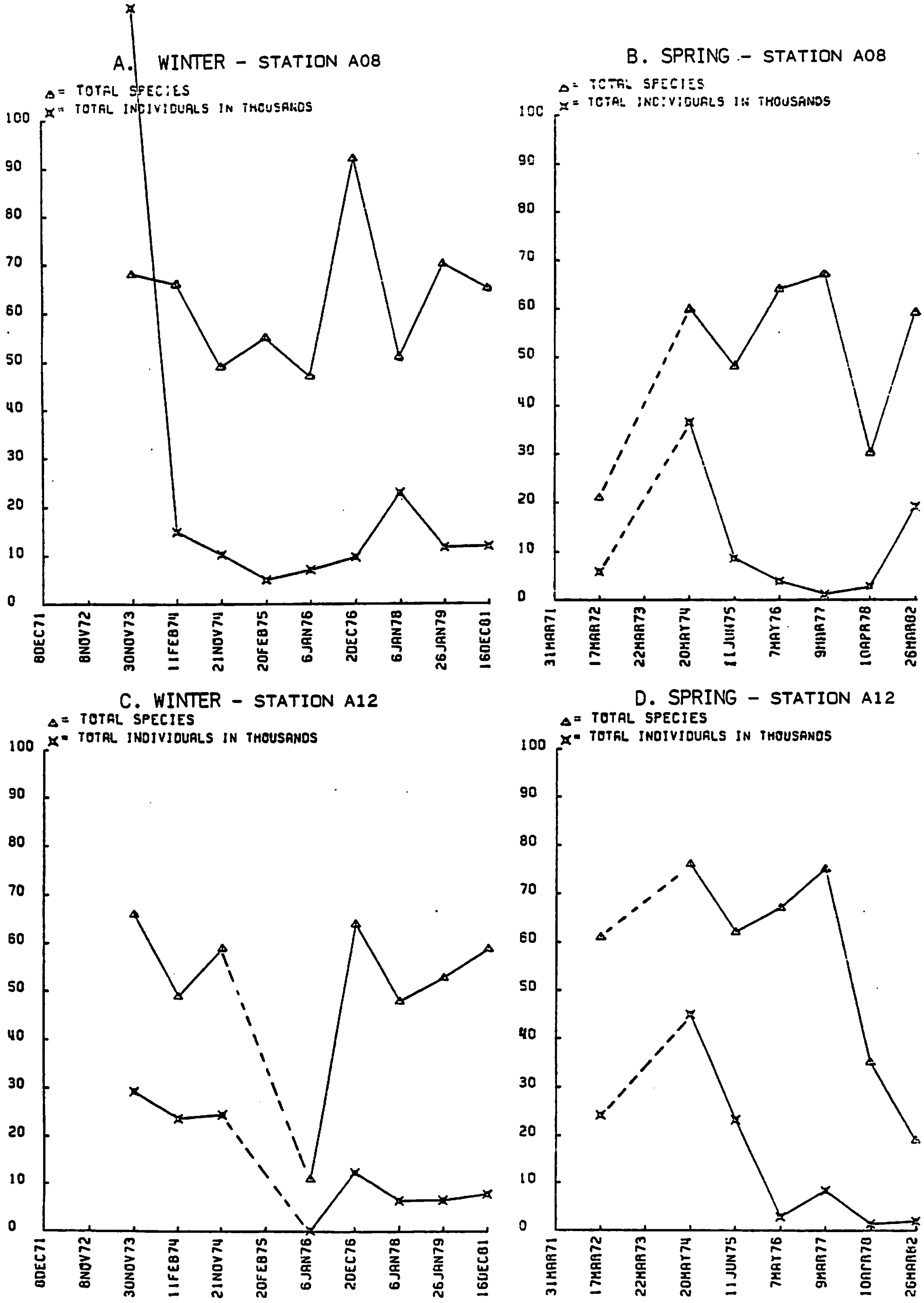


FIGURE 22. TOTAL SPECIES AND TOTAL INDIVIDUALS, WINTER AND SPRING, 1972-1982, AT STATIONS A08 AND A12 IN PER M^2

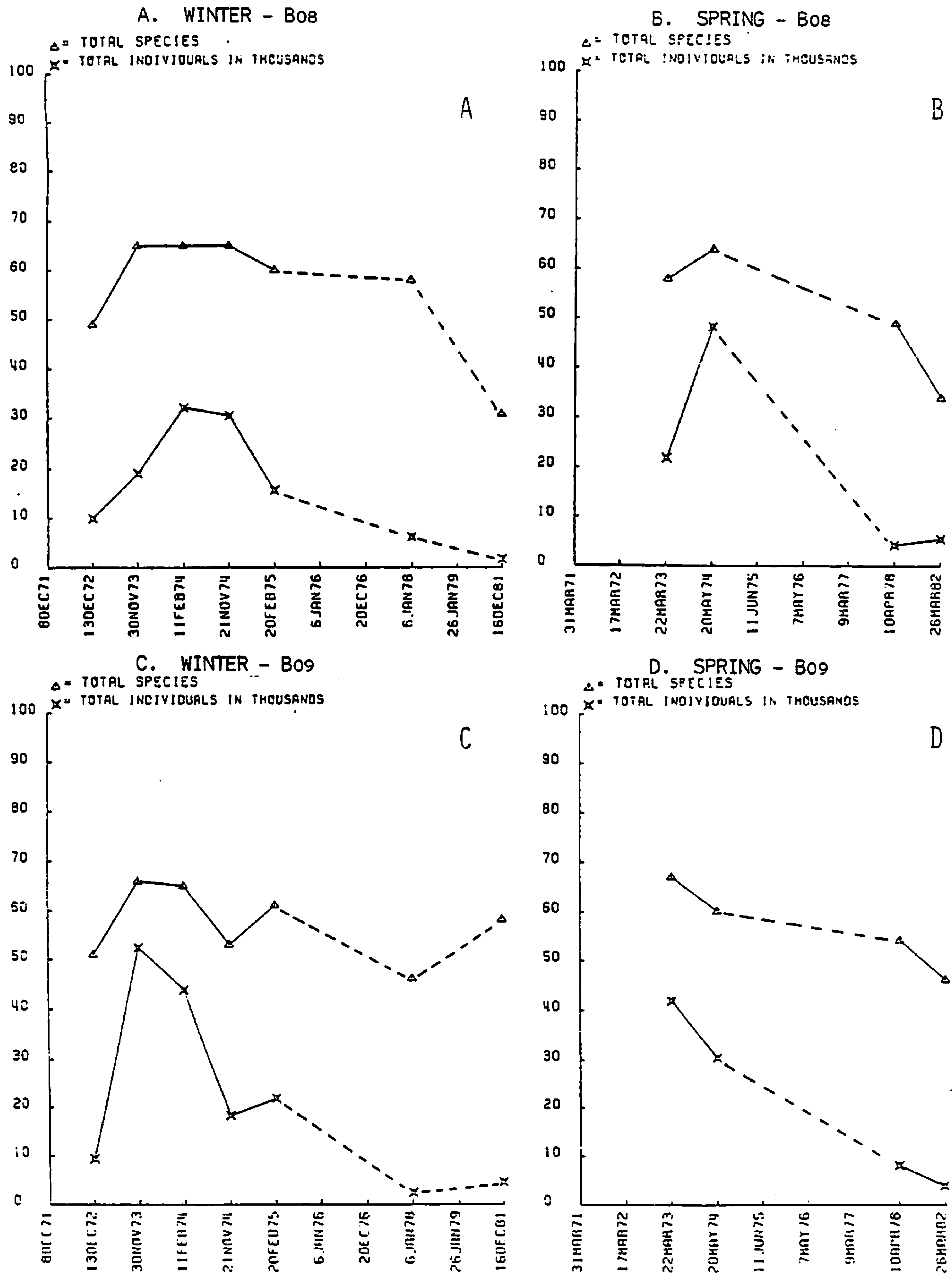


FIGURE 23. TOTAL SPECIES AND TOTAL INDIVIDUALS, WINTER AND SPRING 1972-1975, 1978, 1981-1982, STATIONS B 8 AND B 9 IN PER M^2

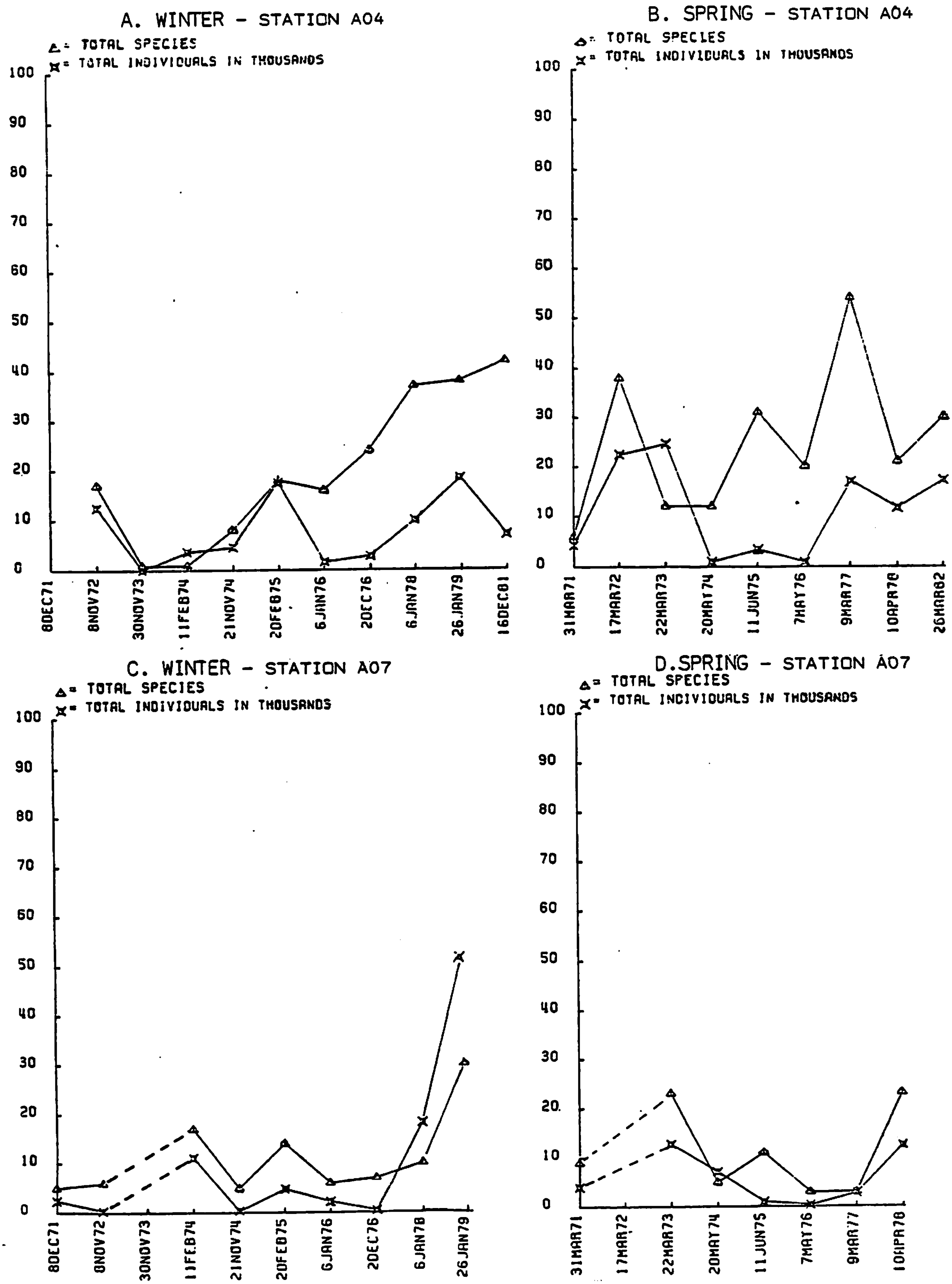


FIGURE 24. TOTAL SPECIES AND TOTAL INDIVIDUALS, WINTER AND SPRING, 1971-1982, AT STATIONS A 04 AND A 07 (A 07 NOW IN FILL)

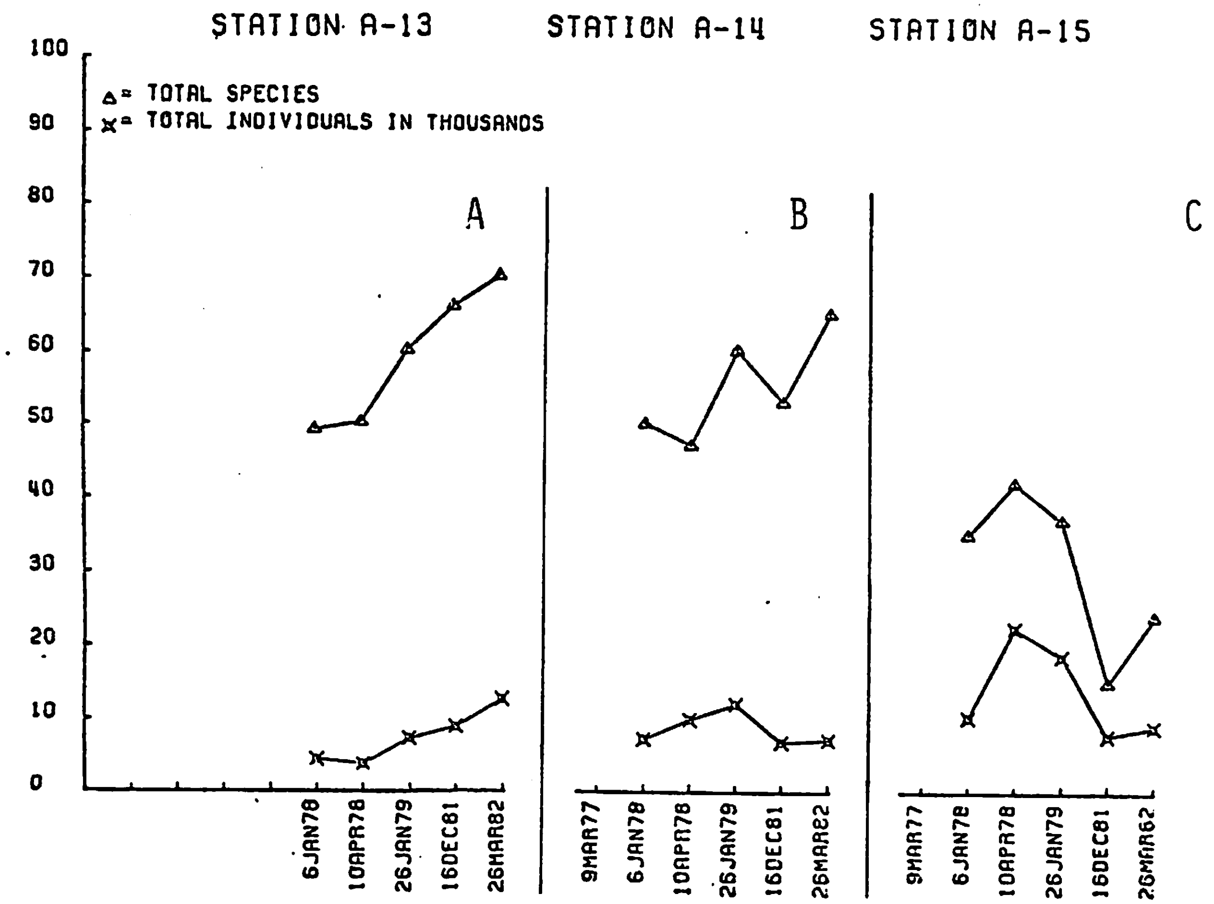
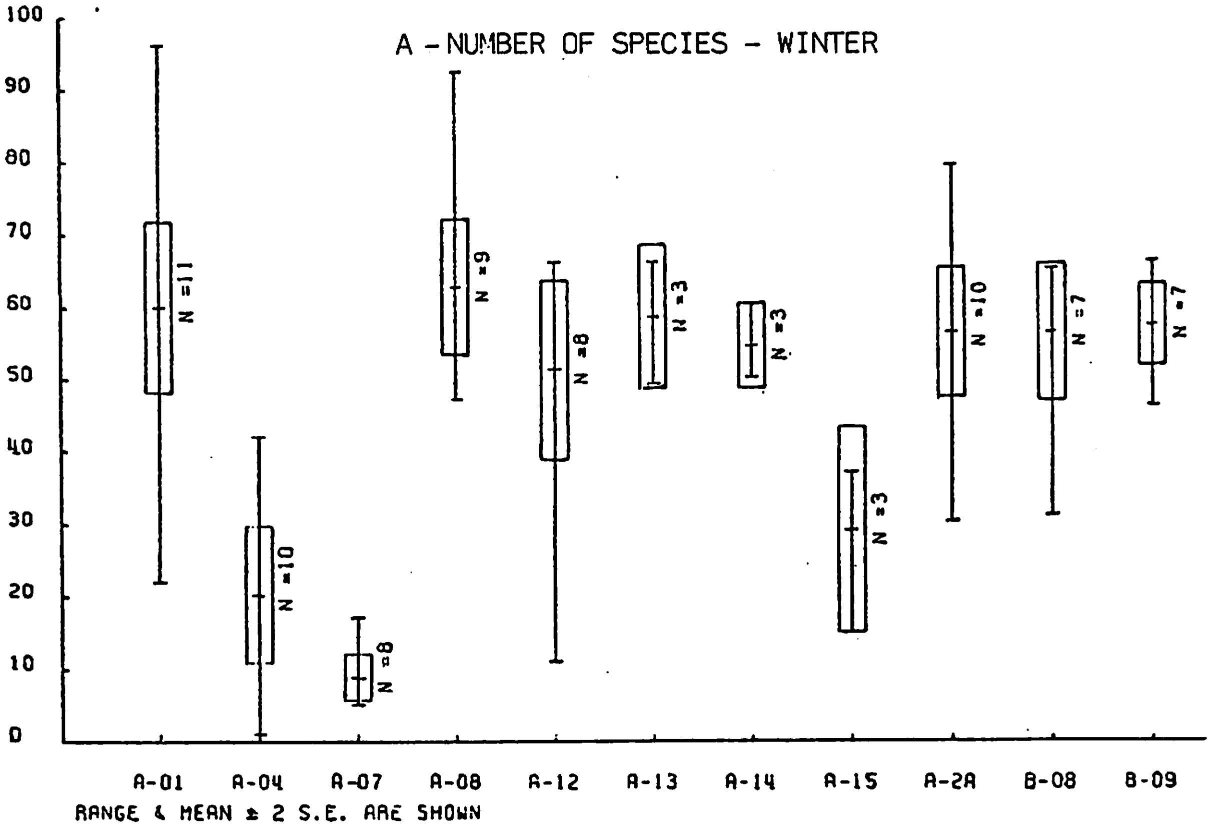


FIGURE 25. TOTAL SPECIES AND TOTAL INDIVIDUALS, 1978–1979, 1981–1982, STATIONS A 13, A 14 AND A 15 IN PER M^2



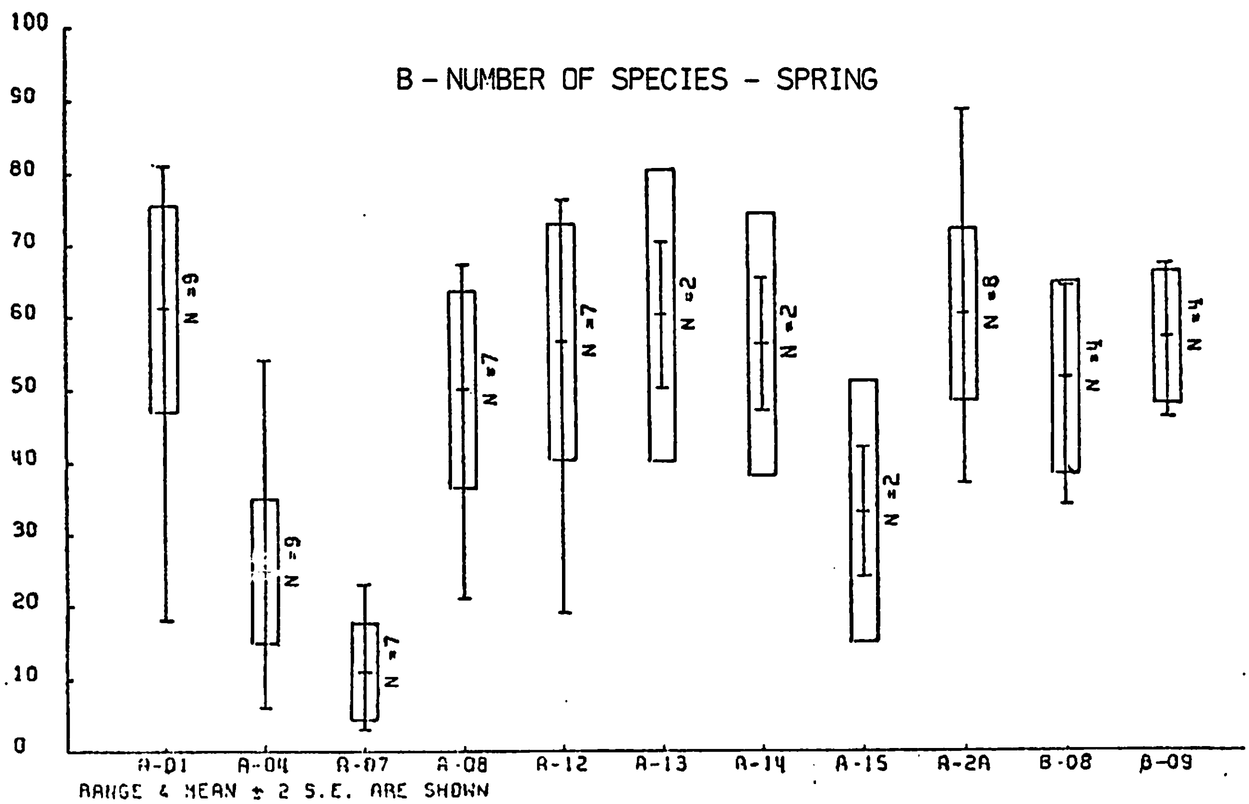
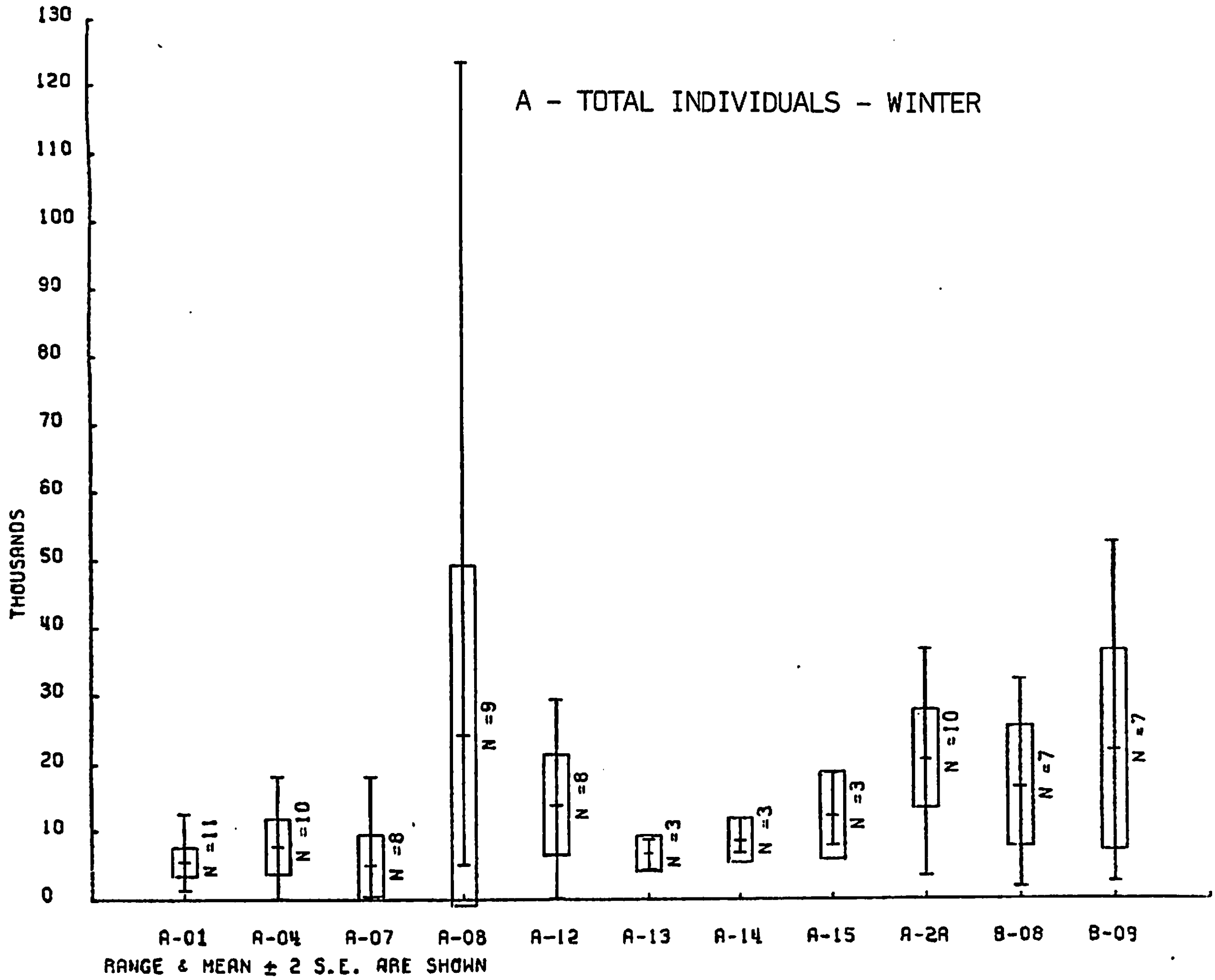


FIGURE 26. BAR GRAPHS OF NUMBER OF SPECIES FOR ALL PERIODS (N=TOTAL). DIFFERENCES ARE SIGNIFICANT



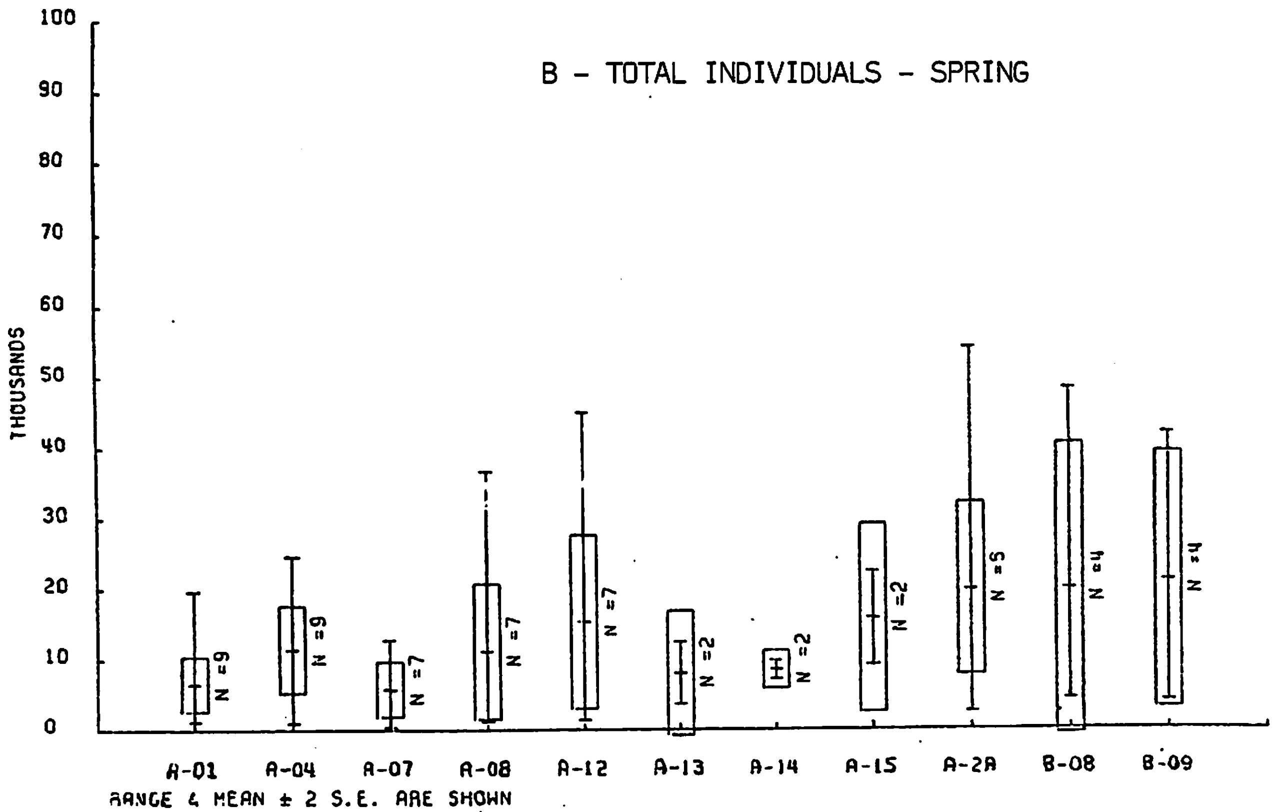


FIGURE 27. BAR GRAPH OF NUMBERS OF INDIVIDUALS, FOR ALL PERIODS (N=TOTAL). DIFFERENCES ARE NOT SIGNIFICANT

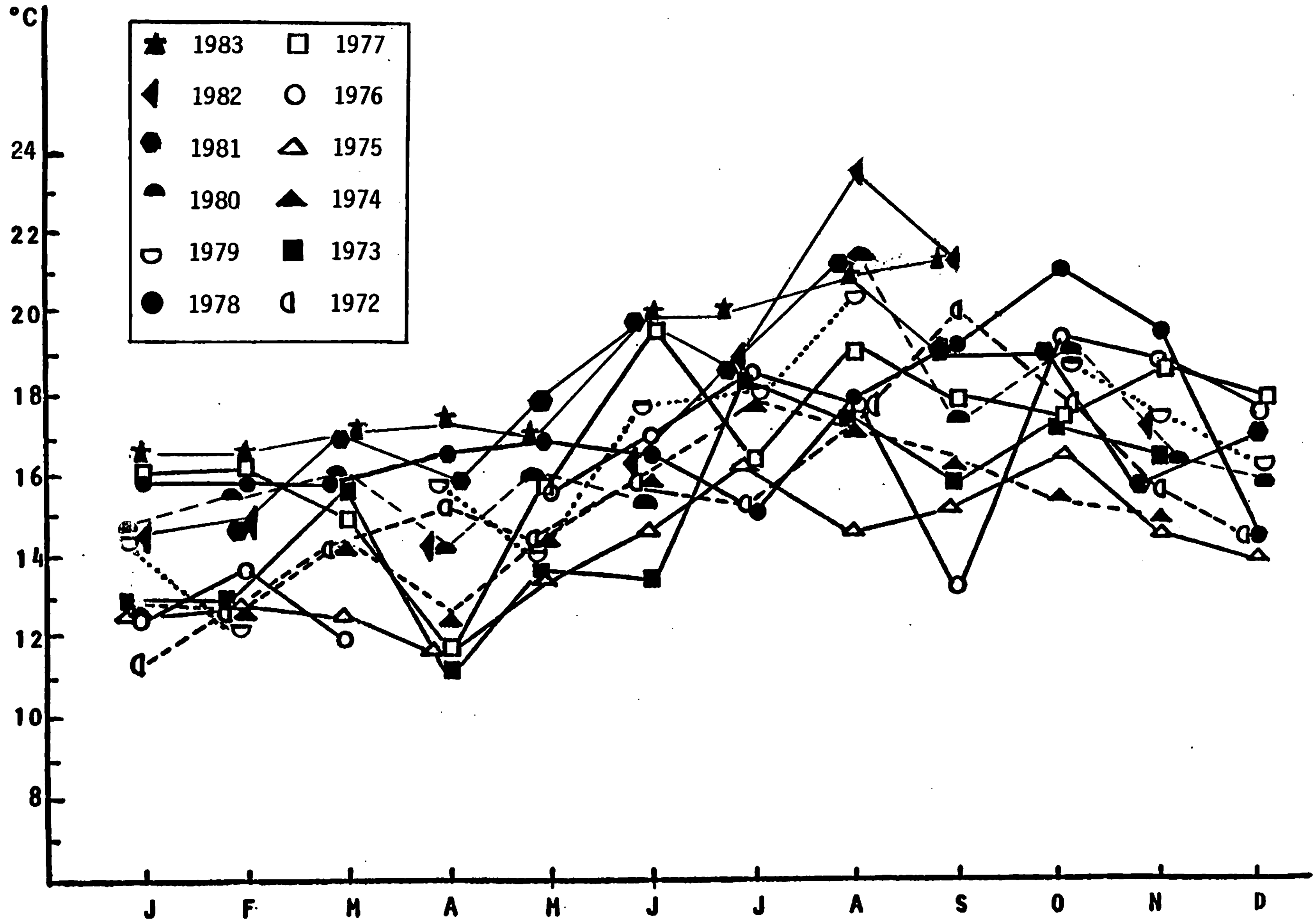


Figure 28. Monthly Temperatures (^{O}C) at the Sea Buoy Outside Los Angeles Harbor 1972-1983. (HEP Data and Los Angeles Harbor Department Data).

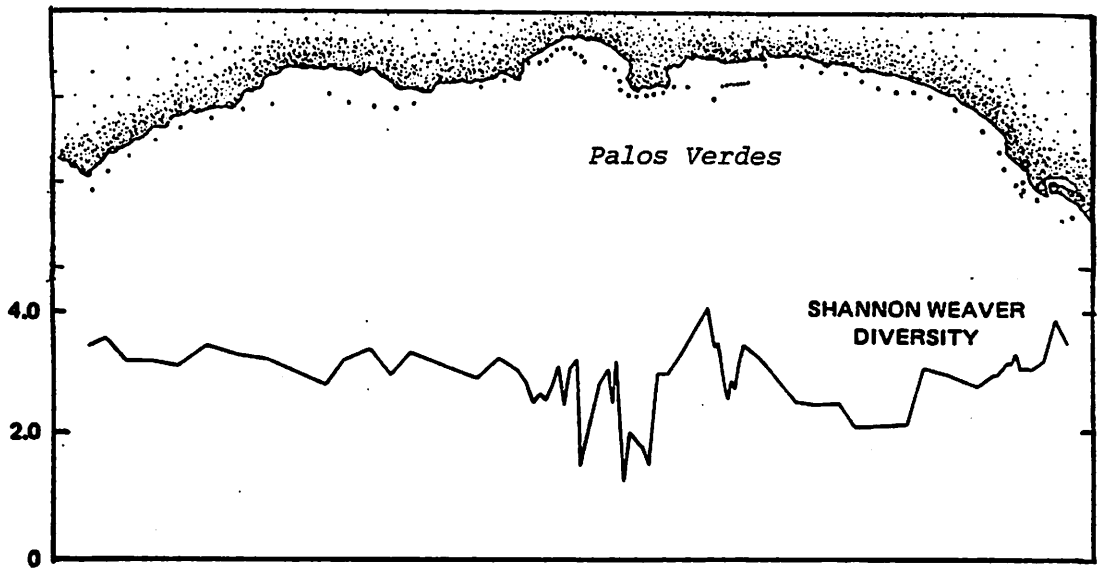


FIGURE 29. SPECIES DIVERSITY IN SOUTHERN CALIFORNIA COASTAL WATERS, SCCWRP 60 METER CONTROL SURVEY, 1977.

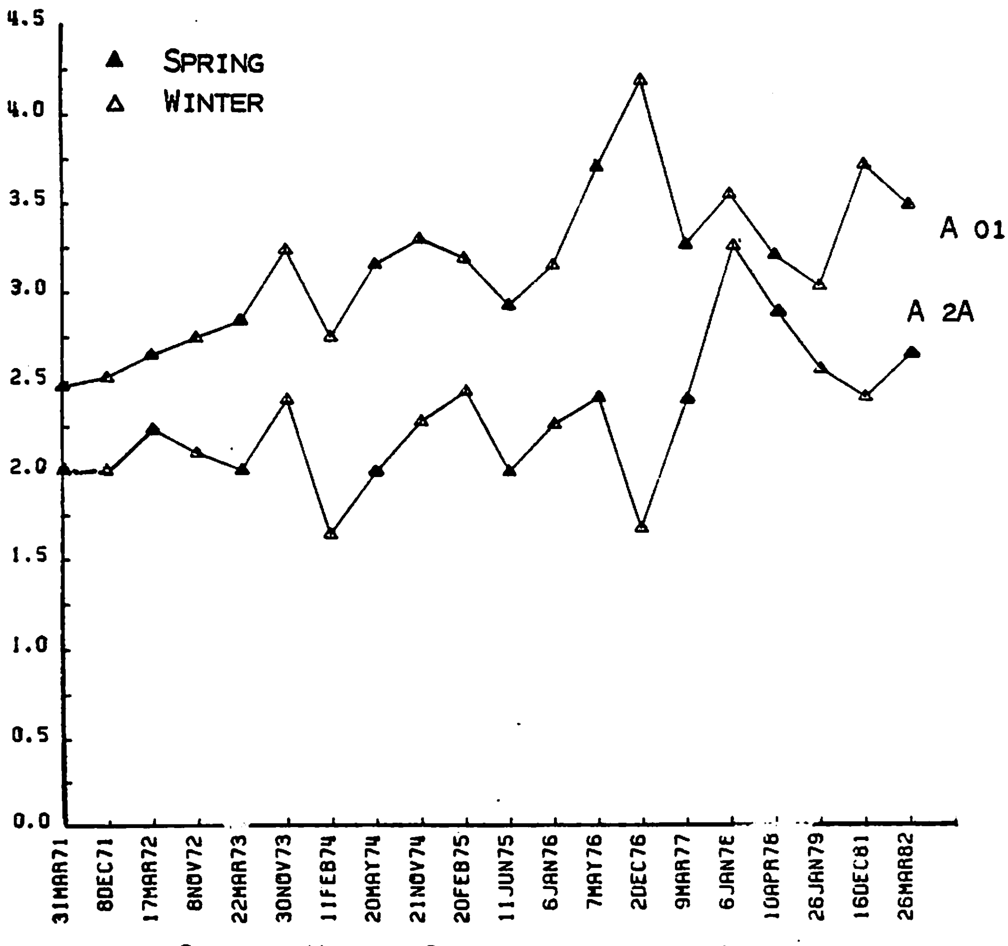


FIGURE 30. SHANNON-WEINER SPECIES DIVERSITY INDEX (H') COMPARING STATIONS A 01, OUTSIDE THE HARBOR, AND STATION A 2A IN THE OUTER HARBOR MAIN CHANNEL.

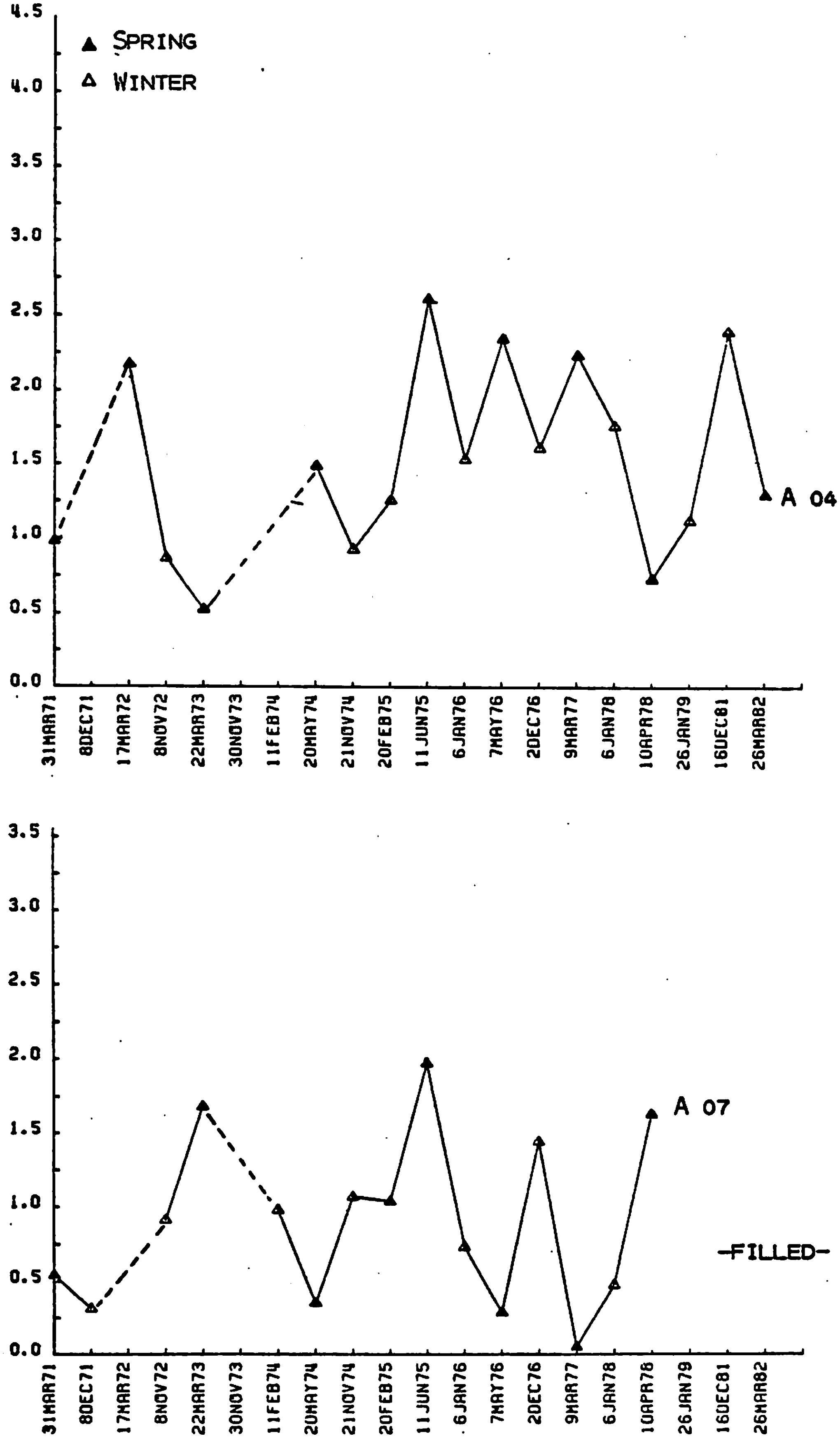


FIGURE 31. SHANNON-WEINER SPECIES DIVERSITY INDEX (H') COMPARED FOR STATION A 04 AT THE ENTRY TO FISH HARBOR AND STATION A 07 IN THE OUTFALLS AREA. BOTH ARE IN SHALLOW WATER (4-5 METERS).

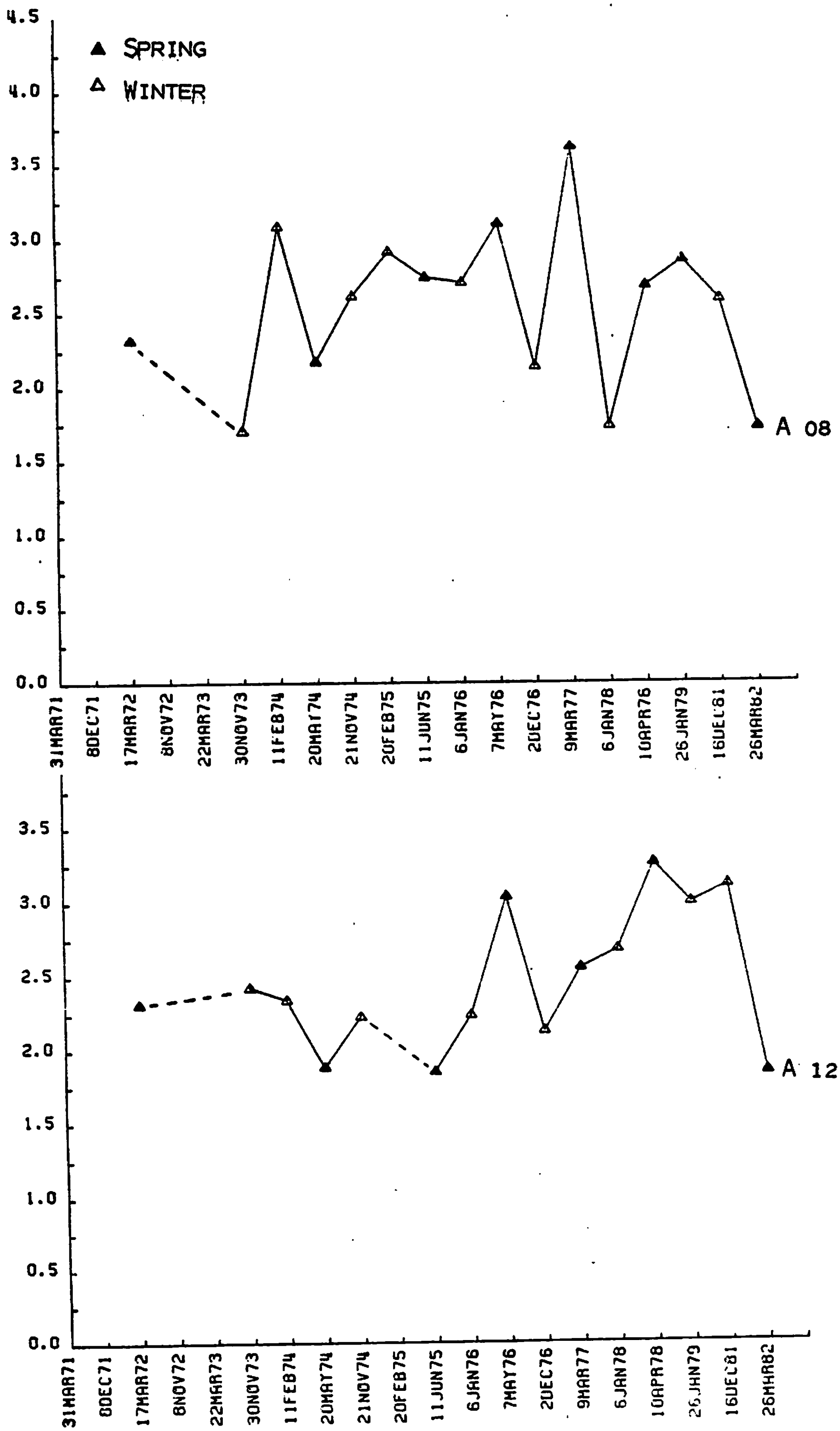


FIGURE 32. SHANNON-WEINER SPECIES DIVERSITY INDEX (H') FOR STATIONS A 08 AND A 12.

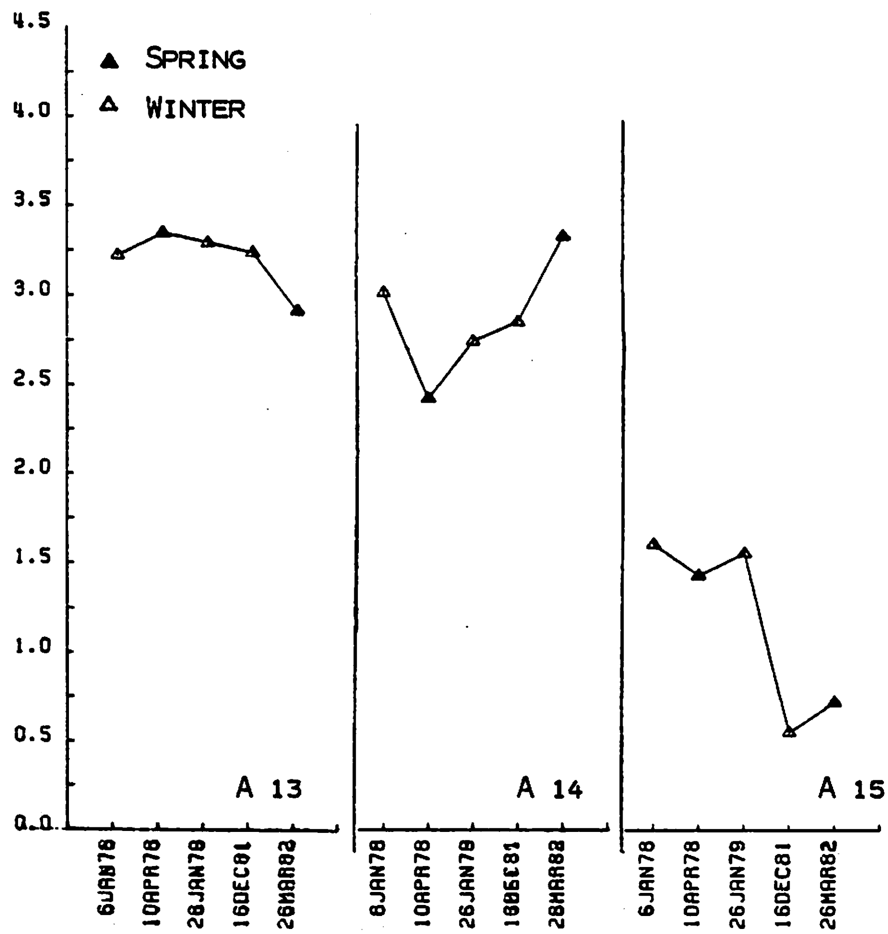


FIGURE 33. SHANNON-WEINER SPECIES DIVERSITY INDEX (H') FOR STATIONS A 13, A 14 AND A 15, MONITORED IN 1978-79 AND 1981-82. A 13, NEAR THE BREAKWATER DROPPED SLIGHTLY, A 14, IN THE CENTER OF THE OUTER HARBOR HAD A NET UPWARD TREND, AND A 15, BESIDE THE FILL, DROPPED SUBSTANTIALLY.

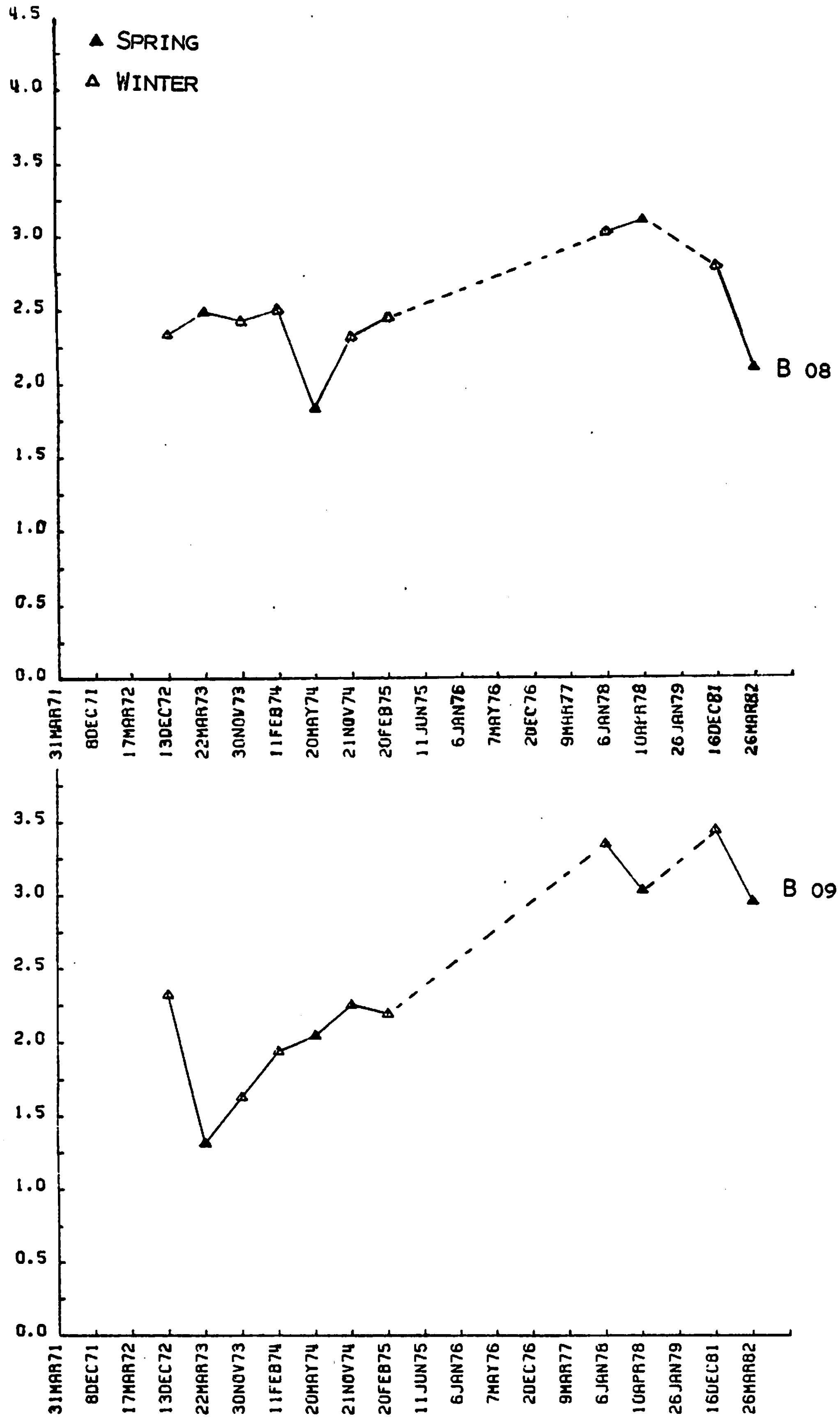


FIGURE 34. SHANNON-WEINER SPECIES DIVERSITY INDEX (H') AT STATIONS B 08 AND B 09. DIVERSITY AT B 08 IS SIMILAR TO 1972-75 LEVELS, WHILE B 09 HAS TRENDED UPWARD.

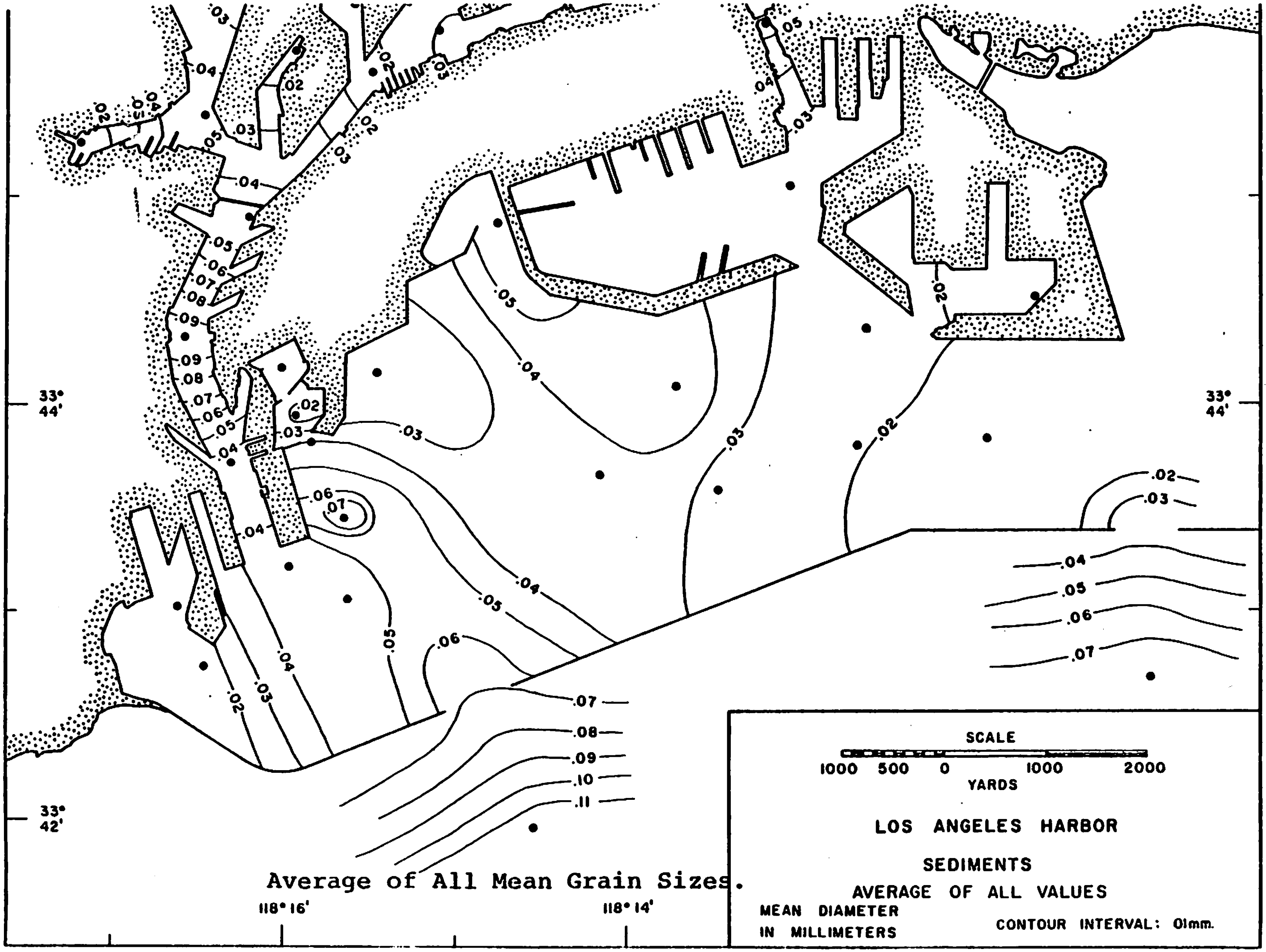


FIGURE 35. 1973-74 MEAN GRAIN SIZES (AHF, 1976).

TABLE 7. NUMBERS OF SPECIES AND INDIVIDUALS, SPECIES DIVERSITY, EVENNESS AND GLEASON INDICES, STATIONS A 01, A 02 AND A 2A, 1971-1982.

STATION A01

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H' (MAX)	(J') EVENNESS	GLEASON
03/31/71	18	1168	2.4745	2.8904	0.8561	2.4069
12/08/71	22	1328	2.5242	3.0910	0.8166	2.9201
03/17/72	80	19664	2.6492	4.3820	0.6046	7.9907
11/08/72	50	4940	2.7471	3.9120	0.7022	5.7612
03/22/73	59	7904	2.8395	4.0775	0.6964	6.4623
11/30/73	52	5280	3.2350	3.9512	0.8187	5.9498
02/11/74	58	9664	2.7459	4.0604	0.6763	6.2117
05/20/74	72	10512	3.1518	4.2767	0.7370	7.6672
11/21/74	69	8064	3.2929	4.2341	0.7777	7.5596
02/20/75	77	12656	3.1842	4.3438	0.7330	8.0458
06/11/75	70	5930	2.9214	4.2485	0.6876	7.9422
01/06/76	60	3640	3.1457	4.0943	0.7683	7.1954
05/07/76	81	2160	3.6973	4.3944	0.8414	10.4196
12/02/76	96	1740	4.1795	4.5643	0.9157	12.7318
03/09/77	60	4610	3.2610	4.0943	0.7965	6.9938
01/06/78	53	2176	3.5455	3.9703	0.8930	6.7662
04/10/78	36	1376	3.1986	3.5835	0.8926	4.8430
01/26/79	45	3872	3.0247	3.8067	0.7946	5.3259
12/16/81	78	6880	3.7085	4.3567	0.8512	8.7140
03/26/82	75	5168	3.4824	4.3175	0.8066	8.6547

STATION A02*

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H' (MAX)	(J') EVENNESS	GLEASON
03/31/71	21	1120	2.1816	3.0445	0.7166	2.8486
12/08/71	36	23728	1.9090	3.5835	0.5327	3.4741

STATION A2A

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H' (MAX)	(J') EVENNESS	GLEASON
03/17/72	61	20992	2.2385	4.1109	0.5445	6.0290
11/08/72	63	28390	2.1086	4.1431	0.5089	6.0465
03/22/73	67	29184	2.0160	4.2047	0.4795	6.4194
11/30/73	79	32016	2.4177	4.3694	0.5533	7.5188
02/11/74	43	24912	1.6621	3.7612	0.4419	4.1489
05/20/74	88	53920	2.0161	4.4773	0.4503	7.9851
11/21/74	57	36624	2.3056	4.0431	0.5703	5.3290
02/20/75	48	17920	2.4783	3.8712	0.6402	4.7990
06/11/75	67	27580	2.0293	4.2047	0.4826	6.4549
01/06/76	58	22100	2.3014	4.0604	0.5668	5.6981
05/07/76	62	11640	2.4553	4.1271	0.5949	6.5156
12/02/76	73	24550	1.7220	4.2905	0.4014	7.1227
03/09/77	61	9270	2.4525	4.1109	0.5966	6.5685
01/06/78	51	3376	3.[illegible]127	3.9318	0.8425	6.1543
04/10/78	37	2432	2.9448	3.6109	0.8155	4.6175
01/26/79	59	11728	2.6298	4.0775	0.6449	6.1901
12/16/81	30	3328	2.4773	3.4012	0.7284	3.5758
03/26/82	37	3472	2.7212	3.6109	0.7536	4.4158

* BUOY MOVED TO A 2A LOCATION IN 1972

TABLE 8. NUMBERS OF SPECIES AND INDIVIDUALS, SPECIES DIVERSITY, EVENNESS AND GLEASON INDICES, STATIONS A 04, A 07 AND A 08, 1971, 1982.

STATION A04

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H'(MAX)	(J') EVENNESS	GLEASON
03/31/71	6	4288	0.9811	1.7918	0.5476	0.5978
03/17/72	38	22448	2.1749	3.6376	0.5979	3.6930
11/08/72	17	12520	0.8667	2.8332	0.3059	1.6958
03/22/73	12	24592	0.5241	2.4849	0.2109	1.0880
11/30/73	1	64	0.0000	•	•	0.0000
02/11/74	1	3680	0.0000	•	•	0.0000
05/20/74	12	992	1.4859	2.4849	0.5980	1.5943
11/21/74	8	4592	0.9257	2.0794	0.4452	0.8302
02/20/75	18	17520	1.2562	2.8904	0.4346	1.7398
06/11/75	31	3350	2.6074	3.4340	0.7593	3.6961
01/06/76	16	1630	1.5319	2.7726	0.5525	2.0280
05/07/76	20	900	2.3431	2.9957	0.7821	2.7931
12/02/76	24	2750	1.6113	3.1781	0.5070	2.9043
03/09/77	54	16910	2.2352	3.9890	0.5603	5.4439
01/06/78	37	9840	1.7576	3.6109	0.4867	3.9155
04/10/78	21	11600	0.7301	3.0445	0.2398	2.1370
01/26/79	38	18256	1.1212	3.6376	0.3082	3.7708
12/16/81	42	6928	2.3919	3.7377	0.6400	4.6363
03/26/82	30	17104	1.2941	3.4012	0.3805	2.9753

STATION A07 (NOW UNDER FILL)

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H'(MAX)	(J') EVENNESS	GLEASON
03/31/71	9	4032	0.5434	2.1972	0.2473	0.9636
12/08/71	5	2390	0.3139	1.6094	0.1950	0.5142
11/08/72	6	320	0.9089	1.7918	0.5073	0.8668
03/22/73	23	12704	1.6781	3.1355	0.5352	2.3281
02/11/74	17	11120	0.9753	2.8332	0.3442	1.7174
05/20/74	5	7080	0.3504	1.6094	0.2177	0.4512
11/21/74	5	330	1.0615	1.6094	0.6595	0.6898
02/20/75	14	4760	1.0315	2.6391	0.3909	1.5352
06/11/75	11	980	1.9622	2.3979	0.8183	1.4519
01/06/76	6	2220	0.7283	1.7918	0.4065	0.6489
05/07/76	3	310	0.2839	1.0986	0.2584	0.3486
12/02/76	7	350	1.4344	1.9459	0.7371	1.0243
03/09/77	3	2720	0.0485	1.0986	0.0442	0.2529
01/06/78	10	18200	0.4713	2.3026	0.2047	0.9175
04/10/78	23	12460	1.6182	3.1355	0.5161	2.3329

STATION A08

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H'(MAX)	(J') EVENNESS	GLEASON
03/17/72	21	5888	2.3229	3.0445	0.7630	2.3040
11/30/73	68	123E3*	1.7052	4.2195	0.4041	5.7158
02/11/74	66	14928	3.0876	4.1897	0.7369	6.7631
05/20/74	60	36512	2.1730	4.0943	0.5307	5.6162
11/21/74	49	10[illegible]	2.6196	3.8918	0.6731	5.1973
02/20/75	55	5040	2.9175	4.0073	0.7280	6.3342
06/11/75	48	8650	2.7439	3.8712	0.7088	5.1846
01/06/76	47	7120	2.7106	3.8501	0.7040	5.1856
05/07/76	64	3860	3.1029	4.1589	0.7461	7.6286
12/02/76	92	9750	2.1362	4.5218	0.4724	9.9074
03/09/77	67	1150	3.6175	4.2047	0.8603	9.3650
01/06/78	51	22864	1.7318	3.9318	0.4405	4.9814
04/10/78	30	2704	2.6836	3.4012	0.7890	3.6697
01/26/79	70	11744	2.8585	4.2485	0.6728	7.3631
12/16/81	65	11952	2.5905	4.1744	0.6206	6.8167
03/26/82	59	19024	1.7201	4.0775	0.4219	5.8863

*=123003

TABLE 9. NUMBERS OF SPECIES AND INDIVIDUALS, SPECIES DIVERSITY, EVENNESS AND GLEASON INDICES, STATIONS A 12, 1972-1982 AND A 13, A 14 AND A 15, 1978-1982.

STATION A12

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H'(MAX)	(J') EVENNESS	GLEASON
03/17/72	61	24240	2.3170	4.1109	0.5636	5.9431
11/30/73	66	29280	2.4236	4.1897	0.5785	6.3201
02/11/74	49	23712	2.3409	3.8918	0.6015	4.7649
05/20/74	76	44912	1.8787	4.3307	0.4338	7.0012
11/21/74	59	24496	2.2267	4.0775	0.5461	5.7390
06/11/75	62	23290	1.8444	4.1271	0.4469	6.0662
01/06/76	11	170	2.2316	2.3979	0.9307	1.9471
05/07/76	67	2870	3.0261	4.2047	0.7197	8.2893
12/02/76	64	12430	2.1202	4.1589	0.5098	6.6823
03/09/77	75	8280	2.5443	4.3175	0.5893	8.2025
01/06/78	48	6480	2.6676	3.8712	0.6891	5.3552
04/10/78	35	1376	3.2467	3.5553	0.9132	4.7046
01/26/79	53	6576	2.9818	3.9703	0.7510	5.9150
12/16/81	59	7840	3.0979	4.0775	0.7597	6.4682
03/26/82	19	1952	1.8323	2.9444	0.6223	2.3757

STATION A13

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H'(MAX)	(J') EVENNESS	GLEASON
01/06/78	49	4256	3.2204	3.8918	0.8275	5.7443
04/10/78	50	3616	3.3457	3.9120	0.8552	5.9806
01/26/79	60	7136	3.2909	4.0943	0.8038	6.6495
12/16/81	66	8752	3.2381	4.1897	0.7729	7.1609
03/26/82	70	12416	2.9161	4.2485	0.6864	7.3196

STATION A14

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H'(MAX)	(J') EVENNESS	GLEASON
01/06/78	50	7168	3.0151	3.9120	0.7707	5.5196
04/10/78	47	9792	2.4247	3.8501	0.6298	5.0058
01/26/79	60	11904	2.7466	4.0943	0.6708	6.2869
12/16/81	53	6816	2.8555	3.9703	0.7192	5.8910
03/26/82	65	7120	3.3289	4.1744	0.7975	7.2148

STATION A15

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H'(MAX)	(J') EVENNESS	GLEASON
01/06/78	35	10352	1.6061	3.5553	0.4518	3.6777
04/10/78	42	22384	1.4342	3.7377	0.3837	4.0934
01/26/79	37	18608	1.5591	3.6109	0.4318	3.6618
12/16/81	15	7856	0.5504	2.7081	0.2032	1.5609
03/26/82	24	9088	0.7226	3.1781	0.2274	2.5234

TABLE 10. NUMBERS OF SPECIES AND INDIVIDUALS, SPECIES DIVERSITY, EVENNESS AND GLEASON INDICES, STATION B 08 AND B 09, 1972-75, 1978, 1981-82

STATION B08

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H' (MAX)	(J') EVENNESS	GLEASON
12/13/72	49	9920	2.3363	3.8918	0.6003	5.2161
03/22/73	58	21824	2.4852	4.0604	0.6120	5.7053
11/30/73	65	19088	2.4253	4.1744	0.5810	6.4930
02/11/74	65	32144	2.5014	4.1744	0.5992	6.1669
05/20/74	64	48192	1.8295	4.1589	0.4399	5.8426
11/21/74	65	30528	2.3163	4.1744	0.5549	6.1977
02/20/75	60	15680	2.4466	4.0943	0.5975	6.1076
01/06/78	58	6128	3.0218	4.0604	0.7442	6.5362
04/10/78	49	4224	3.1037	3.8918	0.7975	5.7495
12/16/81	31	1680	2.7886	3.4340	0.8121	4.0396
03/26/82	34	5504	2.1009	3.5264	0.5958	3.8313

STATION B09

DATE	SPECIES	INDIVIDUALS	(H') SHANNON-WEINER	H' (MAX)	(J') EVENNESS	GLEASON
12/13/72	51	9430	2.3238	3.9318	0.5910	5.4635
03/22/73	67	41824	1.3161	4.2047	0.3130	6.2023
11/30/73	66	52400	1.6350	4.1897	0.3902	5.9816
02/11/74	65	43808	1.9442	4.1744	0.4657	5.9883
05/20/74	60	30368	2.0479	4.0943	0.5002	5.7164
02/20/75	61	21712	2.1958	4.1109	0.5341	6.0086
01/06/78	46	2400	3.3613	3.8286	0.8779	5.7817
04/10/78	54	8080	3.0441	3.9890	0.7631	5.8908
12/16/81	58	4496	3.4595	4.0604	0.8520	6.7769
03/26/82	46	3856	2.9668	3.8286	0.7749	5.4497

Table 11. Peak Periods for Species and Individuals, 1971-1982. In Winter (W) and Spring (S) Periods. (Numbers of Species Above Line; Numbers of Individuals in 1000's Below)

Stations	A 01	A 2A	A 04	A 07	A 08	A 12	A 13	A 14	A 15	B 08	B 09
Time											
S 71	18 1.2	21 1.1	6 4.3	9 4.0	ND	ND	ND	ND	ND	ND	ND
W 71-72					"	"	"	"	"	"	"
S 72	80 19.7	21 20.9	38 22.4		21 5.9	61 24.2	"	"	"	"	"
W 72-73							"	"	"	49 9.9	51 9.4
S 73		79 32.0		23 12.7			"	"	"	65 19.1	67 41.8
W 73-74	58 9.7				68 123.0		"	"	"	65 32.1	66 52.4
S 74	72 10.5	88 53.9			60 36.5	76 44.9	"	"	"	64 48.2	65 43.8
W 74-75							"	"	"	65 30.5	60 21.7
S 75	77 12.7	67 27.6				62 23.2	"	"	"		
W 75-76					92 9.7		"	"	"		
S 76	81 2.2						"	"	"		
W 76-77	96 1.7	73 24.5				69 12.9	"	"	"		
S 77			54 16.9		67 1.1	75 8.2	"	"	"		
W 77-78					51 22.8		49 4.3	50 7.2	35 10.4		
S 78				23 12.4					42 22.4		
W 78-79			38 18.2		70 11.7			60 11.9			
W 81-82	78 6.8	30 3.3	42 6.9	ND	65 11.9	59 7.8	66 8.7	53 6.8	15 7.9	31 1.7	58 4.5
S 82	75 5.2	37 3.5	30 17.1	ND	59 19.0	19 1.9	70 12.4	65 7.1	24 9.1	34 5.5	46 3.9

ND = No Data

Table 12. Comparison, Average Numbers of Species and Individuals in Outer Los Angeles Harbor Station Benthos with off-shore data.

Period	# Species/m^2		Individuals/m^2	
	Range	Average	Range	Average
Winter 1973-74 7 Stations (excluding outfall A7)*	1-79	57	64-123,003	37,339
Spring 1974 7 Stations (excluding outfall A7)	12-88	62	10,512-53,920	33,213
Winter 1974-75 7 Stations (excluding outfall A7)	8-69	51	4,592-36,624	13,278
Spring 1975 7 Stations (excluding outfall A7)	18-77	53	12,656-21,712	9,053
Winter 1977-78 10 Stations (excluding outfall A7)	35-58	48	2,176-22,864	7,509
Spring 1978 10 Stations (excluding outfall A7)	21-54	40	1,376-22,348	6,758
Winter 1981-82 10 Stations (A7 filled)	15-78	50	1,680-11,952	6,653
Spring 1982 10 Stations (A7 filled)	19-75	46	1,952-19,024	8,470
A 01 1981-82 20 m outside harbor	75-78	77	5,168-6,880	6,042
SCCWRP 1977 60 m Control Survey off-shore	64-78	71	3,750-4,710	4,230
Soule and Oguri 1982 37 m Survey off-shore	73-106	88	3,520-8,800	4,623

* Outfall (A7) excluded for comparability

Table I3. Rank Order of Benthic Species with Most Numerous Individuals by Season in Los Angeles-Long Beach Harbors in 1978. *

January 1978

Rank	Species/Group	% Composition
1.	*Cossura candida*	22.60
2.	*Tharyx*, sp.	19.63
3	*Mediomastus californiensis* (=*Capitita ambiseta*)	19.49
4.	*Capitella capitata*	5.06
5.	*Prionospio cirrifera*	3.44
6.	*Paraonis gracilis oc.*	3.15
7.	*Euchone limnicola*	2.66
8.	*Sigambra tentaculata*	2.08
9.	*Chaetozone corona*	1.85
10.	*Haploscoloplos elongatus*	3.75
11.	*Nephtys cornuta fr.*	1.40
12.	*Lumbrineris* sp.	1.21
		86.32

April 1978

Rank	Species/Group	% Composition
1.	*Cossura candida*	30.15
2.	*Mediomastus californiensis* (=*Capitita ambiseta*)	19.65
3.	*Tharyx* sp.	10.30
4.	*Capitella capitata*	8.34
5.	*Prionospio cirrifera*	5.91
6.	*Euchone limnicola*	3.89
7.	*Paraonis gracilis oc.*	3.23
8.	*Sigambra tentaculata*	1.93
9.	*Chaetozone corona*	1.91
10.	*Nephtys cornuta fr.*	1.39
11.	*Haploscolopos elongatus*	1.39
12.	*Lumbrineris* sp.	1.28
		89.36

July 1978

Rank	Species/Group	% Composition
1.	*Cossura candida*	28.27
2.	*Mediomastus calif.* (=*Capitita ambiseta*)	25.07
3.	*Tharyx* sp.	10.78
4.	*Prionospio cirrifera*	5.45
5.	*Nephtys cornuta fr.*	1.53
6.	*Sigambra tentaculata*	1.94
7.	*Lumbrineris* sp.	0.97
8.	*Gyptis brevipalpa*	0.81
9.	*Paraonis gracilis oc.*	2.84
10.	*Theora lubrica*	1.72
11.	*Haploscoloplos elongatus*	1.44
12.	*Chaetozone corona*	1.08
		81.91

October 1978

Rank	Species/Group	% Composition
1.	*Cossura candida*	37.54
2.	*Mediomastus calif.* (=*Capitita ambiseta*)	25.04
3.	*Prionospio cirrifera*	6.70
4.	*Tharyx* sp.	6.70
5.	*Theora lubrica*	2.90
6.	*Paraonis gracilis oc.*	2.20
7.	*Euchone limnicola*	2.10
8.	*Nephtys cornuta fr.*	1.87
9.	*Sigambra tentaculata*	1.45
10.	*Haplocoloplos elongatus*	1.13
11.	*Lumbrineris* sp.	0.97
12.	*Capitella capitata*	0.78
		89.43

* from Soule and Oguri, 1980.

Table 14. Rank Order of Benthic Species with Most Numerous Individuals 1981-82.

December 16, 1981 (10 Stations)

Rank	Species/Group	% Composition (total;66,528)
1.	*Cossura candida*	21.6
2.	*Mediomastus californiensis*	13.2
3.	*Prionospio cirrifera*	8.7
4.	*Nephtys cornuta fr.*	5.8
5.	*Tharyx*, sp.	4.5
6.	*Tauberia oculata*	4.3
7.	Amphipoda, gammarid, unident.	3.2
8.	*Prionospio pygmaeus*	2.7
9.	*Haploscoloplos elongatus*	2.2
10.	Nemertea,Unident.	1.9
11.	*Paraprionospio pinnata*	1.6
12.	*Lumbrineris*, sp.	1.5
		71.2

March 26, 1982 (10 stations)

Rank	Species/Group	% Composition (total;84,704)
1.	*Cossura candida*	22.6
2.	*Mediomastus californiensis*	16.9
3.	*Prionospio cirrifera*	15.4
4.	*Nephtys cornuta fr.*	3.4
5.	*Tharyx*, sp.	3.4
6.	*Tauberia oculata*	3.2
7.	Amphipoda, gammarid, unident.	1.7
8.	*Lumbrineris*, sp.	1.2
9.	Nemertea, unident.	1.1
10.	*Mediomastus acutus*	1.1
11.	*Haploscoloplos elongatus*	1.0
12.	*Chone*, sp. (all from A 01 and A 15)	1.0
		72.0

Table 15. Comparison of Species Rank by Numbers of Individuals at Station A01 in 1981-82, and at the 37 m Offshore Stations in Spring 1982.

Station A 01 (20 m)

Rank	Species/Group	% Composition
1.	Amphipoda, gammarid unident. juvenile	16.7
2.	*Chone*, sp. juvenile	15.5
3.	*Chaetozone setosa*	8.4
4.	*Mediomastus californiensis*	3.7
5.	*Lumbrineris*	2.8
6.	*Prionospio pygmaeus*	2.8
7.	*Prionospio cirrifera*	2.5
8.	Nemertea, sp.	2.5
9.	*Mysella grippi*	2.2
10.	*Owenia collaris*	1.6
11.	Copepoda, cyclopod	1.6
12.	*Haploscoloplos elongatus*	1.2
		61.5

Mean of 7 Stations, (37 m) *

Rank	Species/Group	% Composition
1.	*Acesta catherinae*	4.6
2.	*Mediomastus californiensis*	4.4
3.	*Euchone incolor*	3.9
4.	*Prionospio steenstrupi*	3.8
5.	*Chone gracilis*	3.7
6.	*Spiophanes missionenis*	3.6
7.	*Euphilomedes* (1 station)	3.2
8.	*Lumbrineris*, sp.	2.3
9.	*Parvilucina tenuisculpta*	2.3
10.	*Photis*, sp.	2.3
11.	*Tharyx*, sp.	2.2
12.	*Amphideutopus oculatus*	1.5
		37.8

* Soule and Oguri, 1982

Table 16. Rank Order of Species in 1981, Los Angeles City Bimonthly Survey Totalled.

Rank	Species	% Composition
1	*Amphideutopus oculatus*	21.05
2	*Cossura candida*	10.16
3	*Mediomastus californiensis*	9.20
4	*Tauberia gracilis (=Paraonis)*	8.96
5	Nemertea, unidentified	2.74
6	*Tharyx*, sp.	2.48
7	*Nephtys cornuta franciscana*	2.34
8	*Prionospio cirrifera*	2.07
9	*Paraprionospio pinnata*	1.72
10	*Euphilomedes carcharodonta*	1.66
		62.38

Table 17. Rank Order of Species in Los Angeles City Survey, December 1981.

Rank	Species	% Composition
1	*Tauberia gracilis*	15.05
2	*Cossura candida*	11.29
3	*Amphideutopus oculatus*	10.52
4	*Mediomastus californiensis*	9.83
5	*Nephtys cornuta franciscana*	6.75
6	*Paraprionospio pinnata*	2.91
7	*Lumbrineris*, sp.	2.75
8	Nemertea, Unidentified	2.75
9	*Prionospio cirrifera*	2.30
10	*Tharyx*, sp.	2.18
		66.33

Table 18. Grain Size Distribution Expressed as Percent of the Total in 1982. Bottom Sediment Samples Collected in and Near the Outer Harbor.

Station	% Clay & Silt < 0.075 mm	% Sand Fine 0.075-0.42 mm	Medium 0.42-2.36 mm	Course 2.36-4.76 mm	% Gravel > 4.76 mm
A1 - #1	60.5	27.7	7.7	2.2	1.9
A1 - #2	14.9	75.6	9.0	0.2	0.3
A2A	93.6	6.2	0.2		
A4	96.9	3.1			
A8	39.5	57.6	2.5	0.4	
A12	88.7	11.3			
A13 - #1	64.3	35.1	0.6		
A14	60.6	38.8	0.6		
A15	73.4	26.6			
B8 - #1	48.6	51.0	0.4		
B9	78.9	21.1			

Table 19. Grain Size Distribution in Samples of Bottom Sediment at Stations in the Proposed Dumpsite Area. Percent, and Size in mm; tr=trace. Collected 14 April 1982. (Soule and Oguri, 1982).

Benthic Station Designation	Clay % < 0.005	Silt % 0.005-0.075	Sand Fine 0.075-0.45	Medium 0.45-2.75	Coarse 2.75-4.75	Gravel % <4.75
1. CW 25 fms	2	28	70	---	---	---
2. J1 50 fms	3	35	62	---	---	---
3. CE2 20 fms	5	27	57	9	1	1
4. CE1 25 fms	3	31	58	3	2	3
5. TB 23 fms	3	37	58	1	1	tr
6. TA 24 fms	2	32	63	1	2	---
7. NETA 15 fms	---	2	33	41	8	16

III

BIOASSAY, BIOSTIMULATION AND BIOACCUMULATION TESTS OF SECONDARY TREATED WASTE EFFLUENT AND FISH PROCESSING WASTES

by

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BIOASSAY, BIOSTIMULATION AND BIOACCUMULATION TESTS OF SECONDARY TREATED WASTE EFFLUENT AND FISH PROCESSING WASTES

INTRODUCTION

The Terminal Island Treatment Plant (TITP) processes a mixture of approximately 80 percent urban domestic and industrial wastes and 20 percent liquid fish processing wastes generated by Star-Kist Foods and Pan Pacific Fisheries. There have been intermittent problems at TITP in operating within NPDES permit limits for BOD and suspended solids since the conversion of TITP to secondary waste treatment and the hook-up of cannery process wastes to TITP in 1977-78. It has been hypothesized on the basis of field data gathered from 1971 to 1979, (Soule and Oguri, 1979) that mixing non-secondary treated fish processing wastes with secondary treated effluent would alleviate continuing problems with TITP plant upsets. These appear to be due in part to variations in loadings and in salinity of wastes from the fish processors. Concomitantly it was postulated that returning some non-secondary treated fish waste effluent to the harbor, in combination with the secondary treated TITP waste, would improve the environmental quality of the total effluent in terms of enhancing nutrient bioavailability in receiving waters based on the fact that the harbor had a much more productive ecosystem prior to secondary treatment at TITP, when the fish processors had separate waste outfalls to the harbor.

Bioassay/toxicity tests are an integral part of the regulatory requirements for evaluating the environmental effects of waste effluents. The State Bays and Estuaries Policy requires routine bioassays using 100 percent effluent; these are carried out by the City of Los Angeles using freshwater fish species. A series of different bioassays was carried out by HEP to test various potential waste effluent mixtures and to examine indigenous marine test organisms for potential bioaccumulation and/or biostimulation. In the present bioassays, various effluent mixtures were tested which simulated the proposed combinations of wastes which would be anticipated if mixing of non-secondary fish wastes with secondary treated TITP wastes were to be permitted. Dilutions were selected for testing, based on previous field studies of the TITP plume. Organisms were used which are representative of those found in the receiving waters. Similar bioassays were performed previously in 1978 (Soule and Oguri, 1979).

THE PRESENT STUDY

Bioassays were conducted on 100 percent Terminal Island Treatment Plant (TITP) final effluent and on three mixtures using 80 percent TITP effluent combined with 20 percent of various types of fish processing wastes. A final assay was conducted on fish processing wastes alone. Assays were designed to evaluate for positive effects such as growth or biostimulation, as well as for negative effects, if any, such as acute toxicity or bioaccumulation of material from the test solutions at concentrations likely to occur under actual discharge conditions if the mixing of effluent is permitted by regulatory agencies.

Short-term static bioassay procedures utilizing concentrations ranging from 10 percent to 0.01 percent by volume were used to perform acute (96hr) toxicity tests. Filtered sea water sterilized by exposure to ultra-violet light was used as the diluent. The test solutions were either collected from TITP or the fish processors on the morning of the test, or on the preceeding afternoon, when they were stored at 4°C or lower until the start of the test. The test concentrations were selected to provide a maximum of about one order of magnitude higher concentrations than would be likely to occur in the immediate vicinity of any proposed discharge but would not require salinity adjustments of the low salinity effluent. This was considered important in order to reduce the potential for stressing the test organisms by factors other than exposure to the test solution. The concentrations tested in each of the test series were 10 percent, 1 percent, 0.1 percent, and 0.01 percent, plus controls.

The organisms selected include *Fundulus parvipinnis*, the California killifish; *Mytilus edulis*, the bay mussel; *Neanthes arenaceodentata*, a polychaetous annelid; and *Acanthomysis sculpta*, a mysid shrimp. All are considered to be standard organisms for EPA and Army Corps of Engineers bioassay testing. The bay mussel has been extensively surveyed for ambient metal levels as the subject of study by the California Department of Fish and Game "Mussel Watch" program (State Water Resources Control Board, 1982).

Both fish and mussels for the tests were collected at least two days prior to the start of the test and were not fed during the acclimation period prior to the start of the test to allow gut contents to be voided. The mysids were collected and sorted the day before the test, and the worms, obtained commercially, were delivered on the day of the test.

Three 10 gallon glass aquaria were prepared with 27 liters of the test solution. Approximately 3 liters of each test solution were placed in each 1 gallon wide mouth jar and 200 ml in a crystallizing dish. About 125 ml was set aside for determination of ammonia at the start of the test. The fish and mussels were placed in 10 gallon aquaria, the worms in the gallon jars and the mysid shrimp in the crystallizing dishes.

All concentrations were run in triplicate. Temperatures were held to the ambient sea water temperatures occurring at the USC Fish Harbor Marine Laboratory at the start of the test, $\pm 1^{\circ}C$. Measurements of temperature, salinity, pH and dissolved oxygen were made daily with electronic probes, as were observations of the living and removal of dead organisms during the tests. Ammonia concentrations were determined with an ion probe at the start and at the end of the test.

Biostimulation and bioaccumulation assays were carried out on both mussels and fish. Mussels were measured and weighed prior to the start of the accute toxicity tests, and were reweighed at the end of the four day testing period. The mussels were then returned to the control and the 1.0 percent test solutions for an additional 20 day exposure, after which they were weighed again to determine any change in biomass. All weighing was done by blotting each mussel dry and immediately weighing it on a laboratory balance to the nearest 0.1 g. Also, one set of fish each from the control and from the 1.0 percent test aquaria were continued for 20 days beyond the 96 hour acute toxicity test.

The mussels and fish that survived the total 24 day period of testing were then frozen for storage until later chemical analysis. At the start of chemical analyis the samples were thawed to room temperature and each specimen was rinsed with distilled water. The mussels were removed from the shell, and the stomach and intestine of the fish were removed using clean stainless steel implements, and discarded. Following another rinse with distilled water the wet weight of each specimen was determined. The appropriate aliquots needed for metals and chlorinated hydrocarbon analysis were then made up by random selection of whole specimens from among those in each experimental group. In cases where there was an insufficient quantity of material for both analyses, metals were given precedence over hydrocarbons. The aliquots were placed in chemically cleaned containers; plastic for the metals analysis and glass for the hydrocarbons analysis. Chemical digestion and analysis of the samples followed the methods outlined in Standard Methods (APHA, 1980).

For metals analysis, except for mercury and arsenic, the dried tissue samples were first digested in nitric acid and then in a nitric acid-perchloric acid mixture. Digestion of tissue for analysis of mercury was carried out by refluxing in a nitric acid-sulfuric acid mixture. Digestion for arsenic analysis was a two step process with an initial digestion in a mixture of nitric and sulfuric acids followed by treatment with a nitric acid-perchloric acid mixture.

Analysis of the digested samples was by atomic absorption spectrophatometry (AAS). The cold vapor method was used to analyze for mercury and flame AAS was used for arsenic analysis following conversion to hydride. Flame AAS was used for chromium and zinc analysis and flameless AAS methods were used for aluminum, cadmium, copper, lead, nickel and silver.

Samples for chlorinated hydrocarbons analysis were extracted with 15 percent methylene chloride in N-hexane. The extracts were cleaned and partitioned into 3 fractions which were analyzed in a gas chromatograph with an electron-capture detector.

Metals analysis was performed in the USC Environmental Engineering Laboratories while tissue digestion and hydrocarbon analysis were done at the Los Angeles City Bureau of Sanitation Hyperion Laboratory.

RESULTS AND DISCUSSION

Acute toxicity tests

Test TITP I utilized only final effluent from the Terminal Island Treatment Plant as the test solution. Test II, III and IV used mixtures of 80 percent final effluent from Terminal Island Treatment Plant and 20 percent of various mixtures of fish processing liquid waste effluent then being processed by the treatment plant. Test V used only the fish processing wastes as the test solution.

The data on temperature, salinity, pH, dissolved oxygen and ammonia concentration in the test aquaria are presented in Tables 20 to 24 for the respective tests. The biological data for the acute toxicity phase of these tests are presented in Tables 25 to 29.

The physical and chemical data, except for ammonia concenrations, suggest that the conditions during the bioassays were sufficiently stable to introduce no significant stress to the test organisms. The ammonia levels, with few exceptions, increased 10 to 20 fold in the controls and the two lowest concentrations of the test solutions during the four day test periods. The higher two concentrations, 1.0 and 10 percent, had higher levels of ammonia initially, reflecting the concentrations in the test solutions at the start of the tests. Ammonia values in the latter tanks increased during the test period but less sharply than did those at lower concentrations. The resultant final concentrations of ammonia in the 1.0 and 10 percent solutions were generally higher than those found in the more dilute solutions and in the control aquaria. The increased ammonia levels were undoubtedly produced primarily by the test organisms, as shown by the similarity in increases in the control aquaria and in those of the two lowest concentrations. The contributions from the degradation of the organic matter in the test solutions are apparent in the data from the aquaria containing the two highest concentrations. The significance of this as a factor in the bioassays is not clear in the biological data.

The biological data for the respective tests showed no consistent pattern of increased mortality at the higher concentrations of the test solutions. The assays involving mysids showed consistently high mortality at all concentrations, but this also occurred in the control aquaria, suggesting that these animals were affected by some factor other than exposure to the test solutions. Seasonally, the warmer "El Niño" coastal waters or storms may well have severely stressed the local wild mysid populations. Mortality in the control aquaria of all other species used in the tests was not excessive, and other species in the test aquaria showed no consistent pattern of significantly higher mortality related to concentration of the test solutions. Since mortality of 50 percent or greater did not occur, even at the highest concentration tested, no 50 percent Lethal Concentration (LC_{50}) could be calculated.

Biostimulation/Bioenhancement

The mussels used in the acute toxicity phase of these bioassays were also used to assess the potential for increasing growth. For purposes of the present study, biostimulation was considered as a function of change in biomass of the mussels following exposure to the test solutions.

Data on the average weight change during the four day acute toxicity tests at the different concentrations are presented in Table 30, and data on the average weight change in mussels over a 24 day period (including the 96 hour acute toxicity test) in control and 1.0 percent test solutions are presented in Table 31.

The average weight changes during the initial 96 hour period of exposure to the test solutions show no consistent pattern of change as a function of concentration (Table 30). This suggests that either the 96 hour test exposure time was too short for any apparent change, or that there was no effect of exposure to the test solution.

Following 24 day exposure to the 1.0 percent concentration of the test solutions, however, the situation was different. There was a consistent pattern of greater average weight gain in the mussels held in the 1.0 percent test solution as compared to those held in the control solution. The average change under test conditions ranged from about two to five times the amount gained in the control solutions. This represents a rather considerable increase in weight in a relatively short time, and thus is considered to be an enhancement of normal growth. In only one case, that of the controls in the second test, was there a loss in weight following the 96 hour initial test period.

Bioaccumulation

Analyses of metals and chlorinated hydrocarbons were performed on samples of mussel and fish tissue taken from controls and from the one percent test concentrations of the biostimulation tests for each test series.

The data on metals uptake, as mg/kg dry weight, from the metals analyses are presented in Table 32 for the mussels and in Table 33 for the killifish. The hydrocarbons data are in Tables 34 and 35 for the mussels and fish, respectively. Averages and standard deviations for both control and test condition replicates of the mussels were calculated and, when the difference was significant, an asterisk is shown.

No consistent pattern of significant bioaccumulation by the mussels of any of the nine metals analyzed is apparent in the results of the tests reported in Table 32. In Test II, chromium and zinc showed significantly higher concentrations in the test organisms than in the controls, but there was no similar finding in any of the other tests. The only other significant differences found between concentrations of metals in control and test organisms was for lead and zinc in Test IV and V, and these data suggest depuration rather than bioaccumulation of these metals.

In the fish tests, the lack of replicate values for the tests of metals bioaccumulation precludes statistical treatment of the data shown in Table 33. However, no consistent pattern suggesting bioaccumulation of any metal is apparent in the data from these tests. In Test V, an anomalously high value for silver concentration in the tissues of the test fish was found. Although this value is one order of magnitude higher than was found in any of the other analyses, it is reported here since a careful check failed to produce any evidence suggesting either contamination or a technical error. There was insufficient sample left to permit a reanalysis.

Analyses for chlorinated hydrocarbons included 13 pesticides and 2 polychlorinated biphenyls (PCB). However, values for only 6 pesticides and one PCB are included in Tables 34 and 35 since, with the few exceptions noted below, none of the unlisted compounds were present in detectable levels, except as follows. The unreported compounds are Aldrin, benzene hexachloride (BHC), o,p'-DDD, Endrin, heptachlor, heptachlor epoxide, Lindane and PCB AR 1242. Detectable concentrations of BHC were found in Test samples of control tissue 1 and 3, which showed 12 and 21 mg/kg BHC dry weight, respectively. In Test II, 5 mg/kg dry weight of Endrin was found in tissue from the 1.0 percent solutions in replicate 3.

Among the chlorinated hydrocarbons for which data are available there is no consistent pattern of significant bioaccumulation. Two of the tests did show significant difference between control and test data for specific compounds but such differences were not duplicated in other tests.

Test IV, one of the tests of the mixtures of 80 Percent TITP final effluent and 20 percent cannery waste, showed such significant differences for p,p'DDE and p,p'DDT, with the latter showing a significantly lower concentration in the test mussels than in the control mussels.

In Test V, involving exposure to the cannery wastes alone, o,p'DDE and o,p'DDT were the compounds in which there was a significantly different concentration in the test and control mussels. The test organisms had a lower concentration of o,p'DDE than the controls, suggesting depuration rather than accumulation. In both test IV and V, significant bioaccumulation of total pesticides occurred, but none of the other tests showed a similar results.

It is interesting to note that p,p'DDT was detected in mussel tissue in only one case, in one replicate of the test mussels, from Test I, all the fish showed detectable quantities of this compound. The data are insufficient to permit any conclusion. Since the differences were slight and not significant between test and control concentrations this does not appear to be related to test exposures.

The predominance of reduced concentrations in the test fish as compared to controls suggests that depurations of chlorinated hydrocarbons took place rather than accumulation. Perhaps the utilization of a food source, the waste itself and the bacteria the waste supports, permitted metabolic purging of the ambient concentrations present in the tissues of test animals at the start of the experiment, whereas controls were unfed and perhaps depurated less.

Studies of the TITP and cannery effluents prior to instituting secondary treatment were based on test water collections made from the surface at the points of discharge and may reflect initial mixing of perhaps an order of magnitude. These tests (Soule and Oguri, 1976) showed that there was a selective mortality closest to the point of discharge but, nevertheless, there was an overall increase in diversity and evidence of significant biostimulation outside of that immediate site.

Studies conducted after the installation of secondary treatment at TITP and the diversion of cannery waste to the treatment plant, showed no evidence of toxicity and, again gave evidence that in phytoplanton, some invertebrates and fish growth could be sustained or stimulated (Soule and Oguri, 1979).

CONCLUSIONS

Under the test conditions and concentrations of the waste mixtures of secondary treated TITP waste and non-secondary fish cannery waste, the wastes were found not to be toxic. The maximum concentrations of the wastes tested in these bioassays were probably one order of magnitude higher than would be expected during operational discharge of the two types of waste from the TITP outfall. It is therefore doubtful that any significant adverse biological impact would result from such a discharge.

The pattern of growth, or bioenhancement, observed during these tests suggests that the present discharge provides nutrient input to the present biota that would otherwise be absent from the harbor. The addition of a percentage of non-secondary treated cannery waste apparently significantly enhanced the nutritional value of the effluent, without demonstrating toxicity. The growth studies indicate that the wastes could be managed as a potentially valuable resource.

No consistent findings of significant bioaccumulation of either metals or chlorinated hydrocarbons were apparent in the data from these tests. Some tests did show significant differences between concentrations of specific metals or chlorinated hydrocarbons between the tissues of control and test mussels. However, these differences were not consistent throughout the test series and, in about half of the cases, indicated that depuration rather than accumulation occurred. This suggests that either bioaccumulation or depuration maybe a borderline occurrence under test conditions and is not consistently detectable, if it occurs.

LITERATURE CITED

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Soule, D.F. and M. Oguri. 1979. Ecological changes in outer Los Angeles-Long Beach Harbors following initiation of secondary waste treatment and cessation of fish cannery waste effluent. Marine Studies of San Pedro Bay, California. Part 16. Allan Hancock Foundation and Sea Grant Programs, Institute for Marine and Coastal Studies, Univ. Southern California. 597 p.

Table 20. TITP I Bioassay Water Quality Data. Date: 1-5 October 1982.

Test Substance: TITP final effluent.

	Temp °/C			Sal ‰			DO mg/l			pH			NH_3 µg-at/l		
Replicates	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Control															
Start	20.5	20.5	20.5	33.5	33.3	33.4	7.3	7.3	7.2	8.0	8.0	8.0	15	14	16
Day 1	19.3	19.3	20.0	34.0	33.8	33.4	7.5	7.4	7.3	8.1	8.1	8.0			
Day 2	19.5	19.6	20.0	34.2	34.0	33.9	7.1	7.2	7.1	8.0	8.1	8.0			
Day 3	19.3	19.2	20.2	34.9	34.4	34.2	7.1	7.3	7.1	8.0	8.1	8.1			
Day 4	19.3	19.4	20.1	35.1	35.0	34.6	7.1	7.3	7.0	7.9	8.1	8.1	120	130	130
0,01%															
Start	20.5	20.5	20.5	33.5	33.3	33.4	7.3	7.2	7.3	8.1	8.0	8.0	13	12	15
Day 1	19.4	18.7	19.3	33.1	33.4	34.0	7.4	7.3	7.3	8.1	8.0	8.0			
Day 2	19.5	19.6	19.7	33.8	33.7	33.7	7.2	7.1	7.2	8.1	8.0	8.0			
Day 3	19.6	19.5	19.5	34.2	34.1	34.0	7.2	7.1	7.3	8.1	8.0	8.1			
Day 4	19.5	19.3	19.3	34.7	34.6	34.6	7.3	7.2	7.3	8.1	8.0	8.1	160	190	130
0.1%															
Start	20.1	20.0	20.0	33.9	33.6	33.5	7.2	7.1	7.5	8.0	7.9	8.0	13	11	18
Day 1	19.9	19.6	19.7	33.4	33.6	33.6	7.2	7.1	7.1	8.0	8.0	8.0			
Day 2	20.3	20.2	20.0	33.6	33.7	33.7	7.1	7.1	7.0	8.0	7.9	7.9			
Day 3	19.9	19.8	19.8	33.8	33.8	33.9	7.1	7.1	7.0	8.0	8.0	7.9			
Day 4	19.7	19.7	19.6	34.5	34.3	34.4	7.2	7.1	5.6	8.0	8.0	8.0	150	73	140
1%															
Start	20.4	20.4	20.3	33.3	33.3	33.8	7.1	7.3	7.2	8.1	8.0	8.1	21	26	25
Day 1	20.0	20.0	20.0	33.1	33.0	33.0	7.3	7.3	1.7	8.1	8.0	7.5			
Day 2	20.0	19.9	19.9	33.5	33.4	33.4	7.2	7.2	7.2	8.1	8.0	8.1			
Day 3	20.2	20.1	20.1	33.8	33.7	33.7	7.1	7.1	7.2	8.2	8.1	8.2			
Day 4	20.1	20.0	19.9	34.3	34.2	34.1	7.1	7.1	7.2	8.2	8.1	8.2	130	72	110
10%															
Start	20.3	20.3	20.3	31.1	30.8	30.7	7.3	7.3	7.2	8.0	8.0	8.0	81	100	110
Day 1	20.0	20.0	20.0	30.4	30.0	30.7	7.1	7.2	7.2	8.1	8.1	8.0			
Day 2	19.9	19.9	19.9	30.1	30.0	30.0	7.2	7.2	7.3	8.1	8.1	8.1			
Day 3	20.1	20.1	20.1	30.3	30.3	30.2	7.1	7.1	7.2	8.1	8.2	8.2			
Day 4	19.9	20.0	19.9	30.6	30.6	30.3	7.2	7.2	7.1	8.1	8.2	8.1	140	130	190

Table 21. TITP II Bioassay Water Quality Data. Date: 8-12 October 1982.

Test Substance: 80% TITP final effluent, 20% fish processing effluent.

	Temp °/C			Sal °/oo			DO mg/l			pH			NH_3 µg-at/l		
Replicates:	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Control															
Start	19.9	20.0	20.4	33.8	33.8	33.8	6.8	6.9	6.7	8.0	8.0	8.0	13	10	12
Day 1	19.5	19.7	20.3	34.0	33.9	33.6	7.1	7.0	7.1	8.0	8.0	8.0			
Day 2	20.1	20.2	20.1	34.3	34.5	34.4	7.0	7.0	7.1	8.0	8.0	8.0			
Day 3	20.2	20.3	20.2	34.3	34.2	34.2	7.0	7.0	7.0	8.0	8.0	8.0			
Day 4	19.7	19.7	19.6	34.3	34.2	34.2	7.0	7.1	7.0	7.0	8.0	7.9	40	35	41
0.01%															
Start	19.9	29.0	20.4	33.8	33.8	33.8	6.8	6.9	6.7	8.0	8.0	8.0	10	15	10
Day 1	19.1	19.1	19.4	34.0	34.0	33.8	7.1	7.2	7.1	8.0	8.1	8.0			
Day 2	20.0	19.9	19.8	34.5	34.7	34.8	7.1	7.1	6.9	8.0	8.1	8.0			
Day 3	20.0	19.9	19.9	33.9	34.2	34.1	7.1	7.2	7.0	8.0	8.1	8.0			
Day 4	19.4	19.5	19.5	34.3	34.3	34.2	7.0	7.2	7.3	7.9	8.0	8.1	42	51	110
0.1%															
Start	19.4	19.4	19.6	33.5	34.1	34.0	7.0	7.1	7.1	8.0	8.0	8.1	11	12	15
Day 1	19.4	19.4	19.6	33.6	33.8	33.8	7.1	7.2	7.1	7.9	8.1	8.0			
Day 2	19.8	19.8	19.8	34.3	34.6	34.8	7.0	7.1	7.1	7.9	8.1	8.1			
Day 3	19.9	19.8	20.0	33.8	34.3	34.2	7.0	7.2	7.2	7.9	8.1	8.1			
Day 4	19.5	19.4	19.5	34.1	34.0	34.2	7.1	7.3	7.2	7.9	8.0	8.0	49	44	44
1%															
Start	20.3	20.2	20.2	33.7	33.6	33.8	6.7	6.7	6.8	8.0	8.0	8.0	32	33	22
Day 1	20.2	20.3	20.2	33.4	33.5	33.7	6.8	6.6	7.0	7.9	7.8	8.0			
Day 2	20.0	19.9	19.9	34.5	34.5	34.3	6.9	6.8	7.1	7.9	7.9	8.1			
Day 3	20.0	19.9	19.8	34.0	34.0	34.1	6.6	6.2	7.2	7.2	7.8	8.1			
Day 4	19.5	19.3	19.4	34.1	34.1	34.2	6.2	7.2	5.9	7.8	8.0	7.6	67	210	60
10%															
Start	20.1	20.3	20.1	31.8	30.8	30.8	6.[illegible]	[illegible]	6.9	8.0	8.0	8.0	89	100	110
Day 1	20.3	20.3	20.2	31.7	31.6	31.8	7.0	7.0	6.8	8.1	8.1	8.0			
Day 2	19.9	20.0	20.0	32.6	32.5	32.5	7.0	7.0	3.6	8.1	8.1	7.4			
Day 3	19.8	20.0	19.9	32.1	32.0	32.0	7.1	7.1	6.9	8.2	8.1	8.0			
Day 4	19.3	19.4	19.3	32.3	32.0	32.0	7.2	7.2	7.2	8.1	8.1	8.1	220	160	130

Table 22. TITP III Bioassay Water Quality Data Date: 15-19 October 1982.

Test Substance: 80% TITP final effluent, 20% fish processing waste.

	Temp °/C			Sal °/oo			DO mg/l			pH			NH_3 µg-at/l		
Replicates:	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Control															
Start	19.8	19.8	19.5	34.3	34.2	34.0	6.9	7.1	7.1	8.0	8.0	8.0	35.0	9.6	9.3
Day 1	19.6	16.5	19.5	34.3	34.3	34.3	7.1	7.1	7.2	8.0	8.0	7.9			
Day 2	19.2	19.9	19.8	33.7	33.8	33.9	7.1	7.1	6.5	8.0	7.9	7.9			
Day 3	19.6	19.6	19.3	33.9	33.8	33.8	7.1	7.1	7.0	8.0	7.9	7.9			
Day 4	19.6	19.7	19.4	33.9	33.8	33.8	7.2	7.1	6.9	8.0	7.9	7.8	190.0	72.0	89.0
0.01%															
Start	19.4	19.3	19.2	34.7	34.8	35.1	7.3	7.2	7.1	8.1	8.0	8.0	8.8	9.3	9.9
Day 1	19.4	19.4	19.5	34.2	34.4	34.2	7.3	7.2	7.3	8.0	8.0	7.9			
Day 2	19.7	19.7	19.6	34.0	34.1	34.0	7.3	7.2	7.2	8.1	8.0	8.0			
Day 3	19.2	19.2	19.1	33.9	33.9	33.9	7.2	7.2	7.2	8.1	8.0	7.9			
Day 4	19.3	19.3	19.2	33.8	33.7	33.7	7.4	7.3	7.3	8.0	8.0	7.9	160.0	160.0	170.0
0.1%															
Start	19.2	19.1	19.5	34.8	34.8	34.5	7.3	7.1	6.9	8.0	8.0	8.0	11.0	10.0	11.0
Day 1	19.2	19.2	19.5	34.3	34.2	34.0	7.3	7.3	7.1	8.0	8.0	7.9			
Day 2	19.6	19.6	19.8	34.9	34.0	33.9	7.3	7.3	6.9	8.0	8.0	7.9			
Day 3	19.1	19.0	19.3	33.9	33.9	33.9	7.3	7.2	7.0	8.0	8.0	7.9			
Day 4	19.2	19.2	19.4	33.6	33.7	33.6	7.4	7.3	7.1	8.0	8.0	7.8	85.0	180.0	160.0
1%															
Start	19.3	19.1	19.0	34.5	34.5	34.6	7.1	6.9	6.9	8.0	8.0	8.0	20.0	19.0	17.0
Day 1	19.4	19.3	19.3	34.0	34.0	34.0	7.1	6.4	7.1	7.9	7.7	8.0			
Day 2	19.7	19.6	19.6	33.8	33.1	33.8	7.1	6.6	7.2	8.0	7.8	8.0			
Day 3	19.2	19.1	19.0	33.6	33.6	33.7	6.9	5.9	7.1	7.9	7.7	8.0			
Day 4	19.3	19.2	19.2	33.4	33.3	33.4	7.3	6.7	7.2	8.0	7.8	7.9	510.0	320.0	280.0
10%															
Start	19.0	19.0	19.1	32.0	31.9	31.9	6.9	7.0	6.7	8.0	8.0	8.0	90.0	120.0	100.0
Day 1	19.3	19.3	19.2	31.6	31.5	31.5	7.0	7.2	7.2	7.9	7.0	8.[illegible]			
Day 2	19.6	19.6	19.6	32.2	32.2	32.2	6.9	7.0	7.2	7.9	8.0	8.1			
Day 3	19.0	19.0	19.0	31.3	31.1	31.2	6.9	6.9	7.3	7.9	7.9	8.1			
Day 4	19.9	19.2	19.2	31.0	30.9	30.9	6.8	6.3	7.3	7.9	7.7	8.1	220.0	270.0	380.0

Table 23. TITP IV Bioassay Water Quality Data   Date: 22-26 October 1982.

Test Substance: 80% TITP final effluent, 20% fish processing effluent.

	Temp o/c			Sal o/oo			DO mg/l			pH			NH_3 µg-at/l		
Replicates	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Control															
Start	19.8	19.8	1.99	33.1	33.1	33.1	7.3	7.3	7.3	8.1	8.1	8.2	9.3	7.0	8.1
Day 1	20.5	20.4	20.0	32.8	32.7	32.3	6.1	6.8	7.2	7.6	7.8	8.0			
Day 2	20.3	20.2	20.1	32.8	32.8	32.9	7.0	7.1	7.3	7.9	8.0	8.0			
Day 3	20.3	20.3	20.0	32.4	32.3	32.6	6.8	7.1	7.2	7.9	7.9	7.9			
Day 4	20.2	20.2	20.0	32.9	32.9	32.9	6.9	7.2	7.2	8.0	8.0	8.0	550.0	175.0	150.0
0.01%															
Start	19.8	19.8	19.6	33.1	33.1	33.1	7.3	7.3	7.4	8.2	8.1	8.2	6.5	6.9	7.4
Day 1	20.1	20.0	19.9	32.5	32.7	32.6	7.1	7.2	7.2	7.9	8.0	8.0			
Day 2	20.1	20.0	19.9	32.7	32.7	32.8	7.1	7.2	7.2	7.9	7.9	8.0			
Day 3	20.0	19.9	19.8	32.5	32.5	32.5	7.0	7.2	7.2	7.9	7.9	8.0			
Day 4	20.1	20.0	19.9	32.4	32.9	33.0	7.1	7.2	7.2	7.9	7.9	8.0	170.0	89.0	150.0
0.1%															
Start	19.7	19.6	19.9	33.1	33.2	33.1	7.3	7.3	7.3	8.2	8.2	8.1	9.7	10.0	11.0
Day 1	20.0	19.9	29.2	32.6	32.6	32.6	7.1	7.1	7.1	8.0	7.9	7.9			
Day 2	20.0	29.9	20.2	32.7	32.7	32.1	7.1	7.1	7.0	7.9	7.9	7.9			
Day 3	19.9	19.2	20.1	32.4	32.4	32.4	7.1	7.0	6.9	7.9	7.8	7.8			
Day 4	20.0	20.0	20.0	32.9	32.8	32.9	7.0	7.0	7.0	7.9	7.9	7.9	150.0	135.0	110.0
1%															
Start	19.8	19.6	19.5	33.0	33.0	33.0	7.3	7.4	7.4	8.1	8.2	8.2	17.0	24.0	28.0
Day 1	20.0	19.8	19.8	32.5	32.1	32.4	7.1	7.1	7.0	7.9	8.0	7.9			
Day 2	20.1	20.0	19.9	32.5	32.5	32.2	7.0	7.2	7.0	7.9	8.0	7.9			
Day 3	19.9	19.7	19.7	32.2	32.4	32.3	6.9	7.1	6.9	7.8	7.9	7.9			
Day 4	20.0	19.9	19.9	32.7	32.8	32.8	6.9	7.2	7.1	7.8	8.0	7.9	170.0	110.0	200.0
10%															
Start	19.5	19.5	19.5	31.1	31.0	30.8	7.2	7.3	7.2	8.1	8.1	8.1	170.0	110.0	200.0
Day 1	19.8	19.8	19.7	30.9	30.7	30.4	7.0	7.2	6.9	7.9	8.0	7.9			
Day 2	19.9	19.9	19.9	30.8	30.6	30.4	7.1	7.1	6.8	8.0	8.0	7.9			
Day 3	19.7	19.7	19.6	30.5	30.4	30.0	7.1	7.2	6.9	7.9	9.0	7.8			
Day 4	19.9	19.9	19.9	31.0	30.6	30.6	7.1	7.1	7.0	8.0	8.0	7.9	230.0	240.0	360.0

Table 24. TITP V Bioassay Water Quality Data Date: 19-23 November 1982

Test Substances: 100% fish processing effluent.

	Temp $^0/_C$			Sal $^0/_{00}$			DO mg/l			pH		
Replicates	1	2	3	1	2	3	1	2	3	1	2	3
Control												
Start	14.2	14.3	14.3	34.2	34.3	34.4	7.8	7.8	7.8	8.0	8.0	8.0
Day 1	12.5	12.5	12.6	34.3	34.2	33.5	7.6	7.3	7.1	7.8	7.9	7.9
Day 2	20.0	20.0	20.7	32.3	31.9	31.7	7.0	7.8	6.8	7.9	7.8	7.9
Day 3	20.0	20.0	20.0	32.9	33.3	33.5	7.7	7.2	7.0	7.8	7.9	8.0
Day 4	18.5	18.7	19.0	31.5	31.6	31.3	7.5	7.3	6.8	8.0	7.0	7.8
0.01%												
Start	14.3	14.3	14.3	34.4	34.5	34.6	7.8	7.7	7.8	8.0	8.0	8.0
Day 1	12.5	12.5	12.5	33.1	34.0	32.8	7.3	7.7	7.2	8.0	8.0	8.0
Day 2	20.2	20.2	20.4	31.3	31.7	32.0	6.9	6.5	6.9	7.9	7.8	7.9
Day 3	19.9	20.0	21.1	33.8	33.5	33.5	7.2	6.9	7.3	8.1	8.0	8.2
Day 4	18.5	18.7	19.0	31.6	31.6	31.6	7.4	7.0	7.3	8.0	7.8	8.0
0.1%												
Start	18.2	18.3	18.4	34.6	34.6	34.5	7.7	7.6	7.6	8.0	8.0	8.0
Day 1	20.2	20.5	20.6	32.7	33.2	32.6	6.9	6.8	6.6	7.9	7.9	7.9
Day 2	20.8	21.2	21.7	32.1	32.8	32.7	6.8	6.8	6.5	7.9	7.9	7.9
Day 3	20.5	20.7	20.8	33.5	34.6	33.6	7.2	7.0	7.0	8.0	8.0	8.0
Day 4	19.5	19.7	19.8	31.7	32.2	31.7	7.3	7.1	7.1	7.9	7.9	7.9
1%												
Start	18.0	17.9	17.9	34.7	34.7	36.5	7.8	7.8	7.8	7.8	8.0	8.0
Day 1	19.0	19.3	19.7	33.9	33.2	37.0	6.7	6.8	7.0	7.7	7.8	7.9
Day 2	21.3	21.5	21.7	33.9	34.0	38.7	5.4	6.4	6.6	7.6	7.8	7.8
Day 3	20.1	20.1	20.1	34.4	33.8	37.2	7.2	7.0	6.4	8.1	8.0	7.8
Day 4	19.3	19.2	19.3	32.3	32.2	27.2	7.2	7.3	6.0	7.9	8.0	7.7
10%												
Start	17.7	17.9	17.4	33.8	33.7	34.0	7.6	7.6	7.9	8.0	7.8	8.0
Day 1	20.0	19.4	20.4	33.4	32.8	33.3	4.0	6.4	7.0	7.4	7.6	8.0
Day 2	21.7	21.8	22.0	34.7	36.6	36.9	6.8	6.7	6.8	8.1	8.0	8.0
Day 3	20.1	20.1	20.2	34.3	34.2	33.9	7.2	7.1	7.2	8.2	7.9	8.1
Day 4	19.3	19.1	19.3	32.1	32.6	32.1	7.3	7.2	7.1	8.1	8.0	8.0

Table 25. TITP I Bioassay Date: 1-5 October 1982.

Numbers of Live Organisms Surviving per Day and Dilution in 96 hr Toxicity Test.

	Acanthomysis			Neanthes			Mytilus			Fundulus		
Replicates	1	2	3	1	2	3	1	2	3	1	2	3
Control												
Start	10	10	10	10	10	10	9	9	9	15	15	15
Day 1	7	7	9	10	10	10	9	9	9	15	15	15
Day 2	6	7	8	10	10	10	9	9	9	15	15	15
Day 3	5	5	6	10	10	10	9	9	9	15	15	15
Day 4	5	5	6	10	10	10	9	9	9	15	15	15
0.01%												
Start	10	10	10	10	10	11	9	9	9	15	15	15
Day 1	7	8	9	10	10	11	9	9	9	15	15	15
Day 2	6	6	5	10	10	11	9	9	9	15	15	15
Day 3	4	6	4	10	10	11	9	9	9	15	15	15
Day 4	4	5	3	10	10	10	9	9	9	15	15	15
0.1%												
Start	10	10	10	10	10	11	9	9	9	15	15	15
Day 1	8	8	6	10	10	11	9	9	9	15	15	15
Day 2	6	7	6	10	10	11	9	9	9	15	15	15
Day 3	4	5	5	10	10	11	9	9	9	15	15	14
Day 4	4	4	3	9	10	9	8	9	8	15	15	15
1%												
Start	10	10	10	10	10	10	9	9	9	15	15	15
Day 1	8	9	9	10	10	10	9	9	9	15	15	15
Day 2	6	6	8	10	10	10	9	9	9	15	15	15
Day 3	5	5	6	10	10	10	9	9	9	15	15	15
Day 4	4	5	5	10	10	10	9	9	9	15	15	15
10%												
Start	10	10	10	10	10	10	9	9	9	15	15	15
Day 1	6	6	6	10	10	10	9	9	9	15	15	15
Day 2	4	5	0	10	10	10	9	9	9	15	15	15
Day 3	4	5	0	10	10	10	9	9	9	15	15	15
Day 4	5	5	0	9	9	8	9	9	9	15	15	15

Table 26. TITP II Bioassay. Date: 8-12 October 1982

Numbers of Live Organisms per Day and Dilution in 96 Hour Toxicity Test.

	Acanthomysis			Neanthes			Mytilus			Fundulus		
Replicates	1	2	3	1	2	3	1	2	3	1	2	3
Control												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	9	10	15	15	15
Day 2				10	10	10	10	9	10	15	15	15
Day 3				10	10	10	10	9	10	15	15	15
Day 4				10	10	10	10	9	10	15	15	15
0.01%												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	10	8	15	15	15
Day 2				10	10	10	10	10	8	15	15	15
Day 3				10	10	10	10	10	8	15	15	15
Day 4				10	10	9	10	10	8	15	15	15
0.1%												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	10	10	15	15	15
Day 2				10	10	10	10	10	10	15	15	15
Day 3				10	10	10	10	10	10	15	15	15
Day 4				10	9	10	10	10	10	15	15	15
1%												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	11	10	10	9	10	15	15	15
Day 2				10	11	10	10	9	10	15	15	15
Day 3				10	11	10	10	10	10	15	15	15
Day 4				10	9	9	10	10	10	15	15	15
10%												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	10	10	15	15	15
Day 2				10	10	10	10	10	10	15	15	15
Day 3				10	10	10	10	10	10	15	15	15
Day 4				9	8	10	10	10	10	14	15	13

Table 27. TITP III Bioassay. Date: 15-19 October 1982

Numbers of Live Organisms per Day and Dilution in 96 Hour Toxicity Test

	Acanthomysis			Neanthes			Mytilus			Fundulus		
Replicates	1	2	3	1	2	3	1	2	3	1	2	3
<u>Control</u>												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	8	9	9	10	10	10	10	10	10	15	15	15
Day 2	6	7	8	10	10	10	10	10	10	15	15	15
Day 3	6	6	7	10	10	10	10	10	10	15	15	15
Day 4	3	4	5	10	10	10	10	10	10	15	15	15
<u>0.01%</u>												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	8	9	9	10	10	10	10	10	10	15	15	15
Day 2	8	7	7	10	10	10	10	10	10	15	15	15
Day 3	6	6	5	10	10	10	10	10	10	15	14	15
Day 4	6	6	5	10	10	10	10	10	10	15	14	15
<u>0.1%</u>												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	9	9	8	10	10	10	10	10	10	15	15	15
Day 2	8	6	8	10	10	10	10	10	10	15	15	15
Day 3	7	6	6	10	10	10	10	10	10	15	15	15
Day 4	6	4	6	10	10	10	10	10	10	15	15	15
<u>1%</u>												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	9	9	9	10	10	10	10	10	10	15	15	15
Day 2	8	8	7	10	10	10	10	10	10	15	15	15
Day 3	7	7	6	10	10	10	10	10	10	15	15	15
Day 4	6	4	6	10	10	10	10	10	10	15	15	15
<u>10%</u>												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	10	9	9	10	10	10	10	10	10	15	15	15
Day 2	8	6	6	10	10	10	10	10	10	15	15	15
Day 3	5	6	5	10	10	10	10	10	10	15	14	13
Day 4	4	5	5	9	10	10	10	10	10	14	14	11

Table 28. TITP IV Bioassay. Date: 22-26 October 1982.

Numbers of Live Organisms per Day and Dilution in 96 HOur Toxicity Test.

	Acanthomysis			Neanthes			Mytilus			Fundulus		
Replicates	1	2	3	1	2	3	1	2	3	1	2	3
Control												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	9	9	9	10	10	10	9	10	10	15	15	15
Day 2	8	7	7	10	10	10	9	10	10	15	15	15
Day 3	6	7	7	9	10	10	9	10	10	15	15	15
Day 4	4	5	4	9	10	10	9	10	10	15	15	15
0.01%												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	8	8	8	10	10	10	10	10	10	15	15	15
Day 2	8	7	6	10	10	10	10	10	10	15	15	15
Day 3	7	6	6	10	10	10	10	10	10	15	15	15
Day 4	5	5	4	10	10	10	10	10	10	15	15	14
0.1%												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	7	8	8	10	10	10	10	10	10	15	15	15
Day 2	7	5	6	10	10	10	10	10	10	15	15	15
Day 3	5	4	5	9	10	10	10	10	10	15	15	15
Day 4	5	4	2	9	10	9	10	10	10	15	15	15
1%												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	8	8	8	10	10	10	10	10	10	15	15	15
Day 2	7	7	6	10	10	10	10	10	10	15	15	15
Day 3	6	6	5	9	10	10	10	10	10	15	15	15
Day 4	5	6	5	9	10	10	9	10	10	15	15	15
10%												
Start	10	10	10	10	10	10	10	10	10	15	15	15
Day 1	9	7	5	10	9	10	10	10	10	15	15	15
Day 2	6	7	4	9	9	10	10	10	10	15	15	15
Day 3	5	6	2	9	9	9	10	10	10	15	15	15
Day 4	4	6	1	9	9	9	10	10	10	15	15	15

Table 29. TITP V Bioassay. Date: 19-23 November 1982.

Numbers of Live Organisms per Day and Dilutions in 96 Hour Toxicity Test

	Acanthomysis			Neanthes			Mytilus			Fundulus		
Replicates	1	2	3	1	2	3	1	2	3	1	2	3
Control												
Start	Not done			10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	10	10	15	15	15
Day 2				10	10	10	10	10	10	15	15	15
Day 3				10	10	10	10	10	10	15	15	15
Day 4				10	10	10	10	10	10	15	15	15
0.01%												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	10	10	15	15	15
Day 2				10	10	10	10	10	10	15	15	15
Day 3				10	10	10	10	10	10	15	15	15
Day 4				10	10	10	10	10	10	15	15	15
0.1%												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	10	10	15	15	15
Day 2				10	10	10	10	10	10	15	15	15
Day 3				10	10	10	10	10	10	15	15	15
Day 4				10	10	10	10	10	10	15	15	15
1%												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	10	10	15	15	15
Day 2				10	10	10	10	10	10	15	15	15
Day 3				10	10	10	10	10	10	15	15	15
Day 4				10	10	10	10	10	10	15	15	15
10%												
Start				10	10	10	10	10	10	15	15	15
Day 1				10	10	10	10	10	10	13	13	13
Day 2				10	10	9	10	10	10	13	13	13
Day 3				10	10	9	10	10	10	13	13	13
Day 4				10	10	9	10	10	10	13	13	13

Table 30. Average Weight Changes in Grams of Mussels Following 96 Hour Exposure to the Test Conditions.

Concentration	Test				
	I	II	III	IV	V
0.00% (control)	0.16	0.60	0.02	0.20	0.13
0.01%	-0.01	0.51	0.06	0.31	0.13
0.10%	0.16	0.56	0.09	0.16	0.15
1.00%	0.12	0.60	0.07	0.17	0.17
10.00%	0.13	0.62	0.18	0.10	0.24

Table 31. Average Weight Changes in Grams of Mussels Following 24 Day Exposure to the Test Conditions.

Concentration	Test				
	I	II	III	IV	V
0.00% (control)	0.22	0.33	0.11	0.31	0.20
1.00%	0.40	0.95	0.58	0.59	0.53

Table 32. Bioaccumulation of Metals by *Mytilus edulis*, the California bay mussel (Data are mg/kg dry weight; ND = none detected; St.D = standard deviation; Sig. D asterisk = significant difference where p = <.05).

		Cd	Cr	Cu	Hg	Pb	Zn	Ni	Ag	As
Test I										
Control	1	4.9	--	4.1	0.6	8.8	235	ND	0.04	13.7
	2	7.6	--	10.8	0.8	16.7	683	ND	0.03	5.3
	3	4.7	--	4.4	0.8	10.0	288	ND	0.04	13.9
	Aver	5.7	--	6.4	0.7	11.8	402	--	0.04	11.0
	St.D	1.6	--	3.8	0.1	4.3	245	--	0.01	4.9
1%	1	4.9	--	14.0	--	30.0	727	1.4	ND	11.9
	2	3.2	--	5.7	0.8	10.7	350	11.2	ND	--
	3	5.2	--	10.8	0.8	10.8	333	11.8	0.03	--
	Aver	4.4	--	10.2	0.8	17.2	470	8.1	--	--
	St.D	1.1	--	4.2	0.0	11.1	223	5.8	--	--
	Sig.D	--	--	--	--	--	--	--	--	--
Test II										
Control	1	1.6	0.8	--	0.5	5.0	185	3.3	ND	2.7
	2	1.7	0.5	--	0.3	3.7	158	3.4	0.02	6.1
	3	2.5	0.6	--	1.0	7.3	247	3.0	0.03	12.3
	Aver	1.9	0.6	--	0.6	5.3	197	3.2	0.03	7.0
	St.D	0.5	0.2	--	0.4	1.8	46	0.2	0.01	4.9
1%	1	1.9	1.6	--	0.8	5.9	271	3.5	ND	6.1
	2	2.8	1.7	--	0.6	7.1	247	3.9	0.02	4.9
	3	--	--	--	--	--	--	--	--	--
	Aver	2.4	1.7	--	0.7	6.5	259	3.7	--	5.5
	St.D	0.6	0.1	--	0.1	0.8	17	0.3	--	0.8
	Sig.D	--	*	--	--	--	*	--	--	--

Table 32. Cont'd

		Cd	Cr	Cu	Hg	Pb	Zn	Ni	Ag	As
Test III										
Control	1	2.3	0.5	--	0.7	5.0	506	2.7	0.11	10.5
	2	1.9	0.6	--	0.7	3.3	294	1.4	ND	7.4
	3	3.0	0.7	--	0.6	2.6	1342	2.4	0.02	--
	Aver	2.4	0.6	--	0.7	3.6	714	2.2	0.07	9.0
	St.D	0.6	0.1	--	0.1	1.2	554	0.7	0.06	2.2
1%	1	2.2	0.8	--	0.6	3.8	452	1.5	0.01	9.6
	2	3.0	0.9	--	0.8	6.5	294	2.7	0.04	8.3
	3	2.0	0.5	--	0.9	3.5	400	1.3	0.02	13.6
	Aver	2.4	0.7	--	0.8	4.6	382	1.8	0.02	10.5
	St.D	0.5	0.2	--	0.2	1.7	81	0.8	0.02	2.8
	Sig.D	--	--	--	--	--	--	--	--	--
Test IV										
Control	1	4.7	2.0	6.3	0.8	5.0	363	3.5	0.51	3.4
	2	6.2	1.9	8.5	0.9	5.4	692	2.3	ND	11.8
	3	--	--	--	--	--	--	--	--	--
	Aver	5.5	2.0	7.4	0.9	5.2	528	2.9	--	7.6
	St.D	1.1	0.1	1.6	0.1	0.3	233	0.8	--	5.9
1%	1	4.1	1.7	3.5	0.4	2.9	218	3.4	0.04	--
	2	5.5	2.5	5.0	0.8	3.8	176	2.3	0.05	4.3
	3	5.9	2.1	4.3	0.8	4.3	264	1.2	0.05	10.4
	Aver	5.2	2.1	4.3	0.7	3.7	219	2.3	0.05	7.4
	St.D	0.9	0.4	0.8	0.2	0.7	44	1.1	0.01	4.3
	Sig.D	--	--	--	--	*	*	--	--	--

Table 32. Cont'd

		Cd	Cr	CU	Hg	Pb	Zn	Ni	Ag	As
Test V										
Control	1	6.4	0.8	--	--	14.2	571	4.9	ND	10.9
	2	3.8	1.0	--	--	12.3	682	4.8	ND	15.2
	3	6.3	0.4	--	--	17.3	942	30.6	0.08	12.8
	Aver	5.5	0.7	--	--	14.6	731	13.4	--	13.0
	St.D	1.5	0.3	--	--	2.5	190	14.9	--	2.2
1%	1	3.8	0.8	--	--	9.6	494	17.6	0.09	--
	2	4.1	1.0	--	--	7.9	409	4.9	ND	4.2
	3	--	--	--	--	--	--	--	--	--
Aver		4.0	0.9	--	--	8.8	452	11.3	--	--
St.D		0.2	0.1	--	--	1.2	60	9.0	--	--
Sig.D		--	--	--	--	*	*	--	--	--

Table 33. Bioaccumulation of Metals by Fundulus parvipinnis, the California killifish. Data are mg/kg dry weight.

	Cd	Cr	Cu	Hg	Pb	Zn	Ni	Ag	As
Test I									
Control	--	--	--	--	--	--	--	--	--
1%	0.1	--	8.7	0.1	13.0	143	--	0.04	1.8
Test II									
Control	0.5	ND	--	0.2	1.1	184	4.5	0.04	3.1
1%	0.5	ND	--	0.2	1.0	180	2.0	0.04	5.5
Test III									
Control	0.5	0.5	--	0.2	0.8	146	2.7	0.04	5.7
1%	0.6	0.4	--	0.2	0.9	136	7.6	0.06	1.5
Test IV									
Control	1.0	1.6	7.9	0.2	1.3	158	4.6	0.04	1.0
1%	0.7	0.9	6.8	0.1	0.9	164	5.4	0.04	3.9
Test V									
Control	0.2	ND	--	0.2	1.4	144	5.1	0.04	7.2
1%	0.9	0.4	13.0	0.1	5.3	91	8.0	0.80	1.9

TABLE 34. BIOACCUMULATION OF CHLORINATED HYDROCARBONS BY MYTILUS EDULIS, THE CALIFORNIA BAY MUSSEL. (DATA ARE MG/KG DRY WEIGHT; ND = NONE DETECTED ST.D = STANDARD DEVIATION; SIG.D ASTERISK INDICATES SIGNIFICANT DIFFERENCE WHERE P = <0.05).

		PESTICIDES						TOTALS		
		pp' DDD	op' DDE	pp' DDE	op' DDT	pp' DDT	Dieldrin	Pesti-cides	PCB (AR 1254)	Ident.Chlor Hydrocarbon
Test I										
Control	1	16	120	313	28	ND	83	572	1360	1930
	2	27	39	162	28	ND	66	322	1110	1430
	3	ND	110	286	28	ND	93	538	1600	2140
	Aver	22	90	254	28	ND	81	477	1357	1830
	St.D	8	44	81	0	ND	14	136	245	365
1%	1	40	60	226	41	23	73	463	1595	2060
	2	ND	92	308	ND	ND	76	476	1090	1570
	3	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Aver	--	76	267	--	--	75	470	1343	1815
	St.D	--	23	58	--	--	2	9	357	346
Test II										
Control	1	12	44	520	30	ND	41	647	2160	2810
	2	18	14	112	26	ND	ND	170	1160	1330
	3	26	51	180	36	ND	69	362	1400	1760
	Aver	19	36	271	31	ND	55	393	1573	1967
	St.D	7	20	219	5	ND	20	240	522	761
1%	1	16	28	120	32	ND	ND	196	1265	1460
	2	--	--	--	--	--	--	--	--	--
	3	17	14	356	30	ND	ND	422	996	1420
	Aver	17	21	238	31	--	--	309	1131	1440
	St.D	1	10	167	1	--	--	160	190	28

Table 34. Cont'd

		PESTICIDES						TOTALS		
		pp' DDD	pp' DDE	pp' DDE	op' DDT	pp' DDT	Dieldrin	Pesti- cides	PCB (AR 1254)	Ident.Chlor Hydrocarbon
Test III										
Control	1	8	41	111	20	ND	27	207	802	1010
	2	18	40	111	20	ND	21	232	1174	1410
	3	15	21	99	35	ND	16	186	1158	1340
	Aver	14	34	111	28	--	21	208	1045	1253
	St.D	5	11	13	8	--	6	23	210	214
1%	1									
	2	31	ND	66	36	ND	31	164	1090	1250
	3	45	ND	46	21	ND	43	155	1770	1930
	Aver	38		56	29		160	1430	1590	
	St.D	10		14	11		8	6	481	481
Test IV										
Control	1	--	--	--	--	--	--	--	--	--
	2	31	ND	66	36	ND	31	164	1090	1250
	3	45	ND	46	21	ND	43	155	1770	1930
	Aver	38	--	56	29	--	37	160	1430	1590
	St.D	10	--	14	11	--	7	6	481	481
1%	1	26	39	102	51	ND	25	243	1150	1390
	2	44	23	84	44	ND	18	213	1050	1260
	3	59	24	120	33	ND	20	256	1810	2070
	Aver	43	29	102	43	--	21	237	1337	1573
	St.D	17	9	18	9	--	4	22	413	435
	Sig.D	--	--	*	--	--	*	*	--	--

Table 34. Cont'd

		pp' DDD	op' DDE	pp' DDE	op' DDT	PP' DDT	Dieldrin	Pesti-cides	PCB (AR 1254)	Ident.Chlor Hydrocarbon
Test V										
Control	1	ND	52	178	48	ND	32	310	1565	1880
	2	ND	45	165	26	ND	17	253	1355	1610
	3	ND	31	171	36	ND	14	252	1647	1900
	Aver	--	43	171	37	--	21	272	1522	1797
	St.D	--	11	7	11	--	10	33	151	162
1%	1	37	19	155	69	ND	38	318	1535	1850
	2	30	28	173	54	ND	26	311	1468	1780
	3	--	--	--	--	--	--	--	--	--
	Aver	34	24	164	62	--	32	315	1502	1815
	St.D	5	6	13	11	--	8	5	47	49
	Sig.D	--	*	--	*	--	--	*	--	--

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