ATTACHMENT 22

Final

South Bay Power Plant Receiving Water Monitoring Program with Emphasis on the Benthic Invertebrate Community (1977-1994)

Prepared for

San Diego Gas and Electric Company
San Diego, California

Prepared by

EA Engineering, Science, and Technology
Newburgh, New York
(914) 565-8100

April 1995

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Prepared for

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April 1995

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1. INTRODUCTION

This receiving water monitoring program began in 1977 by requirement of Addendum No. 1 to the San Diego Regional Water Quality Control Board Monitoring and Reporting Program Order No. 76-10 (National Pollutant Discharge Elimination System [NPDES] CA 0001368); and has continued since 1985 as set forth by Paragraph G of Order No. 85-09. It was designed to monitor the condition of the benthic infauna and selected physical/chemical parameters of the sediments and water column in South San Diego Bay during the summer (August-September) at yearly intervals relative to the influence of the thermal discharge from the South Bay Power Plant (SBPP).

The SBPP is located on the southeastern shore of San Diego Bay (back bay region), at an approximate latitude of 32°36' north and 117°06' west, respectively (Figure 1-1). San Diego Gas and Electric Company (SDG&E) began operation of the South Bay fossil-fueled electric generation facility in 1960 with one generating unit. Additional units became operational in 1962, 1964, and 1971:

Unit	Generating Capacity (kW)	Commercial Start-Up	Cooling Water Flow (MGD)
1	147,000	JUL 1960	112.3
2	150,000	JUN 1962	112.3
3	171,000	SEP 1964	179.4
4	222,000	DEC 1971	197.0

Each generating unit draws water for condenser cooling from the Bay and returns the thermally elevated water back to the Bay via a discharge cooling channel. This discharge cooling channel is separated from the Bay by an earthen dike (Figure 1-2).

The areal extent of the thermal plume is dependent primarily on the rate of discharge of cooling water, and the phase of tidal cycles. Prior to the addition of Unit 4 in 1971, the maximum identified extent of the thermal plume was confined to a distance of approximately 1,500-2,000 yd northward from the end of the cooling channel (Ford and Chambers 1973; Marine Advisers 1968). After 1971, the maximum extent of the thermal plume into the Bay with four units operating increased to 3,000 yd (Figure 1-3) from the outer end of the cooling channel (Ford and Chambers 1973). The maximum northward extent of the thermal plume occurs at the end of the ebb tides (Figure 1-3). During flood tides, the thermal plume is confined to a smaller area at the end of the Bay (Figure 1-4). During most of the 1980s and up to the present time, operation of Unit 4 has been limited to occasional periods of peak demand such that typical operation has consisted of three or two units. The smaller extent of the thermal plume up the Bay with 2 units operating at the beginning of a flood tide is shown in Figure 1-5.

1.1 DESCRIPTION OF THE STUDY AREA

San Diego Bay is the largest semi-enclosed marine embayment located along the 900-mi stretch of coast between San Francisco Bay to the north and Scammon's Lagoon, in central Baja California, to the south. It is located approximately 5 mi north of the United States and Mexico boundary (Michael Brandman Associates, Inc. 1990). The Bay is bounded by the cities of San Diego, Coronado, National City, Chula Vista, and Imperial Beach (Figure 1-1).

San Diego Bay is a natural, crescent-shaped estuary. It is approximately 14 mi long and 2.5 mi across at its widest point. The width of the Bay varies from 1,600 to 14,000 ft (Michael Brandman Associates, Inc. 1990; SDG&E 1980). At half-tide level, the surface area of San Diego Bay is estimated to be approximately 18 mi^2 and the water volume to be about 300 million yd^3 (USACE 1974, in Michael Brandman Associates, Inc. 1990).

In San Diego Bay, both water depth and tidal velocities are greatest at the Bay inlet from the ocean, Point Loma, and decrease along a north to south gradient. As a result, there is also a north to south gradient in grain size of bottom sediment ranging from predominantly sand at the mouth of the Bay to predominantly silt and clay at the south end of the Bay.

The shallow south back bay region is a deposition area for silt and clay sized particles and has depths of undisturbed areas ranging from 1 to 8 ft and dredged channels from 8 to 20 ft (SDG&E 1980). The tidal velocities are low (<0.1 m/second) and generally circulate clockwise (SDG&E 1980). The Otay and Sweetwater rivers seldom deliver appreciable freshwater flow to the South San Diego Bay, except following major storms which occur mostly during fall and winter seasons. During a rare period of extraordinary heavy rainfall, salinity has been reduced to 31 parts per thousand (ppt) (Michael Brandman Associates, Inc. 1990). However, because of limited circulation, solar heating, and a high surface to volume ratio that enhances evaporation, salinity, and water temperature in the South back bay region is usually somewhat higher than in more northern portions of San Diego Bay. Salinity in the back bay area, generally approximately 1-2 ppt higher than northern portions, may exceed 36 ppt during the summer (LCMR 1977, 1978, 1979a; LES 1980a; Michael Brandman Associates, Inc. 1990). In July 1950, before the SBPP existed, the gradient in water temperature from the inlet to San Diego Bay at Point Loma (66°F) to the South Back Bay area (75°F) amounted to approximately 9°F (Marine Advisers 1961).

The combined effects of low tidal velocity and wind-driven short, choppy waves are almost always sufficient to thoroughly mix the shallow waters of the South Bay from top to bottom, thereby resulting in a gradient of increasing turbidity from resuspension of fine sediment off the bottom and nearly uniform water temperature, salinity, and dissolved oxygen from surface to bottom.

Like many coastal waterbodies of the United States, San Diego Bay during the Nineteenth Century and early decades of the Twentieth Century experienced substantial alteration of shoreline habitats by dredge/fill and construction projects; and, water quality and the biological community of the Bay were grossly degraded by excessive loadings of pollutants from municipal and industrial waste discharges and stormwater runoff (Michael Brandman Associates, Inc. 1990). Marine Advisers (1958) described an extensive layer of sewage sludge on the bottom of the middle and south portions of the Bay. This was accompanied by excessive algae blooms which reduced Secchi disk transparency of the water to about 1 ft; dissolved oxygen levels were reduced to less than 4 parts per million (ppm), and the benthic invertebrate community was reduced to only a few pollution tolerant species.

The area encompassed by this long-term receiving water monitoring study is the subtidal zone at mean low water in the back bay area located southeast of an imaginary line between Crown Cove and the mouth of the Sweetwater River drainage basin (Figure 1-2). Sewage treatment and diversion of sewage sludge away from the Bay was accomplished by 1963 (Michael Brandman Associates, Inc. 1990). Since that time, much of the bottom of this area has become populated by abundant attached growths of a colonial animal, the bryozoan *Zoobotryon verticillatum*, interspersed with patches of sea lettuce (*Ulva* spp.), red algae (*Gracilaria verrucosa*), and occasional beds of eel grass (*Zostera marina*) (Ford 1968; LCMR 1979a). The distribution of *Zoobotryon verticillatum* in the south end of the Bay is shown on Figure 1-6. *Zoobotryon* are very efficient at filtering plankton and suspended detritus from the water for food. The algae and seagrass provide food for bottom invertebrates (benthos) and other consumers such as water fowl and sea turtles; this entire assemblage of bottom growth increases the diversity of habitats for benthic invertebrate fauna and small fishes.

Additional and more detailed descriptions of San Diego Bay and the study area are provided in Appendix A and in Michael Brandman Associates, Inc. (1990).

1.2 RESULTS OF PREVIOUS STUDIES

Ford (1968) conducted studies prior to commercial startup of Unit 4 at the SBPP which were designed to, among other objectives, characterize the distribution, abundance, and feeding relationships of resident marine life including benthic infauna, benthic and pelagic fish, aquatic and other birds, periphytic diatom populations, and plankton populations; assess the biological effects of the thermal discharge using indicator organisms; and establish standard methods to determine the effects of thermal discharge on marine organisms during later studies in the area. Based on data collected from 28 sampling stations located throughout the south end of the Bay, Ford (1968) observed that, very striking changes had occurred following pollution abatement including: disappearance of former extensive sewage sludge deposits, and a major increase in the variety and biomass of benthic faunal components. Ford (1968) concluded the following:

- South San Diego Bay supported assemblages of marine organisms that are characteristic of the inner portions of relatively undisturbed bays and estuaries in California and Baja California. Ecologically similar forms inhabit bays and estuaries in other temperate areas of the world.

- In general, the forms found in the South Bay are tolerant of moderately wide ranges of temperature, salinity, and dissolved oxygen content and thus are able to survive seasonal and short term changes in these factors that occur there.

- High summer (July-August) bottom temperatures within the cooling water discharge channel (Figure 1-2) have a significant effect in depressing benthic invertebrate species diversity and number of species; however, beyond the end of the channel, species diversity and abundance was not significantly affected, and, in fact, appeared to be enhanced somewhat as compared with locations remote from the discharge pattern.

Based on the results of sampling of a broader cross-section of the food web of the South Bay area, Ford (1968) concluded that the community of benthic plants and invertebrates, "...was the best and most easily evaluated when studying the thermal effects of the discharge...." Subsequent studies were limited to these two segments of the food chain (LCMR 1977). The importance of the benthic plant community in the marine food web of South Bay is described by Ford (1968) as follows:

> Direct observations underwater indicated that these algal mats are an important microhabitat feature, because they provide cover and refuge from predators for many species or fishes and invertebrates, much as marsh vegetation does for ducks and other aquatic birds. The algae also serve as a major, primary food source for many animals, including the California killifish, crabs, isopods, gastropod molluscs, and some aquatic birds.

Ford (1968) also went on to discuss the important link in the food web filled by the benthic invertebrate community:

> The invertebrate fauna living on and in the bottom sediment is dominated in terms of species composition, abundance, and biomass by molluscs and polychaete worms, as it is in San Diego Bay as a whole (Marine Advisers 1958). Several species of the common bivalve molluscs are used as food by man...other small bivalves are used commonly as bait for hook and line fishing.
>
> While none of the other invertebrates are of direct value to man, they are extremely important to the biological economy of the area...The feeding of nematode and polychaete worms, gastropod molluscs, brittlestars, crabs, isopods, and a wide variety of smaller crustaceans serves to transform detritus and other organic material into usable food for larger invertebrates and fishes; the latter, in turn, are eaten by other large fishes and aquatic birds, most of which are of esthetics or direct food value to man. Bivalve molluscs and other suspension feeders serve a similar function in transforming plankton and suspended detrital material into usable food for fishes and birds.

Based on a continuation of sampling at 11 sampling stations, Ford et al. (1970, 1971) again observed lower diversity and abundance of benthic invertebrates in the cooling water discharge channel, particularly within 600-1,300 yd of the plant. Additional sampling a few weeks after startup of SBPP Unit 4 in 1971 suggested that the increased discharge had little or no incremental adverse effect when compared with results of the 1968 and 1970 late summer studies.

Based on sampling of 18 subtidal and 7 intertidal stations during each of four seasons in 1972-1973, Ford and Chambers (1973) concluded that: benthic plant and invertebrate communities remained stable throughout the year, albeit there were some seasonal changes. Reduced diversity and abundance of benthic organisms within the cooling water discharge channel were again attributed to high temperatures in late summer. Somewhat lower overall diversity and reduced abundance of certain species in a portion of the outer discharge area were regarded as local and minor.

This long-term receiving water monitoring study began in 1977 as a condition of SDG&E's National Pollution Discharge Permit for the SBPP. This study is being conducted annually in compliance with specifications set forth by the California Regional Water Quality Control Permit No. CA001368-San Diego Region. The purpose of this study is to monitor any effects of the thermal effluent discharged from the SBPP on the benthic infauna of South San Diego Bay. This study involves sampling of benthic invertebrates and an array of physical and chemical parameters at 11 subtidal stations. The locations of the sampling stations are similar in position to stations sampled during previous studies (Ford and Chambers 1973). The sampling program is designed to: allow representative sampling of the area most influenced by the discharge (the cooling water discharge channel), an area away from the initial impact of the discharge but within the elevated temperature field, and an area judged to be outside the influence of the discharge. Since 1977, SDG&E has submitted annual reports to the California RWQCB, San Diego Region, as follows:

Year of Study	Contractor
1977	Lockheed Center for Marine Research
1978	Lockheed Center for Marine Research
1979	Lockheed Center for Marine Research
1980	Lockheed Environmental Sciences
1981	Lockheed Ocean Science Laboratories
1982	Woodward-Clyde Consultants
1983	Woodward-Clyde Consultants
1984	WESTEC Services, Inc.
1985	CH_2M Hill
1986	Kinnetic Laboratories, Inc.
1987	Kinnetic Laboratories, Inc.
1988	Kinnetic Laboratories, Inc.
1989	Kinnetic Laboratories, Inc.
1990	Kinnetic Laboratories, Inc.
1991	Kinnetic Laboratories, Inc.
1992	Columbia Aquatic Sciences
1993	Kinnetic Laboratories, Inc.
1994	Columbia Aquatic Sciences

The purpose of those annual reports has been to report and briefly describe the monitoring data collected each year.

1.3 PURPOSE OF THE PRESENT 18-YEAR REPORT

The primary purposes of this 18-year report are to:

- Provide an assessment of the environmental effects of the SBPP cooling water discharge with emphasis on analyses of long-term trends in water quality, sediment characteristics and bottom dwelling macro-invertebrates (benthos)

- Compare the results and conclusions from analyses of this 18-year database with those from previous studies by others of San Diego Bay and similar waterbodies.

1.4 ORGANIZATION OF THIS REPORT

Sections 2.1, 2.2, and 2.3, respectively, provide descriptions of the sample station location design, physical/chemical sampling methods, and benthic sampling and analyses methods. Section 2.4 provides a description of the data set used for the analyses. Section 2.5 provides the analytical methods for evaluation of trends in abiotic factors and the benthic community. Section 3.1 discusses the operational history of SBPP and studies conducted regarding measurement of the thermal plume. Sections 3.2 and 3.3 provide a brief synopsis of the findings of the 1977-1994 annual reports and the spatial and temporal variation in the water column and sediment, respectively, for the 18 years of study. These topics are discussed with respect to the benthic infauna in Sections 3.4 and 3.5. Section 3.6 provides an assessment of the factors affecting the density and abundance of the benthic community including the effects of plant operation. Section 4 provides an overall integrated discussion of the results.

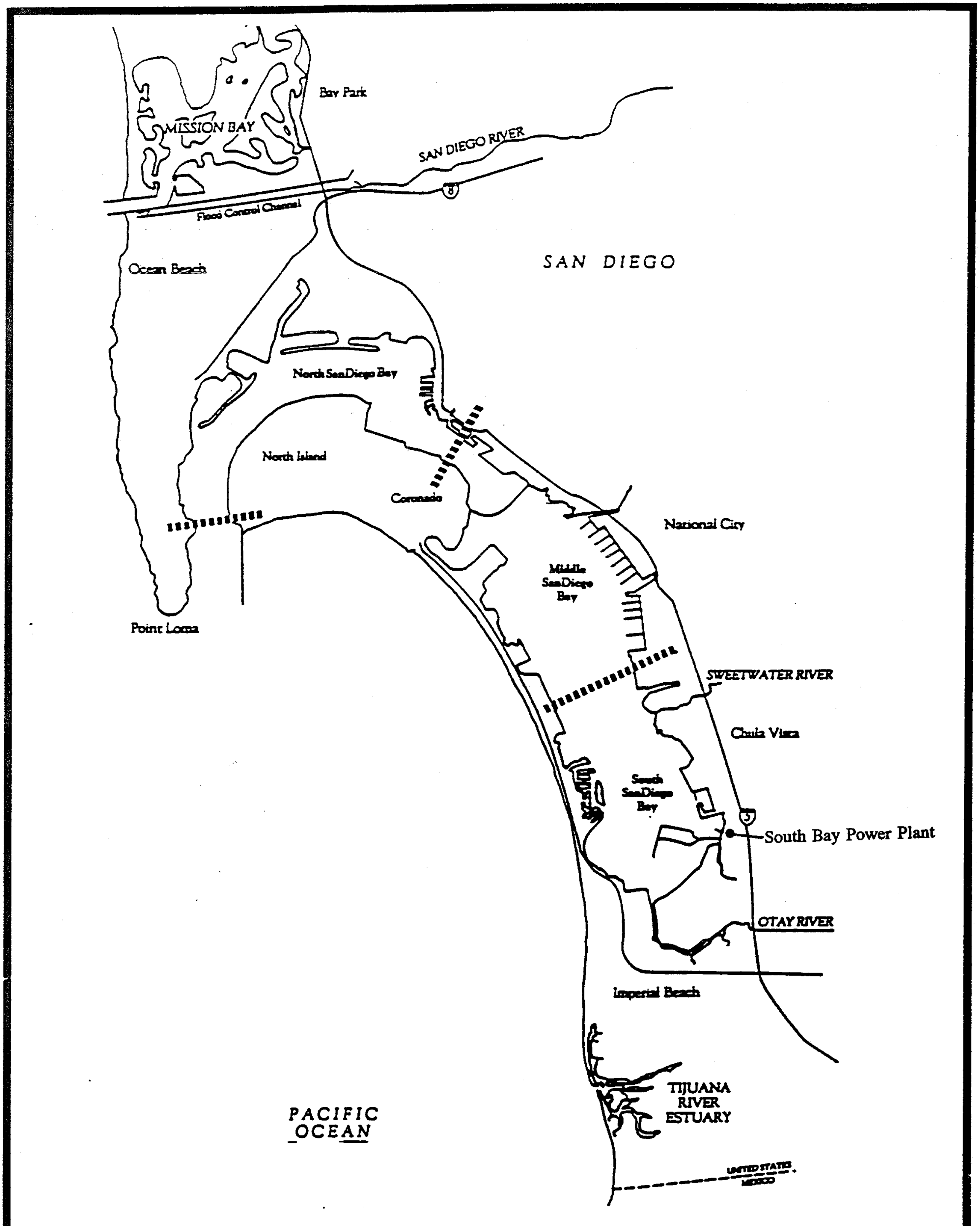


Figure 1-1. General location map of San Diego Bay and the South Bay Power Plant (Ford 1994).

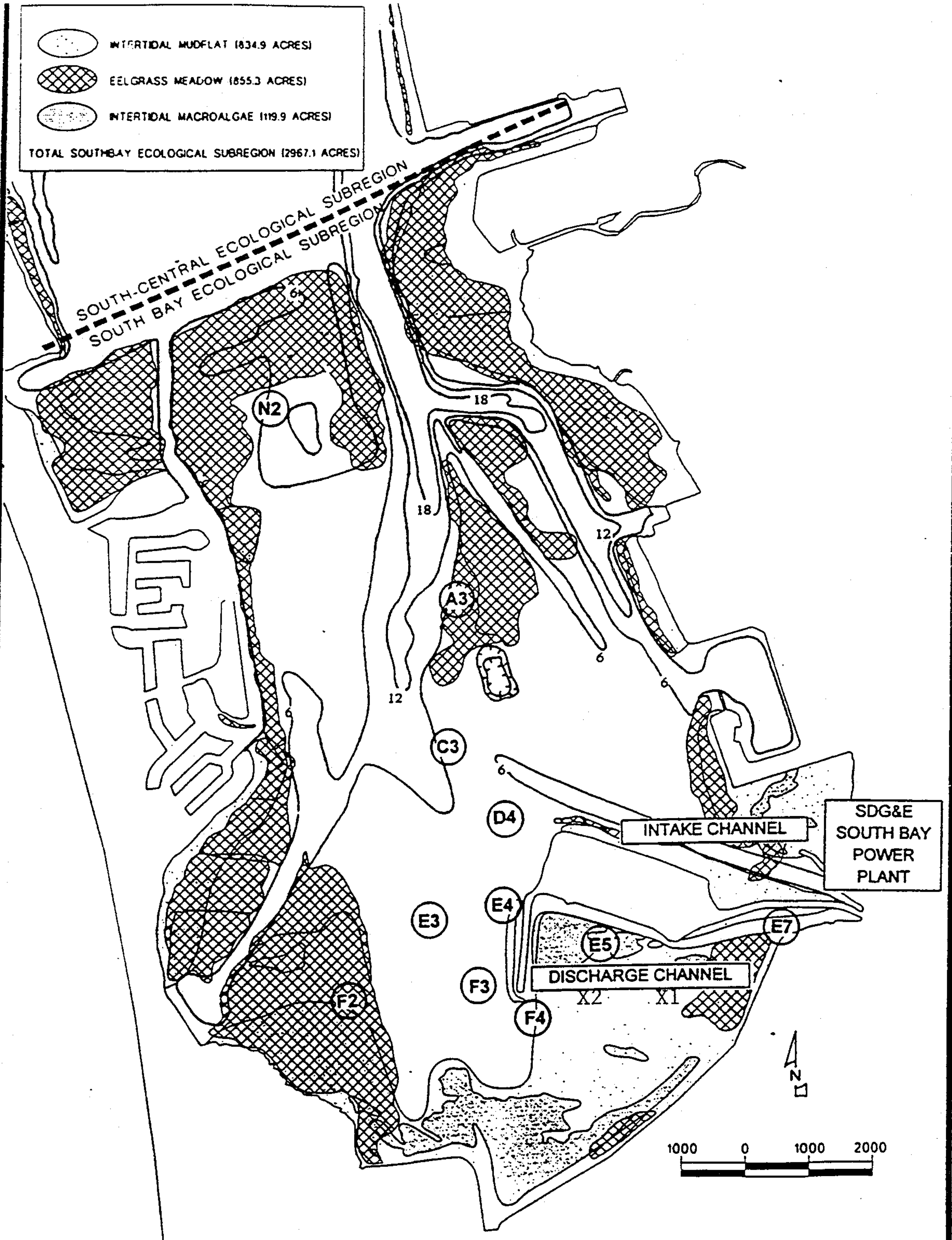


Figure 1-2. South San Diego Bay Study Area distribution of benthic sampling stations.

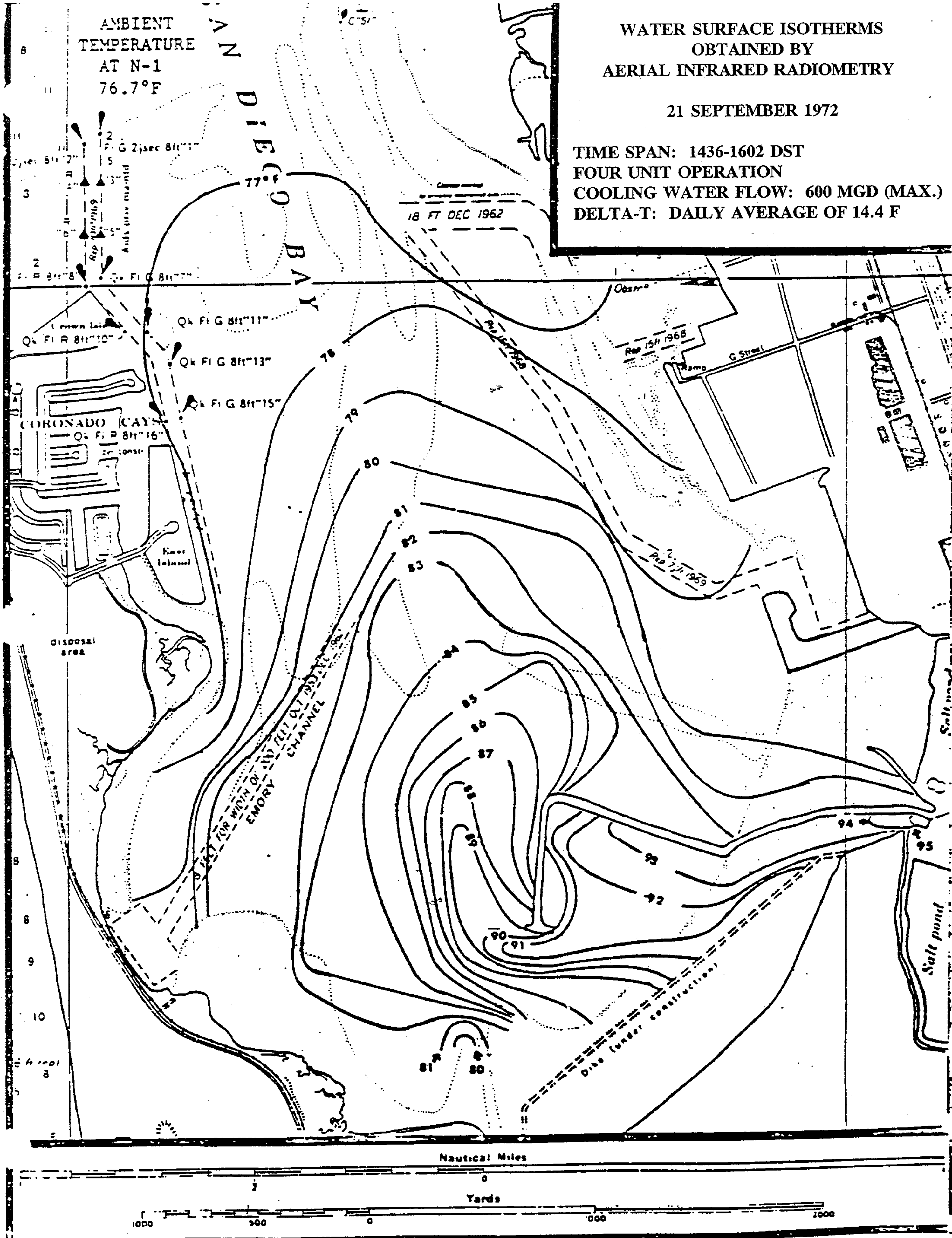
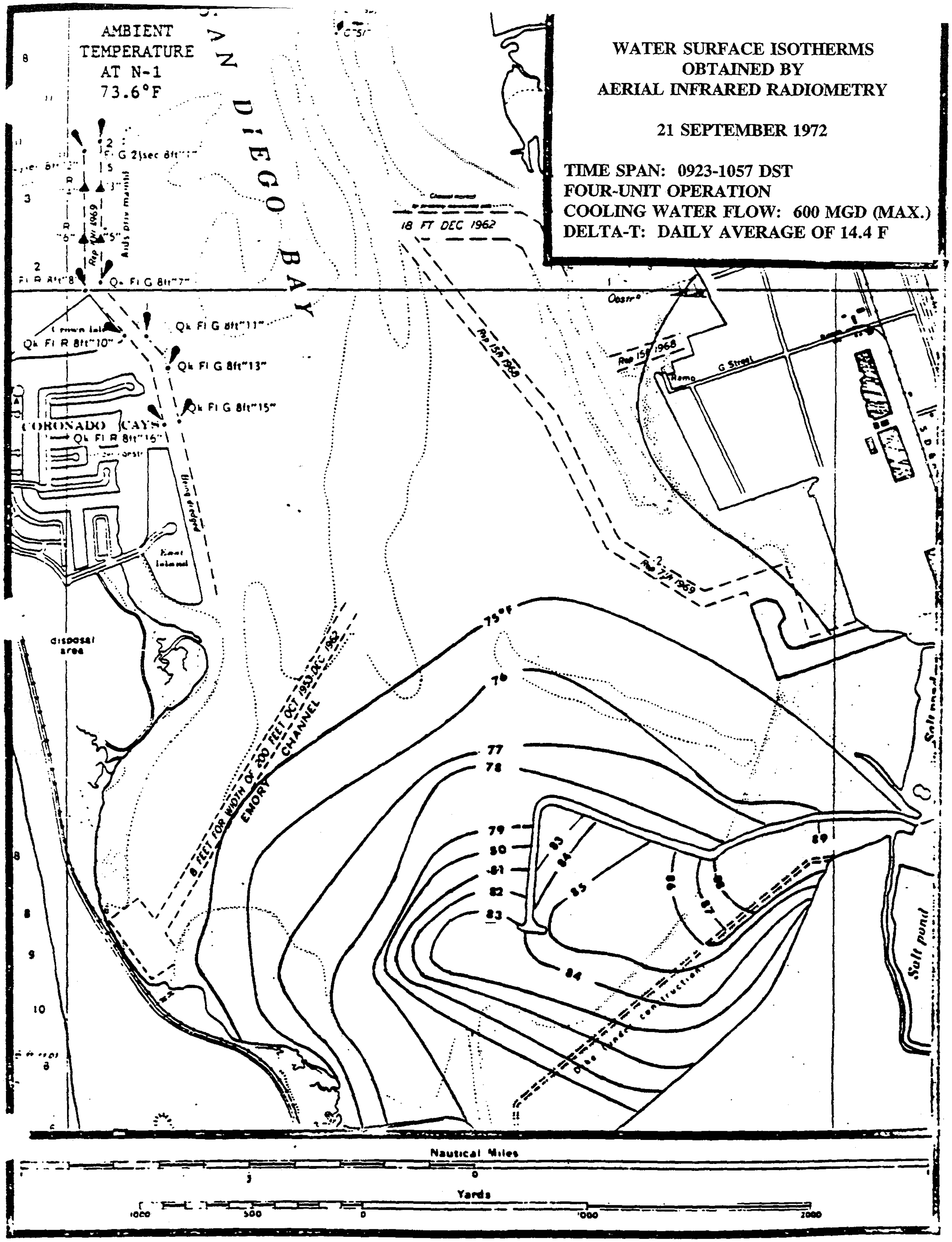

WATER SURFACE ISOTHERMS
OBTAINED BY
AERIAL INFRARED RADIOMETRY
21 SEPTEMBER 1972
TIME SPAN: 1436-1602 DST
FOUR UNIT OPERATION
COOLING WATER FLOW: 600 MGD (MAX.)
DELTA-T: DAILY AVERAGE OF 14.4 F
AMBIENT
TEMPERATURE
AT N-1
76.7°F
SAN DIEGO BAY
77° F
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
81
80
18 FT DEC 1962
EMORY CHANNEL
CORONADO CAYS
disposal
area
G Street
Salt pond
Dike (under construction)
Nautical Miles
Yards
1000
500
0
1000
2000

Figure 1-3



WATER SURFACE ISOTHERMS
OBTAINED BY
AERIAL INFRARED RADIOMETRY
21 SEPTEMBER 1972
TIME SPAN: 0923-1057 DST
FOUR-UNIT OPERATION
COOLING WATER FLOW: 600 MGD (MAX.)
DELTA-T: DAILY AVERAGE OF 14.4 F
AMBIENT TEMPERATURE AT N-1 73.6°F
SAN DIEGO BAY
CORONADO CAYS
EMORY CHANNEL
8 FEET FOR WIDTH OF 200 FEET OCT 1953-DEC 1962
18 FT DEC 1962
G Street
Salt pond
disposal area
75°F
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Nautical Miles
Yards

Figure 1-4

Figure 1-5. Water surface temperature in South San Diego Bay, 11:00 a.m., 26 September 1963 (two units operating).

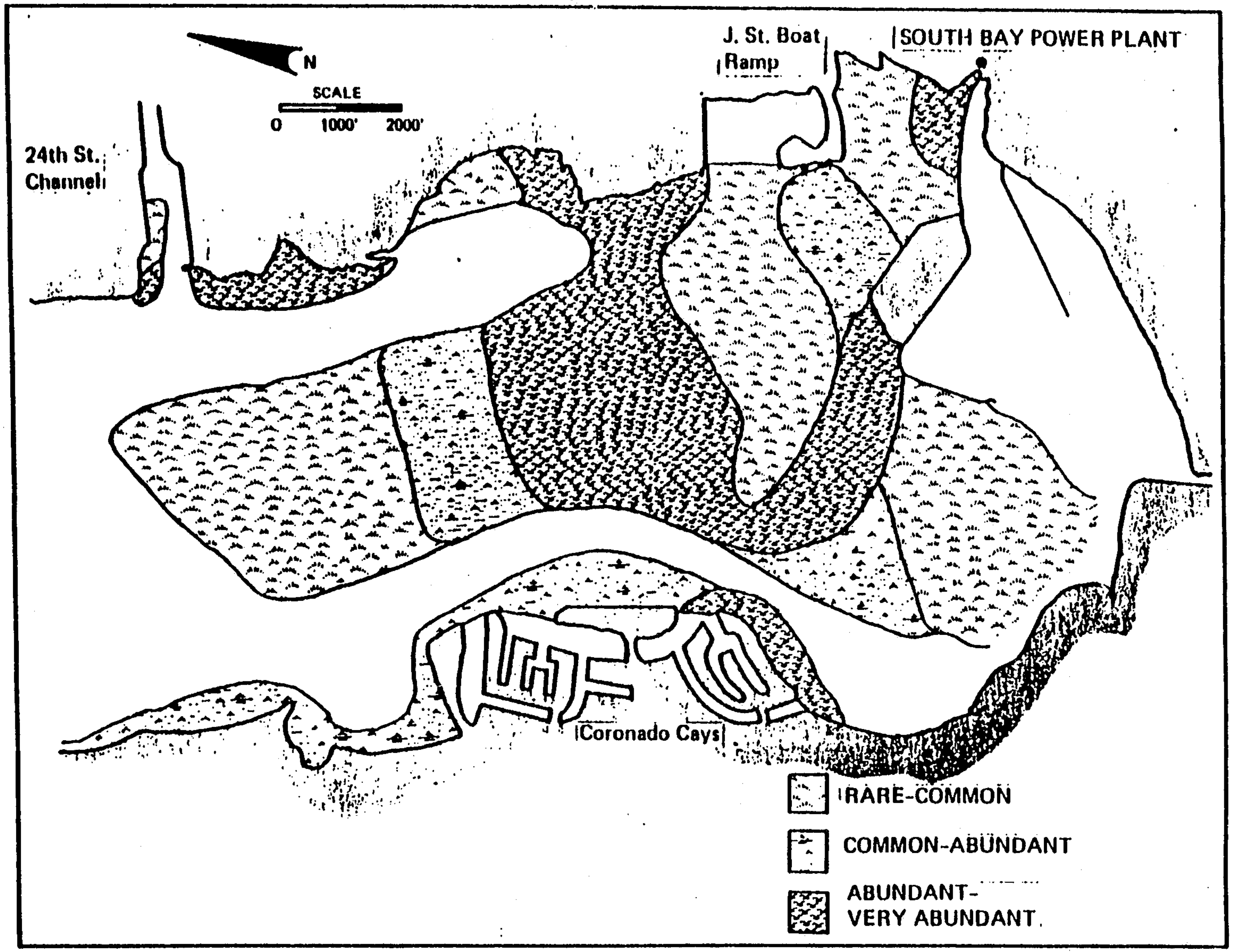


Figure 1-6. Relative abundance of *Zoobotryon verticillatum* determined by otter trawl and diver reconnaissance transect observations, South San Diego Bay, September 1979 (LCMR 1979b).

2. METHODS

The requirements for the monitoring program did not change during the 18-year period (1977-1994). Methods employed for the study remained generally similar, but some changes did occur as improved methods became available and as a result of changes in contractors from time to time over the 18 years. These methods are briefly summarized in this section, with more details in Appendix B.

2.1 MONITORING PROGRAM SAMPLE DESIGN

This monitoring program was designed to provide representative sampling along the entire gradient of water temperatures from near the cooling water discharge (Station E7) to Control Station N2 (Figure 1-2). Eleven benthic grab stations were sampled. These stations were located at positions sampled during previous studies (Ford and Chambers 1973).

Three of the stations (E7, E5, and F4) span the length of the cooling channel, the area most influenced by the discharge; five of the stations (F2, F3, E3, E4, and D4) are located in the near-field plume area exposed to an intermediate range of elevated temperatures; Stations C3 and A3 span the area of the far-field plume occupied by low elevated temperatures, mostly during ebb tide conditions; and Station N2 is located beyond any appreciable influence of the plume.

This is intended to be a summer monitoring program. Accordingly, sampling was conducted during the month of August in all years but 1982, which was sampled on 30 September.

2.2 MONITORING PROGRAM FIELD SAMPLING METHODS

In the early years of the program, sample stations were located by use of transit and sextant coordinates, use of hand held sighting compass, and visual observation of permanent shore landmarks. Electronic positioning by Loran and standard GPS has been added in more recent years. The accuracy of these methods is usually ±50 ft. Since sampling stations are meant to represent the general area of their locations, such methods are adequate and consistent with general practice.

Physical and chemical water column measurements at each station included temperature and salinity at 2-ft intervals from surface to bottom; dissolved oxygen at 2 ft below the surface and 2 ft above the bottom; and transparency was recorded as the depth at which a Secchi disk could not be visually distinguished (Secchi disk extinction depth [m]). Water temperature and salinity were measured using electronic profiling equipment. In the early years, water samples were collected with a Van Dorn bottle for dissolved oxygen determination by standard titration method. More recently, dissolved oxygen has been measured by electronic profiling instruments. These water column measurements were taken before the benthic grab samples to avoid the effects of any bottom disturbance that might occur.

Three replicate benthic samples were collected at each station. A chain-rigged Van Dorn grab with a surface area of 0.1 m^2 was used in 15 of the 18 years; a 0.1 m^2 Smith McIntyre grab was used 2 years (1983 and 1984); and a 0.025 m^2 Ponar grab was used in 1985. The sediment temperature of each replicate was measured immediately after sample retrieval by thermometer at 2 cm below the surface. A subsample from each replicate was collected with a small coring device and preserved for later grain-size and chemical analyses. The remaining portion of each sample was screened in the field through a 0.5 mm mesh nytex screen to remove the benthic organisms. The screened organisms and remaining debris from each replicate were placed in containers and preserved in 10 percent buffered seawater formalin, labeled, and returned to the laboratory.

2.3 MONITORING PROGRAM LABORATORY ANALYSES METHODS

Sediment samples returned to the laboratory were analyzed for grain-size composition, chemical oxygen demand (COD), and total kjeldahl nitrogen (TKN). Sediment percent dry weight/grain-size (percent gravel, sand, silt, and clay) were determined by standard (ASTM 1967) modified hydrometer or USGS sieve categorization and gravimetric analysis. COD and TKN analyses were performed by modified wastewater and seawater techniques (APHA et al. 1975; Strickland and Parsons 1968) or EPA Methods 351.3 and 410.1, respectively.

Organisms from 1/8 or 1/4 splits of each replicate sample were sorted into taxonomic groups. After blotting to remove excess water, organisms were weighed to the nearest 0.01 g. Specimens were identified to species, where practical, and enumerated. All weights (biomass) and counts were converted by calculation to abundance per 0.1 m^2.

2.4 PRESENT 18-YEAR REPORT DATA COMPILATION AND STANDARDIZATION

All data collected from the monitoring study were available in tabular form in a series of 18 annual reports over the period 1977 through 1994. In addition, over the years, the data were stored in several different media, including computer cards, computer magnetic tape, computer discs, repro-quality hard copy, and computer-generated hard copy. There were expected discrepancies in taxonomic identification of organisms among the annual databases because of changes in taxonomic status with passage of time and involvement of scientists from different contractors. Those discrepancies needed to be resolved. In addition, there was need to add certain SBPP operation data (i.e., generation loading and intake and discharge data) and rainfall data to the database. In 1994, SDG&E contracted with Ogden Environmental and Energy Sciences (Ogden) to perform all of those data related tasks in order to generate an updated master database for the study years 1977 through 1993.

This master database was to contain all replicate data for each station and year for the physical and chemical measurements of the sediments and water as well as the mean densities of benthic organisms by species and total biomass by major taxonomic group across all three replicates at each station in each year.

Ogden's approach to standardization of this multiyear dataset with respect to taxonomic classifications was as follows.

First, a Master Distribution Table was prepared that encompassed all species for all stations for all years. The species and densities were those reported in each of the 18 separate annual reports. Second, was the consolidation of species based on spelling differences, questionable specific determinations, and name changes that occurred during the 18-year period. Where there may have been uncertainty in the most recently accepted name, the name most familiar to Ogden's specialist was selected. Examples of these species consolidations are shown below:

Species Name Reported (Year)	Final Species Name
Errano lagunae (1993)	*Lumbrineris lagunae*
Adula diegensis (1977-1981)	*Musculista senhousia*
Eteone lighti (?)	*Eteone lighti*

Third, species that are not infaunal (living in the sediment) were eliminated from the dataset as they are not properly sampled by the techniques used and, if left in the dataset, would be detrimental to the analyses. Examples of these species are *Crucibulum spinosm* and *Crepipatella* (attached to shell debris and rocks), and *Caprella* (associated with the algae).

Fourth, the distribution of species through time was evaluated to see if distributions of taxonomically similar species were complementary through time. Where this was obvious, particularly where the changes coincided with changes in taxonomists, the data was consolidated and the species name Ogden's specialist felt was the most likely correct was selected. Examples of these are listed below:

Species Name Reported (Year)	Final Species Name
Ischadium (Geukinsia) demissum (1982)	*Musculista senhousia*
Musculus senhousia (1983)	
Cylindroleberinae (1977-1984)	*Parasterope barnesi*

Finally, in order to focus on the more abundance species, all species occurring infrequently or at low abundance (<1 percent of the total abundance) and taxa that may represent multiple species (e.g., unidentified nemerteans, unidentified phoronids, *Lumbrineris* spp.) were eliminated from the database. Ogden's data standardization process and resulting database are documented in Ogden (1994).

Upon receipt of this database from Ogden, EA added the data from the 1994 study (Columbia 1994) as well as the following variables for each station from each of the prior studies as reported in each of the annual reports:

- Shannon-weiner diversity index
- Number of taxa identified
- Total density of benthic organisms.

Following completion of the master database, EA further summarized the information to facilitate analysis. First, mean values were calculated for each of the sediment parameters across all replicates at each station. Second, since the water column in the area of the study appears to be well mixed, mean values across all depths were calculated (surface and bottom for dissolved oxygen and salinity; every 2 ft for water temperature). Finally the densities for each species included in the master database were summed into the following larger taxonomic groupings:

- Cnidaria
- Polychaeta
- Arthropoda
- Amphipoda
- Tanaidacea
- Cumacea
- Decapoda
- Isopoda
- Ostracoda
- Stomatopoda
- Pelecypoda
- Gastropoda
- Echinodermata.

This summarized database formed the basis for all subsequent analyses in this report.

2.5 PRESENT 18-YEAR REPORT ANALYTICAL METHODS

The annual reports present the results of each year's monitoring and describe the patterns observed across the stations within that year. In these reports, step-wise multiple regression analysis was used in an effort relate the biological data to the various physical and chemical parameters measured for the sediment and water. The analyses which were repeated for each of the 18 years of study, are summarized and discussed in Section 3.4 of this report. The results of these analyses varied considerably from year to year. However, in general, depositional characteristics of the sediments (e.g., percent silt, clay, or sand) were most commonly selected as important parameters in explaining the observed variability.

For this report, rather then repeat such analyses to investigate all factors affecting the benthic community, the focus was shifted to address three specific questions:

1. Is there any consistent pattern in the physical, chemical and biological parameters among the 11 sampling stations?

2. Is there any evidence of long-term trends in any of these parameters at any of the sampling stations across the 18 years of study?

3. When other parameters known to affect benthic organisms are taken into account, is there any evidence to suggest that the operation of the SBPP is having a detrimental effect on the benthic community in San Diego Bay?

To address these questions a variety of graphical and exploratory analyses were employed in an effort to provide technically sound answers. The results of these analyses are presented in Sections 3.2 through 3.6.

3. RESULTS

3.1 LONG-TERM TRENDS IN SOUTH BAY POWER PLANT OPERATION

3.1.1 Operational History

The SBPP is a gas and oil fueled generating plant with four major steam cycle units. The current net capability of the four steam turbine generators at South Bay is:

Unit	Commercial Start-Up	Generating Capacity (kW)	Cooling Water Flow (MGD)	Percent of Total Flow
1	JUL 1960	147,000	112.3	18.7
2	JUN 1962	150,000	112.3	18.7
3	SEP 1964	171,000	179.4	29.8
4	DEC 1971	222,000	197.0	32.8

Each unit can generate independently or in conjunction with any other unit; however, Units 1 and 2 are typically operated in unison as the "base load" units for the Station. Generation typically cycles on a daily basis in response to electric demand. Power demand in the SDG&E system is typically lowest at night, increasing in the early morning and through the day, and then decreasing again in the evening. Responding to economic dispatch, generation from Units 1 and 2 typically increases as demand increases in the morning. If demand continues to increase, Unit 3 is brought on line. As demand declines in the evening, Unit 3 load is reduced to a minimum and generation may be reduced at Units 1 and 2. Unit 4 was operated extensively from 1971 through the early 1980s, but has been used very infrequently since that time. Unit 4 was designed to be brought on- and off-line rapidly, in order to meet peak demands; because of this design it is very inefficient and, therefore, is only utilized during periods of very high demand.

A portion of the heat from electric generation is rejected to the South Bay by the circulating cooling water system. The increase in temperature of the cooling water from the intake to the discharge (delta-T) is a function of the level of power generation for the period and the volume of cooling water flow. At SBPP, each unit typically generates with two circulating water pumps operating except if maintenance requires the outage of a pump, thus the cooling water flow for each unit typically does not fluctuate. Consequently, under the typical operating scenario described above, an increase in generation at Units 1 and 2 is accompanied by a proportionate increase in delta-T at the discharge and in the discharge cooling channel. When Unit 3 comes online, there is a step increase in total plant cooling water flow. If power generation at Unit 3 is low and the associated delta-T is low, there may be a decrease in delta-T in the discharge cooling channel as a result of the mixing of the cooler Unit 3 cooling water with the warmer cooling water from Units 1 and 2. In compliance with the NPDES permit limit of a daily average delta-T of 15°F, this operating scenario typically results in daily average delta-Ts of 8-15°F.

The size of the thermal plume (volume, cross-sectional area, surface area within a specified delta-T isotherm) will increase or decrease with the increase or decrease in cooling water flow. However, because the daily average delta-Ts from the plant have remained at 8-15°F, the delta-T within the discharge plume has not changed proportionally to the long-term decline in generation (Figures 3-1 and 3-4).

The annual average of monthly (i.e., the average of the individual generation levels for the 12-month period) generation (GWh) has fluctuated over the history of the SBPP (Figure 3-1) in part as a response to system demand, other energy sources, and various cost factors. The sharp increase in average monthly generation with the addition of Unit 4 at the end of 1971 is clearly evident in the 20-year record (Figure 3-1); the peak years for generation (approximately 350 GWh) at SBPP occurred in 1972 and 1977. After 1977, average monthly generation declined steadily through 1986 primarily due to the decreased usage of Unit 4. Generation has fluctuated near or below 200 GWh through 1994.

Generation typically fluctuates with demand during a given year; at SBPP generation has exhibited an annual cycle with the peak monthly average occurring in August and the minimum in late winter (Figure 3-2). Individual monthly generation for the peak generating months of July, August, and September over the period 1968-1994 (Figure 3-3) generally parallels the annual average monthly generation (Figure 3-1); that is, increasing between 1970 and 1977, then decreasing through 1984, and relatively flat through 1994.

Average monthly intake temperatures for the summer months from 1975 to 1994 vary considerably from year to year and have ranged from approximately 73 to 83°F with minimum and maximum values of 68 and 86°F, respectively (Figure 3-4). The associated monthly average discharge temperatures typically parallel the intake temperatures (Figure 3-4), as might be expected based on the operating scenario described above. Average discharge temperatures for these three summer months fluctuated from approximately 79 to 97°F over the 20-year period from 1975 to 1994 with minimum and maximum values of approximately 77 and 100°F, respectively. The highest temperatures typically occur during July, August and September.

3.1.2 Thermal Plume Measurement Studies

Aerial infrared radiometry in conjunction with ground truth measurements was used to map the SBPP cooling water discharge thermal plume during a series of surveys from September 1972 through April 1973 (Chambers and Chambers 1973). Average monthly generations for 1972 and 1973 were the second and third highest during the 1968-1994 period (Figure 3-1) and generation for September 1972 was the second highest of the summer monthly generation factors (Figure 3-3). During the 1972-1973 survey, the SBPP generator was near capacity with all four units operating at 371 GWh and with a maximum cooling water flow of 601 millions of gallons per day (MGD) and a delta-T of 15°F. Average monthly generation during the last 10 years (1985-1994) has typically been 150-200 GWh less than the generations factors for 1972-1973, and approximately 150 GWh less than the generation factors (Figure 3-3) for the period encompassing the September 1972 thermal plume mapping survey. This is primarily the result of infrequent utilization of Unit 4 during recent years. It is likely, therefore, that the volume of cooling water circulated at the time of the mapping survey in September 1972 may have been, on average, 1.5-2 times that typically circulated during the last 10 years. Thus, the size of the plume is likely to have been substantially larger at the time of the 1972-1973 mapping survey than is typical of the present time.

For comparison, a previous aerial mapping survey was conducted during September 1963 (Marine Advisers 1963) with only SBPP Units 1 and 2 operating (Figure 3-5). The discharge temperature at that time was 96°F, similar to the 95°F during the 21 September 1972 survey (Figure 3-6). The surface temperature during the 1963 survey (2 unit operation) at the end of the discharge cooling channel ranged from 84 to 86°F while the temperatures at the same location and similar tide stage, but with substantially higher cooling water flow (4-unit operation) during the September 1972 survey, were 87-91°F.

Use of the 1972 thermal plume mapping information to represent present conditions is, therefore, conservative. That is, the plume isotherm dimensions estimated from the 1972 survey are most likely significantly larger than typically exist under current operating conditions, all other factors being equal including that maximum discharge temperatures are likely to be similar. Thus, the area potentially affected by a given discharge temperature predicted by the 1972-1973 survey is likely to be larger than the area which would potentially be affected under conditions generally existing today and projected for the near future.

3.2 PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE WATER COLUMN

3.2.1 Summary of Findings from Receiving Water Monitoring Program Annual Reports, 1977-1994

Annual reports for the NPDES receiving water monitoring program provide a summary of the water column data collected each year. The reports present the temperature, salinity, dissolved oxygen, and transparency values measured at each of the 11 sampling stations. They also provide an analysis and interpretation of how each year's data vary among stations, and identify any spatial gradients or patterns. The reports do not assess long-term trends, but do make some comparisons to prior year's results, in largely anecdotal fashion.

Water temperatures varied among stations, but were generally noted as being similar to or within the range of temperature values reported during the previous years of study. Temperature gradients resulting from the SBPP thermal discharge were observed in all study years. That is, the northernmost stations were found to have lower water temperatures than the stations most proximate to the cooling channel discharge. At sampling stations in or near the discharge channel, surface temperatures higher than bottom temperatures were often noted, particularly prior to 1983. However, the data also show that the stratification of the SBPP's thermal plume is transient and generally restricted to the discharge channel. During all the years of study, temperature profiles at the near-field and far-field stations showed little variation with depth, as is expected due to the shallow depths and turbulent mixing induced by tides and wind. Most of the later annual reports since 1980 reported a notable reduction in surface temperature being evident at cooling channel Stations E7 and E5, which corresponds with lower thermal discharge from the SBPP (Section 3.1).

Reported salinity values were typical of marine bays and variation among sampling stations was typically about 5 percent. In several of the study years (1985, 1987-1989, and 1991-1992), salinity was reported to be slightly higher at stations closer to the discharge channel; while other annual studies (1986, 1990, and 1993) reported no appreciable differences in salinities among sampling stations.

Dissolved oxygen conditions in the water column were always reported to be near saturation, or even often supersaturated, posing no inhibition to respiratory functioning of the benthic biota. Reported dissolved oxygen values were mostly in the range of 5-7 ppm. Variation among sampling stations and across years was attributed to more local and short period environmental changes (e.g., day-night differences in photosynthesis, rainfall, current, wind, and tidal variations). During most years of study, the dissolved oxygen values were reported to be similar or within the ranges previously reported.

Typically, transparency values were noted as being similar to values recorded in the past. Water clarity was reported to show a positive correlation with depth, and decreased, at times significantly, in samples at the south end of the Bay. The greatest transparency was generally measured at the three northernmost stations.

These factors summarized each year in the annual reports have important biological implication, and are evaluated with respect to long-term trends in the following section.

3.2.2 Long-Term Analysis, 1977-1994

Results of the analysis conducted to examine the long-term patterns regarding the physical and chemical characteristics of the water column in South San Diego Bay are graphically presented and discussed in the following sections. Long-term patterns have been examined spatially throughout the study area, and temporally throughout the 18 years of study.

3.2.2.1 Water Temperature

Temperature acts as a controlling factor related to range of tolerance of species (Reid 1961). In this sense, temperature serves to regulate growth and metabolic rates of various organisms, and often determines the time of reproduction. Temperature is highly important in delimiting the rate of utilization of nutrients and light by plants and the tempo of food intake by animals, to satisfy metabolic demands. Possible thermal effects could account for patterns of distribution and abundance of benthic organisms. These types of effects as examined in laboratory and field studies on a variety of organisms have been the topic of review by Naylor (1965) and others. The major effects known are heat death, altered metabolism and growth, changes in reproduction, and changes in behavior. With the exception of heat death, all of these effects could be either beneficial or detrimental to a particular species.

The 18-year database for water column temperatures shows a trend of increasing water temperature with distance toward the discharge channel (Figure 3-7). Mean temperatures for the period of record were 85-92°F at the stations in the discharge cooling channel (E7, E5, and F4), 79-85°F at near-field stations (F3, F2, E4, E3, and D4), and 77-79°F at the far-field and control locations (C3, A3, and N2). Prevailing currents apparently keep the mean temperature at Station F2 considerably lower than at other near-field stations, despite its location near the discharge cooling channel.

At the far-field and control stations, there has been no long-term trend in water temperature during the 1977-1994 period (Figure 3-8). Temperatures at these stations were consistently between 75 and 80°F, except for an unusually low value in 1982, and warm ones in 1977 and 1984. Temperatures in the cooling discharge channel and at near-field stations vary from year to year but show no general upward or downward trend from 1981 to 1994. Temperatures prior to 1981 are somewhat higher than in later years, this difference being more evident in the discharge channel than at the near-field stations. Higher discharge water temperatures during the 1977-1980 period coincide with 25-35 percent higher summer generating load at SBPP during those years.

3.2.2.2 Salinity

Salinity is an environmental factor which limits organisms, primarily by interactions with physiological processes other than the uptake and utilization of nutrients (Reid 1961). Among animals, generally, tolerance to salinity changes varies greatly, as do the mechanisms associated with adjustment. Population development is often affected by slight changes in salinity.

Salinities for the 18-year period were nearly identical at Stations E7 to D4, and were only slightly lower at Stations C3, A3, and N2 (Figure 3-7). The total range in average salinity among stations of 34-36 ppt is well within the range of natural salinity variation to which the indigenous flora and fauna of marine bays is adapted. There is no upward or downward trend in the annual salinity levels from 1977 to 1994 (Figure 3-9). Except for a single low value at Station A3 in 1982, salinity was consistently between 34 and 38 ppt during most years, and between 30 and 33 ppt in 1979 and 1983.

3.2.2.3 Dissolved Oxygen

Aquatic organisms, including plants, must constantly oxidize organic matter for energy through the process of respiration (Reid 1961). During respiration, plants and animals use large amounts of oxygen. In aquatic communities, oxygen may be limited, and in turn may be a limiting factor in regards to the distribution and abundance of organisms. The minimal requirements of species vary and often limit the spatial distribution of certain forms in the community.

Mean oxygen levels for the 1977-1994 period at all stations ranged from 6.0 to 7.2 mg/L. Dissolved oxygen concentrations showed no appreciable trend upward or downward with distance from the north end of the Bay towards the south end (Figure 3-7). Average levels of dissolved oxygen appear slightly lower in the discharge channel (E7, 6.1 mg/L; E5, 6.0 mg/L; and F4, 6.4 mg/L) than at the other sampling stations (range of 6.6-7.2 mg/L); however, the range of dissolved oxygen reported at these three stations are well within the ranges reported at the other stations.

The data show no strong temporal trend in dissolved oxygen levels from 1977 to 1994 at either the discharge cooling channel stations or the far-field and control stations (Figure 3-10). A slight decline in oxygen levels from the late 1970s to the late 1980s is suggested by the annual values from the near-field stations. Such a trend would not be expected to be caused by operation of the SBPP, since it runs counter to plant thermal loadings of San Diego Bay, which actually decreased in the early 1980s. At all locations, mean dissolved oxygen values during the 18-year period were consistently above 5 mg/L, the water quality objective stipulated by the San Diego Region Water Quality Control Board (CRWQCB-SDR 1994).

3.2.2.4 Transparency

Light appears to be a controlling factor in the distribution of certain animals in time and space (Reid 1961). The vertical extent of effective light transmission is a factor which can be limiting to plant growth. Given sufficient light, submersed plants may exist at any depth. Light penetration may also be a factor in the warming of the water column and the sediments.

For the 18-year study period, water transparency shows considerable variability among the 11 sampling stations, ranging from 0.5 to 3.5 ft (Figure 3-7). For Stations E7 through E3, the overall transparency values exhibited no trend upward or downward with distance from the discharge cooling channel. There was a distinct gradient of increasing transparency from Stations C3 through N2. This is because water depth is greater at these locations and bottom sediments contain a lower proportion of clay/silt than at the more southerly stations closer to the SBPP discharge.

At the far-field and control stations, there is a suggestion of slightly clearer water after 1986, whereas at the near-field stations, there is no obvious pattern regarding changes in water clarity (Figure 3-11). At the discharge cooling channel stations there is a suggestion of a decline in transparency from 1977 through 1982; however, no trend was evident thereafter.

3.3 PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE BOTTOM SEDIMENT

3.3.1 Summary of Findings from Receiving Water Monitoring Program Annual Reports, 1977-1994

Annual reports for the NPDES receiving water monitoring program provide a summary of sediment data collected each year. The reports present the sediment temperature, grain size, TKN, and COD values measured at each of the 11 sampling stations. They also provide an analysis and interpretation of how each year's data vary among stations, and identify any spatial gradients or patterns. The reports do not assess long-term trends, but do make some comparisons to prior year's results, in largely anecdotal fashion. The annual reports for

1977 through 1994 have reported considerable variability in sediment temperature, COD, and TKN among years. However, gradients have consistently been apparent for these sediment variables between the northern and southern extremes of station location habitats (Figure 1-2). Similar to the early observations by Ford et al. (1972) and Ford and Chambers (1973), the 1977-1994 studies report that sediment temperature, COD, and TKN estimates have tended to decrease with distance from the northern to southern stations.

In South San Diego Bay, sediment grain size parameters (e.g., percent gravel, sand, silt, and clay) have been reported during the 1977-1994 studies to show considerable interannual variation. Parameter values at individual stations varied widely over the 18 years of study. Episodic events, such as storm runoff and bay dredging programs, have been considered the most likely controlling factors.

LOSL (1981) concluded that typically low fresh water flow into South San Diego Bay, together with the natural physiography of the area, has produced a distinctive sedimentation gradient in across the inner Bay. Based on SDG&E (1980), Michael Brandman Associates, Inc. (1990) related this sedimentation gradient principally to tidal flushing, modified somewhat by waves and wind-generated currents that exhibit a pattern of decreasing energy across the South Bay study area from Crown Cove towards the Otay River Basin. This pattern of decreasing water motion from northeast to southwest results in the deposition of larger and more dense sediment, primarily the sand fraction, in the northwestern portion of the South Bay, while finer and less dense silt and clay particles are deposited in areas of less water motion. LOSL (1981) and Michael Brandman Associates, Inc. (1990) noted that many hydrodynamic factors affect deposition of sediment, including the density, size distribution, settling velocity, packing, and permeability of sediment particles, as well as water depth, and influences of currents and waves. Because of this, the resulting depositional gradient across the study area was characterized as most likely not linear. However, a clear gradient in sediment particle size across the South Bay study area was noted. High percentages of sand and correspondingly lower percentages of silt and clay consistently characterized the stations to the northwest, while in contrast, proportions of sand were lower and those of silt and clay higher for the stations in the vicinity of the cooling channel and the Otay River Entrance. As discussed by Michael Brandman Associates, this gradient has important biological implications.

3.3.2 Long-Term Trends, 1977-1994

The average spatial and temporal patterns in South San Diego Bay of August-September sediment temperature, COD, and TKN data collected during the 1977-1994 study years are graphically presented in Figures 3-12 to 3-15. Figure 3-16 presents the spatial distribution of clay, silt, and sand and Figure 3-17 shows the temporal pattern of percent silt and clay in the bottom sediment for the 18-year study period.

3.3.2.1 Temperature

The patterns of distribution and abundance of benthic organisms can be affected by temperature. Thermal effects, such as heat death, altered metabolism and growth, reproduction changes, and behavior changes, could be either beneficial or harmful to a particular species.

Across the study years (1977-1994), sediment temperature, ranging from 70.9°F to 94.4°F, exhibits a great deal of variability among the 11 sampling stations (Figure 3-12). Sediment temperatures show a trend of increasing temperature in the direction of the discharge channel. Average sediment temperatures show a increase across the stations from a low of 77.2°F at Station N2 (the up-bay control station) to 88.4°F at Station E7 in the discharge channel.

The average sediment temperatures across the study years, presented in Figure 3-13, are the basis for grouping the sampling stations for further analysis. These groups are as follow:

Station Grouping	Station	Average Sediment Temperature (°F) August/September 1977-1994
Cooling Channel Discharge Stations	E7	88.4
	E5	85.0
	F4	83.6
Near-Field Stations	F3	83.0
	F2	78.8
	E4	83.0
	E3	81.7
	D4	81.1
Far-Field and Control Stations	C3	78.8
	A3	77.4
	N2	77.2

The first group of stations, the discharge cooling channel stations, includes those stations most directly influenced by the heated discharge cooling water. This group includes Stations E7, E5, and F4 which have 18-year average sediment temperatures of 88.4°F, 85°F, and 83.6°F, respectively. The second grouping of stations is referred to as the near-field stations and includes Stations F3, F2, E4, E3, and D4. These stations are clearly out of the discharge cooling channel, in the area occupied by the near-field portion of the thermal plume where the temperatures are intermediate to those in the discharge channel and the far-field. The far-field and control stations include those stations most distant from the discharge channel and are least likely affected by the warmer discharge channel water. Included in this group is control Station N2 which is located beyond the full expanse of the thermal plume.

At the stations included within each of these three groups, very similar temporal patterns in the sediment temperatures occurred through the 18-year period (Figure 3-13). Among stations at the far-field and control stations, annual sediment temperature estimates show less variation (1.3-2.4°F) in any one study year than at the cooling channel discharge stations

(3-6°F) or the near-field stations (4-6.5°F). Sediment temperatures at the far-field and control stations most often (approximately 70 percent of the time) fell in mid- to upper 70s. At near-field stations, sediment temperatures tended to fall in the lower 80s (about 40 percent of the time) and more often fell below 80°F than at the cooling channel discharge stations.

While sediment temperatures at the far-field and control stations show no upward or downward trend over the long-term, there appears to be decreasing trend in sediment temperatures at both the near-field and cooling channel discharge stations over the 18-year period (Figure 3-13). This trend is most apparent at the cooling channel discharge stations, where in earlier study years, sediment temperatures were generally in the high 80s and often reached into the 90s at Station E7. In later study years, sediment temperatures were observed to fall in the low to middle 80s. At the near-field stations, sediment temperatures most frequently fell in the 80-85°F range during the early study years, while in the later study years they were more often in the 70-75°F range.

3.3.2.2 Chemical Oxygen Demand

COD is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant (APHA 1989). For samples from a specific source, COD can be related empirically to biological oxygen demand, organic carbon, or organic matter.

Average COD values for the 1977-1994 period indicate a trend of increasing COD with distance toward the southernmost bay stations (Figure 3-12). COD increases from a mean of 1.2 percent dry weight at the northern control station (N2) to about 3.1 percent dry weight at Station E7. As discussed in Chapter 4, variation in COD among stations is strongly correlated with the percentage of clay/silt composition of the sediment. Therefore, the spatial pattern in COD levels is likely to result primarily from tidal and wind generated hydrodynamic processes in the Bay.

COD levels varied considerably from year to year, but there is no apparent trend at the far-field and control stations, or at the discharge cooling channel stations, over the 18-year period (Figure 3-14). COD values at the near-field stations tend to be slightly lower during the latter half of the study period than in the earlier years. However, there is no indication of a continuing downward trend in COD, and the average COD levels of the near-field stations were consistently in the range of 2.0 to 2.5 percent dry weight.

3.3.2.3 Total Kjeldahl Nitrogen

TKN is one measure of the organic content of the sediment. Analytically, it represents a determination of organic nitrogen and ammonia combined. Organic nitrogen is defined functionally as organically bound nitrogen in the trinegative oxidation state; it includes such natural materials as proteins and peptides, nucleic acids and urea, and numerous synthetic organic materials. Along with other forms of nitrogen, the components of TKN are chemically interconvertible and, thus, are parts of the nitrogen cycle (APHA 1989). The biological significance of TKN is that it is a measure of the nutrient richness of the benthic habitat.

Mean TKN values for the 1977-1994 period indicate a trend of increasing TKN with distance toward the southernmost bay stations (Figure 3-12). TKN increases from a mean of 0.05 percent dry weight at the northern control station (N2) to 0.1 percent dry weight at Stations E7 and E5. As discussed in Chapter 4, variation in TKN among stations is strongly correlated with the percentage of clay/silt composition of the sediment. Therefore, the spatial pattern in TKN levels is likely to result primarily from tidal and wind generated hydrodynamic processes in the Bay.

TKN levels varied considerably from year to year, but there is no continuous trend over the 18-year period (Figure 3-15). TKN values decreased considerably at the discharge channel and near-field stations during 1980 to 1982, possibly as the result of scouring from the exceptionally high discharges from the Otay River during storm events. Substantial drops in TKN which occurred in 1980 and persisted for several years have been related to episodic storm events which occurred during the winter period of that year (LES 1980a), flushing a considerable volume of sediment into the Bay and substantially increased the average particle size of the sediment in South Diego Bay. By 1986, levels of sediment TKN returned to levels more comparable to those observed prior to 1980, and have since remained consistently in the range of about 0.05 to 0.15 percent dry weight.

3.3.2.4 Sediment Grain Size Distribution

The physical properties of the bottom sediments have both direct and indirect effects on the benthic organisms occupying a particular habitat. Some species prefer silt and mud bottoms, while others require sandy substrates that are relatively free of these finer sediment. In addition, sediments with higher silt content usually contain higher amounts of organic and inorganic nutrients which can be utilized by the biota.

The proportions of sand, silt, and clay present in the bottom sediments averaged over 1977-1993 are presented for all the stations on Figure 3-16. The proportions of silt and clay in the sediments generally increases with distance from the northernmost control station toward the southernmost stations. On average, only 23 percent of the sediment is comprised of silt and clay at the control Station N2, compared to 78 percent at Station E5. Hydrodynamic conditions, especially those resulting from wind and tidal induced energy, are substantially different at the more open waters far field and control stations than in the relatively shallow areas in the near-field and discharge areas. The observed spatial gradient in sediment composition likely reflects those hydrodynamic differences.

The proportion of silt and clay in the sediments varies widely from year to year, with no apparent long term trend (Figure 3-17). The proportion of silt and clay decreased considerably at the discharge channel and near-field stations during 1980 to 1981, probably as the result of scouring from the exceptionally high discharges from the Otay River during storm events in 1980.

3.4 BENTHIC FAUNA STUDIES - SUMMARY OF FINDINGS FROM RECEIVING WATER MONITORING PROGRAM ANNUAL REPORTS, 1977-1994

As indicated previously, the summer monitoring program was designed and conducted in fulfillment of NPDES permit requirements stipulated by the San Diego Regional Water Quality Control Board. As such, the annual reports have been prepared for the purpose of providing to the San Diego Regional Water Quality Control Board, a summary of the results of each successive years studies. These reports, therefore, focused on identifying natural and artificially induced spatial patterns in abiotic factors and attempted to identify associations between these abiotic factors and the distribution and abundance of the soft bottom benthic community observed during each individual year. It was not within the scope or capacity of the annual reports to assess long term trends in the composition and spatial distribution of the benthic community. The objective of this report is to utilize analytic and interpretive methods with the 18-year database to identify long-term trends and spatial patterns in the benthic community and evaluate potential effects of the SBPP cooling water discharge which could not be performed within the limitations of the annual reports. This cumulative report will not attempt to repeat the analyses performed for each of the annual reports. However, in order to provide the reader with an historical perspective of the annual monitoring program, Section 3.4.1 summarizes the primary findings and conclusions reported by the specific authors of each of the annual study reports. Section 3.4.2 will present the long-term analyses for the soft bottom infaunal benthic community.

3.4.1 Lockheed Center for Marine Research (1977)

The lowest Shannon diversity indices were measured at Stations E7 (0.25) and E5 (1.93); the diversity indices for all other stations exceeded 2.00. Biomass was highly variable due primarily, "...to the extreme patchiness of the algal taxa encountered, particularly of the rhodophyte *Gracilaria verrucosa*, which was often sampled extensively by one replicate and missed entirely by the next two," at the same station.

Temperature exhibited a significant negative relationship with the number of taxa and diversity, but the effect was limited primarily to the cooling water discharge channel (Stations E7 and E5). Sediment depositional gradients had a significant influence on the abundance and biomass of several of the principal taxa. COD and dissolved oxygen also influenced the distribution of some taxa. LCMR (1978) reported that, "A general comparison of results with the 1972-1973 study (Ford 1973) showed similar species composition between years at comparable stations."

3.4.2 Lockheed Center for Marine Research (1978)

The lowest Shannon diversity indices were measured at Stations E7 (0.48) and E5 (1.83); the diversity indices for all other stations exceeded 2.00. Maximum diversity occurred at Station D4 (2.74). The low diversity at Station E7 reflected the relatively low number of taxa (9) and the high abundance of an unidentified oligochaete. The large observed variation in biomass among stations and replicates "...resulted primarily from differences in algal biomass." This variation reflected the patchy distribution of marine algae and grasses in the study area. The Canberra-Metric analysis distinguished Station E7 from all other stations and divided the remaining stations into two groups, essentially equivalent to the far-field area (Stations N2, A3, and C3) and the near-field area (Stations D4, E3, F2, F4, E4, F3, and the discharge cooling channel Station E5). The authors concluded that the similarity patterns "...indicate that fairly homogeneous conditions in relation to biological composition are present in the South Bay and that the effects of the power plant discharge are restricted to the immediate discharge area." The authors also observed, "that Station E7 was similar to other stations in overall physical/chemical composition but differed considerably is species composition. Temperature was obviously higher at Station E7...and possibly contributed to the lower diversity."

3.4.3 Lockheed Center for Marine Research (1979a)

The lowest Shannon diversity indices were measured at Stations E7 (0.70), F4 (1.14), and E5 (1.25); the diversity indices for all other stations exceeded 2.00. Maximum diversity occurred at Station F2 (2.82). The low diversity at the three stations within and at the mouth of the discharge cooling channel reflected the relatively low number of taxa present and disproportionately high abundance of unidentified oligochaetes and the gastropod, *Crucibulum spinosum*. The authors concluded, "That the low diversity estimates at Stations E7 and E5 probably reflect a community response to the elevated bottom and water column temperatures while the comparatively lower diversity estimates at Station F4 is most likely related to the high percentage of shell debris characteristic of this station." Large variation in biomass among stations and replicates "...resulted primarily from differences in algal biomass." This variation reflected the patchy distribution of marine algae and grasses in the study area.

Analysis of abiotic factors identified several spatial trends in the study area. Percent sand and percent silt/clay were inversely related; with percent sand generally decreasing while percent silt/clay generally increased southward through the study area from the control stations to the discharge. The percent gravel was low at all stations except Station F4 at the mouth of the discharge cooling channel where shell debris tends to accumulate. Salinity and sediment temperatures also increased along the north to south gradient moving toward the discharge. Algal biomass was associated with higher sand proportion and dissolved oxygen, and decreased TKN. Sediment grain size distribution and sediment temperature were also "strongly associated with increasing oligochaete abundance near the discharge (Stations E5 and E7), high abundance estimates of the polychaete *Mediomastus californiensis* at Stations E3 and F4, maximum abundance estimates of the crustacean *Podocerus* spp. at Station F3, and increasing estimates of the polychaete *Fabricia limicola* and the crustacean *Rutiderma* spp. at stations located farthest away from the discharge (Stations N2, A3, and C3)." Amphipod abundance appeared to be influenced by decreasing salinity in association with decreasing COD and sediment temperature. Bottom dissolved oxygen, COD, and TKN were other abiotic factors for which no specific spatial trends were identified by the authors, but which were associated with distribution of several of the principal taxa.

The similarity analysis demonstrated three groupings of stations, similar to prior years, and roughly distinguishable based on distance from the SBPP discharge. These groups included: the discharge cooling channel stations (E7, E5, and F4); the far-field Stations (N2, A3, C3) plus the near-field station E3; and other near-field stations intermediate in distance between the first two groups.

3.4.4 Lockheed Environmental Sciences (1980a)

The lowest Shannon diversity indices were measured at Stations E7 (0.64), E4 (1.47), and Station E5 (1.66); the diversity indices for all other stations exceeded 2.10. Maximum diversity occurred at Station N2 (2.76). The low diversity at the two stations within the cooling water discharge channel reflected the relatively low number of taxa present and disproportionately high abundance of unidentified oligochaetes and the polychaete *Streblospio benedicti*. The authors suggested no cause for the low diversity observed at station E4 during this year; however, they did note that dense mats of the rhodophyte, *Gracilaria verrucosa*, occurred at this station and accounted for peak observed biomass in the study area during 1980. Previously, diversity at Station E4 was similar to the other near-field transitional stations. Large variation in biomass among stations and replicates "resulted primarily from differences in algal biomass." This variation reflected the patchy distribution of marine algae and grasses in the study area. Sediment depositional gradients was the primary abiotic factor which was significant in the distribution of the principal taxa; dissolved oxygen, temperature, and COD also influenced several of the principal taxa.

The similarity analysis demonstrated three groupings of stations, similar to prior years, and roughly distinguishable based on distance from the SBPP discharge. These groups included: the cooling water discharge channel stations (E7, E5, and F4) plus near-field Station E4 adjacent to the cooling water discharge channel); the far-field Stations N2, A3, and C3 plus the northern near-field Stations D4 and E3; and the near-field Stations F2 and F3, intermediate in distance between the first two groups.

The 1980 study period was unique compared to previous study years in response to catastrophic rainstorms during Winter and Spring of 1980 which resulted in record runoff levels unmatched since storms in 1916 and 1927. These significant meteorologic events were reflected by significant changes in the sediment grain size composition and distribution and associated TKN. The percent silt/clay, although lower overall compared to previous years, was still found to decrease with distance from the discharge and the general patterns of benthic community characteristics were similar to previous years.

3.4.5 Four-Year Cumulative Analysis Report (1977-1980) (LES 1980a)

This report examined a four-year database which included a period affected by catastrophic floods and associated record terrestrial runoff from the Otay River into South San Diego Bay in 1980. The objective of this report was to evaluate, using a multi-year database, the hypothesis that a gradient of decreasing power plant effects would be observed with increasing distance from the discharge. Use of this longer term database allowed use of more sophisticated statistical techniques than could be utilized with the individual annual data sets. The statistical analyses were selected to distinguish artificially induced environmental gradients in South Bay associated with the cooling water discharge from other natural gradients in physical and chemical factors, and distribution patterns of the soft bottom benthic community.

A two-way analysis of variance was used to test for significant differences among years and stations. The non-parametric Student-Newman-Keuls multiple range test was used to identify significantly different groups of stations and Pearson's product-moment correlation coefficient was used to test for statistically significant associations between parameters. Multivariate statistical techniques were used to describe patterns of variation in community composition among stations. Classification analysis was used to identify assemblages (associations) of organisms which were assumed to represent an ecological response to local environmental abiotic physical and chemical factors. For this analysis transformed and standardized data were sorted using a Bray-Curtis dissimilarity matrix to generate dendrograms. Sediment temperature, COD, TKN, and sediment grain size were evaluated using principal component analysis. Principal component analysis was used to examine the proportion of the total variance contributed by each of the abiotic factors and the degree of correlation with these factors. The scores for each of the major abiotic factors produced by the principal component analysis were utilized as variables in the weighted discriminant analysis to evaluate the relationship between abiotic and biological variables and to statistically separate station locations.

LES (1980a) reported that sediment temperatures and COD were significantly higher at Stations E7 and E5 (cooling water discharge channel) and lowest at the northernmost (far-field) Stations N2, A3, and C3. The other Stations (D4, E3, F2, F3, and F4) were intermediate between these two groups. Station E4, spatially identified as a near-field station, is located near the dike and was similar to Stations E5 and E7; the authors hypothesized that this association may have been due to naturally elevated sediment temperatures at shallow Station E4. The three far-field stations had the lowest COD, TKN and silt/clay proportions and the highest sand proportion. COD, TKN, and silt/clay proportion generally increase moving south toward the back Bay area.

The number of taxa observed at the cooling water discharge channel Stations E5 and E7 was significantly lower than at all other stations, although differences in the number of individuals and biomass were not significant. The number of taxa generally increased and the species diversity became more similar among stations with increasing distance from the cooling water discharge. As observed for the abiotic factors, the number of taxa and species diversity at Station E4 in the near-field adjacent to the dike were similar to E5 and E7.

The most distinctive pattern reported by LES (1980a) was the consistent discrimination of Station E7 and Stations N2, A3, and C3 as two groups; no consistent patterns were discriminated among the other stations which was attributed to the typically patchy distributions of the principal organisms characteristic of the back Bay region. "The most important and consistent environmental factor...regulating the distribution and abundance of the principal organisms in the study area...was interpreted as a depositional gradient for 1977, 1978, and 1979 sampling periods. During 1980, the principal factor identified by weighted discriminant analysis was a gravel gradient." Sediment temperature also clearly influenced community composition, but was not as important as sediment grain size.

LES (1980a) primary conclusion was that the 4-year database, "revealed that no significant environmental effects could be associated with operation of the SBPP at any stations located outside of the cooling water discharge channel northwest of Station F4. Stations E5 and E7 in the mainstream of the cooling water channel nearest the discharge site exhibited considerably different chemical, physical, and biological characteristics in comparison to data collected at all other stations," however these differences could, "be only partially related to the SBPP cooling water discharge." LES (1980a) also concluded, "that the study area is similar to other southern California bays and has not been adversely affected by the operation of the SBPP." They also observed that, "Although substantial abiotic changes were measured during 1980 [in association with severe flooding], benthic community structure within the study area remained similar to patterns identified during 1977, 1978, and 1979. This indicates the soft bottom benthic community in the study area is resilient to a wide variety of natural perturbations."

3.4.6 Lockheed Ocean Science Laboratories (1981)

The lowest Shannon diversity indices were measured at stations E7 (0.36) and E5 (1.32); the diversity indices for all other stations exceeded 2.10. Maximum diversity occurred at Station F2 (2.84); although N2 and D4 were very similar (2.83). The low diversity at the two stations within the cooling water discharge channel reflected the relatively low number of taxa present and disproportionately high abundance of unidentified oligochaetes and the polychaete *Ctenodrilus serratus*. Large variation in biomass among stations and replicates resulted primarily from differences in algal biomass. This variation reflected the patchy distribution of marine algae and grasses in the study area. Sediment temperature and bottom dissolved oxygen were the primary abiotic factor which were significant in the distribution of the principal taxa; sediment depositional gradient (i.e., increasing proportion silt/clay and decreasing proportion sand from the north end of the study area toward the back Bay) also influenced several of the principal taxa.

As in previous study years, Station E7 was the most dissimilar from all other stations; however no strong groupings were apparent based on the biotic composition of the benthic communities. The authors observed significant differences in the species composition relative to previous years. "Large changes in abundance and occurrence...may be the result of several factors such as alterations in the physical habitat, the patchy distribution of the species, or an opportunistic response of the species to earlier changes in the habitat." Such changes in the benthic community appear to have been due, at least in part, to the depositional changes which resulted from the severe 1980 rain events and associated runoff. The spatial patterns of abiotic factors observed during 1981 were more similar to those associated with the alterations due to the 1980 flooding than previous study years, that is, a higher proportion of sand and lower COD and TKN in the southern portion of the study area. This statistical assessment indicated that sediment temperature and dissolved oxygen were the most important abiotic factors; however, the authors indicated that, "the sediment composition [wa]s still probably a more important determining factor for the community." Again, the primary conclusion of the report was that community patterns in the study area indicate, "that elevated temperature caused by the discharge has little effect on the biota outside the discharge channel."

3.4.7 Woodward-Clyde Consultants (1982)

The lowest Shannon diversity indices were measured at Stations E7 (0.89); however, the diversity indices for all other stations, except A3 and N2, were low compared to previous years. Only Stations D4, N2, and A3 exceeded 2.0; maximum diversity occurred at Station N2 (2.57). The numbers of taxa were considerably lower at all stations than in prior study years and the authors attributed the differences, "...to the fact that the 1982 sampling did not encounter high diversity eelgrass (*Zostera*) communities. Large variation in biomass among stations and replicates resulted primarily from differences in algal biomass. This variation reflected the patchy distribution of marine algae and grasses in the study area. Sediment temperature, depositional gradient, and bottom dissolved oxygen were the primary abiotic factors which were significant in the distribution of the principal taxa. No similarity analysis was performed on the 1982 database.

3.4.8 Woodward-Clyde Consultants (1983)

The lowest Shannon diversity indices were measured at Stations F3 (1.53); however, the diversity indices for most of the stations were low compared to previous years except 1982. Exceptions to this generalization were discharge cooling channel Stations E7 and F4, at which diversity was higher than in any previous year. Only Stations N2, C3, D4, E3, F2, and F4 exceeded 2.0; maximum diversity occurred at Station F4 (2.77) followed by Station C3 (2.66). The numbers of taxa were considerably lower at all stations than in prior study years (except 1982) and the authors attributed the differences to the fact that the 1983 surveys did not encounter high diversity eelgrass (*Zostera*) communities. Another unique feature of the benthic community in 1983 was the virtual absence of benthic algae compared to prior surveys. Large variation in biomass among stations and replicates resulted primarily from the dense population (12,400 individuals/m^2) of the introduced bivalve *Musculista senhousia* locally encountered at Station A3. Sediment temperature, depositional gradient, and bottom dissolved oxygen were the primary abiotic factors which were significant in the distribution of the principal taxa. No similarity analysis was performed on the 1983 database.

3.4.9 WESTEC Services (1984)

The lowest Shannon diversity indices were measured at Stations E7 (1.10); this was the highest diversity observed at station E7 during the period of study since 1977. Diversity at all stations was higher than in 1983. The diversity estimates for the three far field stations N2, C3, and A3 exceeded 2.0; maximum diversity occurred at Station A3 (2.61). The numbers of taxa were still lower at all stations than the study period from 1977 to 1981, but generally higher than in 1982-1983. Similar to 1983, dense mats of red algae were not encountered in 1984. Large variation in biomass among stations and replicates resulted primarily from the dense population of the opportunistic introduced bivalve *Musculista senhousia* locally encountered at Station F2. Sediment temperature, depositional gradient, and bottom dissolved oxygen were the primary abiotic factors which were significant in the distribution of the principal taxa. No similarity analysis was performed on the 1984 database.

3.4.10 CH2M Hill Marine Ecological Consultants, Inc. (1985)

The lowest Shannon diversity indices were measured at Stations E7 (1.32) and Station E5 (1.64); these estimates were higher than in 1984. Diversity at all stations was generally higher than in previous years. The diversity estimates for the remaining stations exceeded 2.0 except at A3; maximum diversity occurred at station C3 (3.08). The numbers of taxa and abundance were more typical of the study period from 1977 to 1981, that is, generally higher than in 1982-1983. Similar to 1982-1984, dense mats of red algae were not encountered in 1985. Large variation in biomass among stations and replicates resulted primarily from the patchy localized dense populations of molluscs. No patterns of biomass distribution were apparent related to proximity to the discharge or distance north-south in the Bay. Sediment depositional gradient and organic content were the primary abiotic factors with significant correlations to the distribution of the principal taxa.

3.4.11 Kinnetic Laboratories, Inc. (1986)

The lowest Shannon diversity indices were measured at Stations E7 (1.53) and Station E5 (1.25). The diversity estimates for the remaining stations exceeded 2.0 except at N2; maximum diversity occurred at Station C3 (2.61). During each previous study year (1977-1985), diversity estimates for Station N2 were consistently greater than 2.00 and one of the two highest among all stations; however, the diversity estimate for Station N2 in 1986 was higher than only the two discharge channel Stations, E7 and E5. The greatest number of taxa abundance were observed at Station N2; however, overall abundance at this station was dominated by the polycheate *Fabricia limicola* which was an order of magnitude more abundant than the next most abundant taxa. The numbers of taxa were more typical of the study period from 1982 to 1983. Similar to 1982-1985, dense mats of red algae were not encountered in 1986 except at Station C3. Large variation in biomass among stations and replicates resulted primarily from the patchy localized dense populations of molluscs. Sediment depositional gradient and temperature were the primary abiotic factors with significant correlations to the distribution of the principal taxa.

3.4.12 Kinnetic Laboratories, Inc. (1987)

The lowest Shannon diversity estimates were measured at Station F2 (0.96) located in the south end of the Bay, but generally considered to be in the transitional portion of the plume. The number of taxa were similar to other stations but the diversity calculation was overwhelmed by the abundance of an unidentified phoronid worm which accounted for 82 percent of the organisms at this station and occurred at approximately 300 times the density of the next most abundant species. The estimated diversity at all other stations except E7 (1.93) and E4 (1.85) exceeded 2.00. The highest diversity was estimated for Station C3 (2.74); the highest number of taxa were observed at Stations A3 (34), D4 (33), and F4 (33). Patchy distribution and localized areas of high abundance had a strong influence on diversity estimates and large observed variation in biomass among stations and replicates. Station N2 had low diversity compared to other stations and other study years and was characterized by high abundance of a few species including the opportunistic introduced mollusc, *Musculista senhousia* (37 percent of collected organisms). "Species richness...was increased in association with increased sediment sand fraction." Molluscs and polycheates were the major component of biomass at most stations. It was observed that gastropod and polycheate biomass was elevated where sediment gravel levels were high and that crustacean biomass was typically higher where water clarity was highest. Sediment depositional gradients and temperature were major factors associated with diversity, abundance and biomass distribution in the study area.

3.4.13 Kinnetic Laboratories, Inc. (1988)

The lowest Shannon diversity estimates were measured at Station F2 (1.68) located in the south end of the Bay, but generally considered to be in the transitional portion of the plume. The number of taxa were similar to other stations but the diversity calculation was overwhelmed by the abundance of an unidentified phoronid worm (*Phoronus spp.*) which accounted for 61 percent of the organisms at this station and occurred at densities an order of magnitude higher than the next most abundant species. The estimated diversity at all other stations exceeded 2.00. The highest diversity was estimated for station F3 (2.69) followed by A3, C3, and F3 all estimated at 2.60. The highest number of taxa were observed at stations A3 (36). Patchy distribution and localized areas of high density for individual taxa had a strong influence on diversity estimates and large observed variation in biomass among stations and replicates. Station N2 had the second lowest diversity and was characterized by high abundance of three species which accounted for 75 percent of the organisms collected including the polycheate *Fabricia limicola*; it is notable that the Asian bivalve *Musculista senhousia*, which accounted for 37 percent of the organisms at this station in 1987 accounted for less than 0.3 percent of the organisms in 1988. Species richness increased in association with increased sand and decreased silt/clay fraction. Sediment depositional gradients were the major factors associated with community structure, abundance and biomass distribution in the study area.

3.4.14 Kinnetic Laboratories, Inc. (1989)

The lowest Shannon diversity estimates were measured at the control station N2 (1.79) located at the north end of the study area. Station N2 had the second highest number of taxa collected (39), but the diversity calculation was overwhelmed by the abundance of the polycheate *Fabricia limicola*) which accounted for nearly 60 percent of the organisms at this station and occurred at densities an order of magnitude higher than the next most abundant species. The estimated diversity at all other stations except E3 (1.81) exceeded 2.00. The highest diversity was estimated for Station F4 (2.62) followed by F2 (2.61). Note that Station F4 is located at the mouth of the cooling water discharge channel and Station F2 had the lowest estimated diversity of the eleven study stations in 1988. Patchy distribution and localized areas of high density for individual taxa had a strong influence on diversity estimates and large observed variation in biomass among stations and replicates. Species richness increased in association with increased sand and decreased silt/clay fraction. Sediment depositional gradients, COD, and sediment temperature were the major factors associated with community structure, abundance, and biomass distribution in the study area.

3.4.15 Kinnetic Laboratories, Inc. (1990)

The lowest Shannon diversity estimates was measured at the cooling water discharge channel Station E5 (1.79) followed by Station A3 (1.83) located near the north end of the study area. The estimated diversity at all other stations except E3 (1.81) exceeded 2.00. The highest diversity was estimated for Station F4 (3.04) followed by N2 (2.88). Note that Station F4 is located at the mouth of the cooling water discharge channel and Station N2 had the lowest estimated diversity of the eleven study stations in 1989. The high variability and patchiness of the benthic community is demonstrated by the fact that the polycheate *Fabricia limicola* which dominated the sampled community at Station N2 in 1989 was not found at this station in 1990. Patchy distribution and localized areas of high density for individual taxa had a strong influence on diversity estimates and large observed variation in biomass among stations and replicates. Species richness increased in association with increased sand and decreased silt/clay fraction. Sediment depositional gradients and depth were the major factors associated with community structure, abundance, and biomass distribution in the study area.

3.4.16 Kinnetic Laboratories, Inc. (1991)

The lowest Shannon diversity estimates was measured at Station A3 (1.92) located near the north end of the study area followed by the cooling water discharge channel Station E5 (2.06). The highest number of taxa were observed at station A3 (53) and the lowest at Station E5 (18). The highest diversity was estimated for Station F2 (2.80). The high variability of the benthic community is demonstrated by the fact that unidentified nematodes accounted for 54 percent of the sampled community at Station A3 affecting the low diversity estimate in 1991, but accounted for less than 7 percent of the organisms at this station in 1990. Patchy distribution and localized areas of high density for individual taxa had a strong influence on diversity estimates and large observed variation in biomass among stations and replicates. Sediment depositional gradients were the major factors associated with community structure, abundance, and biomass distribution in the study area.

3.4.17 Columbia Aquatic Sciences (1992)

The lowest Shannon diversity estimates was measured at station F2 (1.79) and the cooling water discharge channel Stations E7 (1.82), E5 (1.67), and F4 (1.80). The highest number of taxa were observed at station F2 (51) and the lowest at Station E7 (9). The highest diversity was estimated for Station N2 (2.81). This represented a reversal in the relative diversity of Stations N2 and F2 between 1991 and 1992. The high variability of the benthic community is demonstrated by the fact that the gastropod *Barleeia californica* accounted for 64 percent of the sampled community at Station F2 affecting the low diversity estimate in 1992, but accounted for less than 2 percent of the organisms at this station in 1991. Furthermore the low diversity at Station E5 was due to the high abundance of the polycheate *Cirriformia spirabrancha* (65 percent of the organisms) in 1992 which was not present at this station in 1991. Patchy distribution and localized areas of high density for individual taxa had a strong influence on diversity estimates and large observed variation in biomass among stations and replicates. Sediment depositional gradients, sediment temperature, and depth were the major factors associated with community structure, abundance, and biomass distribution in the study area.

3.4.18 Kinnetic Laboratories, Inc. (1993)

The lowest Shannon diversity estimate was measured at the cooling water discharge channel Station E5 (1.06); the number of taxa collected at this station (10) was also comparatively low compared to other stations and years. Abundance was relatively very low and dominated by nematodes and gatropods. The estimated diversity at all other stations exceeded 2.00. The next lowest estimated diversity was at Station E7 (2.09). The highest diversity (3.06) and number of taxa (60) were found at Station N2. Patchy distribution and localized areas of high density for individual taxa had a strong influence on diversity estimates and large observed variation in biomass among stations and replicates. Biomass was dominated by *Musculista limicola* at all stations except A3 and F2 where algae was a major component of the biomass. Sediment depositional gradients and dissolved oxygen were the major factors associated with community structure, abundance, and biomass distribution in the study area.

3.4.19 Columbia Analytical Services (1994)

The lowest Shannon diversity estimate was measured in the cooling water discharge channel Stations E7 (1.87), X1 (1.69), X2 (2.13), and F4 (2.12); the number of taxa collected at these stations ranged from 17-20, lower than all other stations. Stations X1 and X2 were added during 1994 in the central portion of the cooling water discharge channel between Stations E7 and F4 outside of the deep channel which runs adjacent to the dike. The highest diversity (2.99) and second highest number of taxa (51) were found at Station N2. Although diversity estimates for Stations X1 and X2 were similar to other discharge channel stations (E5 and E7), the abundance of organisms at the shallower water Stations X1 and X2 were approximately 2-3 times those of Stations E5 and E7. The highest number of taxa occurred at Station A3. Patchy distribution and localized areas of high density for individual taxa had a strong influence on diversity estimates and large observed variation in biomass among stations and replicates. Biomass was dominated by algae at 6 stations (A3, E3, E4, F3, N2, and X2), bivalves at 6 stations (C3, D4, E5, E7, F2, and X1), and gastropods at Station F4. Sediment depositional gradients and distance from the discharge were the major factors associated with community structure, abundance, and biomass distribution in the study area.

3.5 BENTHIC INFAUNA LONG-TERM ANALYSIS, 1977-1994

3.5.1 Number of Taxa

The maximum numbers of taxa (50-80) identified per year at the near-field (F3, F2, E4, E3, and D4), far-field and control (C3, A3, and N2) stations during the receiving water monitoring program occurred between 1979 and 1981 (Figure 3-18). The numbers of taxa at these stations (20-40) declined through 1984 and remained between 25 and 35 until 1989 except for a small peak between 30 and 55 in 1985. There was a generally increasing trend from 1989 to 1994 at these stations.

The number of taxa observed at the cooling water discharge channel Stations E5 and E7 (10-30 taxa) have generally been similar to each other since 1981; between 1977 and 1981 fewer taxa were consistently observed at E7, the station closest to the discharge. Except for the 1985 peak, the number of taxa at E5 and E7 did not follow the general long-term trends observed at the near and far-field stations. In contrast, Station F4, at the mouth of the cooling water discharge channel, typically had at least 10 more taxa than Stations E5 and E7 and was more consistent with the numbers of taxa and long-term trends observed in the near-field plume area.

The average number of taxa per station over the 18-year period generally increases from south to north through the study area, with the lowest number at Station E7 and the highest at Station N2 (Figure 3-19). The numbers at Stations E5 and E7 are generally 10-20 less than at the near- and far-field stations; however, Station F4 at the end of the cooling water discharge channel has had numbers similar to the near-field stations. The far-field and control stations have average numbers of taxa approximately 5-10 higher than stations in the near-field area and 20-25 higher than at the inner end of the discharge channel.

3.5.2 Density of Infaunal Community

The density (numerical abundance per 0.1 m^2) of the soft bottom benthic infaunal community exhibits considerable variability between years at stations in all three portions of the study area (Figure 3-20). Densities at all of the near-field, and far-field and control stations has typically ranged from approximately 500-5,000 organisms/0.1 m^2 with differences of 3,000-4,000 organisms/0.1 m^2 at a given station between consecutive years not uncommon. One exception to this generalization is Station F3, which has had relative stable densities from 1981-1994 ranging from approximately 400-1,700 organisms/0.1 m^2 and between year differences generally less than 500 organisms/0.1 m^2. In the cooling water discharge channel, the between year variability was less at Station E5 (approximately 200-2,000 organisms/0.1 m^2) than at Stations E7 and F4 (approximately 200-4,500 organisms/0.1 m^2).

Density does not exhibit any trend from south to north through the study area as observed for number of taxa (Figure 3-19). The lowest average density at any station over the 18-year period occurred at Station E5. The average densities at Stations F2 and N2 (approximately 2,600 organisms/0.1 m^2) were approximately 1,000 organisms/0.1 m^2 higher than any other near- or far-field station. The remaining near- and far-field stations and Station F4 had similar long-term average densities (approximately 1,200-1,800 organisms/0.1 m^2).

3.5.3 Long-Term Trends of Principal Benthic Taxa

3.5.3.1 Algae and Marine Plants

As indicated by Ford (1968), dense mats of marine algae, when and where present provide a direct source of food to some invertebrates and fish as well as refuge habitat for other species. The biomass (g/0.1 m^2)of marine algae and plants has been highly variable among years and stations, but with no clear pattern related to the SBPP cooling water discharge. Peaks in biomass were not consistent among stations from year to year (Figure 3-21). At the far-field and control stations, biomass was generally very low between 1983 and 1992 with peaks of biomass from 100 to 200 g/0.1 m^2 before (1977-1981) and after (1993-1994) that period. Biomass at Station C3 was generally low throughout the study period. The same pattern was observed at the near-field where virtually no algal and plant biomass was observed at any stations between 1983 and 1991 (Figure 3-21). Biomass peaks at the near-field stations were generally in a range similar to the far-field and control stations from 1977-1982 and 1992-1994 except for very high biomass density at Station F2 in 1978 (approximately 400 g/0.1 m^2). Except for peaks in 1981 and 1992 at Station E5 biomass of algae and marine plants at discharge cooling channel stations was very low; however, similar to the near-field, far-field, and control stations, no peaks in biomass occurred from 1982 to 1991 (Figure 3-21).

The long-term average biomass density at the near-field and far-field and control stations was slightly higher than at discharge cooling channel stations; however, the within station variability over the 18-year period was very high. Those stations with the highest long-term means (F2, E4, D4, and N2) also had the highest range of biomass values (Figure 3-22) reflecting the effect of a few years with high biomass interspersed among periods of generally low biomass.

3.5.3.2 Echinoderms

Except for 1987, virtually no echinoderms have been collected since 1983 in the control, far-field, and near-field areas (Figure 3-23). Prior to 1984 peak densities were typically between 50 and 100 organisms/0.1 m^2. Almost no echinoderms were collected in the discharge cooling channel throughout the 18-year study period except at Station F4 in 1987 (Figure 3-23).

The lowest long-term mean densities occurred at discharge cooling water Stations E5 and E7. Long-term means in the remainder of the study area were very low and exhibited wide ranges (Figure 3-22). Although the lowest densities were observed in the discharge cooling channel, a spatial effect related to SBPP operation is not clear considering the low area-wide densities throughout the 18-year study period.

3.5.3.3 Gastropods

Densities of gastropods at the control and far-field stations were generally higher prior to 1984 than during the later part of the study period (Figure 3-24). The highest densities in this area have generally been observed at Station C3 and were typically less than 100 organisms/0.1 m^2. In the near-field gastropod densities have been very low except at Station F2 where isolated peaks were observed in 1978 and 1980 at approximately 500 organisms/0.1 m^2, and 1992 with a maximum near 3,000 organisms/0.1 m^2. Densities of gastropods in the discharge cooling channel were highly variable between years, but the higher peaks consistently occurred after 1984 (Figure 3-24) at the inner Stations E5 and E7.

Gastropod long-term mean densities were very low throughout the study area with the exception of Station F2 (Figure 3-22) which was strongly influenced by the 1992 peak which was two orders of magnitude greater than most other sampling events.

3.5.3.4 Pelecypods

No long-term trends were apparent in pelecypod densities within any of the three portions of the study area. The density of pelecypods in the control and far-field area has been highly variable from year to year (Figure 3-25). The long-term pattern has been characterized by isolated peaks generally less than 600 organisms/0.1 m^2 with the exception of Station A3 in 1983 and 1990 when densities were approximately 1,200 organisms/0.1 m^2. Pelecypod densities at the near-field stations generally did not exhibit the level of variability observed in the far-field; peaks in density were typically near to or less than 200 organisms/0.1 m^2 (Figure 3-25). Within the discharge cooling channel densities of pelecypods were more variable at Stations E7 and F4 than at E5 (Figure 3-25). Densities at Station F4 have been relatively low compared to the other discharge channel stations. Densities at discharge Stations E5 and E7 have generally been higher since 1984 and similar to those observed in the near-field area (Figure 3-25).

The long-term mean density of pelecypods generally increase with distance from the discharge (Figure 3-26). The long-term within station range of observed densities also increased from the discharge cooling channel to the near-field to the far-field and control areas.

3.5.3.5 Other Molluscs

The densities of other molluscs in the far-field and control area were typically less than 50 organisms/0.1 m^2 throughout the 18-year study period with the exception of several isolated peaks (approximately 200 organisms/0.1 m^2) at Stations A3 and N2 (Figure 3-27). In the near-field area densities were generally lower than 20 organisms/0.1 m^2 over the 18-year period except for isolated peaks in abundance which reached approximately 60 organisms/0.1 m^2. Densities of other molluscs at discharge cooling channel stations, E5 and E7, were consistently low throughout the 18-year study period; however, densities at Station F4 at the end of the discharge cooling channel exhibited considerable variation with isolated peaks up to 150 organisms/0.1 m^2 (Figure 3-27). No long-term trends were observed at any of the three portions of the study area.

There was no consistent trend in long-term abundance of other molluscs among sampling stations (Figure 3-26). Abundance at discharge Station F4 and far-field/control Stations A3/N2 were at similar relatively high abundance. Abundances were also under but relatively lower at discharge Stations E7 and E5 and at near-field/far-field Stations F3, F2, E4, E3, and D4/C3.

3.5.3.6 Polychaetes

Polychaetes were frequently one of the most abundant benthic taxa in the study area; however substantial year to year variability was typical. At the far-field and control stations changes in density of 1,500 organisms/0.1 m^2 were not uncommon (Figure 3-28). Density at the far-field and control stations exhibited peaks at approximately 2-year intervals during much of the study period, that is, 1979, 1981, 1983, 1985, 1987, and 1989. Maximum density at Stations C3 and N2 exceeded 2,000 organisms/0.1 m^2; other peaks in density were typically between 1,000 and 1,500 organisms/0.1 m^2. With the exception of Station F3, the near-field stations demonstrated a similar 2-year cycle in abundance peaks with densities slightly lower than the far-field and control stations (Figure 3-28). Density of polychaetes was highly variable from year to year with no apparent long-term tends and peaks typically between 700 and 1,500 organisms/0.1 m^2. Densities at the discharge cooling channel stations were generally lower than in the near-field with peaks typically less than 1,000 organisms/0.1 m^2. No long-term trends in density were apparent at Stations E7 and E5; although variable densities at Station F4, at the mouth of the discharge cooling channel, have generally increased since 1983 (Figure 3-28).

The highest long-term mean density of polychaetes was observed at control Station N2. The far-field stations (A3 and C3), the near-field stations (D4, E3, E4, F3, and F2), and Station F4 at the mouth of the discharge cooling channel had similar long-term mean densities and wide within station ranges in density (Figure 3-26). Long-term mean polychaete densities at discharge cooling channel Stations E5 and E7 were slightly lower than the near-field and far-field stations, but also exhibited wide within station ranges.

3.5.3.7 Ostracods

Densities of ostracods were highly variable from year to year throughout the near-field, far-field and control areas over the 18-year study period with no apparent long-term trends. During years of peak abundance at a given station, densities of ostracods typically approached 200 organisms/0.1 m^2 (Figure 3-29). In contrast, densities at Stations E5 and E7 in the discharge channel were consistently less than approximately 5 organisms/0.1 m^2. Densities at Station F4 were also relatively low with peaks of less than 40 organisms/0.1 m^2 (Figure 3-29).

The lowest long-term mean densities for the 18-year period occurred at the discharge cooling channel stations, E5 and E7 (Figure 3-30); the highest long-term means occurred at Station F2 in the near-field area and N2 in the far-field and control area. The within station ranges in the near- and far-field, and control areas were relatively large. Differences in long-term ostracod densities among stations in these areas do not appear to be related to operation of SBPP, although densities of ostracods in the discharge cooling channel area have been consistently reduced.

3.5.3.8 Cumaceans

Densities of the cumaceans were relatively low (less than 10 organisms/0.1 m^2 in the far-field and control, and discharge cooling channel areas [Figure 3-31]). Densities in the near-field area were higher with isolated peaks approaching 30 organisms/0.1 m^2 between 1985 and 1991.

Long-term mean densities of cumaceans were relatively high in the near-field (Stations F2, F3, E3, and D4) and at Stations C3 and N2 in the far-field (Figure 3-30). In contrast, the maximum densities and long-term means over the 18-year study period in the discharge cooling channel and at Stations E4 and A3 were relatively low.

3.5.3.9 Tanaidaceans

The density of tanaidaceans was relatively low in the far-field and control area except for isolated peaks in 1978 (approximately 250 organisms/0.1 m^2), 1981 (approximately 650 organisms/0.1 m^2), and 1991 (400 organisms/0.1 m^2) at Station N2 (Figure 3-32). Virtually no tanaidaceans were collected at Station A3 throughout the period. In the near-field abundance was low at all stations between 1984 and 1992 with isolated peaks before and after this period particularly at Stations F2, E3, and D4. Abundance of tanaidaceans in the discharge cooling channel was low through out the period except for isolated peaks at Station F4 in 1985 and 1993 (Figure 3-32).

The long-term mean density was highest at Stations E4, F2, and N2, but exhibited a wide range over the 18-year period (Figure 3-30). The long-term means and ranges at the other far-field, near-field and discharge cooling channel stations was very low. No spatial pattern related to distance from the discharge is apparent (Figure 3-30).

3.5.3.10 Isopods

The densities of isopods has been highly variable over the 18-year study period in the far-field and control, and near-field areas. Virtually no isopods were collected between 1982 and 1992 (Figure 3-33). Isolated annual peaks in density approaching 400-650 organism/ 0.1 m^2 were observed prior to 1982. Abundance of isopods in the discharge cooling channel have been considerably lower with peak densities of 30-60 organisms/0.1 m^2 at Station F4 (Figure 3-33).

The long-term means densities of isopods in the discharge cooling channel are nearly zero (Figure 3-34). The maximum density over the 18-year study period at each station decreases across the near- and far-field areas moving from south to north through the study area. The long-term means also decreased very slightly along this same axis (Figure 3-34).

3.5.3.11 Amphipods

Densities of amphipods have been highly variable throughout the 18-year study period. In the far-field and control area, isolated annual peaks have ranged as high as 1,200 organisms/ 0.1 m^2, but densities have generally been less than 600 organisms/0.1 m^2 (Figure 3-35). Coincident annual peaks occurred at several near-field and far-field stations in 1981, 1985, 1989, and 1991. Densities of amphipods in the near-field area were typically below 500 organisms/0.1 m^2. Densities at discharge cooling channel Stations E5 and E7 were nearly zero except for peaks in 1989 and 1991 (Figure 3-35). Densities at Station F4 over the 18-year study period were more similar to the near-field stations.

The long-term means were highest at far-field and control Stations C3 and N2 and lowest at discharge cooling Stations E5 and E7 (Figure 3-34). Long-term densities at the near-field stations and discharge Station F4 and far-field Station A3 were intermediate (Figure 3-34). While long-term densities in the discharge cooling channel have been reduced, densities elsewhere in the study area have been highly variable and no spatial patterns in long-term mean densities are apparent that might be related to operation of SBPP.

3.5.3.12 Decapods

Few decapods have been collected in the discharge cooling channel during the study period (Figure 3-36). In contrast densities of decapods have been high at the far-field and control stations, exceeding 200 organisms/0.1 m^2 during several years. Densities in the near-field have been somewhat lower (less than 200 organisms/0.1 m^2) over the long-term than in the far-field (Figure 3-36). No long-term trends in annual density were apparent in the study area.

The highest long-term means occurred at the three far-field and control stations (Figure 3-34) approaching 100 organisms/0.1 m^2. The long-term mean densities in the near-field were approximately half the magnitude of those observed in the far-field; the highest long-term mean in the near-field occurred at Station F2. Long-term mean densities of decapods were clearly reduced in the discharge cooling channel compared to the rest of the study area (Figure 3-34).

3.5.4 Community Diversity

The Shannon Diversity Index (H') is one of several commonly employed measures of relative complexity used for comparison of surveyed communities.

$$H' = -\Sigma p_i \ln p_i$$

where

$$p_i = \frac{N_i}{N}$$

and

N_i = Number of organisms of taxon i in sample
N = Total number of organisms in sample.

This particular index provides a weighted measure of diversity which takes into account the relative number of organisms collected from each taxonomic group in the surveyed community (Pielou 1975, 1977). The Shannon Diversity Indices calculated for each of the far-field and control stations generally varied between 2 and 3 across the 18-year monitoring period. No long-term trends are apparent and the year to year variation was not consistent between the three stations (Figure 3-37). Estimated diversity for near-field stations typically varied from approximately 1.5 to 2.8. The year-to-year changes in calculated diversity followed similar patterns at Stations F2, E4, E3, and D4 with the exception of a sharp decrease at E4 in 1980 and F2 in 1987. Although diversity at Station F3 was generally in the range of the other near-field stations, it did not parallel the annual pattern of variation exhibited by the other near-field stations. After generally declining from approximately 2.5 to 1.3 during the period 1977-1982, diversity at Station F3 has generally increased to approximately 2.8 over the subsequent study period.

Diversity of the benthic infaunal community at cooling water discharge channel Station E7 has increased from a low (among all stations and years) of approximately 0.3 in 1977 to approximately 2.2 in 1988 and has remained relatively steady since that time (Figure 3-37). Diversity at Station E5 has generally varied between approximately 1.3 and 2.1, except for a sharp decrease to approximately 1.0 in 1993 followed by a sharp increase to 2.5 in 1994. The benthic community at Station F4 has exhibited wide annual changes in diversity ranging from approximately 1 to 3, particularly between 1977 and 1984, but has typically been higher than the other two cooling water discharge channel stations (E7 and E5).

The long-term average diversity estimates for all near-field, far-field, and control stations are very similar ranging from approximately 2.1 to 2.3 (Figure 3-19). Average diversity at Station F4 at the end of the discharge channel was also in this same range. No spatial patterns was apparent among these stations. The cooling water discharge channel stations (E7 and E5) had long-term average diversity estimates significantly less than observed for all of the other stations (Figure 3-19).

3.6 FACTORS AFFECTING THE BENTHIC COMMUNITY

The primary purpose of this section is to determine whether the results of the biological monitoring data, collected over the period 1977-1994, provide any evidence that the thermal discharge from the SBPP has had an adverse effect on the abundance and diversity of the benthic community in San Diego Bay. However, since there are many factors either known or expected to be affecting the benthic community, the effects of these factors must be taken into account when investigating the possible effects of the thermal discharge.

The stations included in the South Bay Water Monitoring Program extend from the open deeper waters of South San Diego Bay into the relatively shallow quiescent waters of the Plant's discharge cooling channel. Hence, the hydrodynamic conditions, especially those resulting from tidal current and wind generated waves, differ along the gradient extending from open waters into the discharge cooling channel. As a result of this hydrodynamic gradient, there exists a parallel gradient in the physical and chemical conditions of the sediment and water. These patterns are illustrated in the graphical presentations in the previous sections.

These gradients are also evident in the result of correlation analysis of the physical and chemical data measured at each of the sampling stations. All 7 parameters were significantly ($P \leq 0.05$) correlated with the distance from the Plant's discharge (Table 3-1). Six of the parameters (percent silt and clay, sediment temperature, sediment COD, sediment TKN, water temperature, and salinity) were inversely related to distance from the discharge. This means that the values for these parameters tend to decrease as one moves away from the discharge. The other two parameters, transparency and dissolved oxygen of the water, were positively correlated with distance from the discharge, meaning that the values tend to increase further offshore.

The existence of these gradients also leads to the significant correlations frequently observed among the sediment and water parameters measured with each biological sample (Table 3-1). Some of these correlations are due to common physical processes which affect both parameters simultaneously whereas others are merely coincidental, resulting from different physical processes which happen to vary along the same gradient. For example, while there is likely to be some natural increasing gradient in both summer water and sediment temperatures moving from the deeper open waters of the Bay to the shallow enclosed area of the discharge channel, it is likely the majority of this increase in temperatures closer to the Plant is related to the thermal discharge. Hence, the correlation between sediment and water temperatures can be explained by a common factor (thermal effluent) jointly affecting both. Also, the negative correlation of salinity with distance to the Plant can be explained by increased evaporation and reduced dilution at the southern end of the Bay. Finally, accumulation of finer sediments, including silt and clay which typically contain a higher organic content, increased with decreasing depth and tidal velocity in the south end of the Bay. This accumulation of higher organic materials leads to the higher COD and TKN in the sediments, as well as decreased transparency and dissolved oxygen at the south end of the Bay. On the other hand, the significant correlation between dissolved oxygen and salinity is likely to be spurious, resulting from different, but parallel, physical processes.

The existence of the multiple co-occurring significant correlations among the water and sediment physical and chemical parameters makes it impossible to clearly attribute changes in biological community attributes which occur along the station gradient to any single parameter. For example, if a gradient exists in the diversity and abundance of the benthic community from out in the Bay, into the discharge cooling channel, it is not possible to determine if that gradient is related to changes in the physical and chemical attributes of the sediment, changes in the water conditions, or the Plant's operation. The multiplicity of strong correlations between the physical characteristics of the sediment, known to be an important factor affecting the benthic community (Gray 1974), and the index of thermal effects, makes rigorous statistical analysis to test for the effects of the Plant's thermal discharge impossible. It is difficult to confidently separate the effects of the Plant's thermal discharge from the effects of the naturally-occurring differences in physical sediment characteristics. This was also the conclusion of many previous investigators (e.g., LES 1980a).

Although rigorous hypothesis testing is not possible, the existing data were analyzed to determine if these data provide **any** evidence that the Plant's discharge was having a detrimental effect on the benthic community of San Diego Bay. The approach used was to remove the potential effects of confounding variables so that the remaining patterns can be related to the potential effects of the Plant's thermal discharge. For this assessment, the following five community parameters were selected for inclusion in the analysis:

- Shannon-Weiner diversity index
- Number of taxa identified
- Total count of benthic organisms
- Biomass of molluscs (pelecypods and gastropods)
- Biomass of all other benthic organisms (excluding algae).

Measurements for each of these parameters were available at all 11 sampling stations for each of the 18 study years for a total of 198 data points for each parameter.

Rather than arbitrarily include all measured physical and chemical parameters in this assessment, parameters were included if, and only if, there was a good biological justification for inclusion. This selection criteria avoids the potential for model construction resulting from spurious, coincidental correlations. Based on this criteria, three parameters, the total percent silt and clay, the total biomass of algae and marine grasses, and distance from the discharge (a measure of thermal exposure), were included in this analysis. The sediment grain-size characteristics, of which percent silt and clay is a direct measure, have been reported to be the primary factors affecting the species composition of benthic invertebrates at different locations in South San Diego Bay (LES 1980a; Michael Brandman Associates, Inc. 1990). Additionally, benthic algae and marine grasses can serve as important food and refuge for benthic invertebrates and, thus, affect community structure in the Bay (Ford 1968). The distance from the discharge of the SBPP was selected as the most appropriate measure of the long-term effects of elevated temperatures due to the plant operation on the benthos of San Diego Bay for this analysis. This determination was based on the fact that biological communities respond to long-term exposures to elevated temperatures and not to the short-term variation which would be reflected on either the sediment or water temperatures measured on the day of sampling.

The analysis of these data was conducted in two steps. First, the percent silt and clay and the biomass of algae and marine grasses were included in a multiple regression model relating these two independent parameters to each of the five community biotic parameters. Since the maximum community abundance and diversity are expected to occur at intermediate values between the two extremes of all silt and clay and all sand, the percent silt and clay was also squared and included in the potential regression model to provide for possible quadratic relationships. All three independent parameters were included in the multiple regression model to determine their relative importance in "explaining" the variability in each of the five community biotic parameters. Based on the results of this analysis, the regression models were then re-run excluding any independent parameters for which the Type I Sum-of-Squares was not significant at $P \leq 0.2$, a commonly used rule-of-thumb of construction of multiple regression models (Littell et al. 1991). The results of these regression models are presented in Table 3-2.

Significant regression models resulted for four of the five community parameters and these models accounted for between 4 and 35 percent of the observed variation. The regression model for the non-mollusc biomass was not significant and accounts for a very small portion (<1 percent) of the overall variation in that community parameter. It is interesting to note that for the three models which included the percent silt and clay squared, the parameter estimate is negative indicating a maximum between the two extremes as originally hypothesized. In addition, for all three models which included the biomass of algae and marine grasses, the parameter estimates were positive, suggesting a beneficial effect of algae and marine grasses on the benthic community.

However, it is important to remember that significance in this modeling exercise should not be taken as proof of cause-and-effect. There are other variables, many of which parallel those used in the model, which could also be important controlling factors. Additionally, all of the models, despite their significance, leave much of the observed variation unexplained. While other physical or chemical factors may contribute to this variation, it is likely that most of the unexplained variability is due to other processes including random sampling variation and natural variability across years, as well as changes in contractor or technique. Nevertheless, this modeling exercise is useful in an attempt to remove the effects of confounding variables in the effort to ferret out any evidence of thermal effects on the benthic community in San Diego Bay.

In the second step of the data analysis process, the resulting regression models were used to predict the expected mean for each of the community parameters in each sample, based on the observed silt and clay content and algal and marine grass biomass at that station in that year. The residuals about the regression models (i.e., differences between observed and predicted values) were then taken as a measure of the variability remaining after the effects of the two regression model parameters were removed. These residuals were then summarized for each station and related to the distance from the Plant's discharge, a measure of potential thermal exposure. The resulting patterns in residuals are displayed on Figures 3-38 and 3-39.

The results of this analysis demonstrate that, even with the effects of sediment composition and algal and marine grass biomass removed, there remains considerable variability across the years at any given station. This within-station variability appears much greater than the overall variability across stations for each of the five community parameters. For all five community parameters, stations within the discharge channel (E7 and E5) appear slightly lower than for the other nine stations. For the other nine stations within the Bay proper, there does not appear to be any overall pattern.

Overall, this analysis of the 18-year database suggests that the average diversity and abundance of the benthic community were somewhat lower within the discharge channel of the South by Power Plant. This reduction appears to result from the combined influence of the incremental temperature from the SBPP and the physical characteristics of the shallow south end of the Bay, particularly sediment grain size characteristics (percent clay/silt), and, to a lessor extent, sediment ambient temperatures, COD, TKN, and lower water transparency related to high turbidity. However, the diversity and abundance of benthic infauna at the cooling water channel stations was within the range reported for other stations within the Bay. There were no appreciable long-term trends upward or downward of infaunal diversity, number of species, numerical abundance or biomass at the sampling stations located in the discharge cooling discharge channel over the 18 years of study. This indicates the continued persistence of a functional, resilient, and stable community of infauna within the discharge cooling channel. In addition, lower values for infaunal community characteristics were not evident at other stations within the Bay. This result strongly suggests that effects of South Bay's thermal effluent, if any, are localized minor reductions in the benthic community within the discharge channel and do not extend out into San Diego Bay.

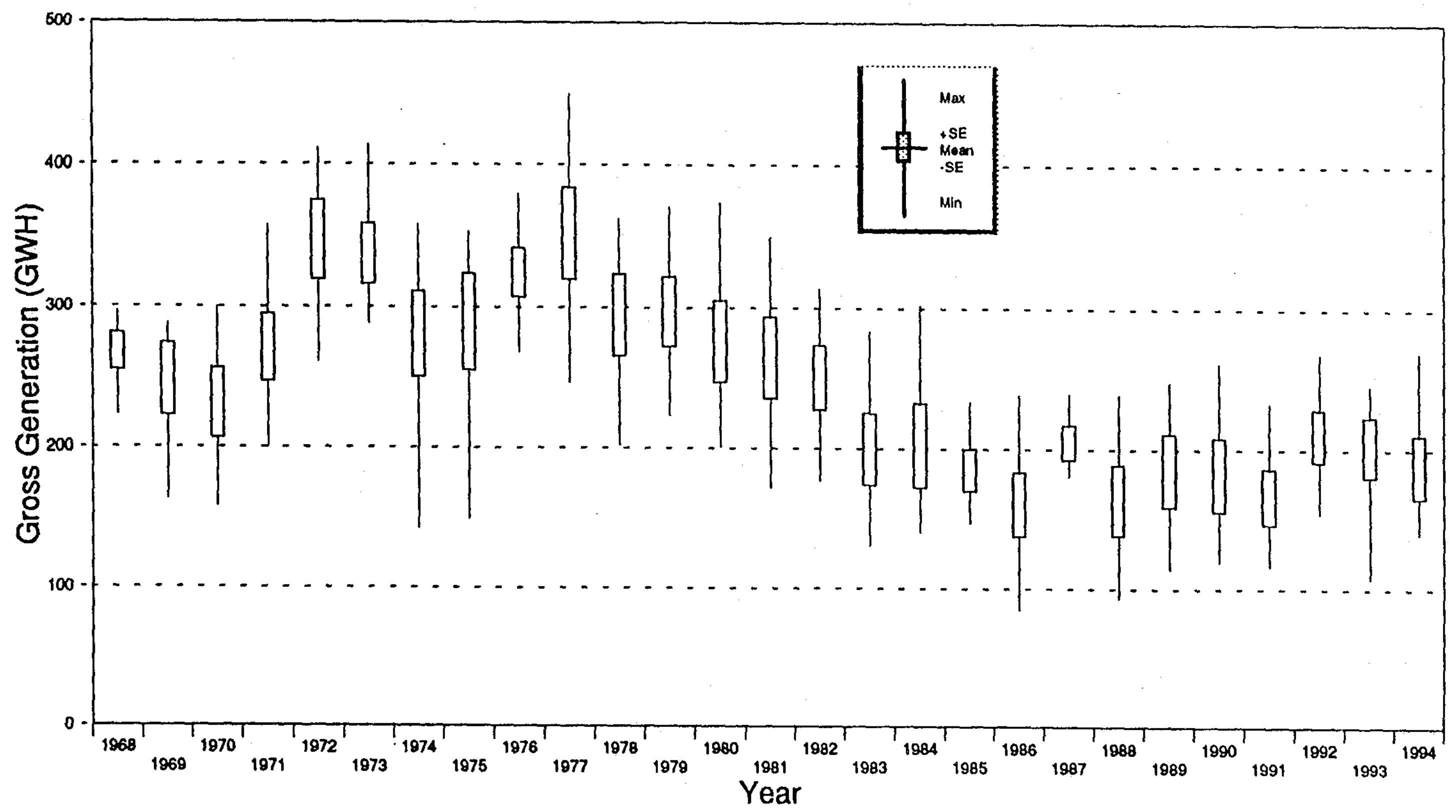


Figure 3-1. Actual average, minimum, and maximum generation for South Bay Power Plant, 1968-1994.

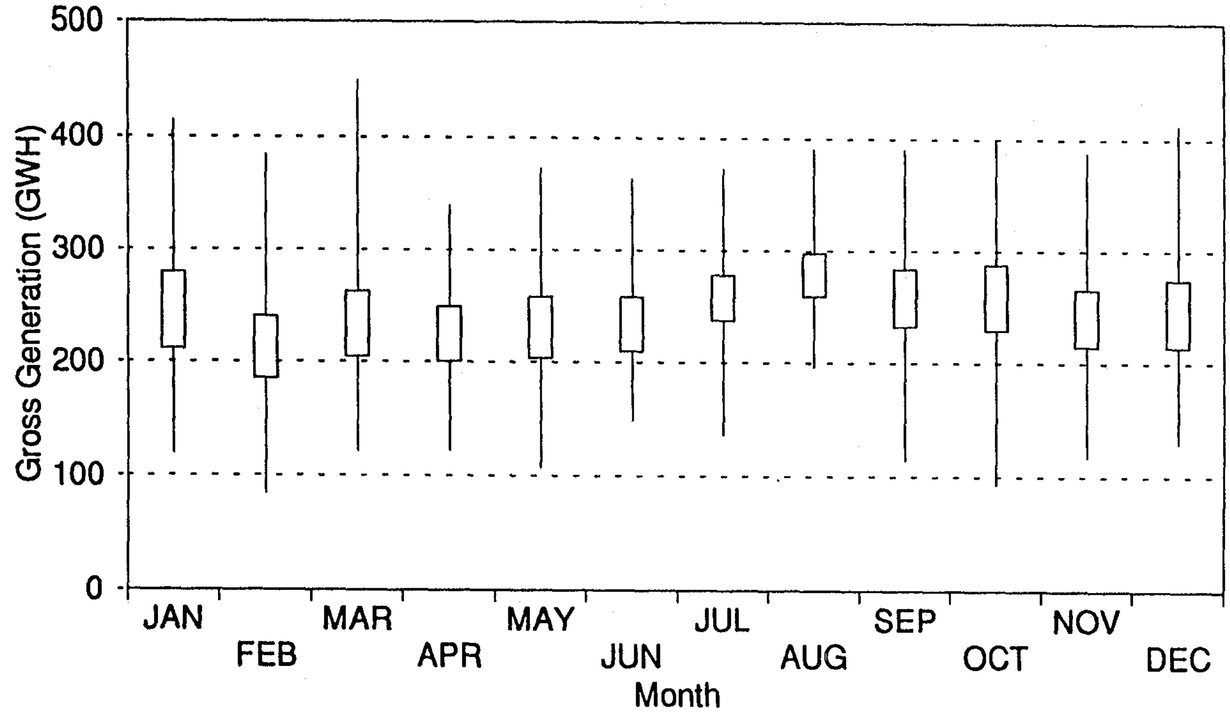


Figure 3-2. Average, minimum, and maximum generation by month for the period 1968-1994 for South Bay Power Plant.

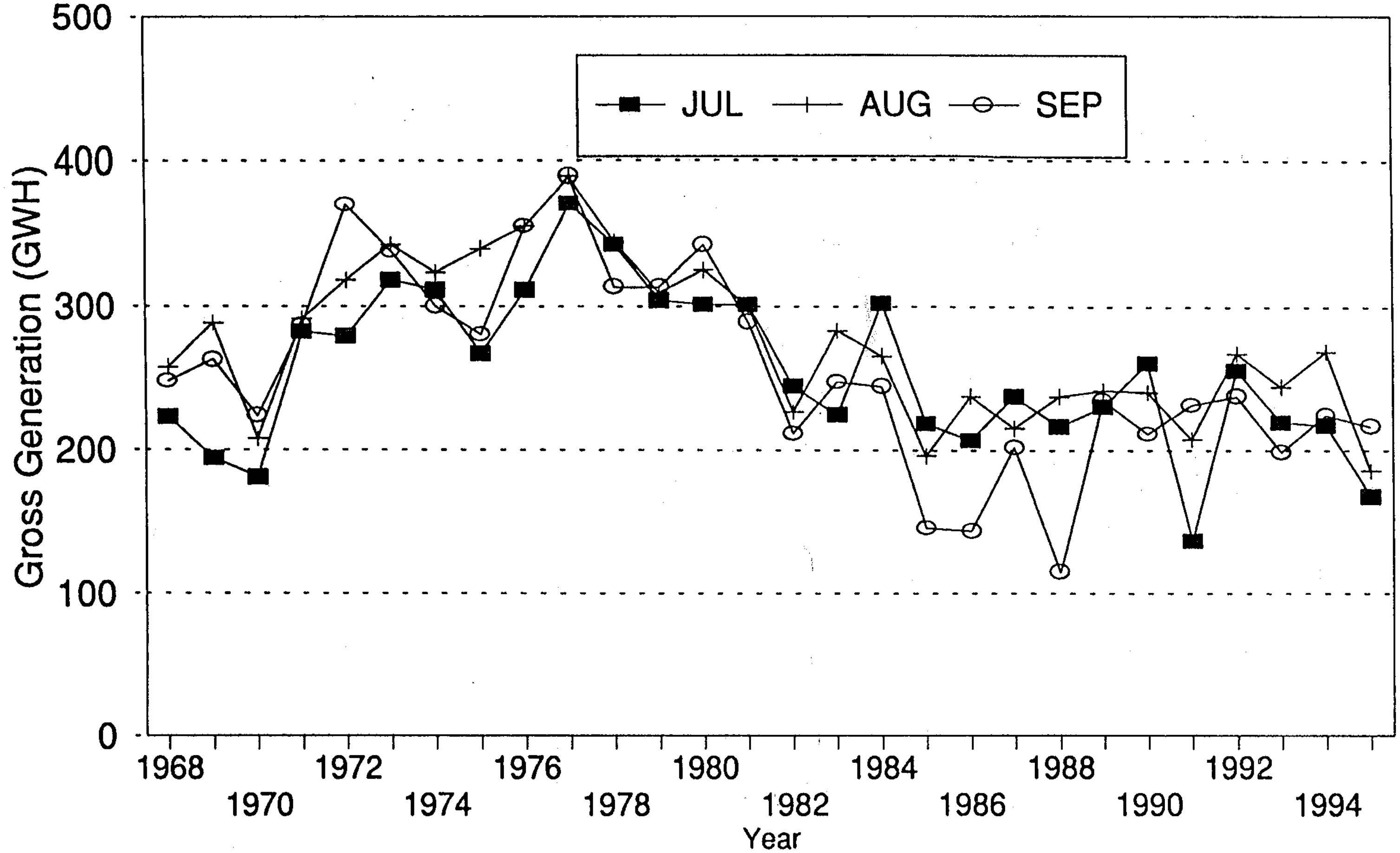


Figure 3-3. Actual and projected monthly gross generation for the period 1968-1994 for South Bay Power Plant.

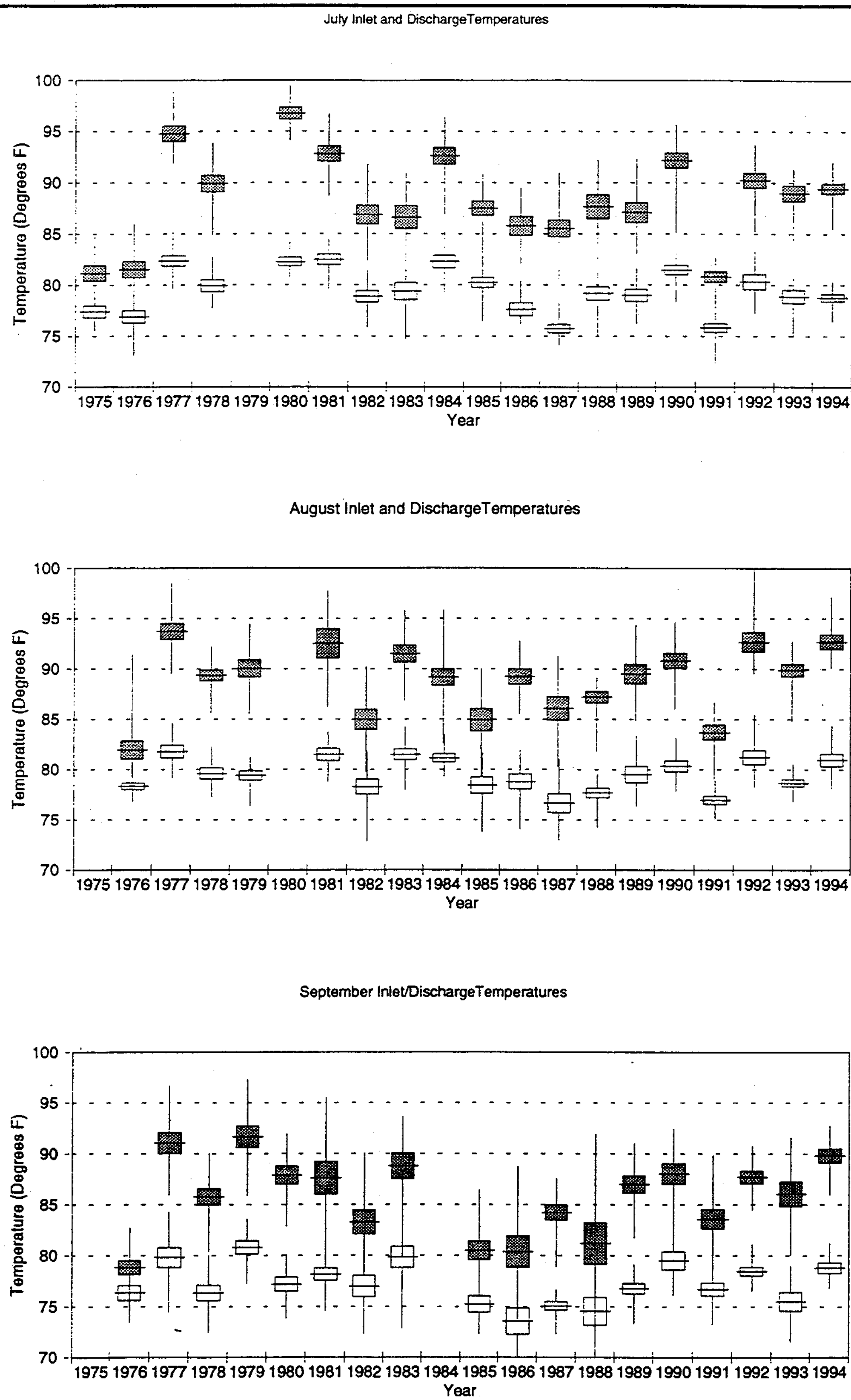


Figure 3-4. Mean and extreme summer intake and discharge temperatures for the years 1975-1994.

Figure 3-5. Water surface temperature in South San Diego Bay, 11:00 a.m., 26 September 1963 (two units operating).

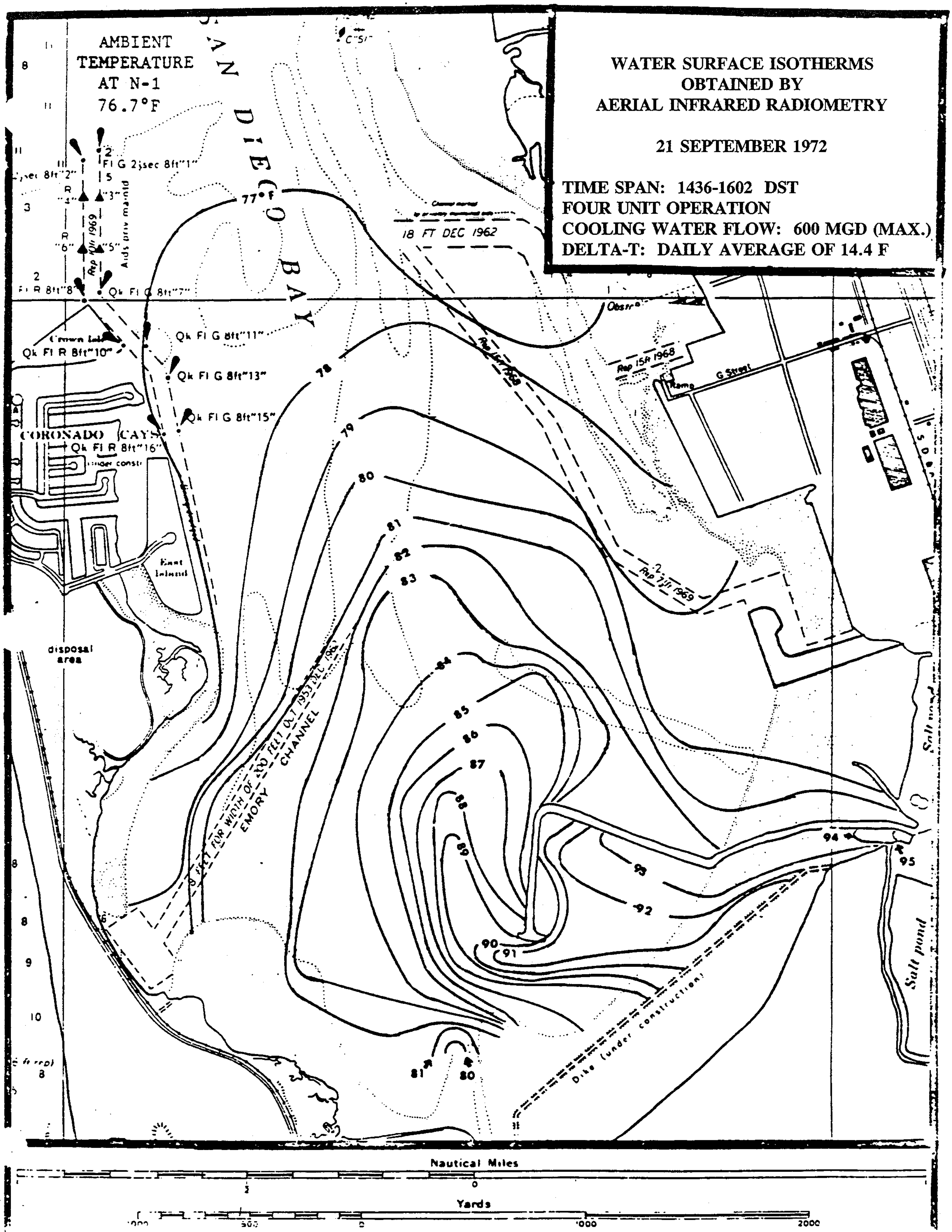


Figure 3-6. Water surface isotherms obtained by aerial infrared radiometry, 21 September 1972 (Chambers and Chambers 1973).

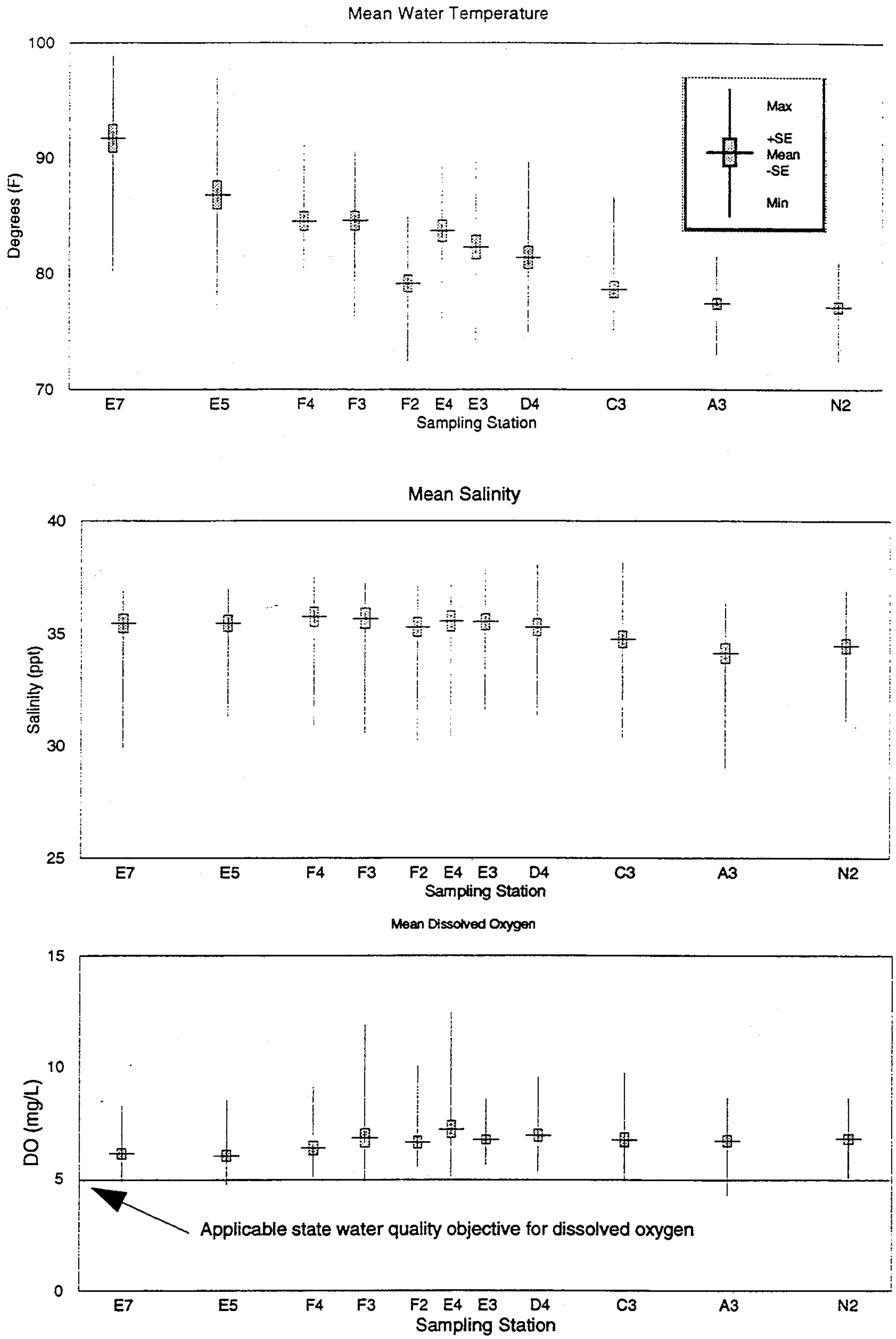
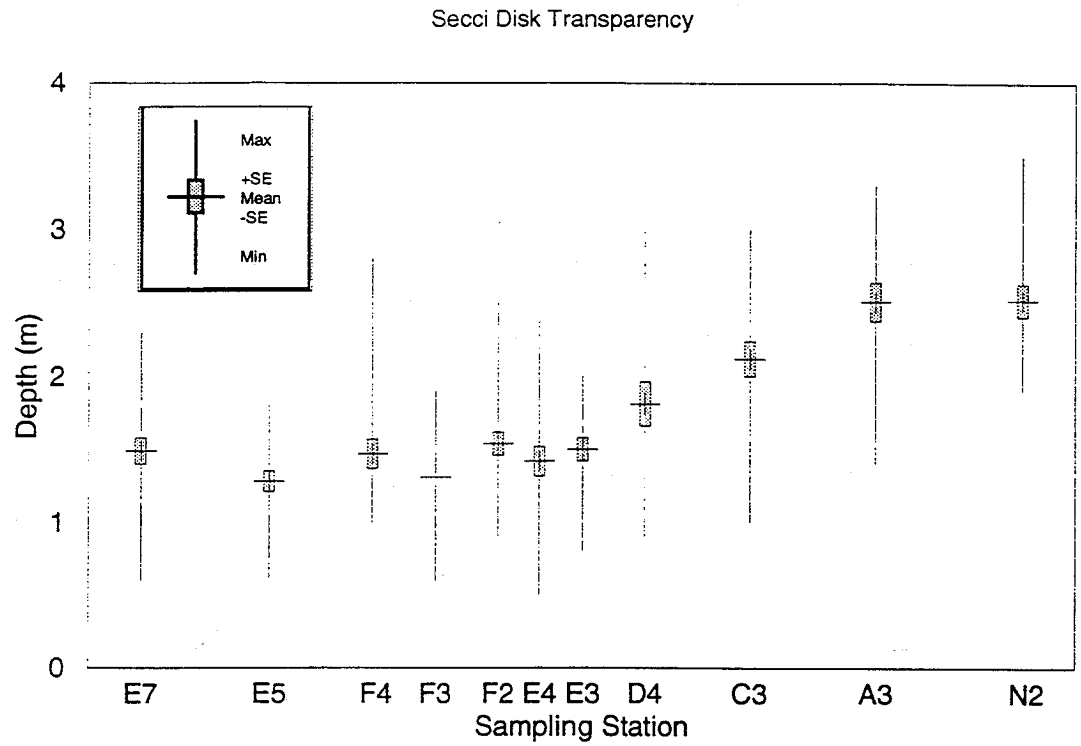


Figure 3-7. Distribution of mean water temperature, salinity, dissolved oxygen, transparency, and air temperature with respect to sampling station for the 1977-1994 South Bay Power Plant receiving water monitoring program.



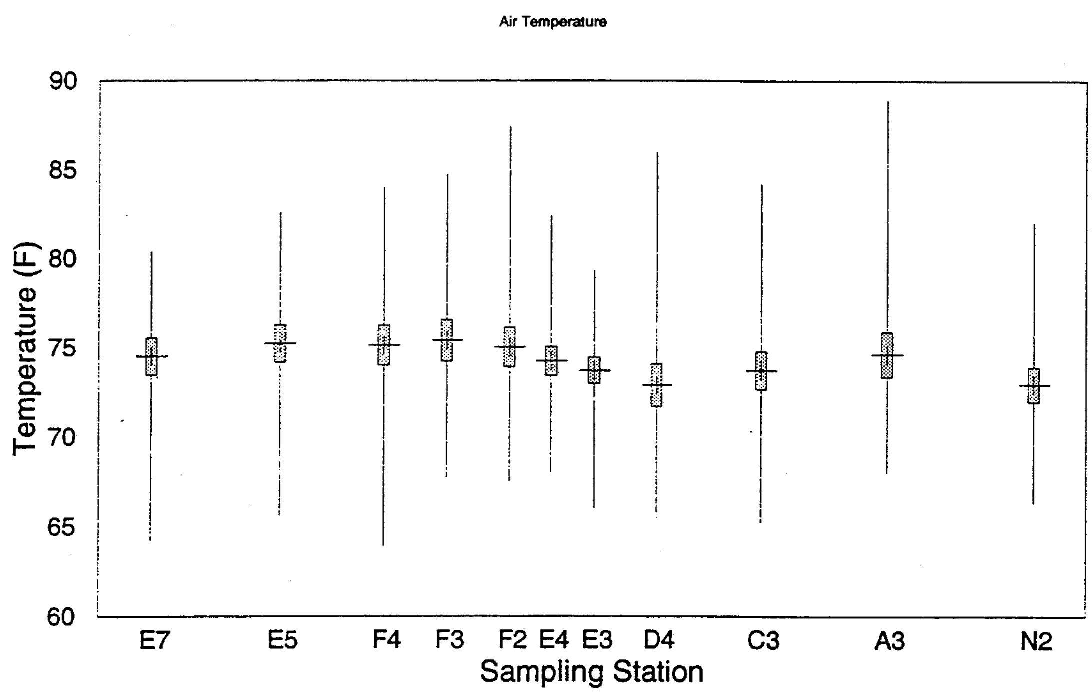


Figure 3-7. Continued.

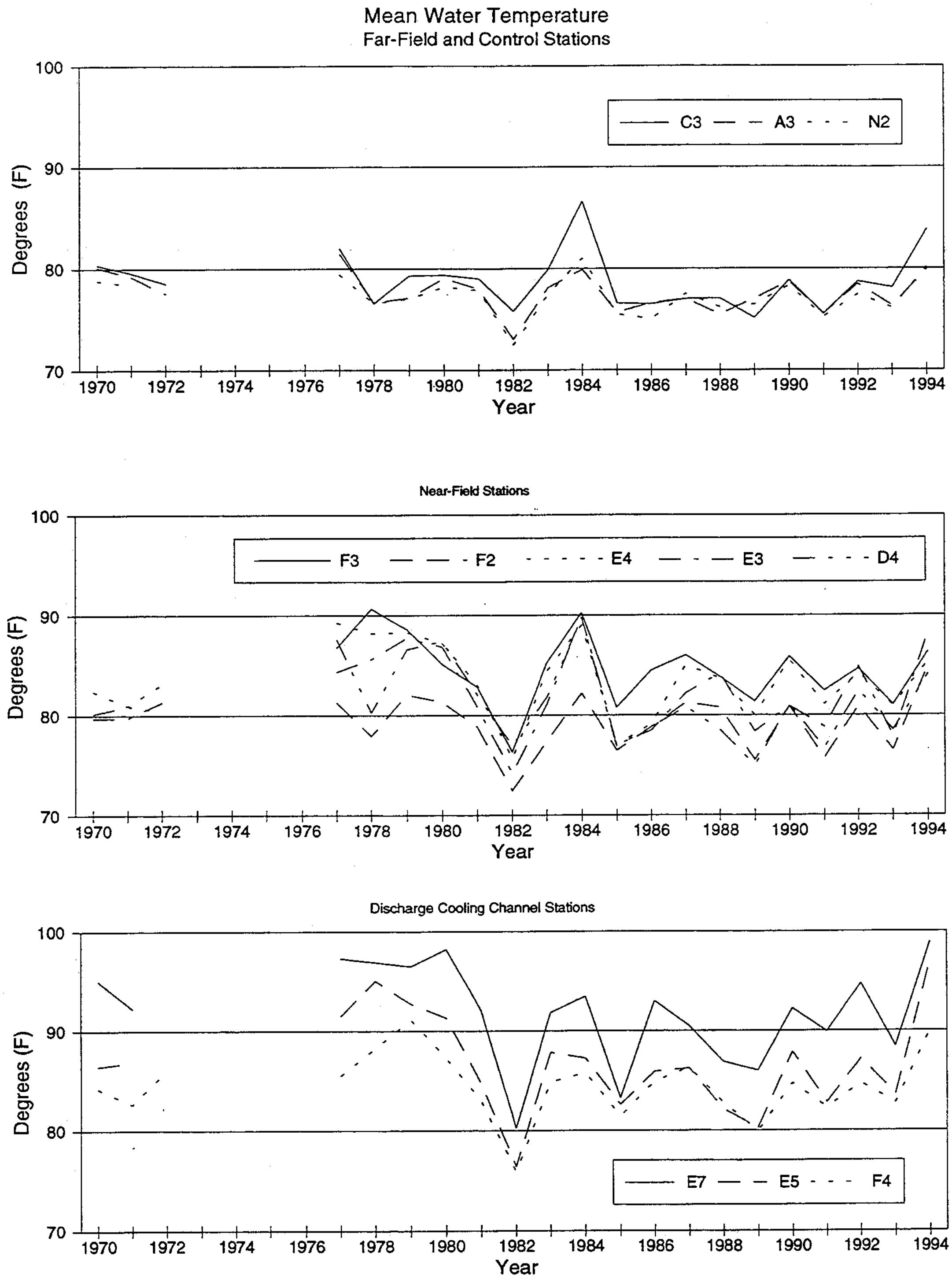


Figure 3-8. Mean water temperature by year and station from the South Bay Power Plant receiving water monitoring program, 1970-1994.

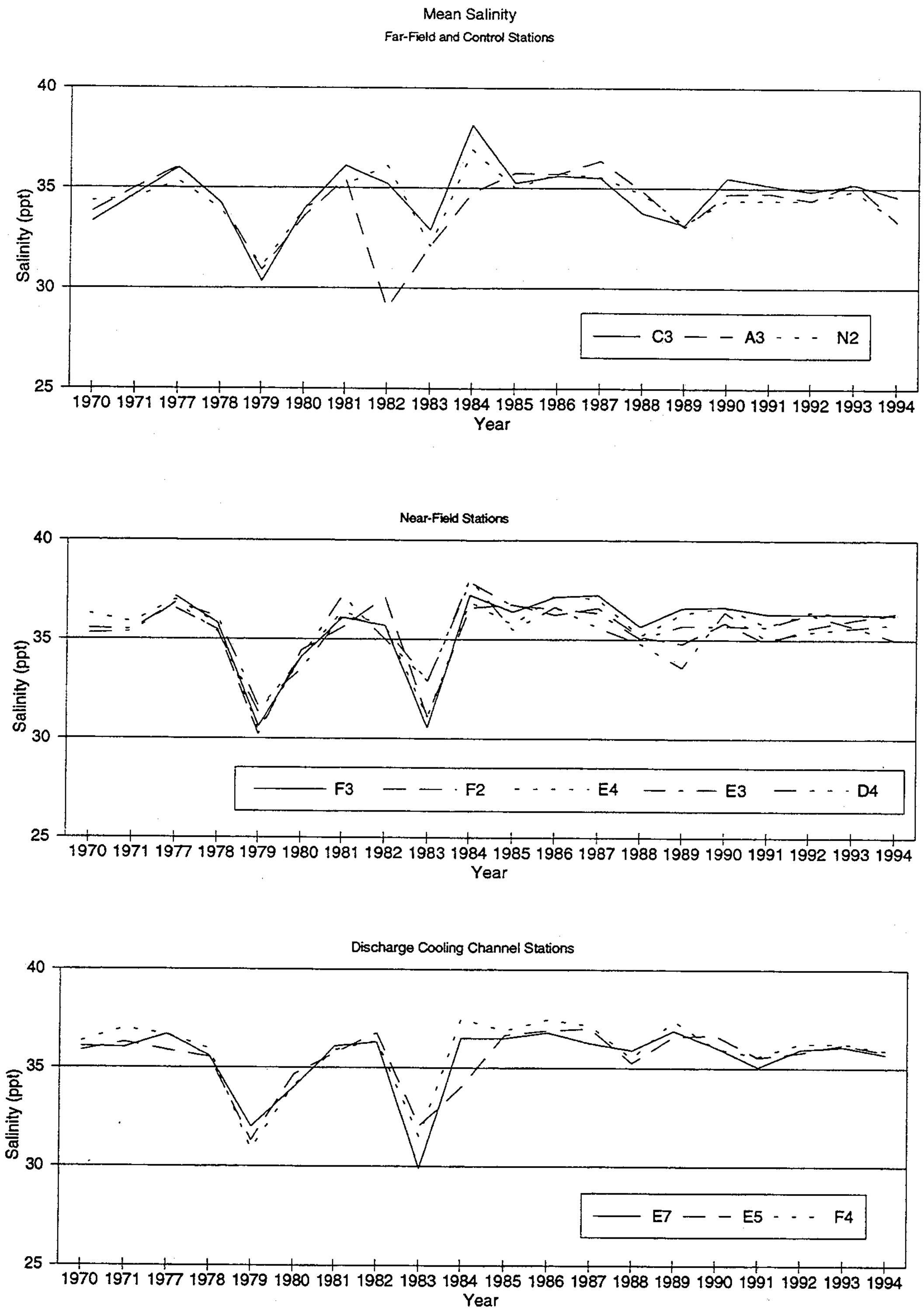


Figure 3-9. Mean salinity by year and station from the South Bay Power Plant receiving water monitoring program, 1970-1994.

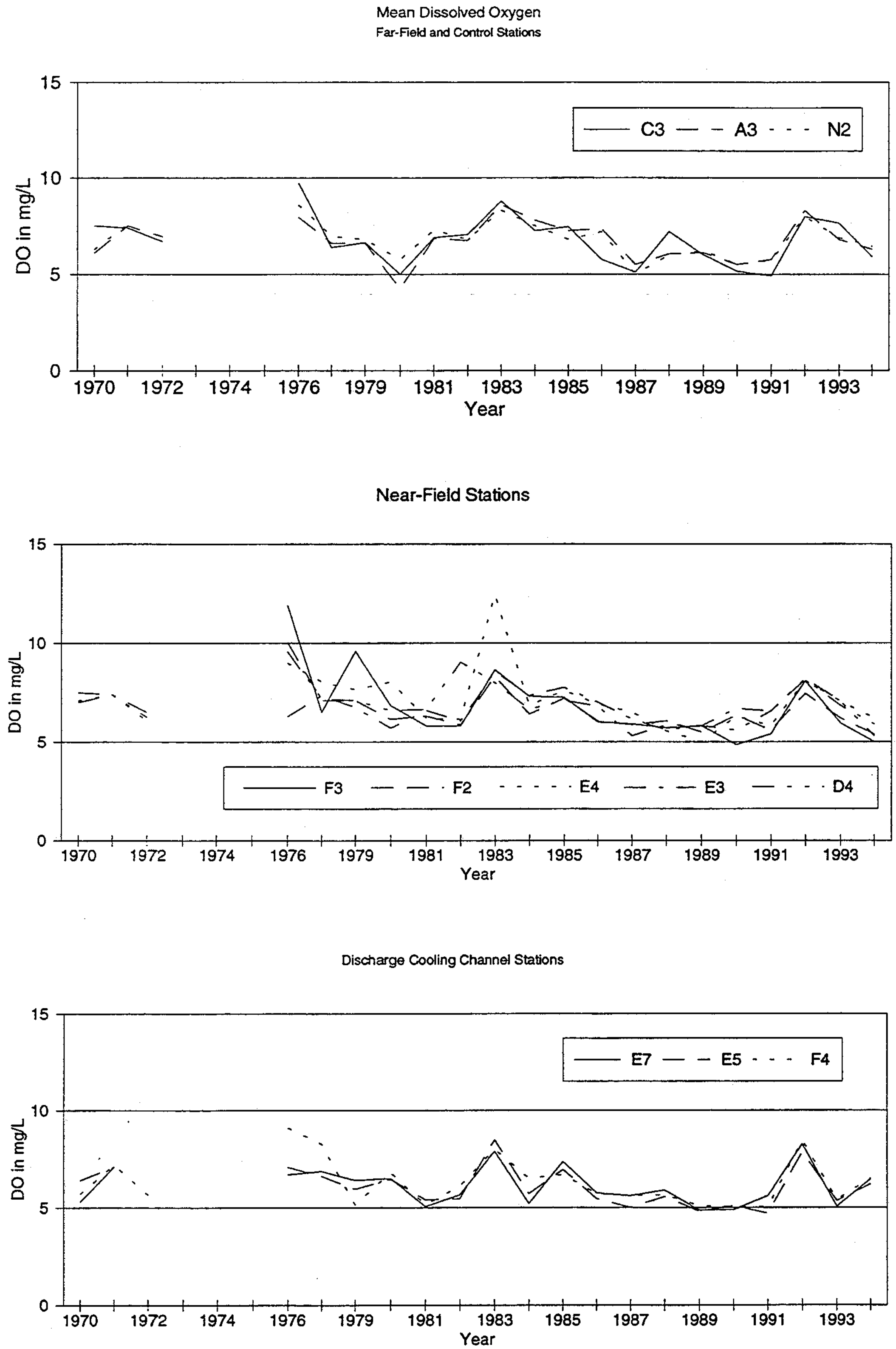


Figure 3-10. Mean dissolved oxygen by year and station from the South Bay Power Plant receiving water monitoring program, 1970-1994.

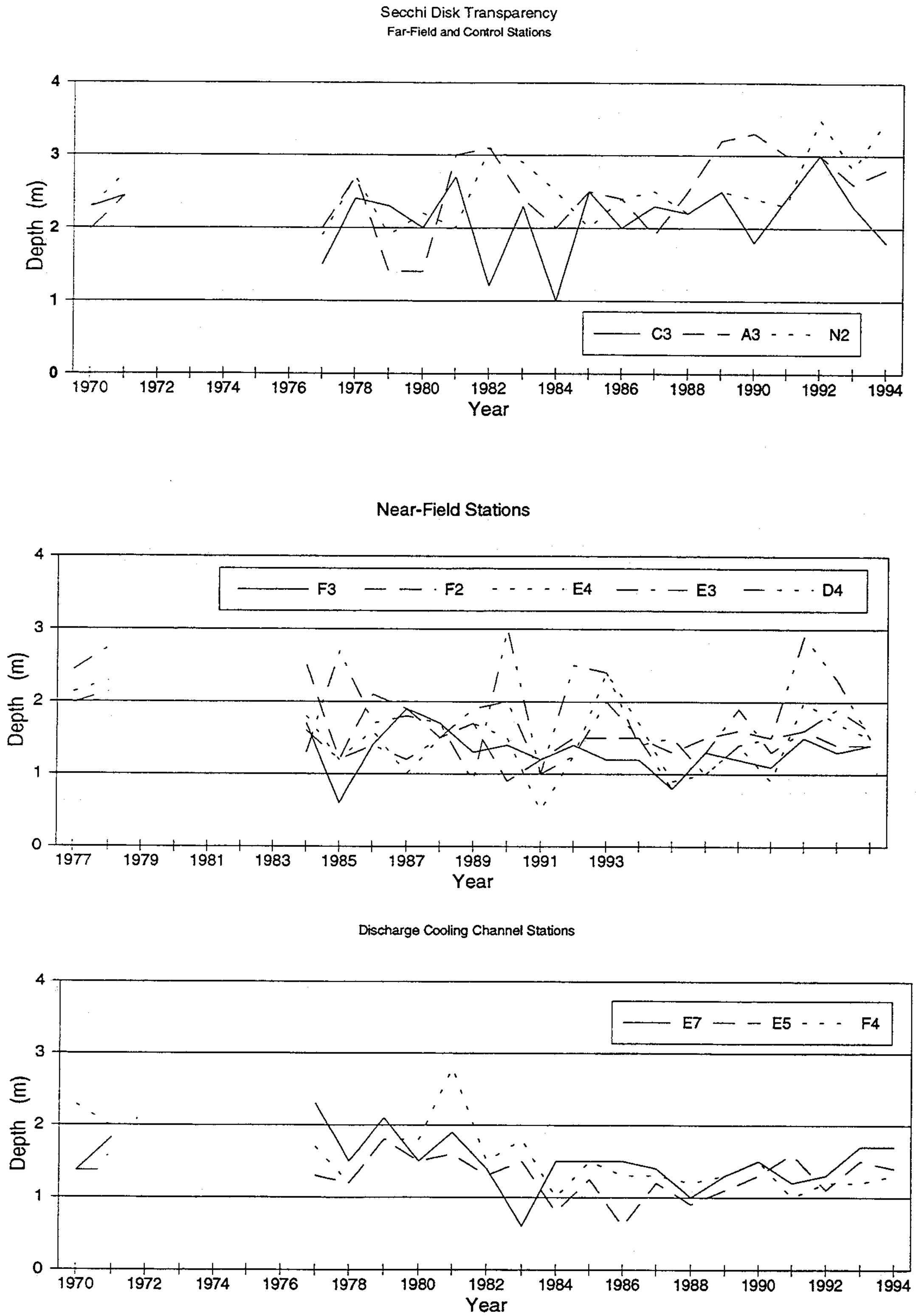


Figure 3-11. Transparency as measured by Secchi disk by year and station from the South Bay Power Plant receiving water monitoring program, 1970-1994.

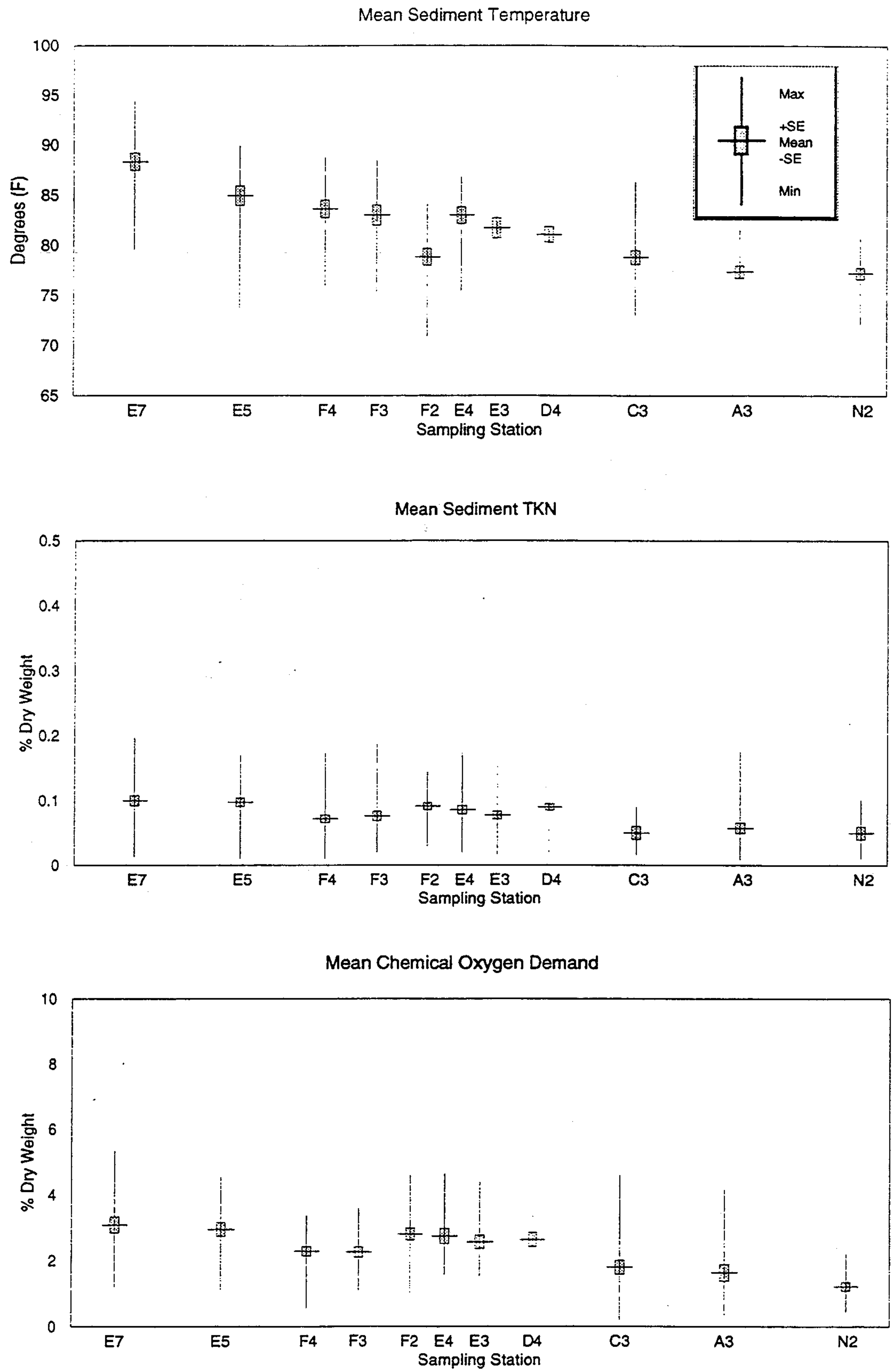


Figure 3-12. Distribution of sediment temperature, chemical oxygen demand, and total Kjedahal nitrogen with respect to sampling station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

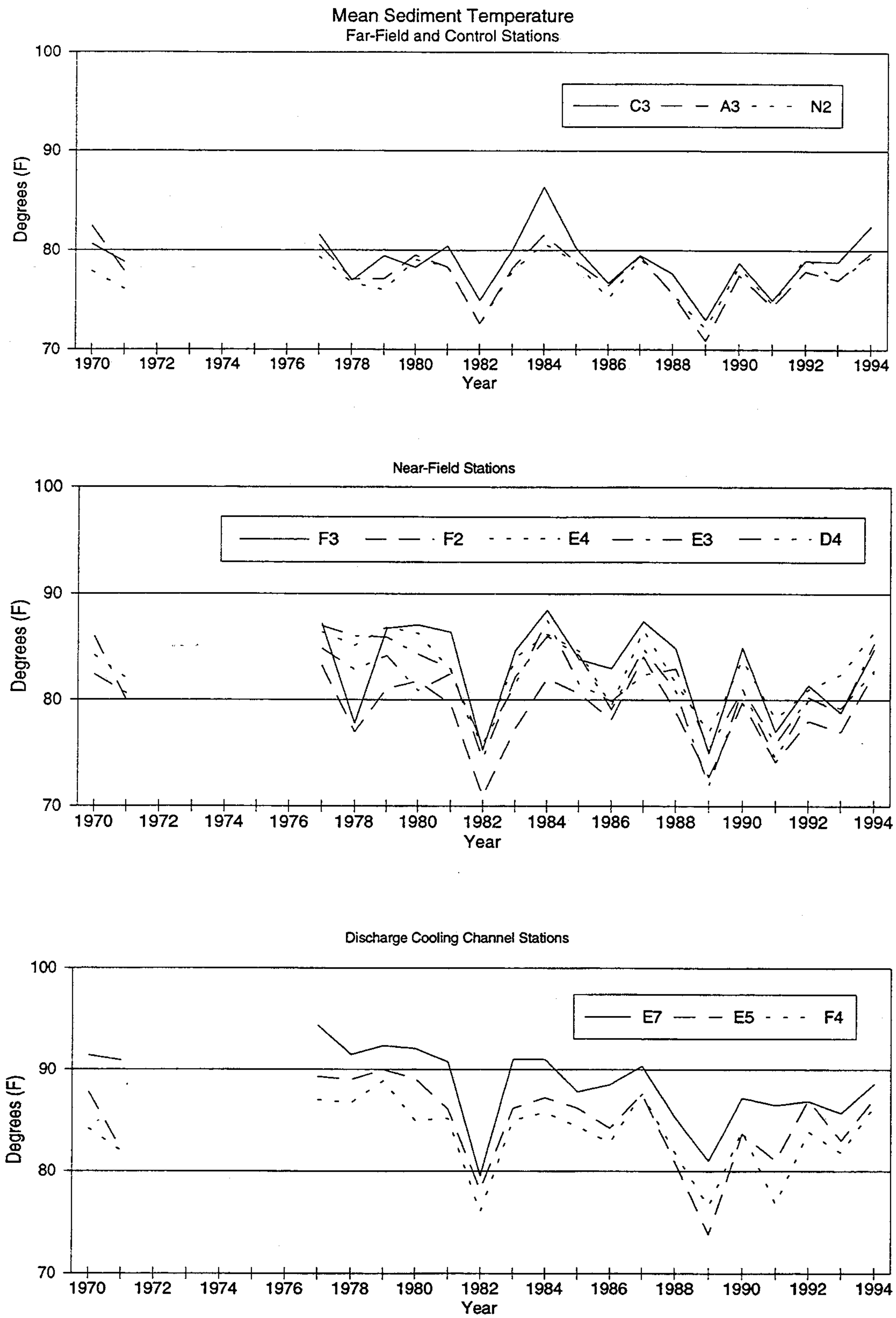


Figure 3-13. Mean sediment temperature by year and station from the South Bay Power Plant receiving water monitoring program, 1970-1994.

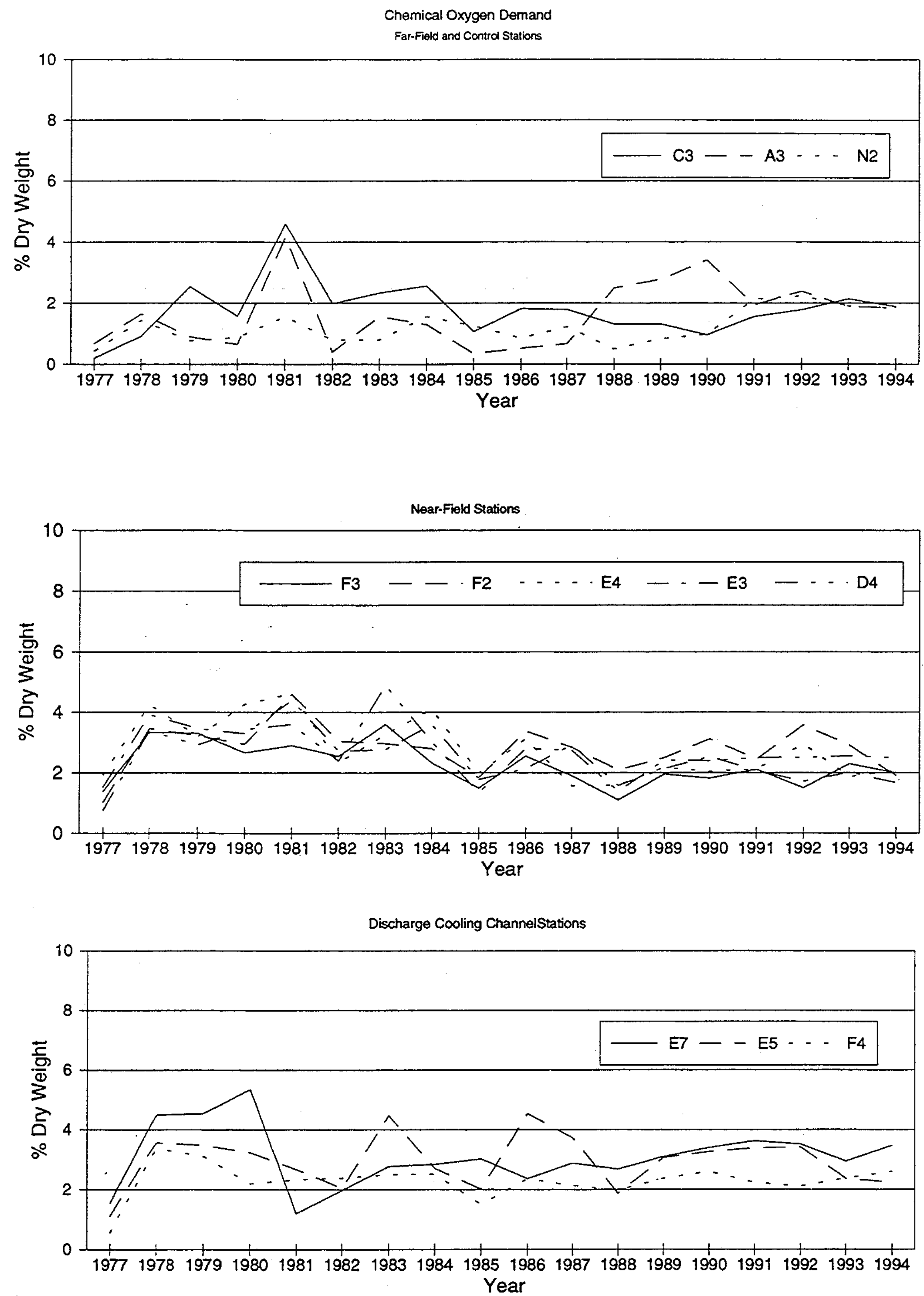


Figure 3-14. Mean sediment chemical oxygen demand by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

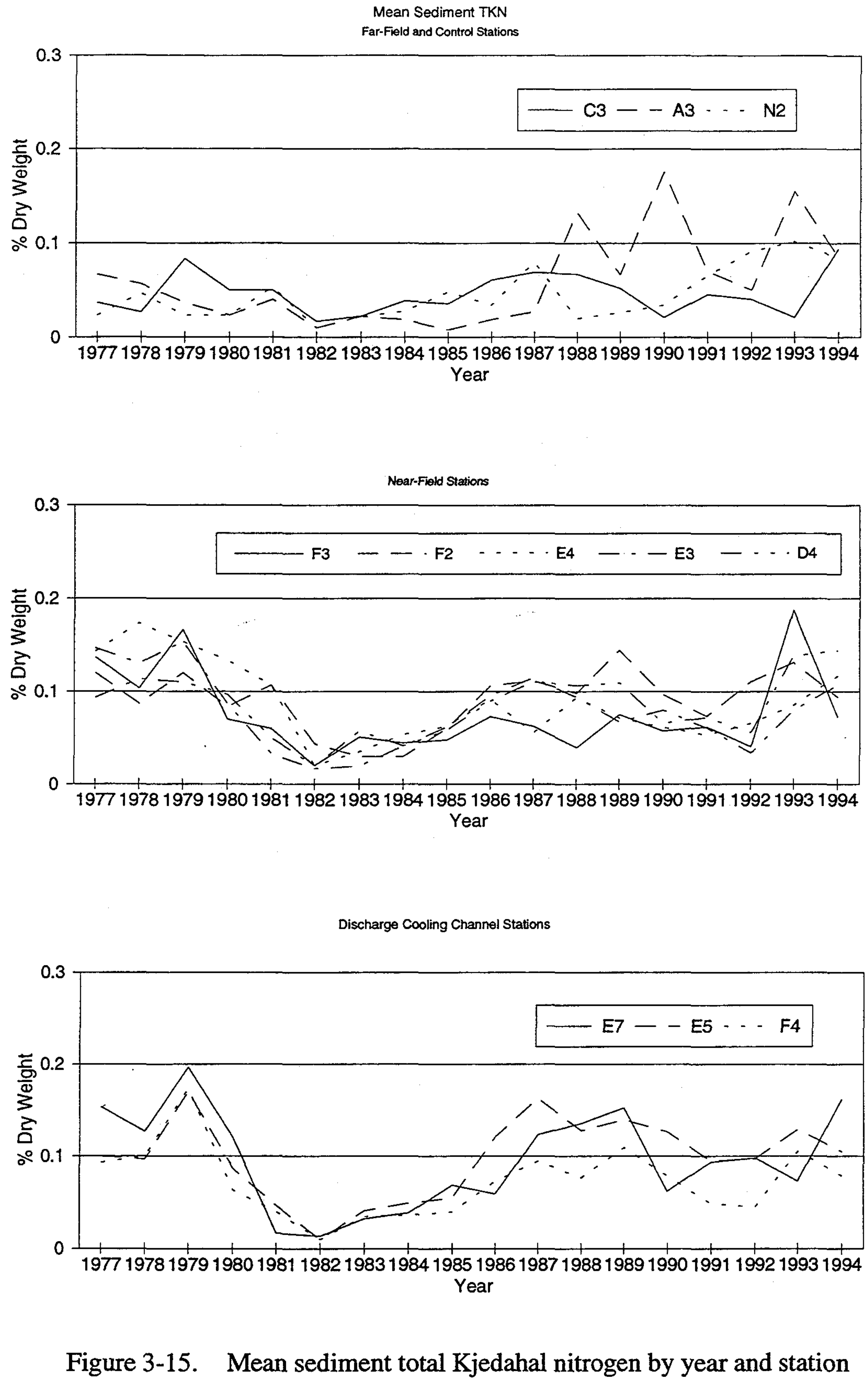


Figure 3-15. Mean sediment total Kjedahal nitrogen by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

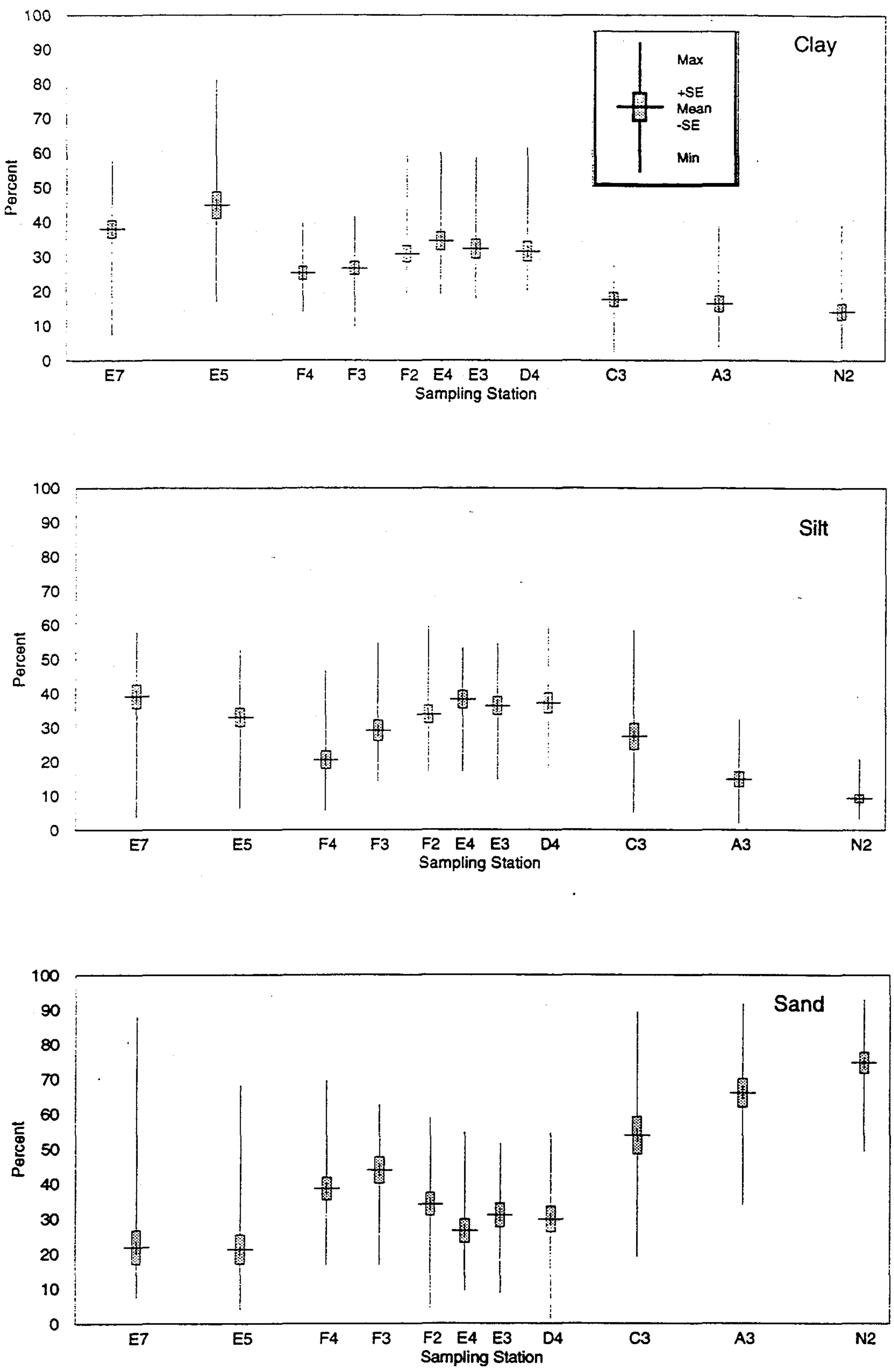


Figure 3-16. Distribution of percent clay, silt, and sand with respect to sampling station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

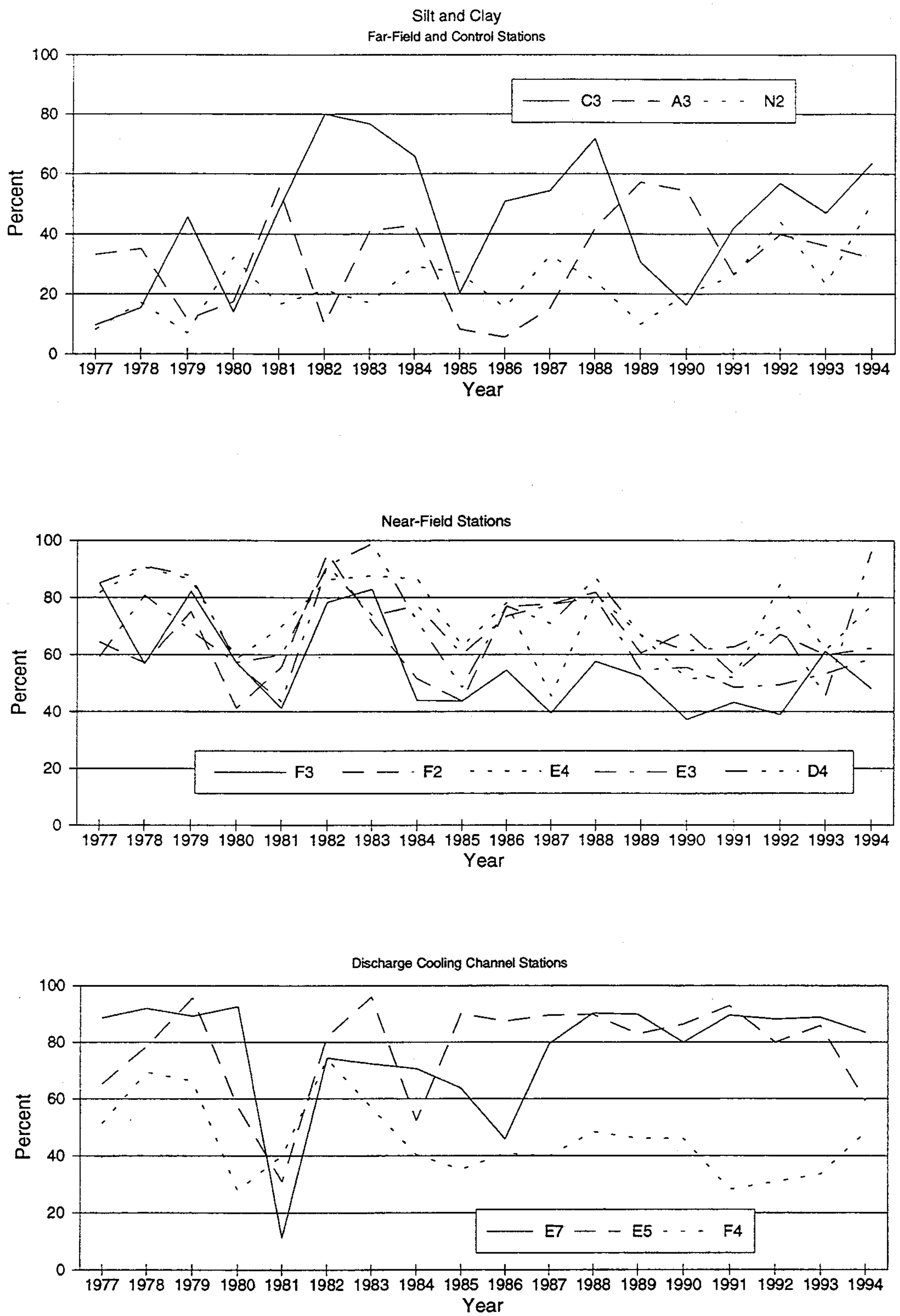


Figure 3-17. Mean percent of silt and clay in sediment by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

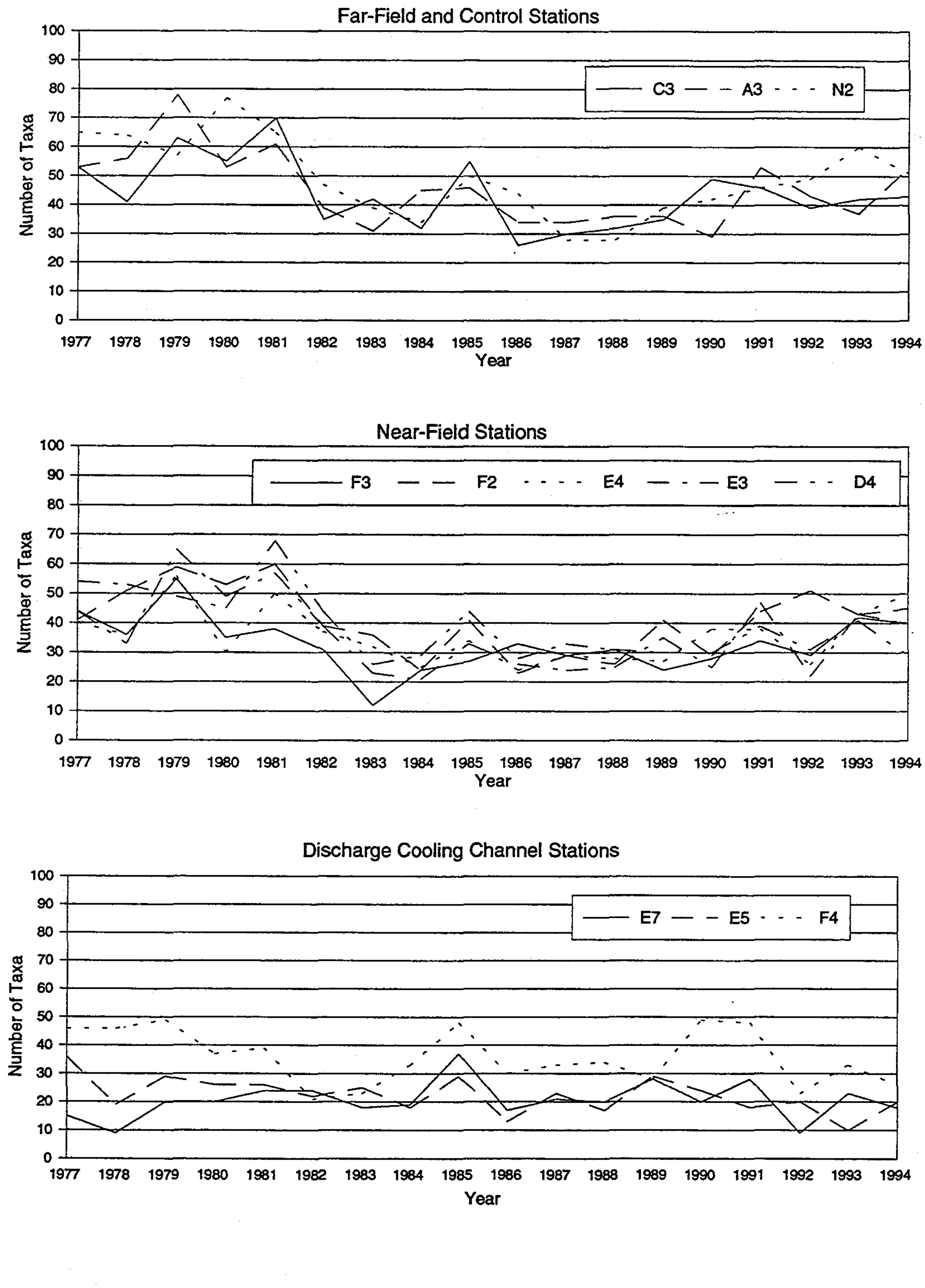


Figure 3-18. Number of benthic infauna taxa collected by year and station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

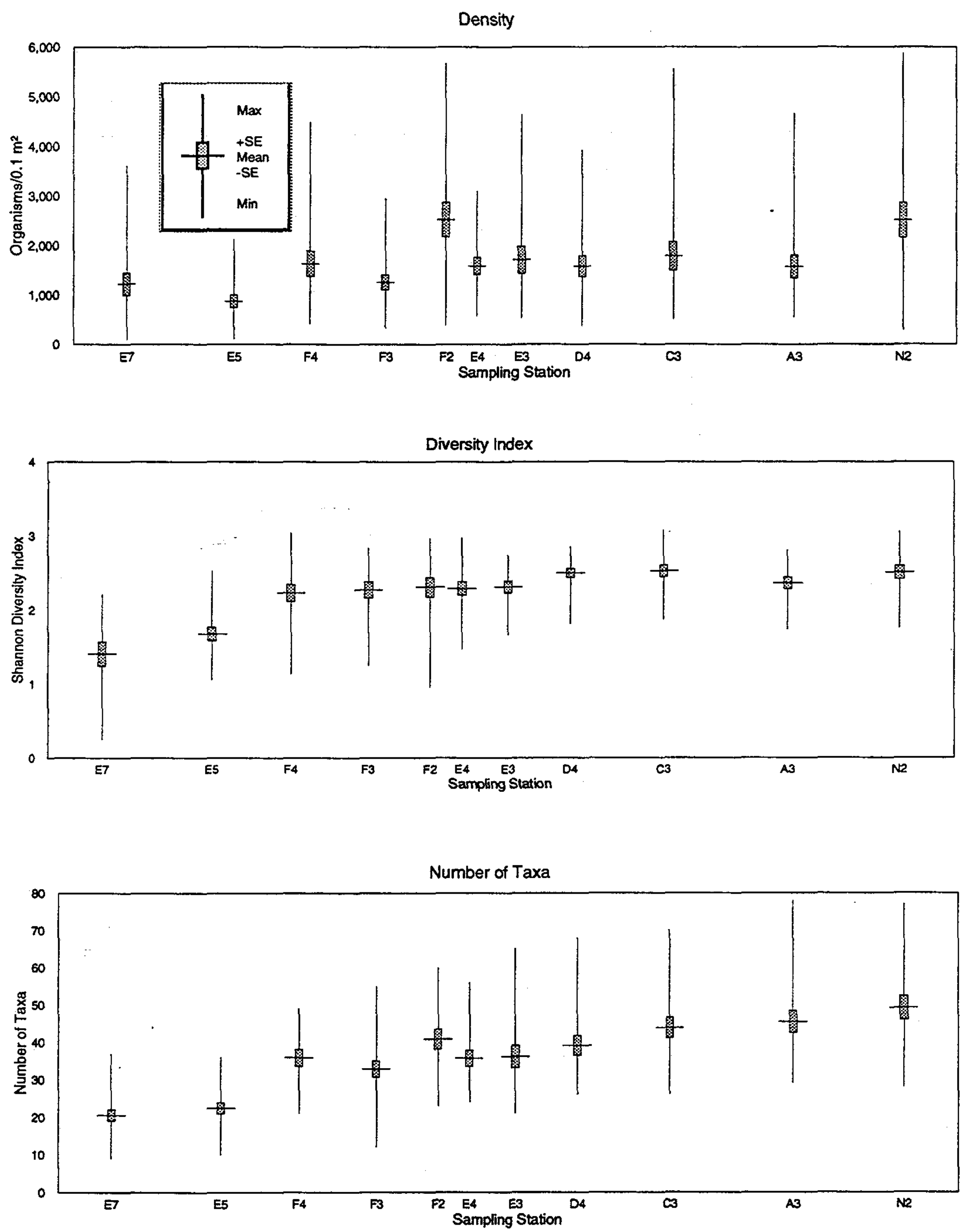


Figure 3-19. Distribution of density, diversity, and number of benthic infauna taxa with respect to sampling station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

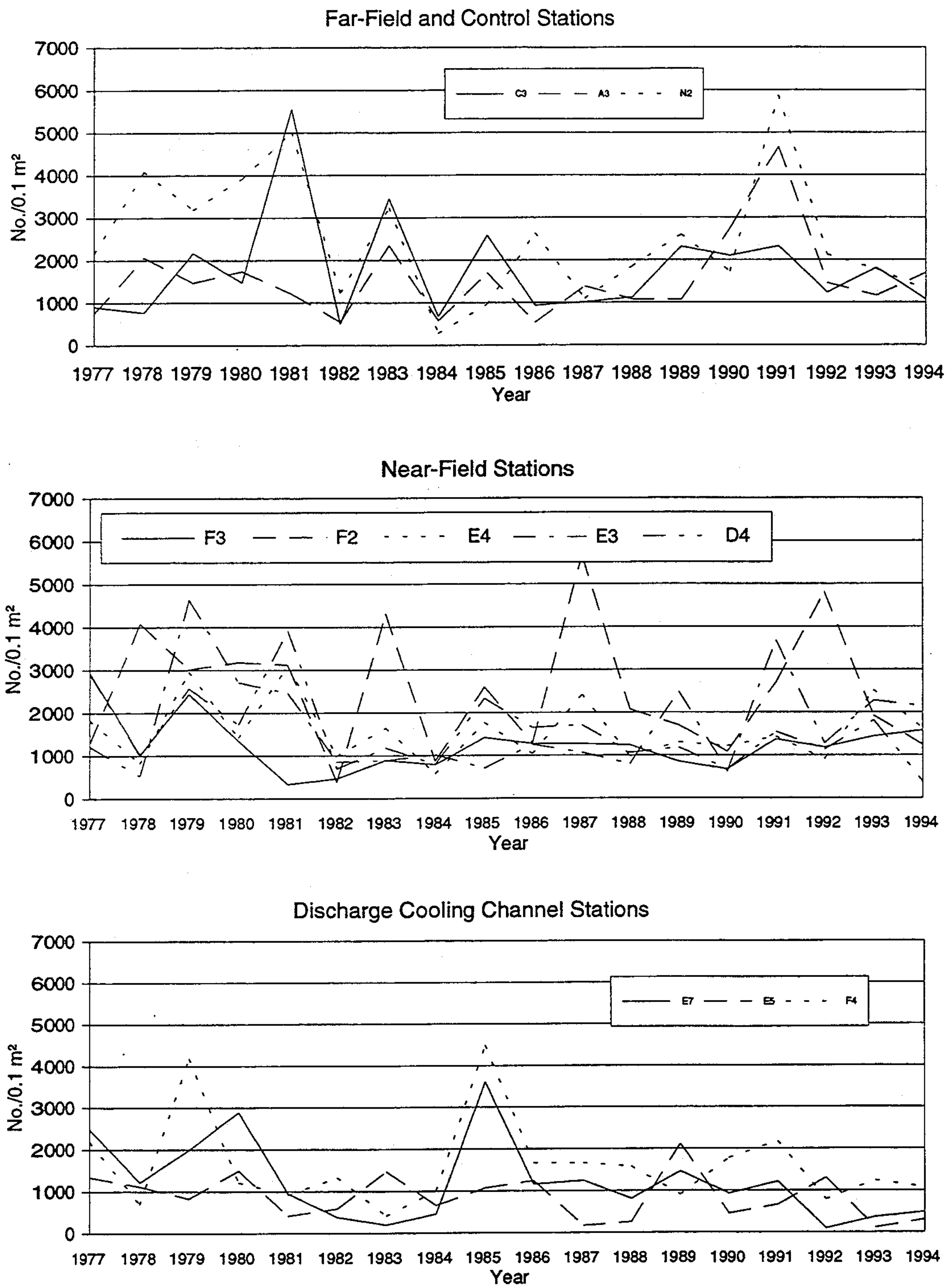


Figure 3-20. Number of benthic infauna by year and station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

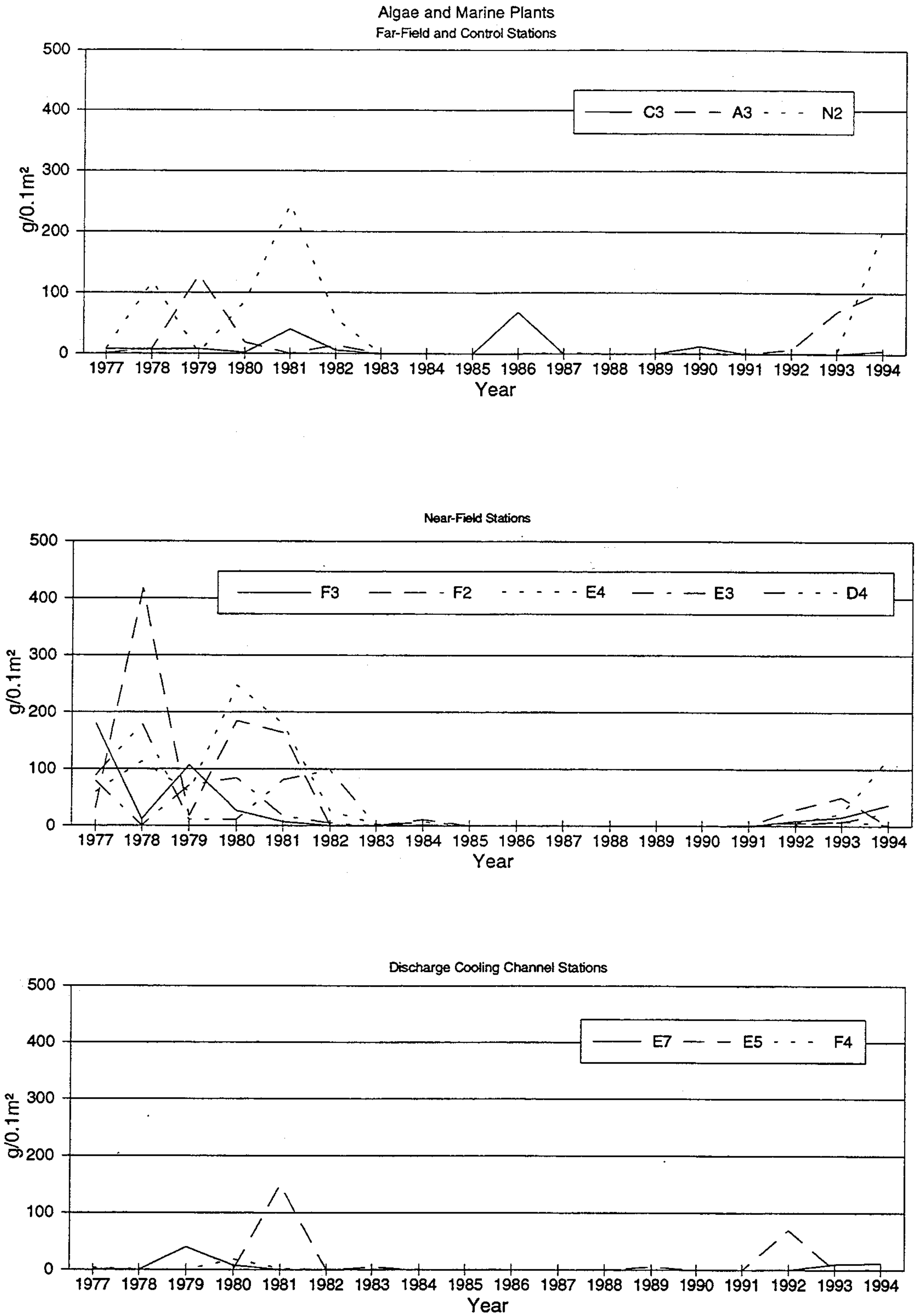


Figure 3-21. Density of algae and marine plant biomass by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

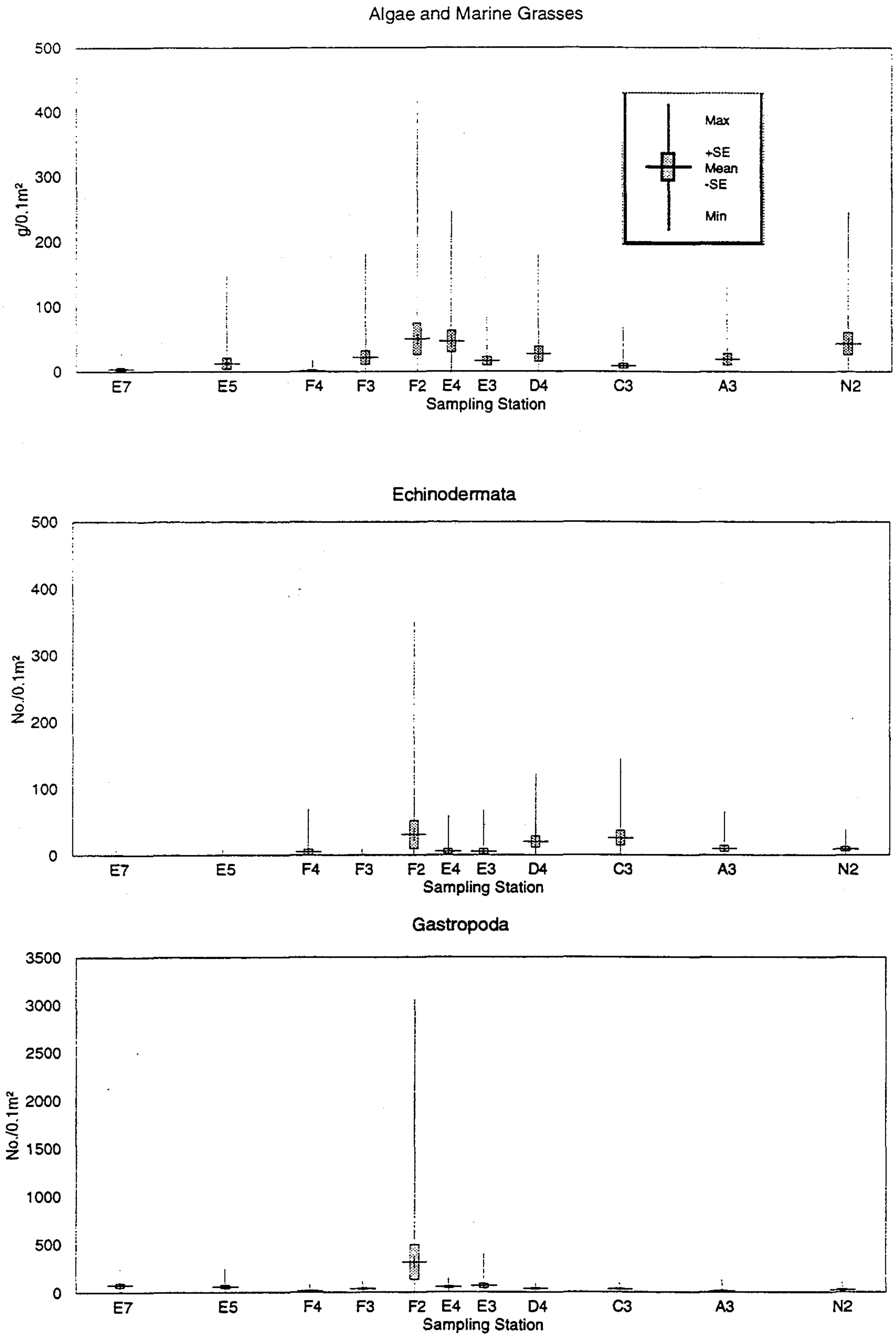


Figure 3-22. Distribution of algae and marine grasses, echinoderms, and gastropods with respect to sampling station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

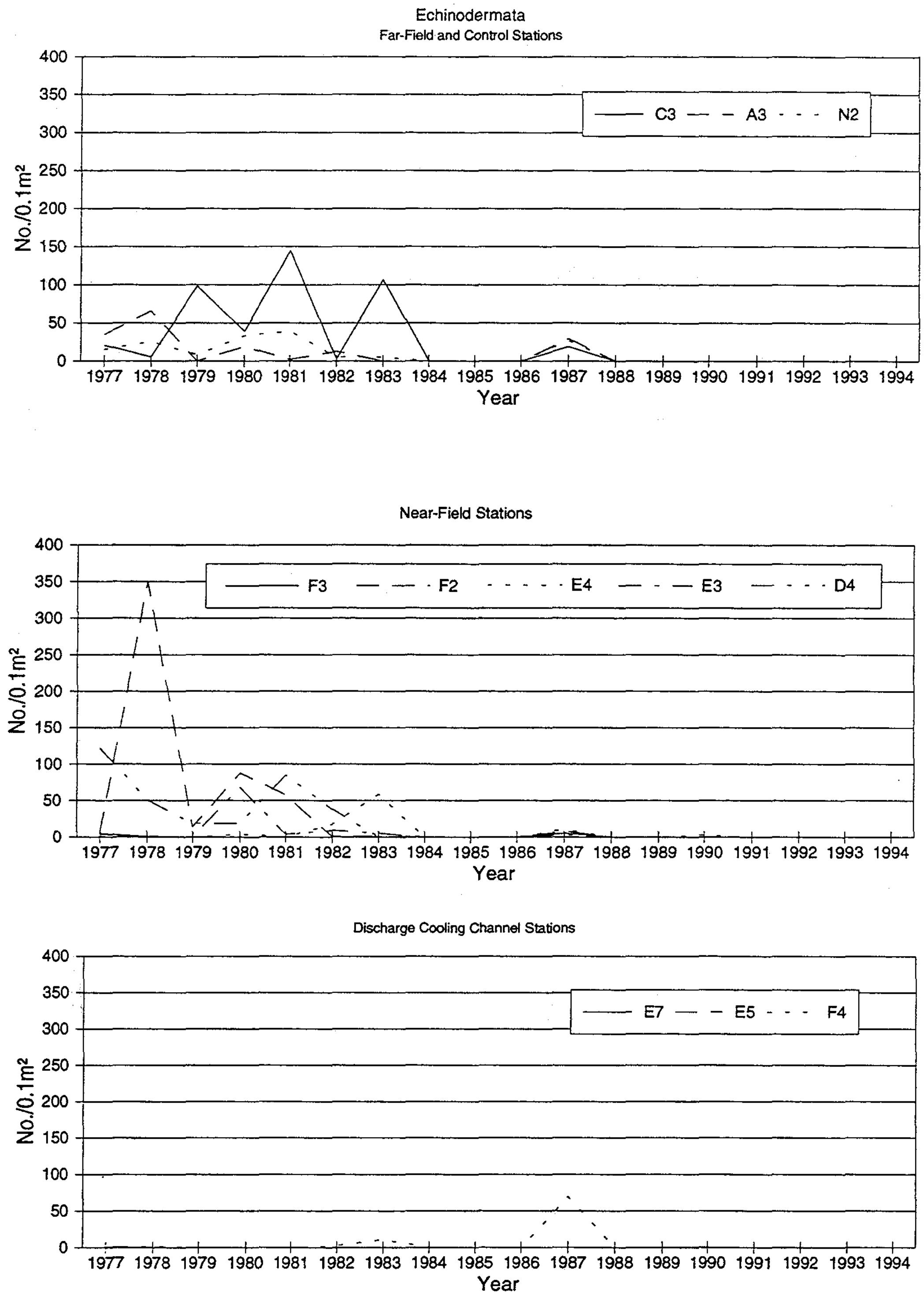


Figure 3-23. Density of echinoderms by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

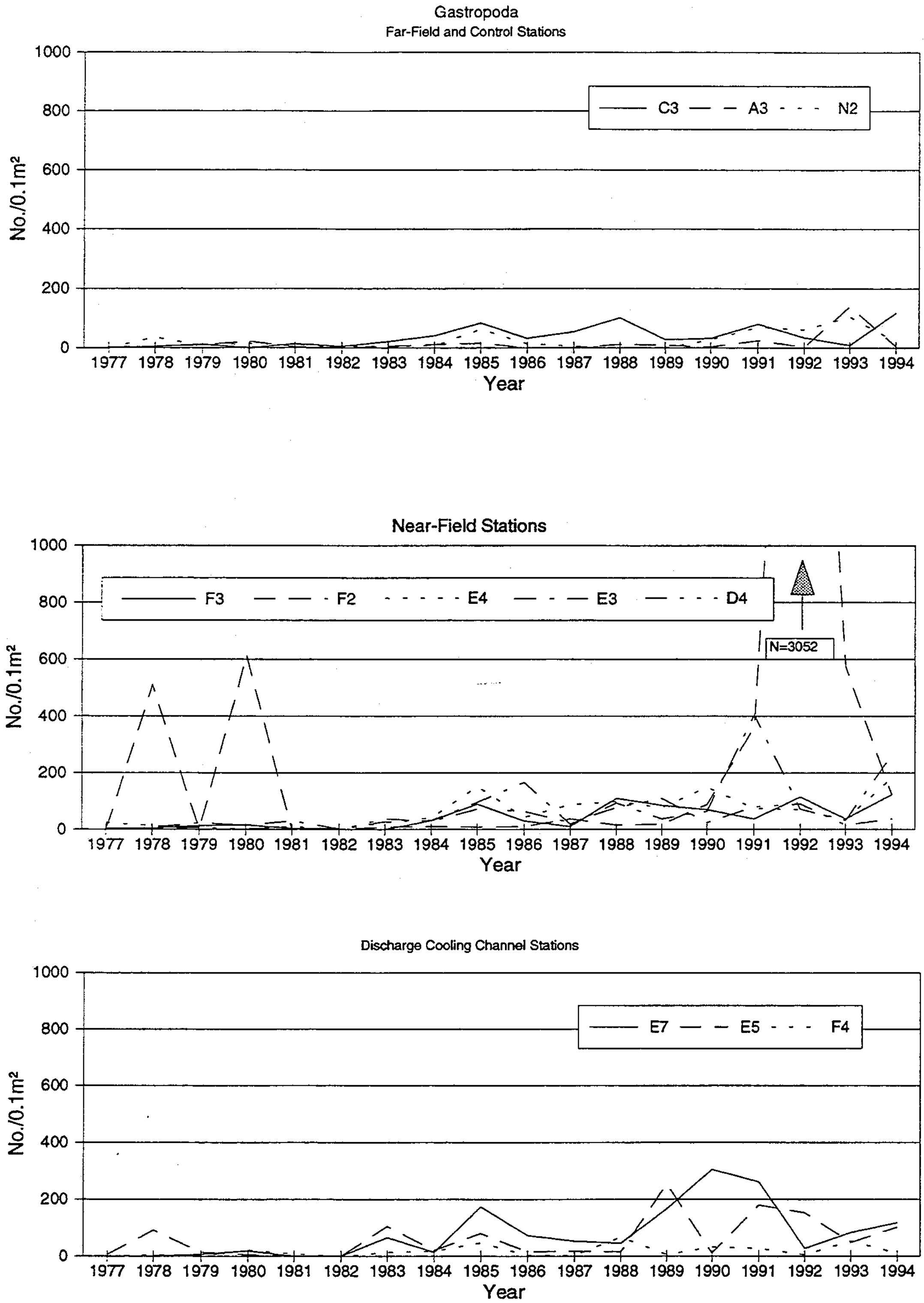


Figure 3-24. Density of gastropods by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

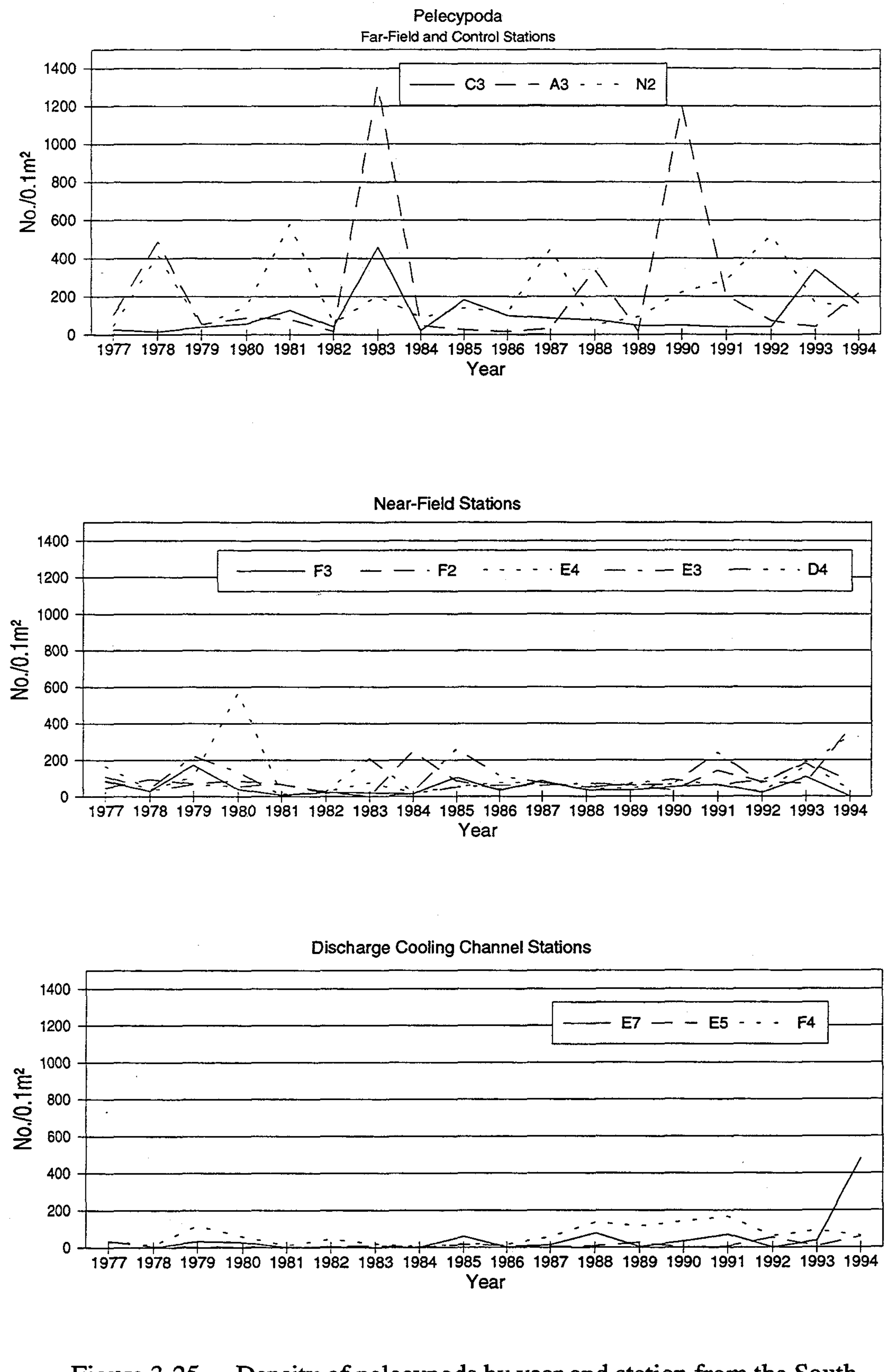


Figure 3-25. Density of pelecypods by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

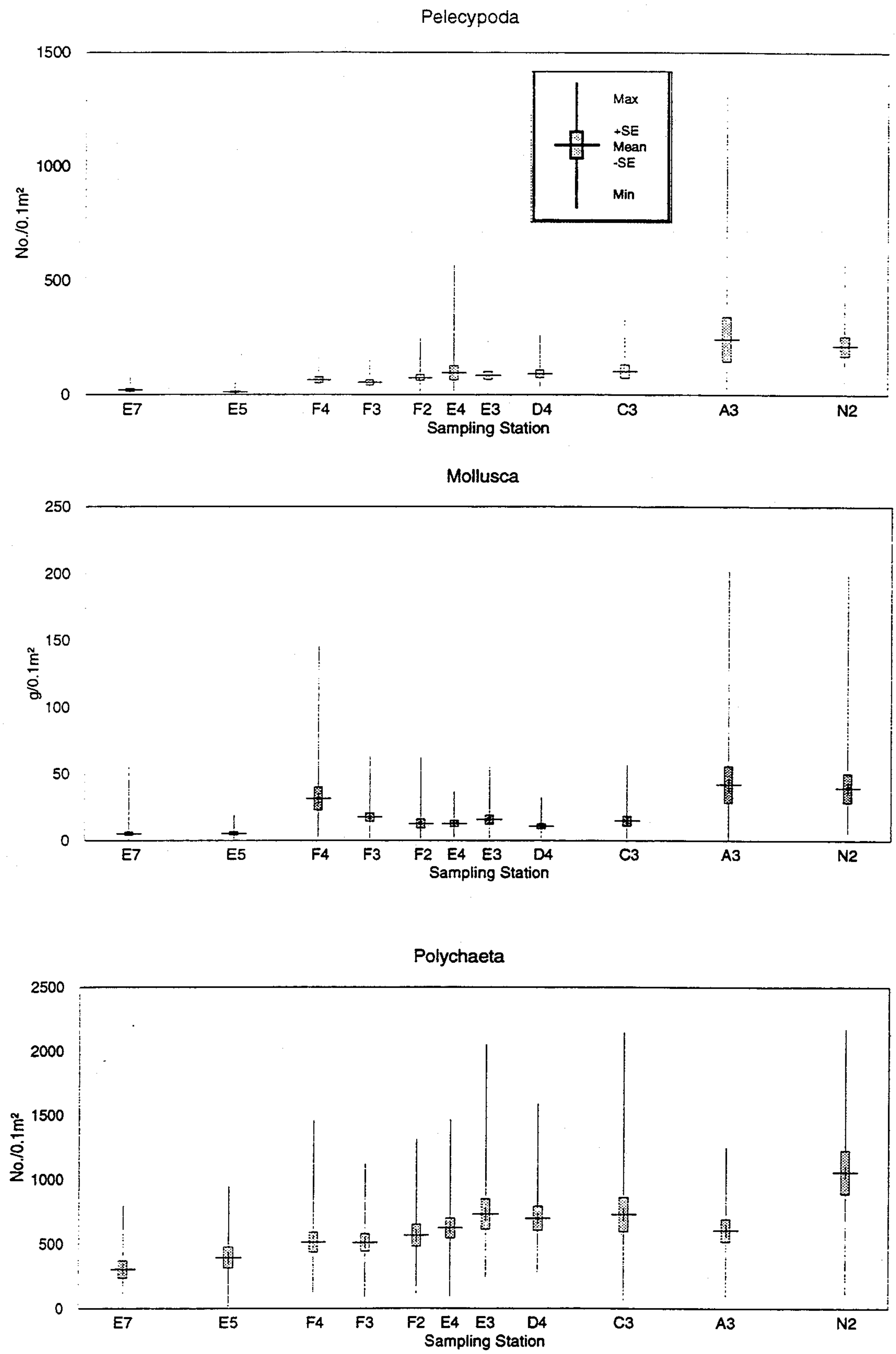


Figure 3-26. Distribution of pelecypods, molluscs, and polychaetes with respect to sampling station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

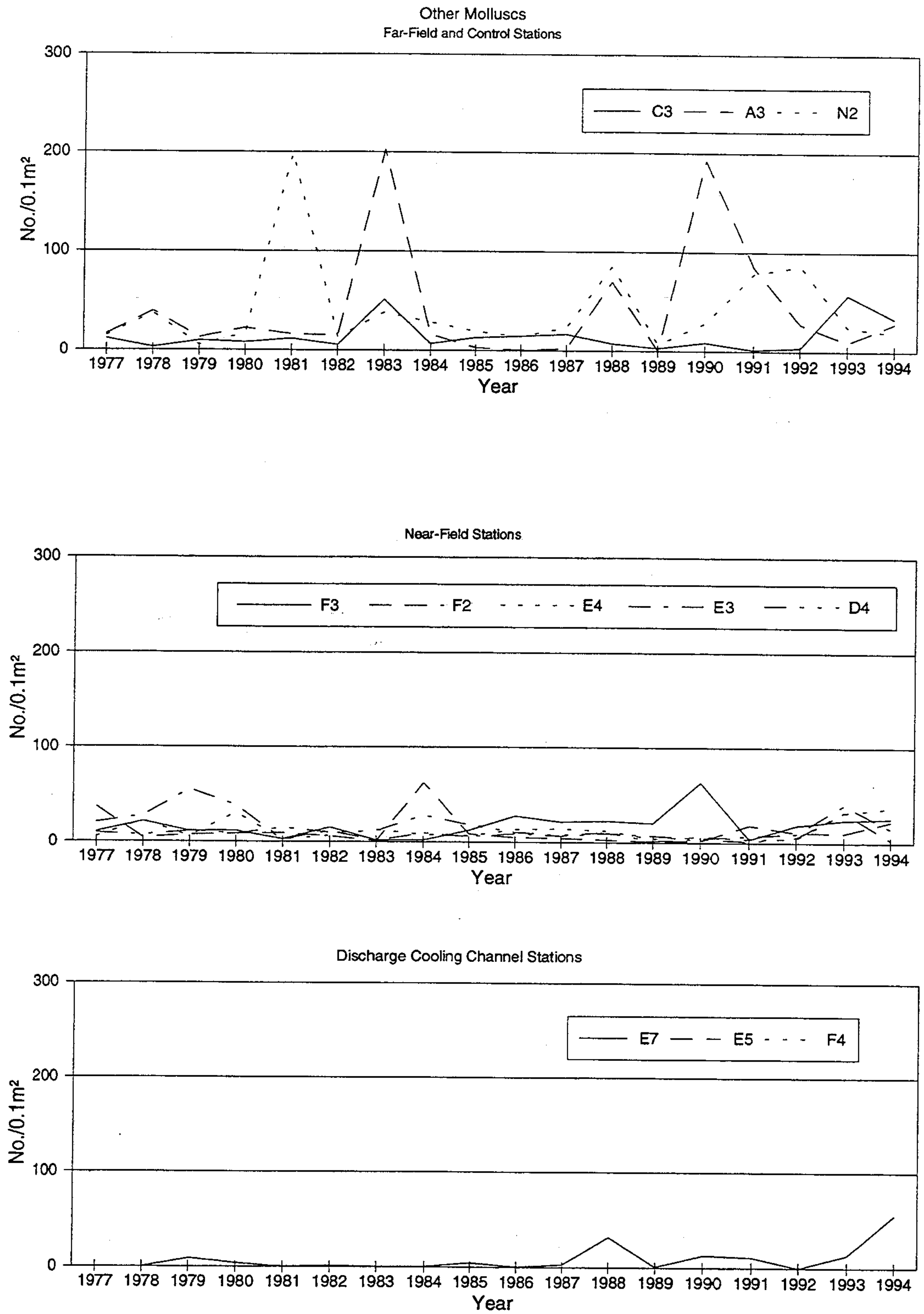


Figure 3-27. Density of other molluscs by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

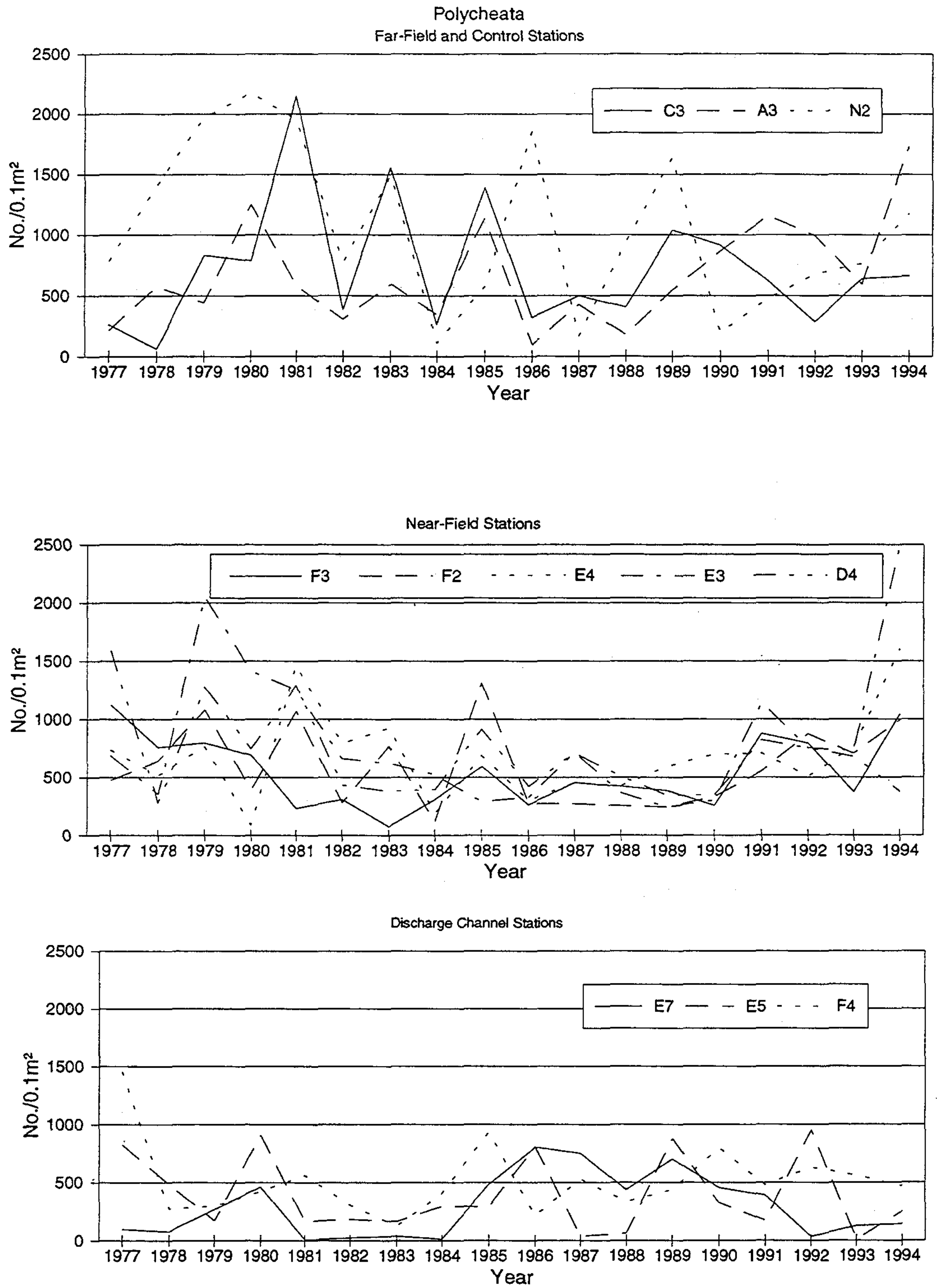


Figure 3-28. Density of polychaetes by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

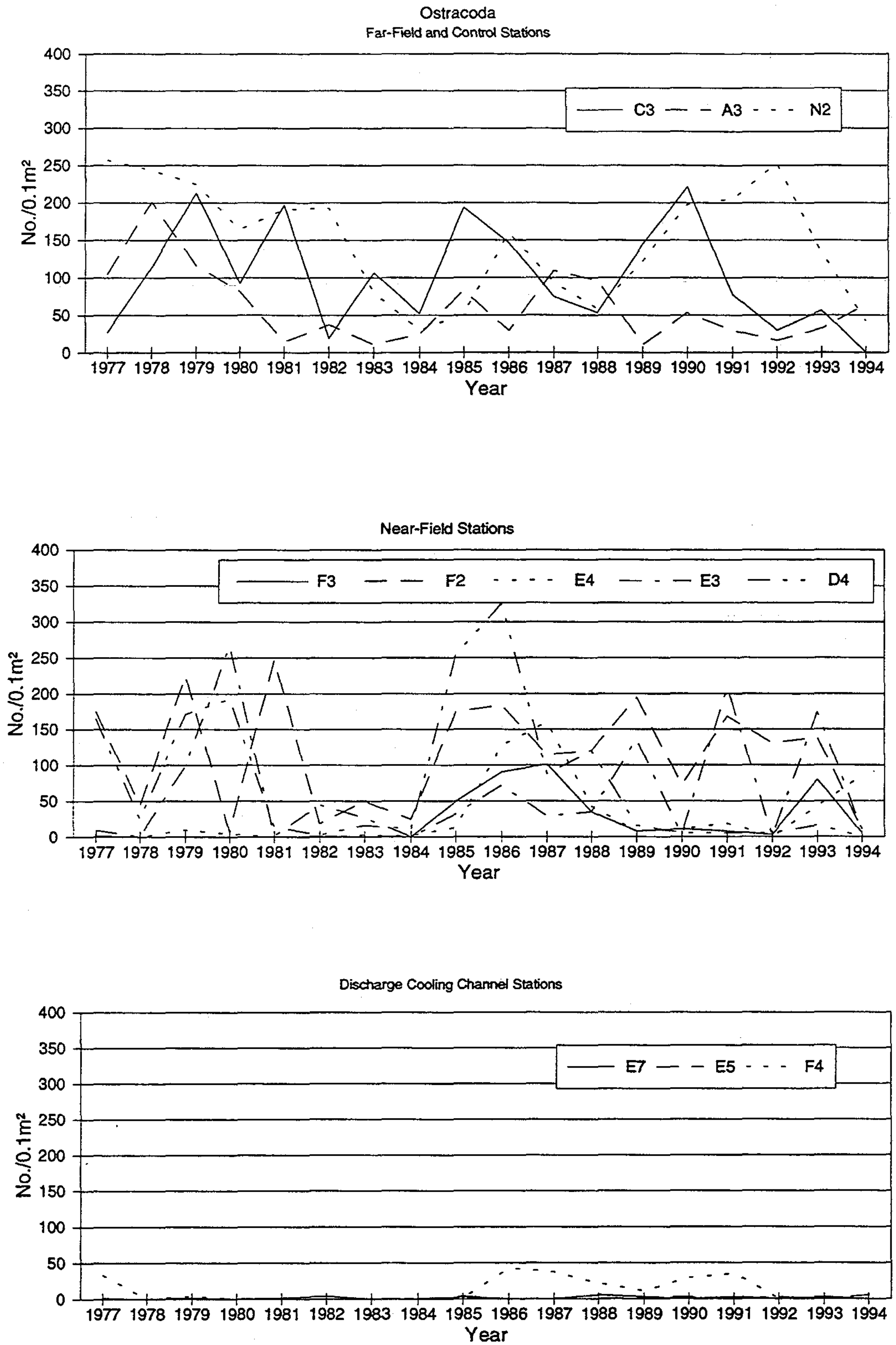


Figure 3-29. Density of ostracods by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

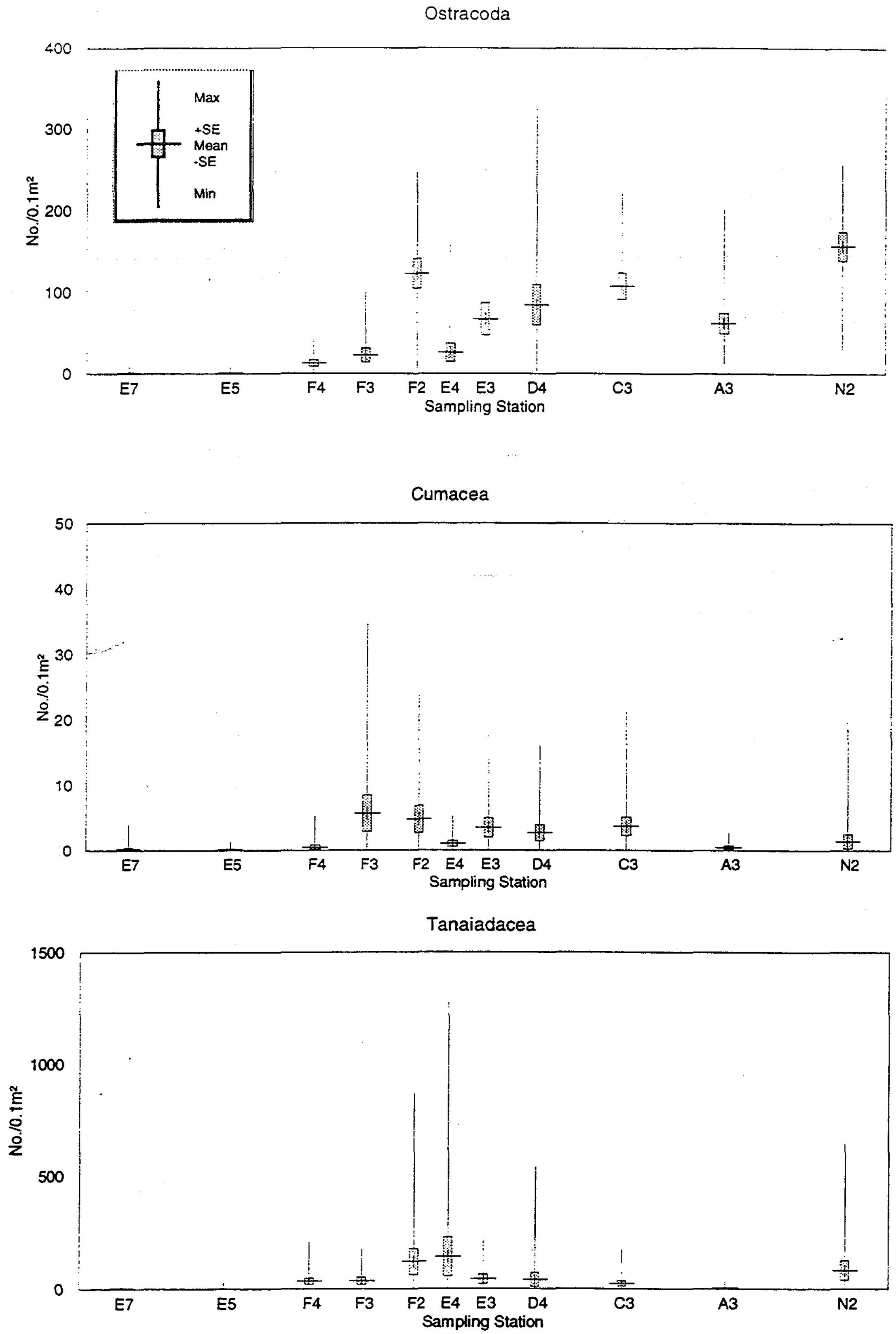


Figure 3-30. Distribution of ostracods, cumaceans, and tanaidaceans with respect to sampling station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

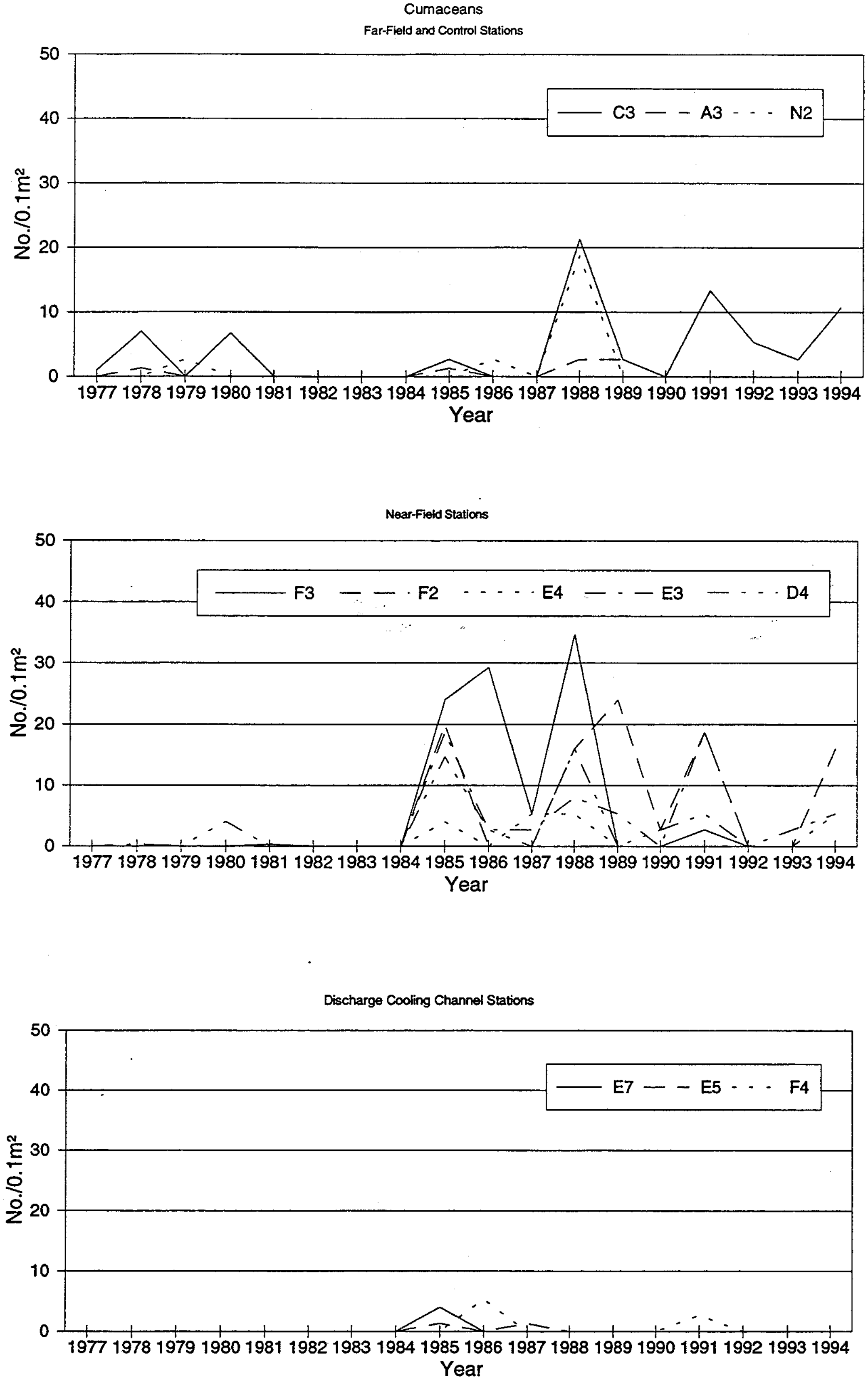


Figure 3-31. Density of cumaceans by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

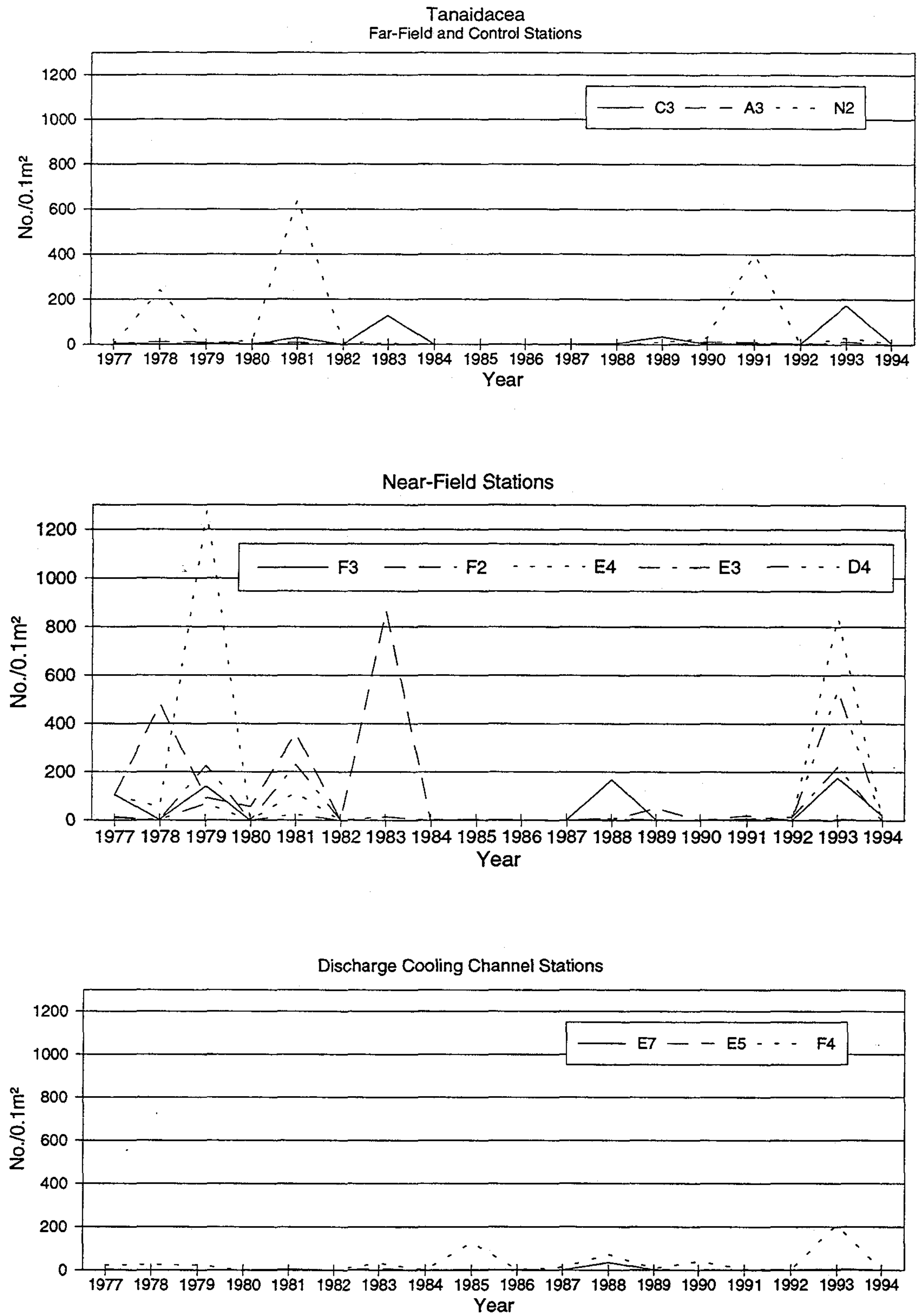


Figure 3-32. Density of tanaidaceans by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

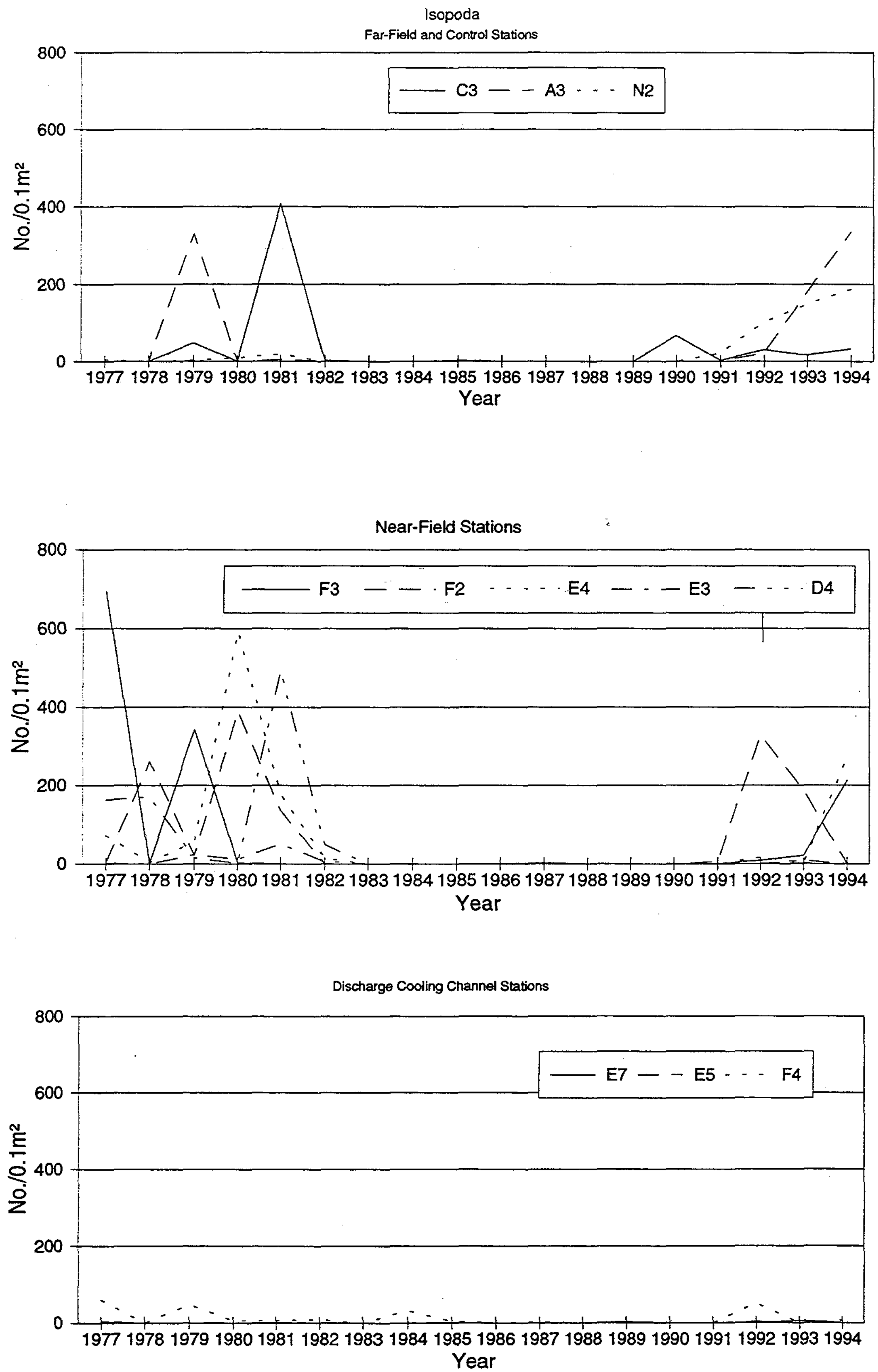


Figure 3-33. Density of isopods by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

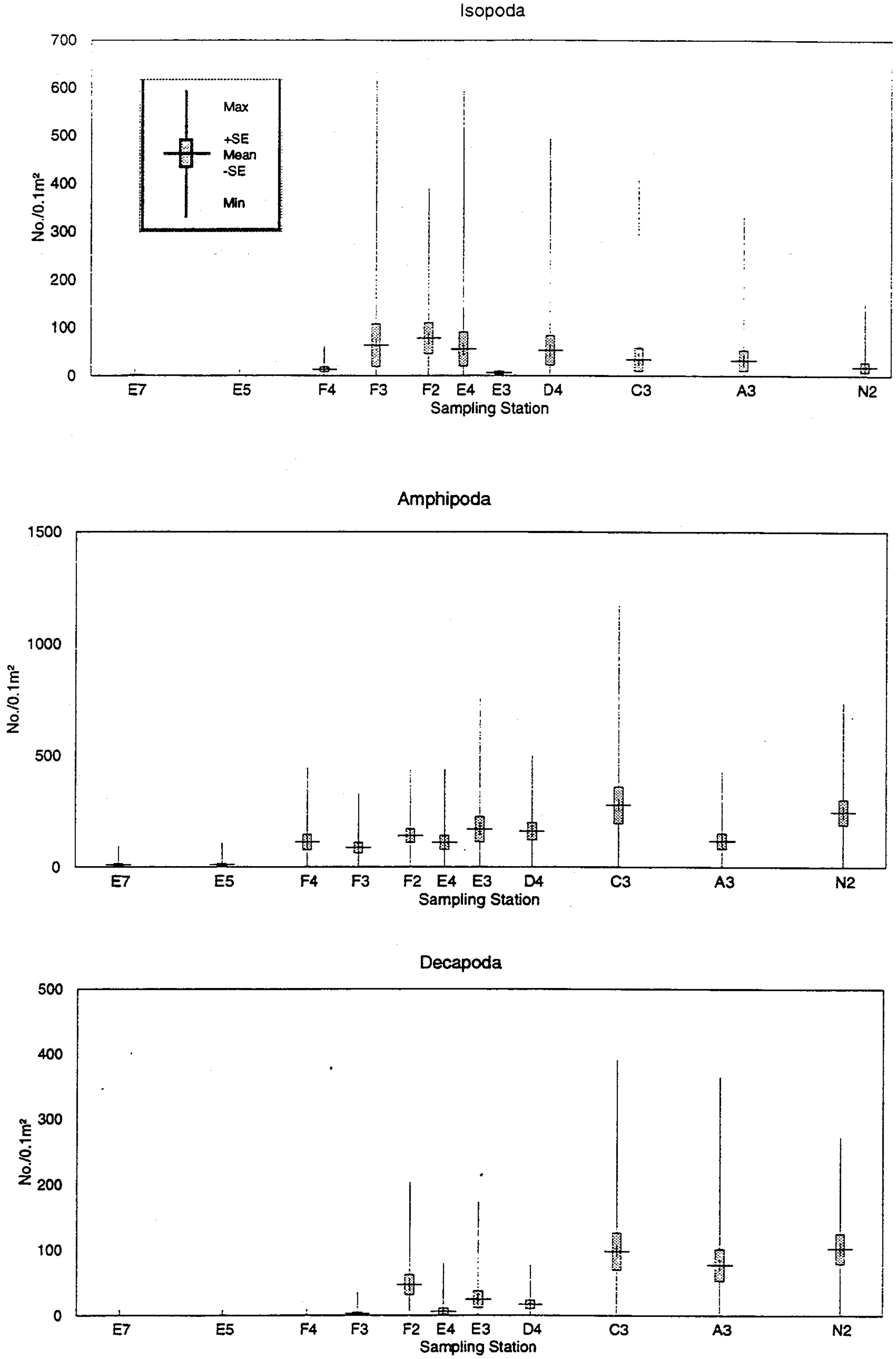


Figure 3-34. Distribution of isopods, amphipods, and decapods with respect to sampling station for the 1977-1994 South Bay Power Plant receiving water monitoring program.

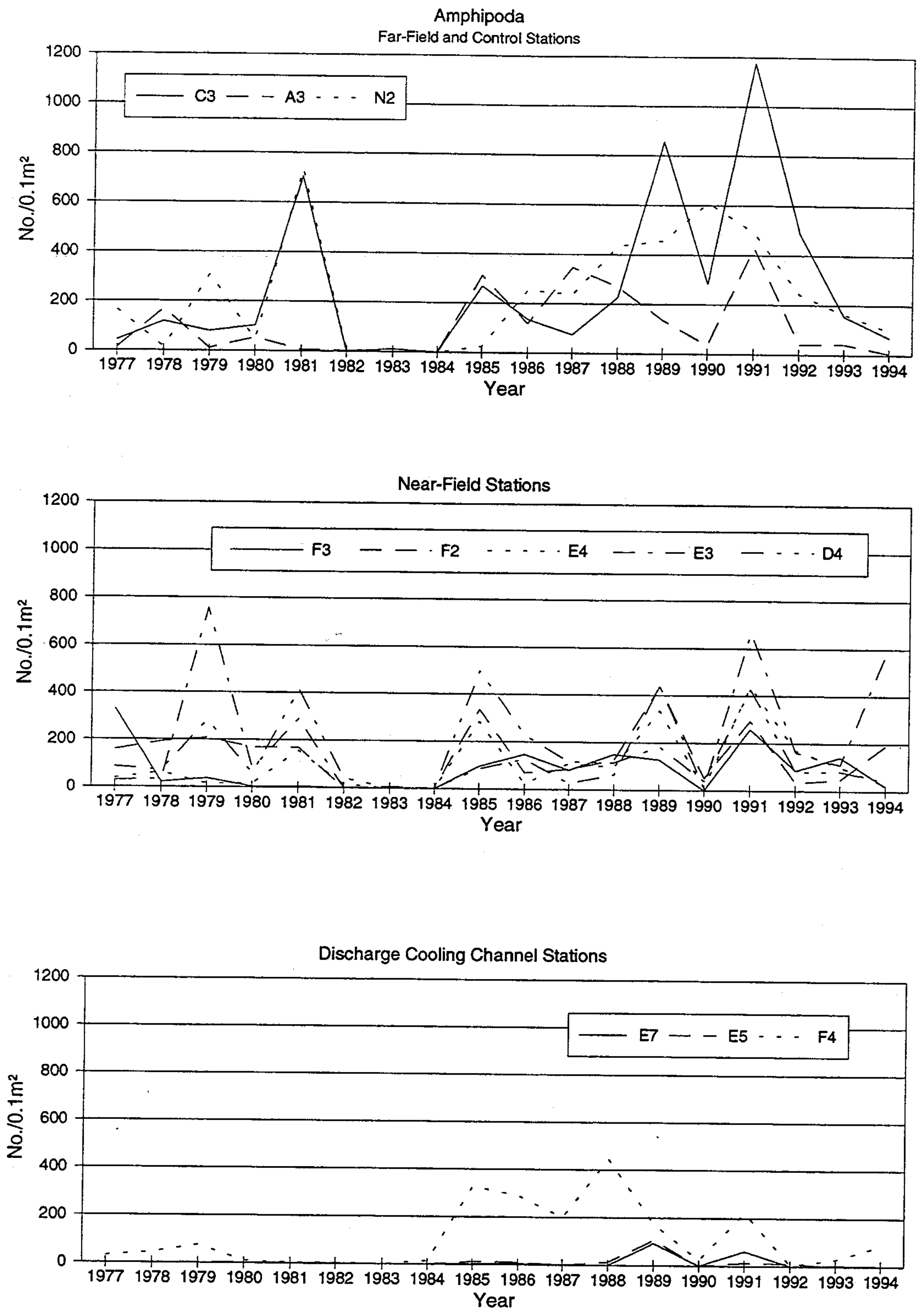


Figure 3-35. Density of amphipods by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

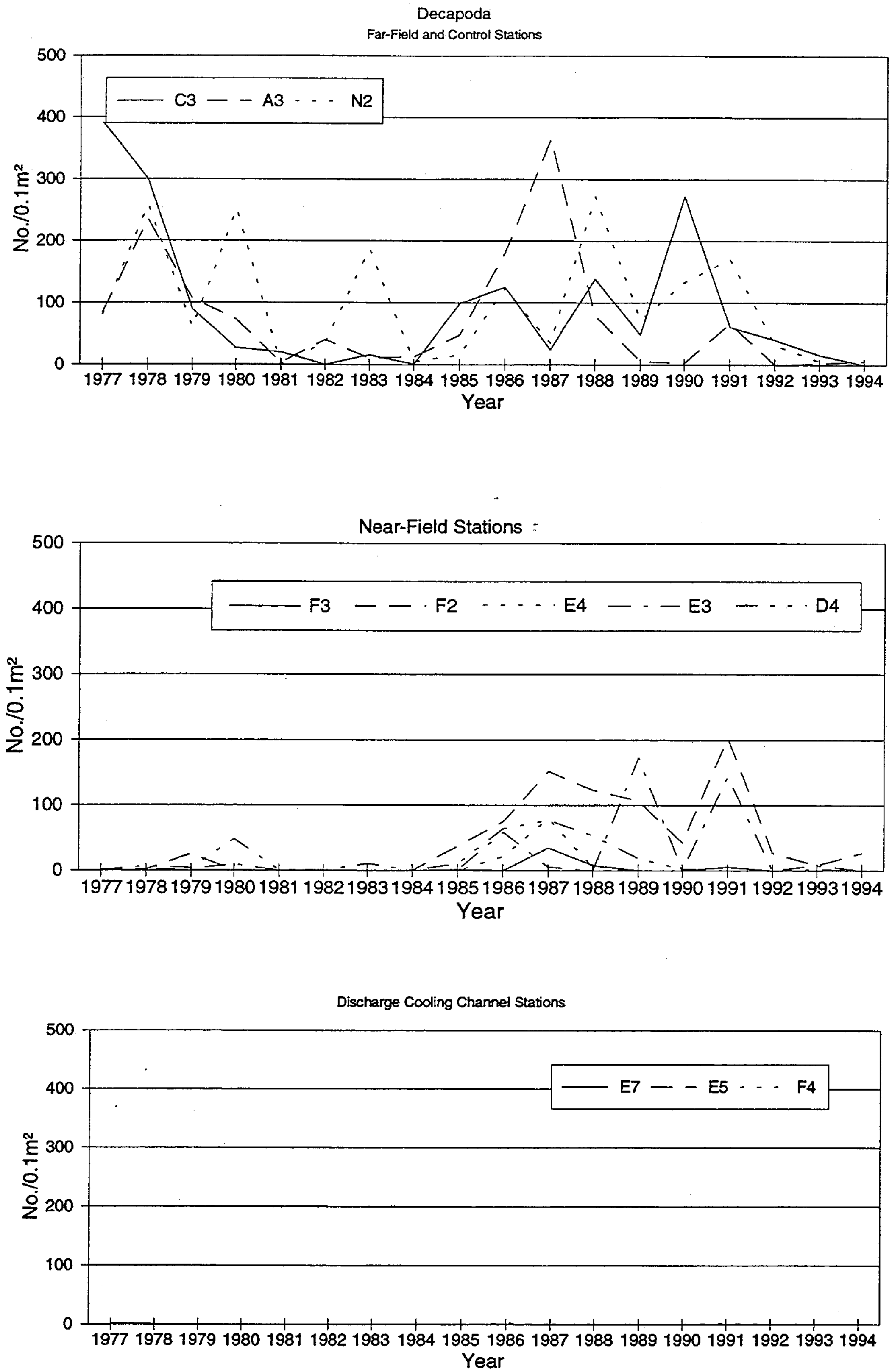


Figure 3-36. Density of decapods by year and station from the South Bay Power Plant receiving water monitoring program, 1977-1994.

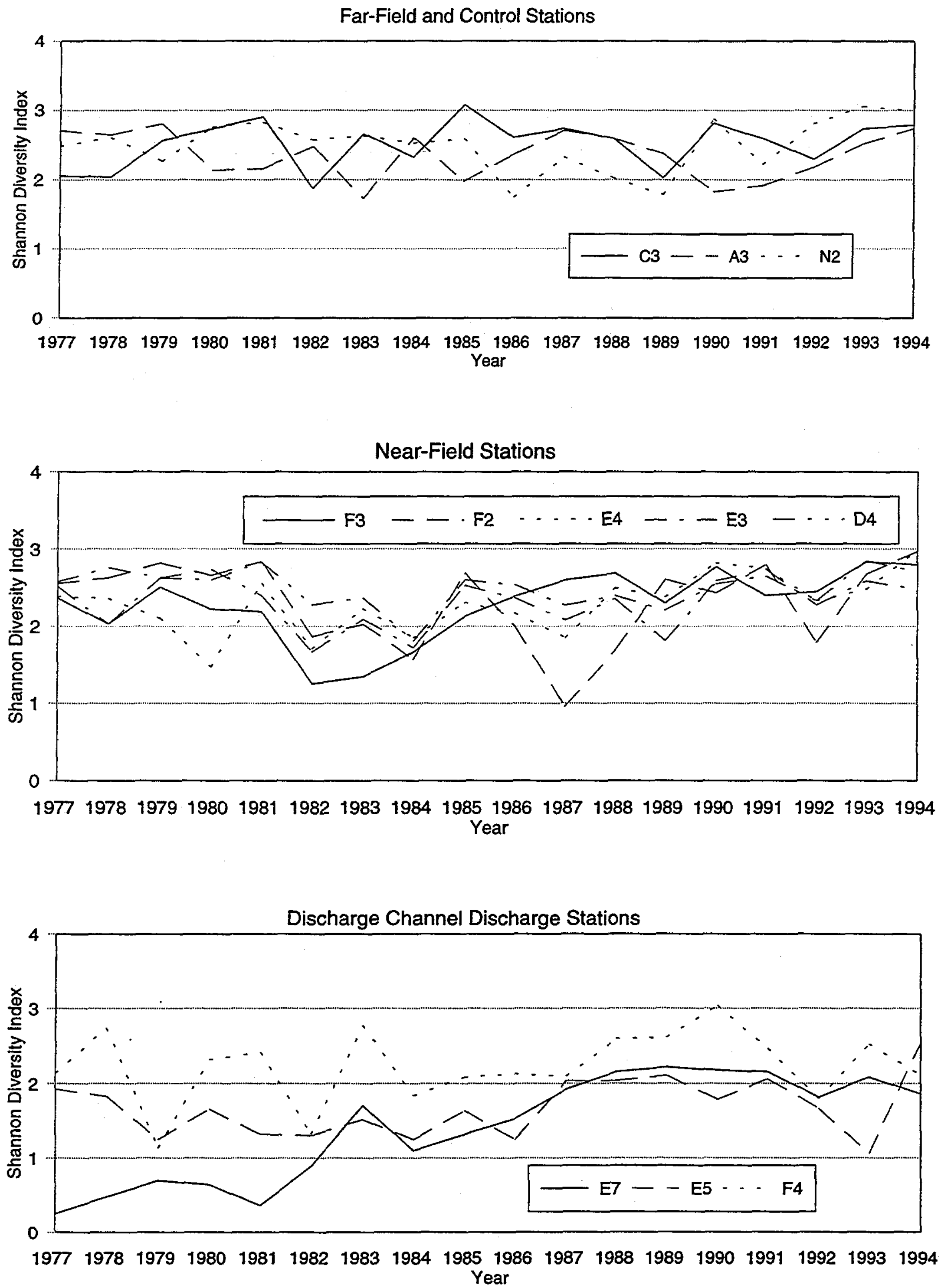


Figure 3-37. Diversity of the benthic infauna community by year and station estimated as part of the South Bay Power Plant receiving water monitoring program, 1977-1994.

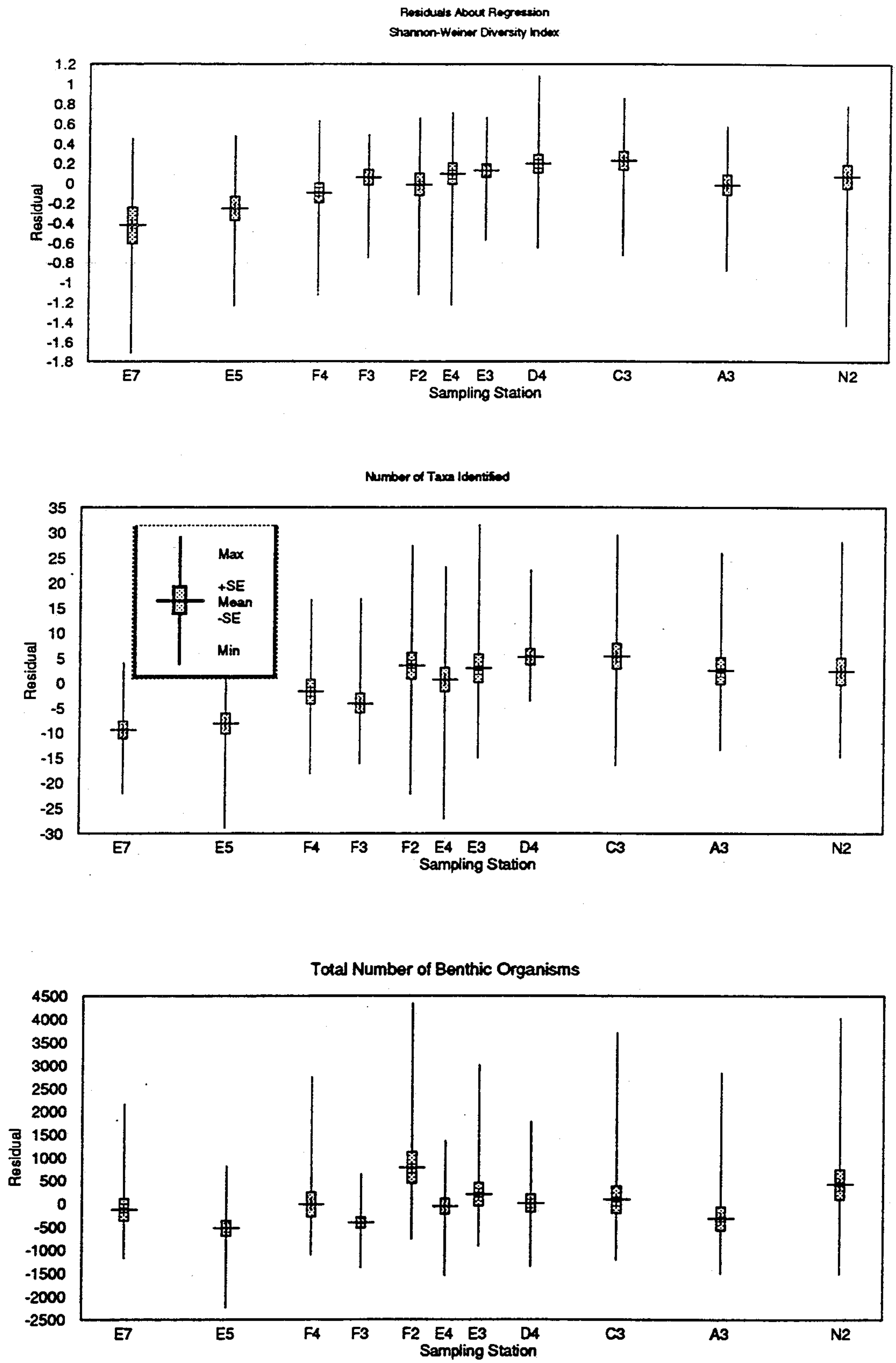


Figure 3-38. Distribution of residuals about multiple regressions with respect to sampling station for diversity, number of taxa, and total density from the 1977-1994 South Bay Power Plant receiving water monitoring program.

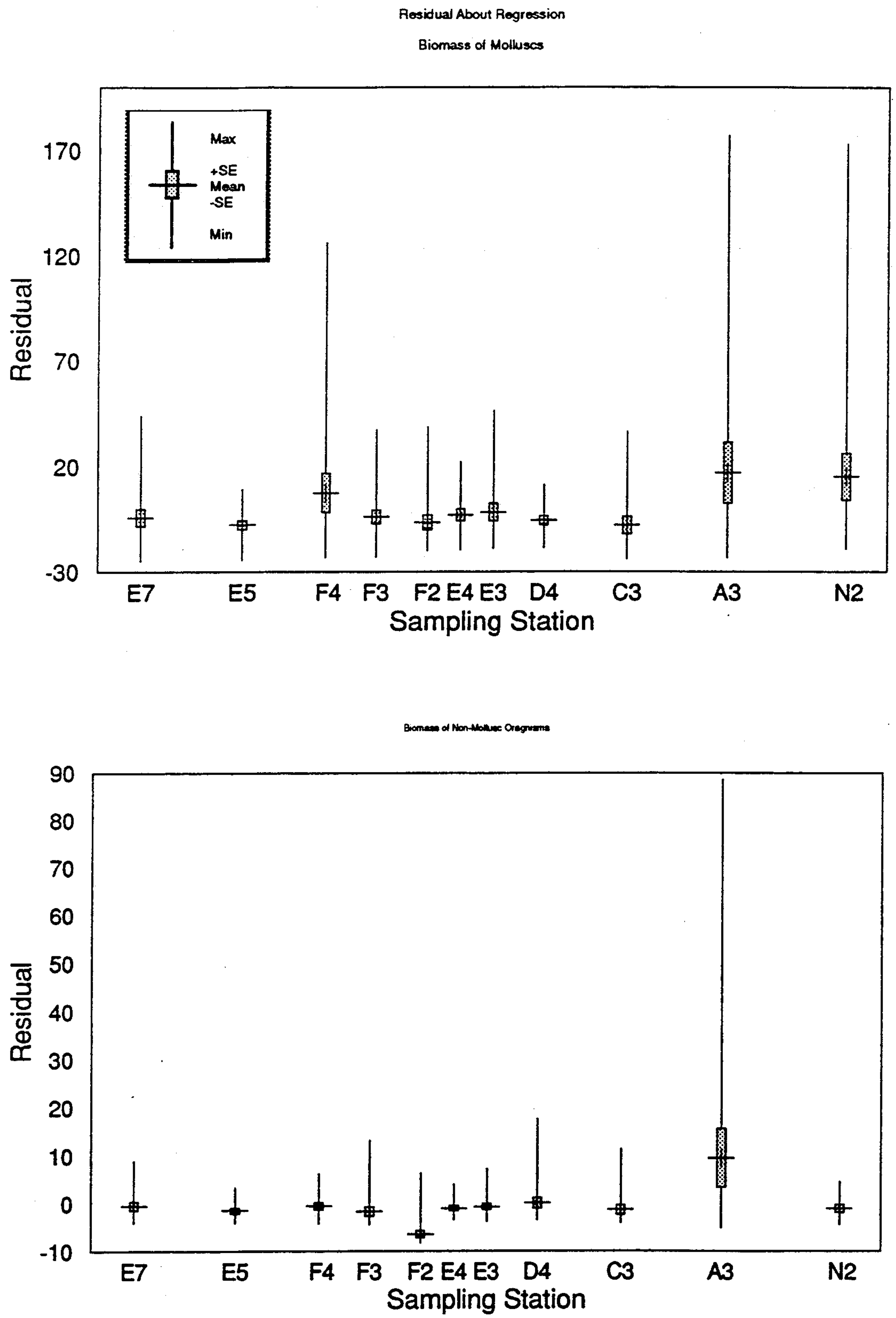


Figure 3-39. Distribution of residuals about multiple regressions with respect to sampling station for mollusc and non-mollusc biomass from the 1977-1994 South Bay Power Plant receiving water monitoring program.

TABLE 3-1 CORRELATION COEFFICIENTS AMONG PHYSICAL AND CHEMICAL PARAMETERS OF THE WATER AND SEDIMENT FROM THE SOUTH BAY POWER PLANT RECEIVING WATER MONITORING PROGRAM, 1977-1994

		Percent Silt and Clay	Sediment Temperature	Sediment COD	Sediment TKN	Water Temperature	Water Transparency	Water DO	Water Salinity
Distance from Discharge	r	-0.5797	-0.6318	-0.4722	-0.3253	-0.6995	0.5538	0.1700	-0.2042
	P	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0166	0.0039
	n	198	198	197	198	198	198	198	198
Percent Silt and Clay	r		0.3684	0.6430	0.4881	0.4176	-0.3855	0.0669	0.0628
	P		0.0001	0.0001	0.0001	0.0001	0.0001	0.3493	0.3792
	n		198	197	198	198	198	198	198
Sediment Temperature	r			0.3359	0.3317	0.8712	-0.3604	0.1211	0.1063
	P			0.0001	0.0001	0.0001	0.0001	0.0892	0.1361
	n			197	198	198	198	198	198
Sediment COD	r				0.4222	0.4277	-0.2588	-0.0350	-0.0318
	P				0.0001	0.0001	0.0002	0.6251	0.6576
	n				197	197	197	197	197
Sediment TKN	r					0.4070	-0.1411	-0.1039	0.0089
	P					0.0001	0.0474	0.1451	0.9013
	n					198	198	198	198
Water Temperature	r						-0.4297	0.0373	0.0734
	P						0.0001	0.6024	0.3041
	n						198	198	198
Water Transparency	r							0.1379	-0.2650
	P							0.0528	0.0002
	n							198	198
Water DO	p								-0.2079
	p								0.0033
	n								198

NOTE: COD = Chemical oxygen demand; DO = Dissolved oxygen; n = Number of data points; P = Significance; r = Correlation value; TKN = Total Kjeldahl nitrogen.

TABLE 3-2 RESULTS OF MULTIPLE REGRESSION ANALYSIS OF SILT AND CLAY CONTENT OF THE SEDIMENT AND ALGAL BIOMASS ON FIVE BENTHIC COMMUNITY PARAMETERS FROM THE SOUTH BAY POWER PLANT RECEIVING WATER MONITORING PROGRAM, 1977-1994

Community Parameter	Intercept	Parameter Estimate			Model R^2	F Ratio
		Percent Silt and Clay	Percent Silt and Clay Squared	Biomass of Algae and Marine Grasses		
Diversity Index	1.8036	0.0268	-0.0003	0.0014	0.1767	15.095 ($P<0.001$)
Number of Taxa Identified	48.8436	-0.2504	---	0.0922	0.3430	52.424 ($P<0.001$)
Total Number of Benthic Organisms	2082.9897	-9.7405	---	5.9054	0.1163	13.968 ($P<0.001$)
Biomass of Molluscs	22.5128	0.2720	-0.0049	---	0.0415	5.269 ($P=0.0059$)
Biomass of Other Benthic Organisms	5.2063	---	-0.0003	---	0.0025	1.503 ($P=0.2216$)

NOTE: Dashes (---) indicate excluded from model.

4. DISCUSSION

The receiving water monitoring program focused on the assessment of the influence of the SBPP thermal discharge on physical and chemical characteristics and benthic infauna community in the South Bay during the summer period. The focus on the benthic community originated from a comprehensive study of all of the benthic categories (plankton, periphyton, fish, and benthos) by Ford (1968). Based on the results from those studies, Ford (1968) concluded that the benthic community was the best and most easily evaluated indicator of long-term response of the biological community to changes in the environment including sediment and water temperatures, dissolved oxygen, salinity, organic carbon, and nitrogen concentrations. The focus on the summer season was based on the consideration that the cumulative effect of maximum natural annual ambient temperatures occurring during the summer and SBPP thermal discharges were likely to be most stressful to the aquatic community during this time of the year.

Ford (1968) and Ford and Chambers (1974) conducted seasonal surveys of the aquatic community which generally supported focus of the long-term monitoring program on the summer season. The authors reported "that the species composition of benthic plant and invertebrate associations remained moderately stable throughout the year...although there were some evident seasonal changes. In general, numbers of species and densities were lowest during the warmwater conditions of late summer-fall." The authors concluded that the 1972-1973 studies, "...suggest that high temperatures caused by the thermal discharge in the late summer-fall, and to a lesser extent in July, had adverse effects on the number, diversity, and abundance of many groups of species within the cooling channel itself (Stations E5, E7, and F4). Importantly, however, these effects were much less obvious during the winter and spring periods when both ambient water temperatures and those within the thermal discharge were lower. Much the same general pattern appeared to hold for both the intertidal and subtidal areas, which also share a majority of their species in common...During all seasonal periods, the adverse effects appeared to be confined primarily to the inner portion of the cooling channel." Finally, the authors reported that "there were no statistically significant differences for numbers and diversity of species between the outer discharge and control areas in either January or April 1973. This suggested strongly that the adverse effects...were confined only to the summer and early fall period of high ambient and effluent water temperatures."

The analysis of data in the individual annual reports from the receiving water monitoring program focused on evaluating whether there were differences among sampling stations in water and sediment physical and chemical characteristics, and characteristics of the benthic infaunal community. Differences among stations were observed in the form of gradients from the Stations E7 and E5 in the SBPP discharge cooling channel at the south end of the Bay, northward toward the far-field plume (Stations C3 and A3) and control sampling Station N2).

Among the significant, consistent, and relevant of these gradients associated with distance from the cooling discharge channel at the south end of the Bay were:

- Percent silt/clay in bottom sediment - decrease
- Sediment temperature - decrease
- Water temperature - decrease
- Sediment COD - decrease
- Sediment TKN - decrease
- Water transparency - increase
- Dissolved oxygen - increase
- Infauna diversity - increase
- Infauna numerical abundance - increase

The physical/chemical gradients, such as sediment grain size, sediment COD and TKN, and water transparency reflect the inherent characteristics of the shallow end of the Bay. The water and sediment temperature gradients reflect the combined collective influence of natural ambient water temperature gradient and the SBPP thermal discharge.

Consistent with the conclusions from previous studies (Ford 1968; Ford et al. 1970, 1971, 1972; Ford and Chambers 1973, 1974), the authors of the 18 annual summer water monitoring program reports indicated that species diversity, abundance, and to a lesser extent, biomass of the infaunal community at the sampling stations in the discharge cooling channel were lower than at the near-field thermal plume and far-field sampling stations. While this difference may have been caused in part by high water temperatures, their analysis indicated that there was little, if any, indication of negative effects on the benthic infauna community in the Bay beyond the discharge cooling water channel. Ford (1968), as well as authors of some of the annual monitoring reports, interpreted the data they collected to suggest that the increment of water temperature from SBPP operation in the near-field area outside of the cooling water discharge area appeared to moderately enhance the biomass of benthic invertebrates.

The authors of the annual reports and the 1980 four-year report applied multiple regression analyses to the data in an effort to determine which of the physical/chemical gradients were most strongly correlated with the benthic infauna community characteristics of diversity, numerical abundance, and biomass. Generally, the reported negative correlations were strongest for increased sediment (percent silt and clay) with somewhat weaker negative correlations with increased water and sediment temperature and sediment concentration of COD and TKN. Strongest positive correlations were with increased algae and plant detritus. The authors generally concluded that sediment grain size (percent of silt/clay) is the principal factor regulating benthic community structure as secondarily modified by water and sediment temperatures. Both sediment grain size and temperature were significant factors within the SBPP discharge cooling channel. Multiple regressions analyses were not capable of distinguishing the relative influence of sediment grain size versus temperature in the discharge channel. Otherwise, various of the authors concluded that the physical, chemical, and biological characteristics of the South Bay study area are similar to other natural Southern California back bay areas.

Analyses of the complete 18-year summer monitoring database in this report provided the opportunity to not only look for long-term trends in the measured physical/chemical factors and benthic infauna characteristics relative to plant operation, but also to re-examine the relationship and correlations among those physical, chemical, and biological characteristics.

Although there were the expected year-to-year variations within sampling stations for all parameters, there were no appreciable within-sampling-station long-term trends upward or downward of the important parameters such as sediment temperature, COD, TKN, grain size characteristics, water temperature, dissolved oxygen, salinity, or transparency (Section 3.2). A modest trend downward in water and sediment temperature at the discharge cooling channel stations was observed from the 1970s into the 1980s.

For the most part, the gradient in physical, chemical, and certain of the benthic infaunal characteristics from the south end of the Bay northward toward the far-field and control sampling stations listed above from the annual reports were again evident from analysis of the 18-year set of data (Section 3.6).

Moderate to weak significant correlations among the multiple co-occurring gradients of those physical and chemical sediment and water characteristics noted by authors of annual reports were again detected by analyses of the 18-year database. Again, most of these characteristics are features of South San Diego Bay unrelated to operation of the SBPP. The exceptions are water and sediment temperature which reflect the combined (additive) influence of ambient and thermal plume temperatures.

The gradients in benthic infaunal characteristics summarized earlier from the annual reports were again detected from analyses of the 18-year data set, especially for community diversity, number of taxa, and to a lesser extent the total number of benthic organisms. There was very little evidence of a gradient of increased infauna biomass from the cooling channel stations outward toward the far-field and control stations.

A different approach (Exploratory Data Analyses) from those used in the annual reports was used for analyses of the 18-year database in an attempt to sort out the separate influences of physical and chemical factors on the benthic infauna.

Analysis of the 18-year data set also supports the conclusions from the previous studies: that the summer time average diversity and abundance of the benthic community were somewhat lower within the discharge cooling channel than at the near-field, far-field, and control sampling stations; that those lower values appear to be related to the combined influences of the incremental temperatures from the SBPP and the natural physical and chemical characteristics of the south end of the Bay; and that there is little, if any, indication of similar effects outside of the discharge cooling channel (Section 3.6). However, the benthic infaunal average diversity and abundance observed in the discharge cooling channel are within the range reported for the sampling stations outside of the cooling channel in the near-field and far-field areas of the thermal plume and at the control sampling station (Figure 3-19).

Although the daily average temperature increment (delta-T) added to the cooling water has continued to range typically between 8-15°F, gross electrical generation in July, August, and September, typically was about one-third higher throughout the 1970s than during the period from 1982 to 1994. This generally is a result of the reduced operation of Unit 4 during the last decade. Since the cooling water flow of Unit 4 is 33 percent of the total SBPP flow, the size of the thermal plume resulting from the thermal discharge is also approximately one-third smaller when Unit 4 is not operating. The smaller thermal plume is reflected by a general downward long-term trend in summer water and sediment temperatures observed at the near-field and discharge cooling channel sampling stations (Figures 3-8 and 3-13).

The data indicated a step-down in trend during the early 1980s for a number of benthic fauna taxa at both the far-field and near-field sampling stations but not at the discharge cooling stations (Figure 3-18). Although the mean numerical abundance of benthic fauna was more variable from year-to-year (than number of taxa), the long-term trends in organism abundance at most of the sampling stations was either mildly downward or flat (Figure 3-20).

These summer time biological results coincided with the generally downward trends in mean sediment temperatures, particularly at the near-field and discharge cooling channel stations. These coincident biological and sediment temperature long-term downward trends indicate both that sediment temperature has not been a primary factor regulating benthic fauna taxa richness and abundance in the study area and that the warmwater appears to have provided a mild stimulus to benthic fauna abundance, particularly at certain of the near-field sampling stations, as reported previously by Ford (1968).

The absence of appreciable long-term trends, upward or downward, in infaunal diversity, number of species, numerical abundance or biomass at the sampling stations in the discharge cooling channel indicates the continued persistence of a functional, resilient, and stable community. The substantial numbers and biomass of infauna present in the cooling channel including oligochaetes, the polychaetes *Streblospio benedicti* and *Capitella capitata*, and variety of gastropods are available as food for consumers such as the numerous birds observed feeding in that area (Appendix A).

Consistent with conclusions from previous studies (Ford 1968; Ford and Chambers 1973; Michael Brandman Associates 1990; Ford 1994a, 1994b), analysis of the 18-year database indicates that the physical and chemical characteristics and benthic infaunal community in South San Diego Bay are similar to those of other back bays along the California Coast. This indicates that moderate adverse effects of the SBPP thermal discharge on benthic infauna during the summer are confined to the localized area of the discharge cooling channel. Previous studies (Ford 1968; Ford and Chambers 1973) indicated during other cooler seasons of the year the number of benthic fauna taxa and abundance in the discharge cooling channel were more similar to fauna in the near-field, far-field, and control sampling areas.

In summary, the results of this evaluation of the long-term receiving water monitoring database indicate that the species composition, relative abundance, and total abundance of the subtidal benthic fauna in the study area remained much the same in 1994 as they were in 1977. This is consistent with the fact that most of the environmental conditions monitored do not indicate any appreciable long-term trends of change. The exception is that there has been a reduction of about one-third in total generation and associated thermal discharge from the SBPP. There has been no corresponding trend of increased number of benthic taxa or abundance which indicates that: the increment of water temperature due to operation of the SBPP has not been a primary limiting factor for the benthic community outside of a localized area in the cooling water discharge channel; a combination of other factors such as sediment grain size, algal biomass, COD and TKN have been and continue to be controlling benthic community species diversity and abundance; and, there is no evidence which suggests that the operation of the SBPP is having an appreciable detrimental effect on the benthic community in San Diego Bay. These conclusions are consistent with those of Michael Brandman Associates (1990):

> "Detailed examination of these data suggests that the species composition, relative abundances, and seasonal dynamics of the subtidal infauna and epifauna, were much the same in 1988-1989 as they were in previous years when they were studied intensively (see, for example, Ford and Chambers 1973, 1974). This indicates that the conditions in these South Bay habitats have remained relatively stable over the past 15-20 years and that there have been no evident, long-term changes in the habitats or their associated organisms. It also indicates that the detailed information summarized in this review on characteristics of these infaunal and epifaunal communities, and the seasonal changes in them, still apply to present condition."

> "Based on the evidence available, it appears that nearly all of the seasonal and shorter term changes observed in the infauna of South San Diego Bay during recent years are the result of natural environmental changes. The primary exception to this appears to be localized effects of thermal effluent from the South Bay Power Plant, which are limited to the warmer months of the year (Ford and Chambers 1973, 1974)."

Keeping in mind that the long-term receiving water program focused on assessment of the benthic community as an indicator (or surrogate) for the entire biological community of the Bay, the results and conclusions summarized in this section logically apply to the entire biological community as well. This premise is supported by the Resources Atlas compiled by Michael Brandman Associates (1990) on behalf of the San Diego Unified Port District and the California State Coastal Conservancy which concluded that the compilation of existing information suggests very strongly that the species composition, relative abundances, and biomass of dermersal and open water fishes, marine algae, and invertebrate assemblages have remained similar over the 21-year period 1968-1989.

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Appendix A

Physical and Ecological Description of San Diego Bay

APPENDIX A
CONTENTS

A. PHYSICAL AND ECOLOGICAL DESCRIPTION OF SAN DIEGO BAY

A.1 PHYSIOGRAPHY AND BATHYMETRY

San Diego Bay is the largest semi-enclosed marine embayment located along the 900-mi stretch of coast between San Francisco Bay to the north and Scammon's Lagoon, in central Baja California, to the south. It is located approximately 5 mi north of the United States and Mexico boundary (Michael Brandman Associates, Inc. 1990). The Bay is bounded by the cities of San Diego, Coronado, National City, Chula Vista, and Imperial Beach.

San Diego Bay is a natural, crescent-shaped estuary. It is approximately 14 mi long and 2.5 mi across at its widest point. The width of the Bay varies from 1,600 to 14,000 ft (Michael Brandman Associates, Inc. 1990; SDG&E 1980). At half-tide level, the surface area of San Diego Bay is estimated to be approximately 18 mi^2 and the water volume to be about 300 million yd^3 (USACE 1974, in Michael Brandman Associates, Inc. 1990).

Water depths in the South Bay are quiet shallow, generally ranging from 0 to 8 ft below mean low low water (MLLW), except in dredged channels (Ford and Chambers 1974; Michael Brandman Associates, Inc. 1990); the average depth in the inner bay is approximately 3-4 ft below MLLW (Ford and Chambers 1974). In contrast, water depths in the outer bay generally exceed 30 ft MLLW and may reach 70 ft MLLW.

The Bay exists as a shallow extension of the Sweetwater and Otay alluvial plains on the south and east, the San Diego River delta on the north, and the littoral accumulation of Silver Strand on the west (Peeling 1974, in SDG&E 1980). Relatively flat lowlands border the southern portion of San Diego Bay. To the southeast, alluvial deposits predominate and foothills appear approximately 3-4 mi inland. Approximately 1.4 mi east of the Bay, the lowlands rise gradually to a Pliocene rock mesa, about 200-400 ft above sea level, on which most of the City of San Diego rests. North of the Bay, the flat lowland is constricted to a narrow strip (through which the San Diego River once flowed) and is bordered by Point Loma (SDG&E 1980).

The floor of the Bay and its margins consist of sand, silt, clay, and mud or mudstone deposits. Sands are most common near the Bay entrance and along the western side, while silt and muds are predominant in the eastern and southern areas of the Bay (SDG&E 1980). The muds of the Bay floor average 5-20 ft in thickness (SDG&E 1980). These mud layers rest upon sand and sandy silt layers, which in turn rest upon older consolidated sedimentary deposits. In deeply dredged areas, the lower sandy strata have been exposed by removal of the Bay floor mud.

The tidelands of San Diego Bay, encompassed by the historic mean high tide line, include approximately 14,951 acres of filled and submerged lands and a shoreline about 54 mi long.

South of the Sweetwater Channel, San Diego Bay presently encompasses an area over 4,700 acres, including subtidal and intertidal bay-bottom habitats, adjacent intertidal saltmarshes, and the South Bay salt ponds (Michael Brandman Associates, Inc. 1990).

South San Diego Bay, less developed than north or central San Diego Bay, has several thousand acres of shallow baywaters, some 600 acres of mudflats, approximately 200 acres of salt marsh, over 1,250 acres of salt ponds, and a riparian corridor along the Otay River (Michael Brandman Associates, Inc. 1990).

A.2 HYDROLOGY

The tides in San Diego Bay are classified as the mixed type, with marked variation (on average) between the heights of the two daily high tides and the two daily low tides (SDG&E 1980). As noted by SDG&E (1980), the higher high tide always precedes the lower low tide. Near the Bay entrance at Ballast Point, the average tidal range is 3.9 ft; the range between mean high high water (MHHW) and MLLW is 5.6 ft. The extreme range of tidal change is 9.5 ft in the outer bay and 10.4 ft in South San Diego Bay (Ford and Chambers 1974). The tidal prism (between MHHW and MLLW) in San Diego Bay is approximately 96.1 million yd^3 (Michael Brandman Associates, Inc. 1976, in SDG&E 1980). This represents a ratio of about 1:3 of the tidal prism volume to the volume of the entire Bay below the tidal prism.

As estimated by the U.S. Army Corps of Engineers ((USACE 1974, in SDG&E 1980), San Diego Bay at half-tide level has an area of about 18 mi^2; at low tide, about 15.8 mi^2. This indicates that about 2.1 mi^2 of intertidal mudflats become exposed as the water level decreases from mid-tide to the level of MLLW. Almost all of this exposure occurs in the southern portion of San Diego Bay (SDG&E 1980).

In the southern part of San Diego Bay, horizontal currents are caused primarily by the changing tide levels (Falter 1971, in Michael Brandman Associates, Inc. 1990; SDG&E 1980). Except during conditions of relatively strong winds, tidal currents predominate over other water movements produced by wind and wave action. Tidal current speeds are markedly lower in the southern part of the Bay than at its entrance or in its northern sections. Typical surface and bottom current speeds measured in the southern portion of the Bay in August 1968 ranged from 1.5 to 11.3 cm/second (from <0.2 to 0.1 m/second) over the tidal cycle (Ford 1968). Based on a large series of such measurements by SDG&E (1980), tidal currents in the southern part of the Bay have speeds less than 10 cm/second (0.1 m/second) about 80 percent of the time. In comparison, near the Bay entrance, the current speed at peak flood averages about 0.6 m/second and at peak ebb about 0.8 m/second (U.S. Navy 1950, in Michael Brandman Associates, Inc. 1990; National Ocean Survey 1979, in Michael Brandman Associates, Inc. 1990). During tidal extremes, surface current speeds near the Bay entrance reach 1.5 and 1.1 m/second during peak ebb and peak flood tides, respectively (SDG&E 1980).

Tidal action is responsible for continual flushing of San Diego Bay. However, tidal flushing is relatively inefficient except at the outer end of the Bay (Michael Brandman Associates, Inc. 1990). The flushing rates of the southern and central portions of San Diego Bay are extremely low (Marine Advisers 1963, in Michael Brandman Associates, Inc. 1990; Fishackerly 1974, in Michael Brandman Associates, Inc. 1990; USACE 1974b, in Michael Brandman Associates, Inc. 1990). Thus, water near the entrance is replenished much more frequently than water in the South Bay. As tidal ranges fluctuate throughout the 2-week tidal cycle, the rates of exchange vary considerably. During neap tide periods, the rates of exchange may be only one-third to one-quarter as high as during spring tide periods (periods of maximum ranges of tidal height) (Ford and Chambers 1974). Along the margins of the South Bay, local mixing is also influenced by the drainage of water from intertidal mud flats, marshes, and tidal channels (Michael Brandman Associates, Inc. 1990; SDG&E 1980). This small-scale local mixing appears to be fairly good, however, larger scale exchange appears to be poor (Michael Brandman Associates, Inc. 1990).

Unlike most Atlantic and Gulf coast estuaries, as well as those found in higher rainfall areas to the north, San Diego Bay is rarely subject to the influx of large quantities of fresh water (MacDonald 1986; Zedler 1982). Freshwater flows occur only during the winter and spring; and even during rare periods of extreme flooding, runoff rates are very low relative to the tidal transport of seawater. Consequently, dilution of the Bay water is usually very limited in both time and extent. Even episodes of extraordinary storm events as occurred during the early winter and spring of 1980 (LES 1980) which resulted in a considerable volume of coarser sediment being flushed into the Bay (SDCFCD 1980) have no long lasting effect on salinity.

A.3 WAVE CONDITIONS

San Diego Bay with its large but narrow entrance is well protected from the intrusion of ocean waves. During most of the time, its surface is relatively calm. Local winds generate steep, short period waves or chop within the Bay; these seldom exceed 2-3 ft in height (SDG&E 1980). During spring and summer months, persistent wind wave action in the southern (shallow) end of the Bay causes a marked increase in water turbidity (Ford and Chambers 1974).

During windy, winter months, seiches have been observed frequently. These seiches had heights between 2 and 10 cm and periods between 5 and 20 minutes (SDG&E 1980).

Water motions resulting from upwellings, internal waves, convection, and wakes from man-made obstacles also occur in South San Diego Bay, however, these are weak in nature and are of minor significance (Michael Brandman Associates, Inc. 1990; SDG&E 1980).

A.4 RECENT TRENDS IN WATER/SEDIMENT QUALITY AND PRODUCTIVITY IN SAN DIEGO BAY

The development of San Diego as a major commercial port and industrial complex progressed rapidly since its establishment in 1872. San Diego's growth and development also resulted in significant stress to the San Diego Bay ecosystem. By the early 1940s, the Bay had become polluted to the point of eutrophy. Sewage treatment and diversion of sewage sludge was not instituted until 1963, and nearly another 20 years passed before most other waste discharges were curtailed. The U.S. Navy eventually controlled sewage emissions from their ships tied up at North Island and elsewhere in San Diego Bay by the mid-1980s. Sewage treatment and diversion brought about spectacular improvements in water quality by the late 1960s. By the standards of traditional water quality indicators, such as coliform counts, the Bay has been relatively clean ever since. All fish species described from the Bay in the late 1800s have re-established (Van Rhyn and Gauthier 1994).

In the 1980s, concern shifted to the presence of potentially toxic chemicals in the water and sediment, and the potential for these to accumulate in the tissues of bay animals. There are literally dozens of monitoring programs in San Diego Bay targeting such chemicals (Johnson et al. 1990). Studies throughout the 1980s and 1990s have made it clear that many chemicals of concern are present at levels that exceed current recommendations, and that at some locations these concentrations are high enough to have measurable effects on the health of marine species (McCain et al. 1992). Although many monitoring plans are currently in place, most of them have been instituted only recently, or were abandoned after collecting 1 or 2 years of data. Unfortunately, there are few sources of data collected in a uniform way over long periods of time (15 years or more).

The California State Mussel Watch has analyzed the tissues of native and transplanted mussels at a number of stations in San Diego Bay since 1977 (SWRCB 1988). These samples are analyzed for metals (consistently for aluminum, cadmium, chromium, copper, lead, manganese, mercury, silver, and zinc, and sporadically for arsenic, nickel, and selenium) and organic compounds (polycyclic aromatic hydrocarbons, polychlorinated biphenyls, chlordane, and organotins). However, these data do not suggest any consistent trends in water or sediment quality.

The U.S. Navy Statutory Organotin Monitoring Program has monitored tributyltin concentrations in water, sediment, and mussel tissues at a number of stations in San Diego Bay since 1983 (Johnson et al. 1990). Tributyltin concentrations increased until 1987, reaching levels acutely toxic to some organisms at some sites. Restrictive legislation on the usage of tributyltin in marine antifouling paints and coatings was passed in 1988. Since then, concentrations in the water have dropped rapidly to levels that are below the water quality objectives in most of the Bay. Concentrations in mussel tissues have also declined since 1988; however, as of 1990, no such declines have been detected in sediment concentrations.

The failure of sediment concentrations of tributyltin to follow the decline in water is similar to observations in San Francisco Bay (Flegal and Sañudo-Wilhelmy 1993). In that paper, the authors report that the two bays have similar concentrations of trace metals, even though concentrations in south San Francisco Bay are correlated with wastewater discharge, whereas all wastewater discharges to San Diego Bay were terminated in 1964. They suggest that, "In both systems, the sediment may now represent essentially infinite sources of contamination." Many of the present monitoring programs are designed to identify local hot-spots. As these are found, they are eliminated or remediated. The monitoring programs lead to continual small improvements to conditions in the Bay.

Although harder to quantify, what might be called the "ecological health" of the Bay appeared to continue to improve over the past decade or so. Eel grass beds, which are very important in providing food and cover for fish and invertebrates, have increased markedly by natural propagation. The Sweetwater Marsh National Wildlife Refuge is the site of several major mitigation projects; marshlands that by 1984 (Zedler and Langis 1991) had been filled to the point that they were heavily used by off-road vehicles are being restored to intertidal salt marsh. Other recent restoration activities have included the construction of artificial wetlands at the end of the dike separating the intake and discharge channels at the South Bay Power Plant. A sign that the Bay ecology is continuing to improve is the recent return of the "giant" or Pacific seahorse (*Hippocampus ingens*) (Jones et al. 1988). Only nine Pacific seahorse had been reported in the Bay before 1984, seven of them in the 1800s. None were found during a survey of San Diego Bay eel grass beds in 1980-1981; however, 22 seahorse were observed from 1984 to 1988.

A.5 ECOLOGY

This section describes the marine ecology of South San Diego Bay with emphasis on the trophic or feeding relationships of benthic invertebrates among the major habitats and biological groups present (Figures A-1, A-2, and A-3). This section is also intended to provide background for discussing the results of the long-term benthic monitoring program as they relate to protection and propagation of a balanced, indigenous community of aquatic life in and on San Diego Bay.

Important features of the South San Diego Bay food web and their feeding relationships first presented by Ford (1968) and adopted by others follows.

A.5.1 Salt Marshes

Salt marshes are rich and productive areas where nutrients such as phosphorus and nitrogen are concentrated and recycled and where productivity of both plant and animal species is enhanced. Salt marshes provide habitat for a wide variety of invertebrates (e.g., molluscs and crustaceans) and juvenile fish, as well as shorebirds and waterfowl. South San Diego Bay formerly contained eight salt marshes totaling more than 1,700 acres. As of 1984, only about 200 acres remained. The largest is Sweetwater Marsh which is still considered a high quality marsh (Michael Brandman Associates, Inc. 1990). Cordgrass (*Spartina foliosa*), glasswort (*S. subterminalis*), Beach lotus (*Lotus nuttallianus*), and yerba beuna (*Frankensia palmeri*), all sensitive plant species, are present. Salt marsh bird's beak, *Cordylanthus maritimus*, an endangered species, is also known to occur on Sweetwater Marsh. There is a small freshwater inflow, and low, middle, and high marsh habitats, as well as tidal creeks, a brackish marsh, and mudflats.

A.5.2 Algae, Seaweeds, and Eel Grass

A large area of the bottom of South San Diego Bay is covered by an extensive mat of algae, seaweed, and detrital materials. Many plant species drift along the bottom; other plant species are anchored to the substrate by a holdfast. Associated with the algal mat is the flexible, tree-like bryozoa, *Zoobotryon verticillatum*, which is discussed in more detail below. In summer, the mat is sometimes 30-60 cm thick, but can vary seasonally and from year to year in size, biomass, and species composition. Detritus from at least 19 species of red, green, and brown algae, and the eel grass, *Zostera marina*, form the plant mat (Michael Brandman Associates, Inc. 1990). In the South Bay, the dense and heavily branched red alga, *Gracilaria verrucosa*, contributes to the integrity of the mat. Green algae, including *Ulva* spp., *Chaetomorpha* spp., *Cladophora* spp., and *Enteromorpha* spp., also contribute to the mat community. The plant mat forms an important habitat that provides both refuge and food for a variety of benthic invertebrate animals (e.g., gastropods, isopods, and crabs) and fish.

Eel grass beds form another important habitat in San Diego Bay. Eel grass is a seed bearing plant inhabiting sheltered shallow substrates. It is rooted in surface sediments deriving nutrients through root hairs. There is ample evidence to conclude that eel grass quickly re-established and spread following sewage diversion and treatment in the mid-1960s (Ford 1968; Ford and Chambers 1974; Michael Brandman Associates, Inc. 1990). The distribution of eel grass is dependent upon available light intensity and turbidity. In South San Diego Bay, the lower depth limit of eel grass was determined to be 36-48 in. below MLLW (Michael Brandman Associates, Inc. 1990). As eel grass beds continue to re-establish and spread, they become an increasingly important habitat for both invertebrates and fish.

Algae, seaweeds, and eel grass are fated either to be eaten by herbivores such as sea urchins, snails, certain crustaceans, waterfowl, and sea turtles, or to be degraded into small particles of detritus by wave action. As plant tissues wear away, soluble organic materials are released into the water column and are remineralized.

A.5.3 Plankton

Pelagic phytoplankton and zooplankton concentrations in San Diego Bay are similar to those of other estuaries in California although there are some differences in species composition (Ford 1968). Abundances, as well as the diversity of species, are lower in South San Diego Bay when compared with the outer Bay. This condition may be relative to high turbidity/low transparency and poor penetration of light which is needed to support the phytoplankton. The lower abundances of zooplankton may be related to the feeding activity of *Zoobotryon* during which the zooplankton may be filtered by the feeding. The dominant species of phytoplankton are pennate and chain-forming diatoms which provide a important food source for filter feeding zooplankton, a wide variety of benthic invertebrates, as well as the slough anchovy, *Anchoa delicatissima*. The dominant species of zooplankton are calanoid copepods of which *Acartia* spp. is the most common form. Harpacticoid copepods are also present but in lower relative abundances. Larval and post-larval stages of many benthic invertebrates, e.g., bivalve molluscs, crab, mantis shrimp, and polychaetes, also inhabit the plankton community seasonally. Phytoplankton, zooplankton, and detritus are all food sources for an array of benthic invertebrates and fish larvae, particularly gobies and flatfish, that are also seasonally present in the plankton.

A.5.4 Benthic Invertebrates

As determined by Ford (1968), Ford and Chambers (1974), and others, the invertebrate fauna of both the intertidal and subtidal zones of San Diego Bay is dominated by polychaetes, crustaceans, and molluscs. Of 292 species encountered in field studies conducted over the period of 1976-1989, approximately 40 percent were polychaetes, 29 percent were crustaceans (crabs, shrimp, amphipods, and isopods), and 18 percent were molluscs (bivalve and gastropod) (Michael Brandman Associates, Inc. 1990). The remaining 13 percent included oligocahetes, echinoderms, bryozoans, tunicates, phoronids, nematodes, flatworms, nemerteans, sipunculids, sponges, and coelenterates (hydroids and sea anemonies). Many of the species occurring subtidally also occur intertidally. Many are species important to man including cockle clams (*Chione* spp.), bent-nosed clam (*Macoma nasuta*), and native littleneck clam (*Protothaca staminea*). Other bivalves, including jackknife clams (*Tagelus* spp.), rosy razor clam (*Solen rosaceus*), and ghost shrimp (*Callianassa californiensis*), are sold as bait for fishing. The bryozoan, *Zoobotryon verticillatum*, is present in San Diego Bay where it forms extensive, flexible, tree-like masses during the summer months. Some clumps attach to shell material in surface sediments or on pilings and other hard substrates, while other clumps are moved about the Bay freely by the currents. The introduced Asian clam, *Musculista senhousia*, has been found to exploit disturbed benthic habitats, both in deep and shallow waters, and to reach extremely high densities, e.g., $445/m^2$ (Michael Brandman Associates, Inc. 1990). At these densities, it clearly would affect abundances of natural infauna.

While most of the invertebrates are of no direct value to man, they are of central importance in the food web of the San Diego Bay ecosystem. Microorganisms, particularly colonial diatoms, have been identified as an important food source for many deposit feeding infauna, including polychaetes and molluscs. Other polychaetes, molluscs, brittlestars, crabs, isopods, and small crustaceans feed on detritus and other organic materials. Still other infauna, particularly bivalve molluscs, filter the water column for pelagic diatoms and other microorganisms. Bryozoa are effective filter feeders on plankton and suspended detritus, but are of only moderate biological importance as food themselves for a variety of invertebrates and small fish. Many species of infauna and epifauna, in turn, are important food resources for many species of fish and shorebirds.

A.5.5 Fish

At least 67 species of bottom and pelagic fish are found in San Diego Bay (Michael Brandman Associates, Inc. 1990). Twenty-one species were considered common in South San Diego Bay (Ford 1968). California halibut (*Paralichthys californicus*), diamond turbot (*Hypsopsetta guttulata*), striped mullet (*Mugil cephalus*), spotted sandbass (*Paralabrax maculatofasciatus*), and barred sandbass (*P. nebulifer*), are all important commercial or recreational species. Other abundant species include bat ray (*Myliobatis californica*), topsmelt (*Atherinops affinis*), deepbody anchovy (*Anchoa compressa*), shiner surfperch (*Cymatogaster aggregata*), bay pipefish (*Syngnathus leptorhynchus*), California killifish, (*Fundulus parvipinnis*), and arrow goby (*Clevelandia ios*). The most dominant species (first in abundance and biomass) collected in recent surveys was the round stingray, *Urolophus halleri* (Michael Brandman Associates, Inc. 1990). Second and third in abundance were slough anchovy (*Anchoa delicatissima*) and California halibut, respectively. The latter consisted primarily of juveniles and small adults.

As with invertebrates, different fish species feed at different levels within the food web. Mullet and topsmelt feed on detritus and small organisms in surficial sediments. The flatfishes (California halibut and diamond turbot) as young forage on polychaetes, small crustaceans, and small bivalves. As they grow larger, they feed mainly on other fish. Killifishes inhabiting tidal creeks consume large numbers of polychaetes and small crustaceans. Pipefish and seahorse feed on small zooplankton (copepods and mysids) by sucking their prey into a tubular snout. The slough anchovy is a filter feeder of small zooplankton. Rays have jaw parts adapted for seizing and crushing molluscs. Most other species common to South San Diego Bay feed on other fish species.

A.5.6 Birds

South San Diego Bay is an important resting, feeding, and breeding area for a wide variety of both resident and migratory shore birds and other water birds (Ford 1968; Michael Brandman Associates, Inc. 1990). Common species include the brown pelican (*Pelecanus occidentalis*), double crested cormorant (*Phalacrocorax auritus*), snowy egret (*Egretta thula*), black-crowned night heron (*Nycticorax nycticorax*), snowy plover (*Charadrius alexandrinus*), black-bellied plover (*Pluvialis squatarola*), ruddy turnstone (*Arenaria interpres*), dunlin (*Calidris alpina*), willet (*Catoptrophorus semipalmatus*), least sandpiper (*Calidris minutilla*), Western sandpiper (*Calidris mauri*), short-billed dowitcher (*Limnodromus griseus*), marbled godwit (*Limosa fedoa*), black-necked stilt (*Himantopus mexicanus*), Western gull (*Larus occidentalis*), Heerman's gull (*Larus heermanni*), Forster's tern (*Sterna forsteri*), Caspian tern (*S. caspia*), royal tern (*S. maxima*), elegant tern (*E. elegans*), least tern (*S. albifrons*), surf scoter (*Melanitta perspicillata*), bufflehead (*Bucephala albeola*), and lesser scaup (*Aythya affinis*).

Most of the shore birds with the exception of the snowy plover and black-legged stilt are fall migrants from northern breeding grounds that winter in San Diego Bay. Adult birds precede the young in migration. Western gull, brown pelican, cormorant, some snowy egrets, and black crowned night herons are also permanent residents. Herman's gull and elegant tern are winter residents. The common tern is present in spring and fall during migration. Brown pelicans, gulls, and terns use the dike of the South Bay Power Plant for resting. The least tern uses these same areas in summer for nesting. Ducks, particularly surf scoter and lesser scaup, winter in large numbers on San Diego Bay. The brown pelican, least tern, Belding's savanna sparrow (*Passerculus sandwichensis beldingi*), light-footed clapper rail (*Rallus longirostris*), and the California black rail (*Latterallus jamaicensis*) are listed as endangered species by the State of California (Department of Fish and Game 1992).

The food web for major bird species in San Diego Bay is shown on Figure A-3 as originally drawn by Ford (1968). Brown pelican, double-crested cormorant, and terns feed almost exclusively on small fish. These birds are mostly ocean feeders, but they also feed in the Bay to a lesser extent. Herons and egrets feed on small fishes but include in their diets rodents, reptiles, and insects. Sandpipers feed intertidally by probing a few millimeters into the sediment for polychaetes, small molluscs, and plant materials. Other sandpipers and plovers feed on similar prey but from the sediment surface. Gulls are scavengers that forage on all aquatic life as well as man's waste.

A.5.7 Sea Turtles

Sea turtles were first reported to occur in South San Diego Bay in the vicinity of the South Bay Power Plant by Ford (1968). They occur there between November and April and appear to be attracted to the warm water discharge (Ford and Chambers 1974). While their taxonomic status remains in question (mitochondrial DNA analyses are in progress), Dutton and McDonald (1990) have tentatively identified six of seven captured specimens as the black turtle, *Chelonia agassizi*. The seventh could have been a green turtle, *C. mydas*. Black turtles nest in Mexico while green turtles nest in other areas of the Pacific Ocean, e.g., Hawaii. The black turtle is considered a subspecies of the green turtle, which is listed as endangered by the State of California (Department of Fish and Game 1992). Sea turtles are thought to feed on eel grass, other seagrasses, and algae, e.g., *Ulva* sp. and *Polysiphonia* sp. (McDonald et. al 1994). Further important information about sea turtles of South San Diego Bay is provided by McDonald et al. 1994.

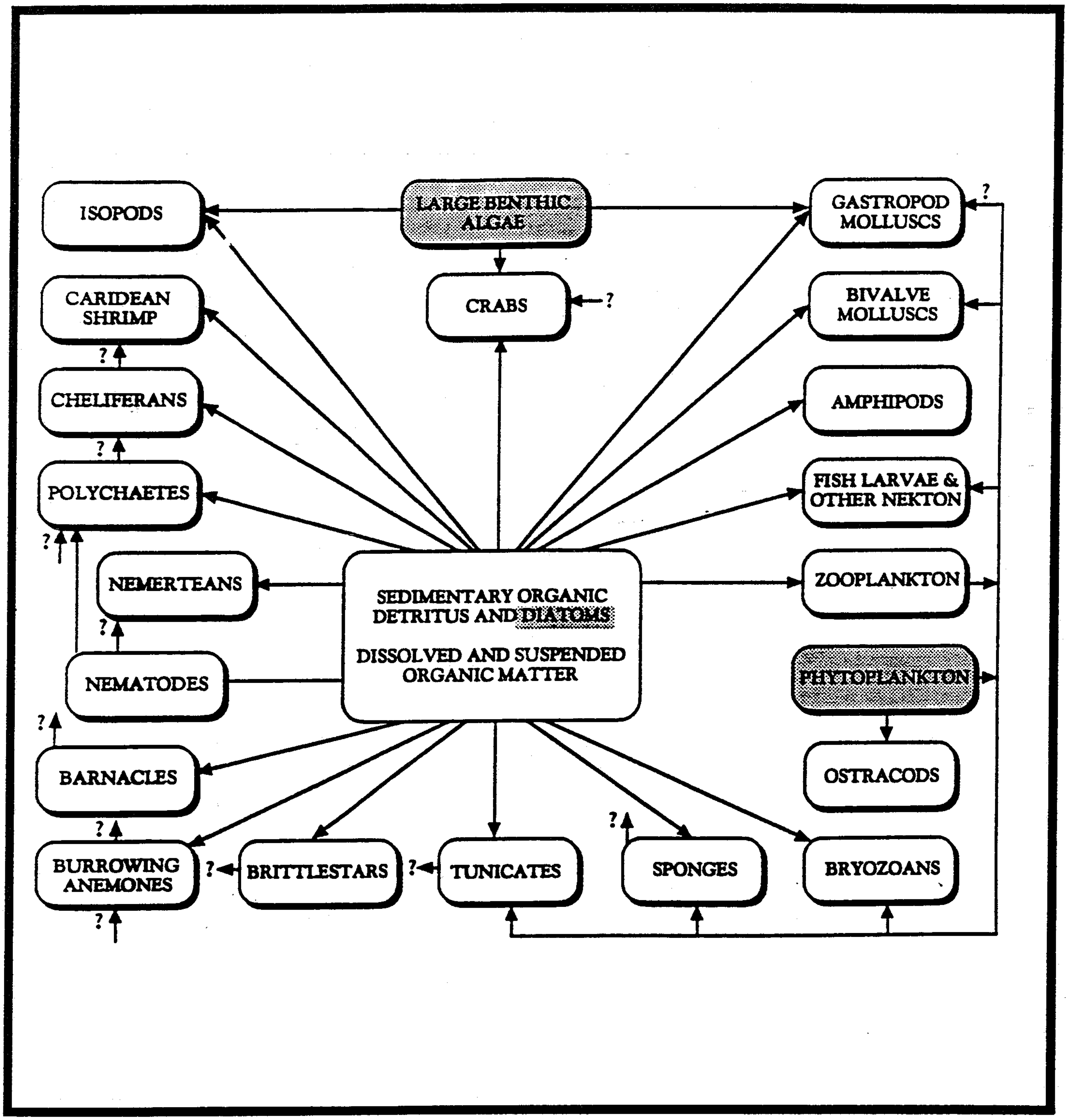

Figure A-1. Generalized summer sub food web for marine invertebrates and algae in South San Diego Bay, based on gut analyses and published data. Primary producers are shaded. These plants photosynthesize food from inorganic chemicals in the presence of sunlight. Direction of arrow indicates direction of food and energy (Michael Brandman Associates, Inc. 1990, redrawn from Ford 1968).

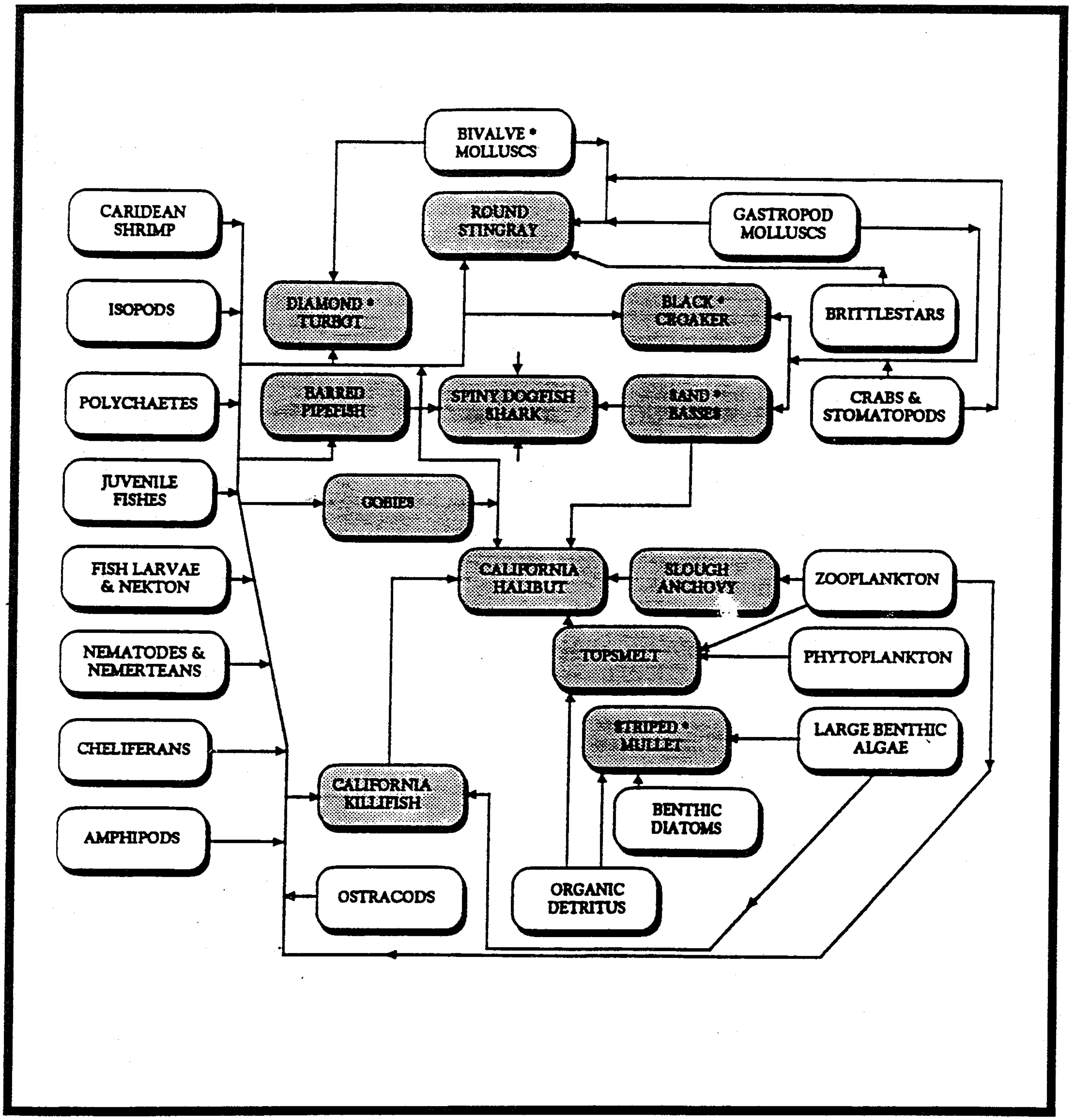

Figure A-2. Generalized summer sub food web for benthic and pelagic fishes in South San Diego Bay, based on gut analyses and published data. Species or groups marked with "*" are animals used as food by man. Fish are shaded. Direction of arrow indicates direction of food and energy. The spiny dogfish shark eats nearly all medium-large sized invertebrates and small-medium sized fishes (Michael Brandman Associates, Inc. 1990, redrawn from Ford 1968).

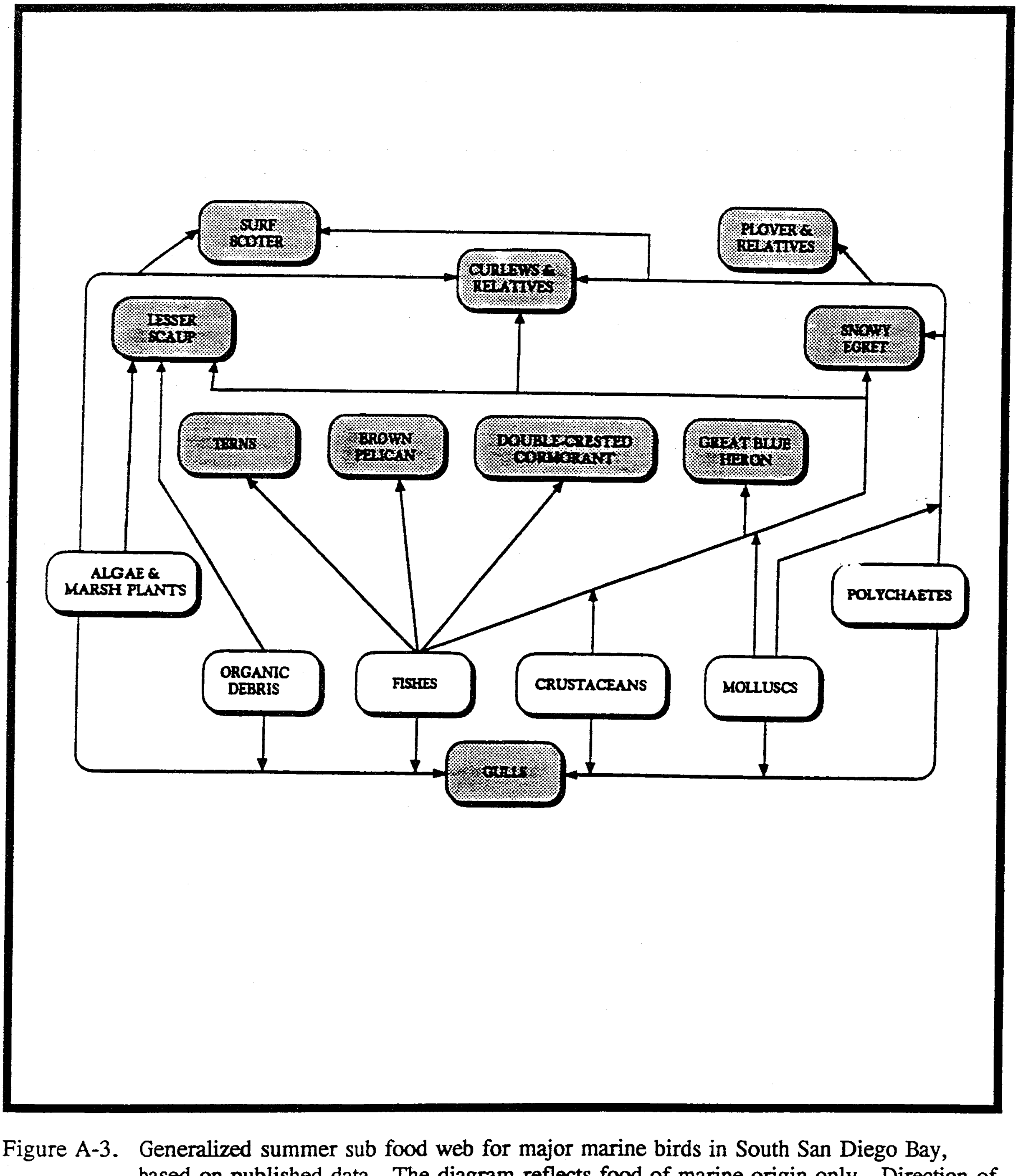

Figure A-3. Generalized summer sub food web for major marine birds in South San Diego Bay, based on published data. The diagram reflects food of marine origin only. Direction of arrow indicates direction of food and energy. Birds are shaded (Michael Brandman Associates, Inc. 1990, redrawn from Ford 1968).

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Appendix B

Comparison of Study Methods Used for SDG&E's South Bay Power Plant Annual Receiving Water and Sediment Monitoring Conducted During 1977-1994

APPENDIX B

COMPARISON OF STUDY METHODS USED FOR SDG&E'S SOUTH BAY POWER PLANT ANNUAL RECEIVING WATER AND SEDIMENT MONITORING CONDUCTED DURING 1977-1994

Year	1977	1978	1979
Contractor	Lockheed Center for Marine Research	Lockheed Center for Marine Research	Lockheed Center for Marine Research
No. of Stations	11	11	11
Replicates	3/station	3/station	3/station
Sample Date(s)	3-4 August	1-2 August	1-2 August
Gear	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)
Field Handling	Core subsample; preserved for chemical analyses Sediment temperature - calibrated thermometer Field screened - 0.5 mm Nytex screen Preserved in 10% buffered seawater formalin	Core subsample; preserved for chemical analyses Sediment temperature - calibrated thermometer Field screened - 0.5 mm Nytex screen Preserved in 10% buffered seawater formalin	Subsample preserved for chemical analyses Sediment temperature - calibrated thermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin
Physicochemical			
In Situ	Temperature - 2-ft intervals S to B; Martek XMS Secchi disc reading	Temperature - 2-ft intervals S to B; YSI telethemometer Secchi disc reading	Temperature - 2-ft intervals S to B; YSI telethermometer Secchi disc reading Salinity - 2 ft of surface and off bottom; YSI salinometer
Van Dorn Sample	Fixed for D.O. analysis; salinity	Fixed for D.O. analysis	Fixed for D.O. analysis
Biological Analysis	Sort to major taxonomic groups - wet weight to nearest 0.01 g ID to species, enumerated	Sort to major taxonomic groups - weight to nearest 0.01 g ID to species, enumerated	Sort to major taxonomic groups - wet weight to nearest 0.01 g ID to species, enumerated
Physical/Chemical Laboratory			
Sediment	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland and Parsons 1968); % dry weight Grain size - modified hydrometer technique (ASTM 1967); % gravel, sand, silt, clay	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland & Parsons 1968); % dry weight Grain size - modified hydrometer (ASTM 1967); % gravel, sand, silt, clay	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland & Parsons 1968); % dry weight Grain size - modified hydrometer (ASTM 1967); % gravel, sand, silt, clay
Water	D.O. - modified Winkler (Strickland & Parsons 1968) Salinity - argentometric titration (APHA et al. 1975; Strickland & Parsons 1968)	D.O. - modified Winkler (Strickland & Parsons 1968) Salinity - argentometric titration (APHA et al. 1975; Strickland & Parsons 1968)	D.O. - modified Winkler (Strickland & Parsons 1968)

APPENDIX B (Continued)

Year	1980	1981	1982
Contractor	Lockheed Environmental Sciences	Lockheed Ocean Science Laboratories	Woodward-Clyde Consultants
No. of Stations	11	11	11
Replicates	3/station	3/station	3/station
Sample Date(s)	1-2 August	1-2 August	30 September
Gear	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)	Smith-McIntyre grab (0.1 m2)
Field Handling	Core samples by divers; preserved for chemical analyses Sediment temperature - calibrated thermometer Field screened - 0.5 mm nytex screen; elutriated Preserved in 10% buffered seawater formalin	3 core samples by divers; preserved for chemical analyses Sediment temperature - calibrated thermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin	Separate grab(?) preserved for chemical analysis Sediment temperature - calibrated thermometer Field screened - 0.5 mm Nytex screen Preserved in 10% buffered seawater formalin
Physicochemical			
In Situ	Temperature - 2-ft intervals S to B; YSI telethermometer Secchi disc reading Salinity - 2 ft of surface and off bottom; YSI salinometer; by diver	Temperature - 2-ft intervals S to B; YSI telethermometer Secchi disc reading Salinity - 2 ft of surface and off bottom; YSI salinometer, by diver	Temperature - 2-ft intervals S to B; Martek VIII WQ Analyzer Secchi disc reading Conductivity measured using Martek Model VIII; converted to salinity D.O.; Martek Model VIII
Van Dorn Sample	Fixed for D.O. analysis; by diver	Fixed for D.O. analysis; by diver	
Biological Analysis	Sort to major taxonomic groups - wet weight to nearest 0.01 g Aliquoted ID to species, enumerated	Sort to major taxonomic groups - wet weight to nearest 0.01 g Subsampled ID to species, enumerated	Sort to major taxonomic groups - weight to nearest 0.01 g Aliquoted ID to species, enumerated
Physical/Chemical Laboratory			
Sediment	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland & Parsons 1968); % dry weight Grain size - modified hydrometer technique (ASTM 1967); % gravel, sand, silt, clay	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland & Parsons 1968); % dry weight Grain size - modified hydrometer technique (ASTM 1967); % gravel, sand, silt, clay	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland & Parsons 1968); % dry weight Grain size - standard sieve/hydrometer technique (ASTM 1967); % gravel, sand, silt, clay
Water	D.O. - modified Winkler (Strickland & Parsons 1968)	D.O. - modified Winkler (Strickland & Parsons 1968)	

APPENDIX B (Continued)

Year	1983	1984	1985
Contractor	Woodward-Clyde Consultants	WESTEC Services, Inc.	CH2M Hill
No. of Stations	11	11	11
Replicates	3/station	3/station	3/station
Sample Date(s)	3-4 August	28 August	7 August
Gear	Smith-McIntyre grab (0.1 m2)	Van Veen grab (0.1 m2)	Ponar grab (0.025 m2)
Field Handling	Sediment subsample (each rep) for chemical analysis Sediment temperature - calibrated thermometer Field screened - 0.5 mm Nytex screen Preserved in 10% buffered seawater formalin	3 core samples by divers; preserved for chemical analyses Sediment temperature - calibrated thermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin	3 Ponar grabs for sediment; core subsample taken Sediment temperature Field screened - 0.5 mm Nytex screen Narcotized prior to preservation Preserved in 10% buffered formalin
Physicochemical			
In Situ	Temperature - Air, surface, & 2-ft intervals B; Hydrolab Model 6D WQ Analyzer Secchi disc reading Depth - by soundings Salinity - near surface and near bottom;Hydrolab Model 6D D.O. - near surface and near bottom; Hydrolab Model 6D	Temperature - 2-ft intervals S to B; Montedoro-Whitney telethermometer Secchi disc reading Salinity - 2 ft of surface and near bottom; YSI Model 57 salinometer D.O. - YSI Model 58 D.O. meter	Temperature - 2-ft intervals S to B; YSI Model 33 S-C-T Secchi disc reading Salinity - 2-ft intervals S to B; YSI Model 33 S-C-T
Van Dorn Sample			1 ft depth and 1-2 ft off bottom; preserved Rinsed with water and transferred to 70% ethanol after 48 hours
Biological Analysis	Sort to major taxonomic groups - wet weight to nearest 0.01 g Aliquoted ID to species, enumerated	Sort to major taxonomic groups - wet weight to nearest 0.01 g Subsampled ID to species, enumerated Tentative IDs marked by ?	Sort to major taxonomic groups - wet weight to nearest 0.01 g ID to species, enumerated
Physical/Chemical Laboratory			
Sediment	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland & Parsons 1968); % dry weight Grain size - standard sieve/hydrometer technique (ASTM 1967); % gravel, sand, silt, clay	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland & Parsons 1968); % dry weight Grain size - modified hydrometer technique (ASTM 1967); % gravel, sand, silt, clay	COD, TKN - Standard Methods Section 508 and 421 Grain size - sieve and hydrometer Hydrometer methods (ASTM Method D422)
Water			

APPENDIX B (Continued)

Year	1986	1987	1988
Contractor	Kinnetic Laboratories, Inc.	Kinnetic Laboratories, Inc.	Kinnetic Laboratories, Inc.
No. of Stations	11	11	11
Replicates	3/station	3/station	3/station
Sample Date(s)	11-12 August	5-6 August	25-26 August
Gear	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)
Field Handling	Sediment subsample (each rep) for preserved for chemical analysis Sediment temperature - telethermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin	Sediment subsample (each rep) preserved for chemical analysis Sediment temperature - telethermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin	Sediment subsample (each rep) for chemical analysis; held at 2-4 C Sediment temperature--telethermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin
Physicochemical			
In Situ	Temperature - 2-ft intervals S to B; Montedoro-Whitney telethermometer Secchi disc reading Salinity - 2 ft of surface and near bottom; YSI Model 57 salinometer D.O. - YSI Model 58 D.O. meter	Temperature - 2-ft intervals S to B; YSI Model 43 TD telethermometer Secchi disc reading Salinity - 2 ft of surface and near bottom; Hanna Model 55 salinometer D.O. - YSI Model 58 D.O. meter	Temperature - 2-ft intervals S to B; YSI Model 43 TD telethermometer Secchi disc reading Salinity - 2 ft of surface and near bottom; Hanna Model 55 salinometer D.O. - YSI Model 58 D.O. meter
Van Dorn Sample			
Biological Analysis	Sort to major taxonomic groups - wet weight to nearest 0.01 g Subsampled ID to species, enumerated	Sort to major taxonomic groups - wet weight to nearest 0.01 g Split to 1/8; noted as done in past surveys ID to species, enumerated	Sort to major taxonomic groups - weight to nearest 0.01 g Split to 1/8; noted as done in past surveys ID to species, enumerated
Physical/Chemical Laboratory			
Sediment	COD, TKN - modified wastewater and sea water techniques (APHA et al. 1975; Strickland & Parsons 1968); % dry weight Grain size - USGS gravimetric analysis,modified hydrometer technique (ASTM 1967); % gravel, sand, silt, clay	COD, TKN - EPA-approved methods Grain size - standard USGS seive categorization and gravimetric analysis (Plumb 1981); % (weight) gravel, sand, silt, clay	COD, TKN - EPA-approved methods Grain size - standard USGS seive categorization gravimetric analysis; % (weight) gravel, sand, silt, clay
Water			

APPENDIX B (Continued)

Year	1989	1990	1991
Contractor	Kinnetic Laboratories, Inc.	Kinnetic Laboratories, Inc.	Kinnetic Laboratories, Inc.
No. of Stations	11	11	11
Replicates	3/station	3/station	3/station
Sample Date(s)	30-31 August	1-2 August	21-22 August
Gear	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)
Field Handling	Sediment subsample (each rep) for chemical analysis; held at 2-4 C Sediment temperature - telethermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin	Sediment subsample (each rep) for chemical analysis; held at 2-4 C Sediment temperature - telethermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin	Sediment subsample (each rep) for chemical analysis; held at 2-4 C Sediment temperature - telethermometer Field screened - 0.5 mm Nytex screen; elutriated Preserved in 10% buffered seawater formalin
Physicochemical			
In Situ	Temperature - 2-ft intervals S to B; YSI Model 43 TD telethermometer Secchi disc reading Salinity - 2 ft of surface and near bottom; Hanna Model 55 salinometer D.O. - YSI Model 58 D.O. meter	Temperature - 2-ft intervals S to B; YSI Model 43 telethermometer Secchi disc reading Salinity - 2 ft of surface and near bottom; salinometer D.O. - YSI Model 58 D.O. meter	Temperature - 2-ft intervals S to B; YSI Model 51A D.O./Temperature meter Secchi disc reading Salinity - 2 ft of surface and near bottom; LabComp salinometer D.O. - YSI Model 51A D.O./Temperature meter
Van Dorn Sample	Transferred to 70% ETOH when split	Transferred to 70% ETOH when split	Transferred to 70% ETOH when split
Biological Analysis	Sort to major taxonomic groups - weight to nearest 0.01 g Split to 1/8; noted as done in past surveys ID to species, enumerated	Sort to major taxonomic groups - wet weight to nearest 0.01 g Split to 1/8; noted as done in past surveys ID to species, enumerated	Sort to major taxonomic groups - wet weight to nearest 0.01 g Split to 1/8; noted as done in past surveys ID to species, enumerated
Physical/Chemical Laboratory			
Sediment	COD, TKN - EPA-approved methods Grain size - standard USGS seive categorization and gravimetric analysis; % (weight) gravel, sand, silt, clay	COD, TKN - standard methods Grain size - standard USGS seive categorization and gravimetric analysis; % (weight) gravel, sand, silt, clay	COD, TKN - standard methods Grain size - standard USGS seive categorization and gravimetric analysis; % (weight) gravel, sand, silt, clay
Water			

APPENDIX B (Continued)

Year	1992	1993	1994
Contractor	Columbia Aquatic Sciences	Kinnetic Laboratories, Inc.	Columbia Aquatic Sciences
No. of Stations	11	11	13
Replicates	3/station	3/station	3/station
Sample Date(s)	26-27 August	25-26 August	17-18 August
Gear	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)	Van Veen grab (0.1 m2)
Field Handling	Sediment subsample (each rep) for chemical analysis; held at 2-4 C	Sediment subsample (top 2 cm of each rep) for chemical analysis; held at 2-4 C	Sediment subsample for chemical analysis, held at 4 C
	Sediment temperature - telethermometer	Sediment temperature - telethermometer	Sediment temperature - Orion Model 140 telethermometer
	Field screened - 0.5 mm Nytex screen; elutriated	Field screened - 0.5 mm stainless steel screen; elutriated	Field screened - 0.5 mm mesh Nitex screen; elutriated
	Preserved in 10% buffered seawater formalin	Preserved in 10% buffered seawater formalin	Preserved in 10% buffered seawater formalin
Physicochemical			
In Situ	Temperature - 2-ft intervals S to B; Micronta 64-843 telethermometer	Temperature - 2-ft intervals S to B; SeaBird Seacat SBE-19 CTD Model 299	Temperature - 2-ft intervals S to B; Orion Model 820 D.O./Temperature meter
	Secchi disc reading	Secchi disc reading	Secchi disc reading
	Salinity - 2 ft of surface and 2 ft of bottom; Orion Model 140 S-C-T	Salinity - 2 ft of surface and 2 ft of bottom; SeaBird Seacat SB-19 Model 299	Salinity - 2 ft of surface and 2 ft of bottom; Orion Model 140 S-C-T meter
	D.O. - 2 ft of surface and 2 ft of bottom; Orion Model 840 DO/Temp	D.O. - 2 ft of surface and 2 ft of bottom; SeaBird Seacat With Orion 840 O2 probe	D.O. - 2 ft of surface and 2 ft of bottom; Orion Model 820 D.O./Temperature meter
		pH - 2 ft below S and above B; SeaBird Seacat SBE-19 Model 299	
Van Dorn Sample	Transferred to 70% ETOH when split	Transferred to 70% ETOH after 72 hour	Transferred to 70% ETOH when split
Biological Analysis	Sort to major taxonomic groups - wet weight to nearest 0.01 g	Sort to major taxonomic groups - wet weight to nearest 0.01 g	Sort to major taxonomic groups - wet weight to nearest 0.01 g
	Split to 1/8; noted as done in past surveys	Split to 1/8; noted as done in past surveys	Split to 1/8; noted as done in past surveys (box splitter)
	ID to species, enumerated	ID to species, enumerated	ID to species (if possible), enumerated
Physical/Chemical Laboratory			
Sediment	COD, TKN - EPA-approved methods	COD, TKN - EPA Methods 351.3, 410.1, respectively	COD, TKN - standard methodologies
	Grain size - gravimetric method (Plumb 1981)	Grain size - USGS seive categorization and gravimetric method	Grain size - gravimetric method (Plumb 1981)
		Plumb (1981); %(weight) gravel sand, silt, clay	
Water			