ATTACHMENT 13

Review of the Long-Term Receiving Water Monitoring Done for the South Bay Diego Bay Power Plant

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Prepared for

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1. INTRODUCTION

1.1 SCOPE OF WORK

Evaluate and summarize results of studies conducted since 1977 to monitor water quality and infaunal assemblages in the vicinity of SDG&E's South Bay Power Plant.

1.1.1 OBJECTIVES

The primary objective of the evaluation is to assess if the data show environmental impacts, beneficial effects, relationships between physical and biological factors, and trends in community structure.

A secondary objective is to compare information derived from this set of reports to results and conclusions described in a Four-year Cumulative Analysis Report and the 1972-73 Biological Studies Report.

1.1.2 APPROACH

The approach taken for this evaluation was to accumulate all data, enter it into a database, and conduct rigorous quality control checks against the original report data. Descriptive statistics and long-term plots of densities were prepared to provide a description of the basic assemblages. The plots were also used to demonstrate temporal and spatial patterns. To provide an overview of how the assemblages are changing through time and space, and how they are responding to environmental variables such as temperature, sediment chemistry, and sediment physical characteristics, ordination analysis of dissimilarity values was done for the entire data set and for each station and survey. The results of this analysis along with selected biological variables (e.g., densities of selected species) were analyzed for relationships to the environmental variables to provide information on what factors may be important to the distribution and abundance of infaunal species.

1.2 DESCRIPTION OF DATA SET

The data used in this evaluation were taken from 17 annual reports prepared to meet the Receiving Water Monitoring and Reporting requirements for SDG&E's South Bay Power Plant. Data collected during each survey were sediment samples for infaunal, grain size, temperature, and chemical measurements/analyses; water column measurements of temperature, dissolved oxygen, transparency, and salinity; and general observations such as air temperature, depth, and station location. Selected components of this data were used for the evaluation of biotic and physical environment of the south bay area.

The requirements of the monitoring program did not change during the 17 year period. Eleven stations were sampled with three replicates for each of the sediment analyses. Water column profiles were done at each of the stations. Station locations were selected by the program designers from an original grid of stations sampled during the Thermal Effects Study in 1972-1973 using results from that study to select the stations most likely to represent areas of impact (discharge channel), control/reference (stations outside the impact area of the thermal plume), and stations located in-between these areas. Initially the stations were located using visual marks recorded during the Thermal Effects Study. As the project passed from one consulting group to another, it became likely that the stations were not consistently located, particularly as new construction on land and along the bay (e.g., J Street Marina, Coronado Cays) changed the available landmarks. Electronic positioning has been used for the past several years. While this does not ensure exact positioning (the accuracy is usually ±50 ft for Loran and standard GPS), use of this plus the visual landmarks should provide fairly consistent sampling locations. An examination of the south bay chart (Figure 1), shows that positioning is critical for the stations adjacent to deeper (N2, A3, C3) or shallower (E7 and F4) areas.

1.2.1 ENVIRONMENTAL CONDITIONS

Description of sampling sites, accuracy in site relocation, sampling techniques and laboratory techniques

1.2.1.1 Water Column Conditions

Required variables to be sampled in the water column included temperature, dissolved oxygen, pH, and, salinity. Generally these were measured using electronic profiling equipment, thus providing fairly instantaneous surface to bottom measurements. Also, measured was water transparency using the depth at which a secchi disk could not be distinguished (secchi disk extinction coefficient). The electronic equipment provides accurate measurements for temperature, salinity, pH, and depth. Dissolved oxygen measurements are often more problematic as the probes require more maintenance and response time during sampling. To ensure accurate measurements, it is advisable to take discrete samples for analysis by titration methods to ground-truth the results of the probe.

Water quality measurements were not used in the long-term analyses. The main reason for this is that these measurements describe the conditions at the time of sampling, but may change quickly and thus may not represent the conditions that the biota are subjected to through time.

1.2.1.2 Sediment Variables

Required sediment sampling included sediment temperature, chemical oxygen demand (COD), total Kjedahl nitrogen (TKN), and grain size characteristics. Sediment temperature generally was measured when the sample was still in the grab sampler. If the temperature was not taken immediately, air temperature could affect the temperature reading.

Subsamples of each grab (replicate) were taken and analyzed separately for the sediment chemistry and grain size. Standard chemical analysis procedures were used for COD and TKN. Grain size was generally analyzed by sieving for coarse sediments and use of a special hydrometer for determination of the fine categories.

Each of the sediment variables was used in analyses with the biological variables. It was felt that the sediment variables provide a better measure of the conditions potentially affecting the biological populations.

1.2.2 BIOLOGICAL

Sampling of the biological populations in the area was done using a chain-rigged Van Veen grab sampler with a surface sampling area of 0.01 m^2. This apparatus was used for all sampling except 1985 when a small Ponar grab was used with a surface sampling area of 0.004 m^2.

Following collection of the sample, measurement of sediment temperature, and collection of aliquots for later chemical analysis, the sample for biological description was washed through a 0.5-mm mesh screen. This process was done either by directly placing the sample on the screen or by elutriation (washing in a turbulent water flow and allowing the lighter organisms [i.e., annelids, arthropods] to float to the surface and onto the screen; heavier organisms [i.e., molluscs] were separated from the remaining sediment). The residual material on the screens, animals and debris, were placed in a storage container and preserved using buffered sea-water formalin. During some years the organisms in the sample may have been treated with a chemical to relax the organisms.

In the laboratory, formalin was washed from the samples by screening the sample through a 0.5-mm mesh screen. The sample was then preserved with a mixture of 70% alcohol and water. Individual samples (replicates or grabs) were then split into equal subsamples (generally quarters or eighths) and one subsample processed. If subsampling was done as originally defined, the whole sample was processed to make it a fairly homogeneous sample before subsampling. This means that large organisms and pieces of debris (e.g., shells, eelgrass blades, etc.) were removed (and counted for the organisms) to allow the sample to be split into representative subsamples.

Processing of the subsamples or samples that could not be subsampled properly consisted of removal of each organism from the debris, identification to as low a taxon as practical (usually species), counts by each species, and wet-weight biomass for each phyletic category. Identification levels differed among consultants and through time as new taxonomic literature became available. Following completion of laboratory processing, subsample counts were extrapolated to a total number of individuals for each grab (replicate). If organisms were removed prior to subsampling, the counts for each species were then added to the extrapolated total from the subsamples. This sum was the number of individuals reported for each replicate in each of the annual reports.

2. METHODS

Methods described below are those used for this review and not those done during each of the individual years. They describe the data used and the sources of the data.

2.1 PHYSICOCHEMICAL CONDITIONS

2.1.1 WATER

The following information for water related variables was used in this review's analyses for comparison with biological variables. Annual means calculated for the year prior to the time of sampling (i.e., from August through July) were used for most analyses. Where interest was in the period immediately prior to the time of sampling (i.e., was delta T for the month prior to sampling a determining factor rather than for the entire year), values for the variables were used from the month preceding sampling (i.e., July for samples in early August, August for samples in late August or early September, or September for samples taken in late September).

Variables used as descriptors for the water characteristics were those that integrate information over a relatively long period of time (e.g., at least one month). Consequently, survey measurements of water column variables (i.e., dissolved oxygen, salinity, and transparency) were not used as they represent the conditions during the time of sampling. While this is valuable information in determining the environmental conditions at the time of sampling, it may not provide a good measure of the longer-term environmental conditions.

2.1.1.1 INTAKE TEMPERATURE.

Intake temperatures were available from company operations reports for all years as monthly means. The mean for the month preceding sampling was used for comparisons. The annual mean was used to evaluate temperature trends between years. This variable was considered the best measure of ambient temperature conditions for the south bay.

While these temperatures may be affected by tidal change and insolation, it is likely that they provide a good measure of the ambient water temperature conditions in the south bay. Use of monthly and annual means smooth over the impacts of extreme tides and warm periods, but still integrate the effects those environmental conditions into the temperature regime used for analyses.

2.1.1.2 COOLING WATER DISCHARGE TEMPERATURE

Cooling water discharge temperatures were available from company operations reports for all years as monthly means. The mean for the month preceding sampling was used for comparisons. The annual mean was used to evaluate plant temperature trends between years. This variable along with the difference between plant (discharge) and intake temperatures (Delta T) was used to evaluate the effect of the plant.

2.1.1.3 COOLING WATER FLOW RATES

Cooling water flow rates were available from company operations reports for all years as monthly means. The annual mean was used to evaluate plant flow trends between years.

2.1.1.4 ESTIMATED HEAT LOADING

This term was calculated by multiplying the Delta T by the flow for each month. It is an estimate of the total heat load added to the discharge channel.

2.1.1.5 SALINITY AND RAINFALL

Salinity measurements were available from annual water column measurements. Because of the variability associated with water column measurements and the high likelihood that the infaunal community is responding to extremes in salinity, it was decided to use a different factor that would help describe the large range of salinity values the south bay area may be experiencing. This factor is rainfall as the major cause of reduced salinity is terrestrial runoff from rainfall entering primarily through the Otay River and through a flood control channel (Telegraph Canyon Creek) near the intake for the power plant. Rainfall data was available on disk through 1992 and hard copy for 1993 from NOAA. Annual means based on years starting in July (most sampling was done during early August) were used for comparison with biological variables.

2.1.2 SEDIMENT

Sediment characteristics were used extensively in the analyses for this review because they provide direct information on the environmental conditions of the habitat in which the infaunal organisms are residing. As these characteristics generally are formed over time and not instantaneously, they provide the best measures available of the conditions defining the distribution and abundance of the organisms.

2.1.2.1 GRAIN SIZE

Means were calculated for percent gravel, sand, silt, and clay for each station during each year. The values for sand, silt, and clay were used in analyses for this review. Because gravel percentages were low and comprised primarily of shell debris, this measurement was not used.

2.1.2.2 SEDIMENT CHEMISTRY

Chemical oxygen demand (COD) and total Kjedahl nitrogen (TKN) are chemical analyses done to provide a measure of the organic content in the sediment. COD provides the concentration of carbon, both organic and inorganic. TKN provides the concentration of nitrogen, both organic and inorganic.

2.1.2.3 SEDIMENT TEMPERATURE

Sediment temperature was taken for each replicate. This temperature integrates the changes in near-bottom water temperature for an unknown period prior to sampling as it is relatively slow to change compared to water temperature. Because it is taken in the sediments in which the organisms were residing and provides a measure of temperature through time, it was used in the analyses with the biological variables.

2.2 INFAUNAL ASSEMBLAGES

This review is unique in that no field collections were done directly for the project. Instead, data was acquired from several consulting companies that had conducted the required monitoring studies for the South Bay Power Plant from 1977 through 1993. These companies and the years that they performed the monitoring studies are listed below.

Lockheed	- 1977 through 1981
WESTEC	- 1984
Woodward-Clyde	- 1982, 1983
CH_2M-Hill/MEC	- 1985
Kinnetic Labs	- 1986 through 1991, 1993
Columbia	- 1992

Within the companies, personnel important to the proper sample collection and laboratory analysis also changed. The taxonomic experts used were generally familiar with southern California infaunal taxonomy as most were members of the Southern California Association of Marine Invertebrate Taxonomists or attended the meetings of its predecessor group supported by the Southern California Coastal Wastewater Research Project. The taxonomists listed for each of the years of the study for the major taxa encountered are shown below.

Year	Annelids	Arthropods	Molluscs
Lockheed			
1977	J. Elliott	J. Carter	R. Walty/J. Elliott
1978	J. Elliott	J. Carter	R. Walty/J. Elliott
1979	J. Elliott	J. Carter	R. Walty/J. Elliott
1980	J. Elliott	J. Carter	R. Walty/J. Elliott
1981	J. Elliott	J. Carter	R. Walty/J. Elliott
Woodward-Clyde			
1982	D. Norris	D. Norris	D. Norris
1983	T. Jones/D. Norris	T. Jones/D. Norris	
WESTEC			
1984	J. Elliott	T. Jones/J. Carter	J. Elliott
CH_2M-Hill			
1985	L. Lovell	NR	NR
Kinnetic Labs			
1986	NR	NR	NR
1987	L. Harris	S. Hamer-Charter/T. Parr	J. Shrake
1988	L. Harris	S. Hamer-Charter/T. Parr	J. Shrake
1989	L. Harris	S. Hamer-Charter	J. Shrake
1990	L. Harris	S. Hamer-Charter	J. Shrake
1991	S. Williams	G. Gillingham	J. Shrake
Columbia			
1992	S. Williams	T. Parr	T. Parr
Kinnetic Labs			
1993	G. Ruff	D. Cadien	J. Shrake

NR - Not reported

While the methods specified in the NPDES permit were generally followed, changes among contractors and taxonomists added an additional level of complexity in the evaluation of the multi-year data set as the data forming the data set had to be made consistent through years as well as across stations. The following describes Ogden's approach to acquiring the data, standardizing the data set to make it consistent, and analyzing the data.

2.2.1 DATA ACQUISITION, PROCESSING, AND QC

The data was handled differently for each year and for different data types. This was necessary because the data was available to us in several different media including computer cards, computer magnetic tape, computer discs, repro-quality hard copy, and computer generated hard copy. Data from the cards, magnetic tape, and computer disc were entered directly into the computer. Data from the repro-quality hard copy were scanned and remaining data were entered by keypunching. For the infaunal data, the years that each media were available are listed below.

Data Source	Years
Cards	1977, 1978, 1981
Magnetic Tape	1984
Computer Disk	1990, 1991, 1993
Repro-Quality Tables	1985, 1986, 1987, 1988, 1989, 1992
Computer Printout	1979, 1980, 1982, 1983

After data was on computer file, the data created from each of the different sources was subjected to different levels of QC based on the likelihood of errors being introduced in the entry technique. The levels of QC are listed below.

Data Entry Technique	Complete Checks	Random 10% Check	Correction Check
Cards	1	0	1
Magnetic Tape	1	0	1
Keypunch Entry	2	0	2
Scan	1	1	1
Disk	0	1	1

Other data were handled similarly depending on the entry technique and the complexity of the data. The entry techniques for the various sources are listed below.

Data	Entry Technique
Biomass	Scan
Physical	Scan
Plant Operations	Keyboard Entry
Rainfall to 1993	Computer disk
Rainfall 1993	Keyboard Entry

2.2.2 STANDARDIZATION OF DATA SET

In order to properly accomplish the analyses of this multi-year data set, the data was standardized across all years with respect to taxonomic classifications. This was done in several steps. 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 17 separate annual reports. Second, consolidation of species based on spelling differences, questionable specific determinations, and name changes that occurred during the 17 year period. Where there may have been, uncertainty in the most recently accepted name, the name most familiar to the author was selected. Examples of these species consolidations are shown below.

Species Names Reported (Year)	Final Species Name
Errano lagunae (93)	*Lumbrineris lagunae*
Adula diegensis (77-81)	*Musculista senhousia*
Eteone lighti?	*Eteone lighti*

Third, species that are not infaunal (living in the sediment were eliminated from the data set as they are not properly sampled by the techniques used and, if left in the data set, 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 the author felt was the most likely correct was selected. Examples of these are listed below.

Species Names Reported (Year)	Final Species Name
Ischadium (*Geukinsia*) *demissum* (82) *Musculus senhousia* (83)	*Musculista senhousia*
Cylindroleberinae (77-84)	*Parasterope barnesi*

The data set resulting from these consolidations was the primary working data set for all analyses. The list of species comprising this data set and the consolidations made to form it are presented in Appendix A. To properly perform ordination and cluster analyses, the data set was altered by deleting species that occurred infrequently or had low abundances (<1% of the total abundance) and taxa that may represent multiple species (e.g., unidentified nemerteans, unidentified phoronids, *Lumbrineris* spp).

2.2.3 ASSEMBLAGE ATTRIBUTES

Analyses for this review are conducted on means calculated from the replicates at each station for each year. Replicated information will be presented only in appendices as standard deviation or standard error. Basic attributes calculated are number of taxa, species density, species diversity, and species evenness. As these values were calculated from the consolidated species list generated for all surveys, they may differ from those previously reported for each survey. Also calculated were number of species for each station during each year based on the pooled data for the station.

2.2.3.1 NUMBER OF TAXA

Total and average number of taxa per sample set. Referred to in some analyses as S.

2.2.3.2 SPECIES ABUNDANCE OR DENSITY

Total and average number of individuals per sample set. Referred to in some analyses as N.

2.2.3.3 SPECIES DIVERSITY

Composite Shannon-Wiener (H') based on pooled species data for each sample set.

2.2.3.4 BIOMASS

Total and average biomass per sample set.

2.2.4 ORDINATION AND CLUSTER ANALYSIS

The results of cluster analysis using Bray-Curtis dissimilarity analyses and group-averaging sorting strategy were compared with the output of Detrended Reciprocal Averaging ordination (see Appendix B for a description of the calculations). The ordination approach provided substantially better insight into relationships among the infaunal organisms and the distribution of the biota among the sites and was adopted as the method of choice for these analyses for this review.

Ordination was conducted on a two-way matrix juxtaposing total abundance of selected species against sites examined in each survey. This matrix was subjected to Detrended Reciprocal Averaging (DRA) as described by {Pimentel, 1993 #1} and performed by BIOΣTAT II software. DRA was conducted using abundance data corrected to 0.1-sq.m. densities. Analyses were conducted from the perspective of: 1) individual sites (e.g., 17 data sets representing each year from 1977 until 1993 at Site N2): 2) individual years (e.g., eleven data sets representing each site sampled in any one of the years), and 3) a composite data set including all sites for all years (187 individual data sets).

DRA calculates scores for each sampling unit (sites or species in this review) that describe its relationship to each of the other sampling units in 3-dimensional space. The process then searches this space to identify the axis that accounts for (describes) the largest amount of variability in the cloud of data points (Axis 1). DRA then searches the cloud orthogonally to Axis 1 to identify the axis that describes the greatest amount of variability on that plane (Axis 2). Subsequently, it identifies Axis 3 on the plane at a right angle to Axis 2 and Axis 4 at a right angle to Axis 3. These axes do not have units but generally can be related to some of the physical, chemical, and biological variables that characterize the study area by simple or multiple regression. In most cases, the axes appear to represent an average response to more than one variable and also incorporate sampling error and natural variability. Thus, the strength of the regression for any axis is usually somewhat less than unity and a variable may exhibit a strong relationship with more than one axis. This implies that the gradient for the variable lies along an vector that is not parallel to either of the axes with which it exhibits a strong relationship.

2.2.5 EXAMINATION OF TIME SERIES

Investigation of temporal trends and spatial patterns for selected species was done using bar graphs showing changes through time or space (stations) for each species. Species density was compared to selected physical and chemical variables using regression analyses done for all station and survey data. This comparison softens the impact of differences of individual years or stations and provides a measure of what factors the species is reacting to throughout the duration of sampling.

3. RESULTS

3.1 GENERAL

3.2 PHYSICOCHEMICAL CONDITIONS

3.2.1 Water

3.2.1.1 INTAKE AND PLANT TEMPERATURES

Annual mean intake temperature (August through July), a measure of ambient south bay temperature, was fairly consistent through time showing no obvious increases or decreases (Figure 2). There was little apparent effect of the large El Niño in 1982 through 1984 (1984 did have a slightly higher mean temperature) that was characterized by much higher water temperatures offshore in 1984.

Annual mean plant temperature had slightly higher temperatures from 1977 through 1981, 1984, and 1993 compared to the other years. Years with the lowest plant temperatures were 1982 and 1991.

Rather than annual means, most analyses involving intake and plant temperatures were done using the mean for the month prior to sample collection. This month was usually July, but was August for 1984, 1988, 1989, 1991, 1992, 1993 and September in 1982. The plant temperature for the month was approximately 10°F higher than the annual mean (Figure 2). Three years showed marked temperature decreases from the previous year: 1978, 1982, and 1991. Intake temperature for these months was similar to the annual plant temperature and showed decreases in 1982, 1987, and 1991.

Also potentially important is the Delta T, the difference between plant and intake temperatures (Figure 3). Annual Delta T was highest from 1979 through 1981. Delta T for the months prior to sampling showed decreases in 1978, 1981 through 1985, and 1991. Differences between the 17-year mean and the annual monthly means showed that Delta T was lower than the 17-year mean in 1983 and from 1985 through 1992 (Figure 3B). Annual monthly mean differences were higher than the multi-year mean from 1979 through 1981, in 1984, and in 1993. The differences for the month preceding sample collection showed more variability with periods with more than 2°F higher in 1977, 1979, and 1980. Periods with the difference lower than -2°F were 1982 through 1985 and 1991.

3.2.1.2 FLOW RATES

Annual mean flow rates for the plant ranged from 300 to 500 MGD (Figure 4). A fairly steady decrease occurred from 1977 through 1989 followed by a steady increase through 1993. Flow was not used directly in the analyses.

3.2.1.3 ESTIMATED HEAT LOADING

An estimate of heat load discharged into the receiving waters was calculated by multiplying flow rates with Delta T. It was characterized by a fairly steady decrease from 1979 through 1989 (Figure 5).

3.2.1.4 RAINFALL AND SALINITY

Mean annual rainfall had four peak years of rainfall (Figure 6). These were characterized by variable levels of terrestrial runoff. The 1978 and 1993 periods had particularly high levels of runoff which deposited large amounts of sediment offshore of the mouths of creeks. Two years, 1983 and 1988, had violent storms that created large coastal problems. While the south bay area was buffered from the forceful waves that caused coastal destruction, the storms and high winds that caused the offshore waves may have affected the study area.

3.2.2 SEDIMENT

3.2.1.1 SEDIMENT TEMPERATURE

Sediment temperature was consistently highest at Station E7, the station in the discharge channel nearest to the plant, and coolest at Station N2, located closest to the middle of the Bay (Figure 7). The years with the coolest sediment temperatures were 1982, 1989, and 1991.

3.2.1.3 CHEMICAL OXYGEN DEMAND (COD)

Mean levels of COD were lowest during the initial survey followed by considerable variability for all stations throughout the period reviewed (Figure 8). There was no recognizable pattern among years or stations other than Station N2 usually had one of the lowest values and no evidence of an increase through time.

3.2.1.4 TOTAL KJELDAHL NITROGEN (TKN)

Mean concentrations of TKN showed a pattern of high values (relative to this study) through 1981, low values in from 1982 through 1985, returning to levels similar to the initial years by 1986 and remaining there through the remainder of the sampling (Figure 9). No consistent pattern was evident among stations.

3.2.1.5 GRAIN SIZE

Grain size was reported as gravel, sand, silt, and clay percentages (Figure 10). Grain size commonly is considered a major factor in the distribution of infaunal species as it affects their feeding, movement, and, for tube builders, ability to construct tubes. Clay was found in the highest proportions at Station E5 and lowest proportions at Stations N2, A3, and C3 (Figure 10b). The remainder of the stations including E7, while having lower proportions than Station E5, generally had proportions considerably higher than Stations N2, A3, and C3. There was not a consistent pattern through time (Figure 10a).

Generally, the proportions of gravel were low except at Station F4 that is characterized by large amounts of shell debris (Figure 10b). No temporal trends were obvious, however, Stations N2 and A3 did increase during the later years of the monitoring (starting in 1990) from the near zero levels recorded earlier (Figure 10a). Other stations (C3, D4, E3, E4, and F2) show occasional peaks in percent gravel during this later period.

Proportions of sand were highest at Stations N2 and A3, and lowest at Station E5 (Figure 10b). Station E 7 had relatively low levels of sand from 1977 through 1979 and 1987 through 1993, but moderately high levels from 1980 through 1986 (Figure 10a).

Percent silt was lowest at Stations N2 and A3 (Figure 10b). Station F4 also had relatively low proportions of silt beginning in 1985, except for a high value in 1988 (Figure 10a).

3.3 INFAUNAL ASSEMBLAGES

3.3.1 ASSEMBLAGE ATTRIBUTES

3.3.1.1 NUMBER OF TAXA

The total number of taxa for all samples and years combined is 246. The totals across years ranged from 63 in 1983 and 1984 to 101 in 1979 (Table 1). Polychaetes, marine annelid worms, had the largest number of taxa for all but the 1991 survey when there were more arthropod taxa. With the exception of the 1991 survey, arthropods had the second highest number of taxa. Molluscs, gastropods (snails) and pelecypods (clams), always had the third and fourth highest number of taxa. While nemerteans, oligochaetes, sipunculids, and phoronids had only one taxa reported for each phyletic group, these were all unidentified and most likely represented multiple species. Because the taxonomy of these groups is not well known or literature has not been distributed widely, the grouping of multiple species in unidentified categories is expected.

Plots of the number of taxa (Figure 11) show that Station E7, the station in the discharge channel nearest to the plant had the fewest taxa during a majority of the 17 years sampled (9). Other stations with multiple years supporting the fewest number of taxa were Stations E5, also in the discharge channel (5 [including one tie with F4 and one with E7]), and F3 (3). The highest number of taxa present in a year was generally found at one of the three stations located furthest from the plant (N2 - 6 times, A3 - 5 [3 ties], and C3 - 5). Thus, in general, there tended to be more taxa at the stations furthest from the plant (and the back of the Bay) and fewer in the discharge channel with the remaining stations having an intermediate number of taxa. This pattern was least evident in 1985 through 1989. It is generally evident for the number of arthropod and pelecypod taxa throughout the study and for the polychaete taxa from 1977 through 1984 and in 1993.

3.3.1.2 SPECIES ABUNDANCE OR DENSITY

A total of 284,002 individuals were included in the infaunal data set created from the data from samples collected from the 11 stations located in south San Diego Bay sampled annually for 17 years. Over 50% of the individuals collected were annelids (42% polychaetes and 12% oligochaetes). Arthropods, generally small amphipod and ostracod crustaceans, were the next most abundant phyla. Phoronids were 9% of the total. The species representing this phyla were unidentified, but, as the number of species in the phyla are low in southern California, there may be one very abundant species or a few abundant species. Because of the high densities of this phyla, it may be worth additional time to identify the species present.

The most organisms were collected during 1979 (25,663) and the least in 1982 (6978) (Table 2). The 1982 through 1985 period was characterized by large oscillations in the total number of individuals (Figure 12). This was a result of similar oscillations in the number of polychaetes, arthropods, and pelecypods. Plots of the densities by phylum through time show several striking patterns. Gastropods and phoronids have increased in abundance from the mid-1980's to 1992. This increase has been evident at several stations. The phoronid densities decreased in 1992 to levels similar to those recorded before 1985. The gastropods had a very high abundance in 1992, mostly due to a large number of one species complex (*Assiminea/Barleeia*) at one station. Abundances of echinoderms were high from 1977 through 1983 and again in 1986 and 1987. Few have been present since 1987. Oligochaetes also decreased in abundance through time with considerably fewer found following 1985 with the exception of 1989.

3.3.1.3 SPECIES DIVERSITY AND EVENNESS

Species diversity (based on calculations using natural logarithms) and evenness were calculated on the full infaunal data set. Species diversity (H') provides a numerical measure of the diversity of the replicate or station based on the number of individuals and number of species. Evenness (J) is a measure of the degree to which a sampled community is dominated by one or a few species Values of evenness range from 0 to 2.3 (all species with identical abundances).

Several temporal patterns in species diversity (H') were evident (Figure 13). Station E7 generally increased from 1977 through 1989. Station F2 had two periods with large decreases in species diversity (1982 through 1984 and 1986 through 1988. Diversity was also reduced at Station F3 during the 1982 through 1984 period. Diversity at the remaining stations, while variable, showed no decrease or increase that remained for more than a year.

Species evenness (J) showed similar temporal patterns as the species diversity (Figure 14). This included the increasing values at Station E7 during the early years of the study and the large decrease at Station F2 during 1987 and 1988. The decrease between 1982 and 1984 at Station F2, however, was much less for the species evenness.

3.3.1.4 BIOMASS

Biomass proved to be a difficult variable to prepare for analysis because of the variability in the manner in which it was recorded among years (i.e., different groups were reported for different years). In general, the years 1977, 1978, 1981, 1984, and 1986 through 1993 were reported similarly. Categories included in the final biomass represent a compromise between those presented in the majority of the years and those in the remaining years. For example, molluscs and echinoderms were generally reported separately, were grouped for the years 1979, 1980, 1982, and 1983. In order to include this information, all years were grouped. Infrequently occurring phyla and phyla with consistently low biomass were grouped into the "other" category. This category may not be composed of the same phyla as past years (particularly 1985 when its composition was not described). The other category for this analysis included Cnidaria, Nemertea, Nematoda, Platyhelminthes, Sipunculida, Hemichordata, Branchiopoda, and Urochordata. Groups incidental to infaunal collection (i.e., fish) were not included in the biomass analysis except for the algae and marine grasses, which although not infaunal may provide information on habitat differences among sites.

Total biomass was largest during the 1977 through 1981 period with the lowest biomass for this period (670.4 g) during 1977 (Figure 15a). The years following this period were characterized by much lower total biomass (mean for the years 1982 through 1993 was 299.2 with a standard error of 32.25). Only the biomass measured in 1993 (522.8 g) began to approach that present during 1977 through 1981. A large reason for this disparity before and after 1981 was the relatively large biomass of algae and marine grasses recorded in 1977 through 1981 and the near zero values recorded from 1983 through 1991 (Figure 15a).

Total infaunal biomass was more evenly distributed through the years, with peaks showing in 1981, 1983, 1988, 1990, and 1993 (Figure 15a). These peaks were caused by higher than usual biomass at one or two stations during all but 1993 (Station N2 in 1981, Station

A3 in 1983 and 1990, and Stations N2 and A3 during 1988). The 1993 infaunal biomass was higher due to increases at several stations (C3, D4, E3, and E4).

Infaunal biomass was dominated by mollusc biomass (81.6%). None of the remaining phyletic groups accounted for more than 8% of the total infaunal biomass (others - 7.8%, annelids and phoronids - 7.7%, and arthropods - 2.7%). Dominance of the biomass totals by molluscs is expected because of their comparatively large size and heavy shells. Mollusc biomass showed no obvious patterns among years (Figure 15a). Highest biomass occurred during 1983 and 1990, lowest in 1989. Relatively high biomass values occurred during 1981, 1988, 1991, and 1992 at Station N2 and during 1983, 1988, 1990, and 1991 at Station A3. Annelid and phoronid biomass showed three years with high biomass followed by periods with lower levels (1977 followed by 1978 through 1980, 1981 followed by 1982 through 1987, and 1988 followed by 1989 through 1991). Each of these peaks was characterized by an increase at one station (Station E7 during 1977 and 1988, Station C3 during 1981). Arthropod biomass was generally low with higher values during 1977, 1981, 1992, and 1993 (Figure 15a). Biomass of other phyla was also generally low, with peaks present in 1981, 1988, and 1989.

Total biomass for all years was highest at Stations N2, A3, and F2 and lowest at Stations C3, E5, and E7 (Figure 15b). Biomass of algae and marine grasses accounted for a high proportion of the total biomass at Stations F2, E4, and D4. Total infaunal biomass formed two station groups: Stations N2, A3, and F4 with relatively high biomass (>600 g/year) and the remaining stations with moderate biomass (<400 g/year). These groups were primarily a result of differences in mollusc biomass among stations as the three high biomass stations all had high mollusc biomass. Annelid biomass was similar among all stations, arthropod biomass was similar among stations except Station A3 which had a very high biomass in 1977, and biomass of other phyla was low except at Station A3 which had high biomass levels in 1981, 1988, and 1989.

3.3.3 BIOLOGICAL RELATIONSHIPS

3.3.3.1 ORDINATION

Analysis by Detrended Reciprocal Averaging provided considerable insight into spatial and temporal patterns demonstrated by the infauna in south San Diego Bay. A total of 29 separate analyses were run. These included analyses of the annual data for eleven sites, site data for seventeen years, and one analysis that included all sites and years. These analyses indicate that spatially, the infauna in South San Diego Bay varies strongly with reference to the discharge channel and, temporally, these distribution patterns were quite persistent over the period of the study.

3.3.3.1.1 PERSISTENCE OF SPATIAL PATTERNS

DRA site scores in any sampling period display a persistent relationship in the planar depictions for Axis 1, 2, and 3, the axes that explain the largest amount of the variability encompassed by the cloud of scores. The strongest component of this pattern was a distinct separation on Axis 1 of near-field sites closest to the plant (E7 and E5) and the far field sites (N2, A3, and C3). This pattern, consistently apparent among the sites from 1977 through 1993, is demonstrated by Figure 16, which shows the clouds of annual site scores "marching" along the axis from near-field sites to far-field sites.

Site scores were averaged for all years to provide the simplified picture of relationships exhibited in Figure 17. The sites within each of these two groups were distributed in close proximity at opposing ends of Axis 1. The far-field sites were associated with lower scores on Axis 1 (scores ranging from 0 to 200) whereas the near-field sites were associated with higher scores (scores ranging from 262 to 421). Near-field and far-field sites defined the limits of the range of variation in scores on Axis 3.

The relationships among the sites in these groups was less distinct along Axis 2. The far-field sites again were closely grouped on Axis 2 and were associated with higher scores (145 to 249; Figure 17a). Scores for the near-field sites covered nearly the entire range of scores for Axis 2 (0 to 236; Figure 17a). As above, near-field and far-field sites defined the limits of the range of variation in scores on Axis 2.

All sites were located within a narrow band on Axis 3 (Figure 17b, c). As above, near-field (72 to 218) and far-field sites (0 to 253) defined the limits of the range of variation in scores on Axis 3.

Generally, variation among the annual scores for sites was fairly low. Coefficients of Variation (CVs) averaged 25, 36, and 38 percent for Axes 1, 2, and 3. On Axis 1, they were somewhat lower for the near-field sites than for the far-field sites.

In summary, the site scores generally form an elongated cloud that extends diagonally in 3-dimensional space from a point representing lower scores for Axis 1 and higher scores for Axis 2 to higher scores for Axis 1 and lower scores for Axis 2 within a narrow zone on Axis 3. Sites determined to be nearest neighbors on the basis of the average DRA scores are depicted with connecting lines in Figure 17. The sites separated clearly into the two groups discussed above (near-field and far-field groups) as well as in intermediate group (Sites D4, E3, E4, F2, F3, and F4).

Relationships between the axis gradients and physical, chemical, and biological variables are discussed in the Discussion section.

3.3.3.1.2 PERSISTENCE OF TEMPORAL PATTERNS

A relatively consistent temporal pattern in the distribution and abundance of species was identified at several of the sampling sites. Generally, several sites appeared to fall into three temporal groups. The pattern shown for Station D4 typifies this pattern (Figure 18a, b, and c). On a site-specific basis, the biological assemblages exhibited considerable similarity from 1977 until 1984 and from 1986 until 1991. Biological assemblages observed in 1992 appear to have been substantially different from previous years but, in 1993, appeared to return to a condition more consistent with that observed prior to 1992. Preliminary comparison with long-term temperature trends does not appear to support the idea that these temporal patterns are related to the effects of the El Niño Southern Oscillation.

Long-term trends are not apparent in an examination of time sequences in the data cloud for the comprehensive data set. While a considerable shift in 3-dimensional space is observed between years at many sites, the direction of the shift does not appear to be consistent among sites within years (Figure 19) or within the three time periods described above (Figure 18).

3.3.4 EXAMINATION OF TIME SERIES

3.3.4.1 SPATIAL AND TEMPORAL PATTERNS OF SPECIES DENSITIES

Species considered to be important were selected for analysis of temporal patterns and comparisons with physical variables (Table 3). These species were comprised primarily of abundant species and frequently occurring species. Abundant species were determined from the data set by selecting species that accounted for at least 1% of the total abundance for all stations combined during each survey (Appendix C). Frequently occurring species were selected by determining the species which were present at 8 or more stations during each survey (Appendix D). Because of the large number of taxa meeting the criteria for either abundant or frequently occurring taxa, the species to be analyzed were selected if they were in the top 20 of both categories and it is likely that the taxonomy of the species was consistent through the years. Additional species with an adequate number of individuals for analysis were added for analysis if a review of the data showed a trend or dramatic change in density, a consistent difference among stations, or ordination analysis suggested they were important.

Plots of these species (Figure 20) showed five general spatial patterns: 1) higher densities at the stations furthest from the plant, 2) higher densities at the stations located in the discharge channel, 3) higher densities at the remaining stations, 4) higher densities for all stations in the back Bay area, and 5) higher densities at stations outside of the discharge channel. Species with pattern 1 were the polychaetes *Fabricia limnicola*, *Euchone limnicola*, and *Mediomastus* sp.; the bivalve molluscs *Musculista senhousia* (nestling mussel) and *Solen rosaceus* (razor clam); and the microcrustaceans *Acuminodeutopus heteruropus* and *Parasterope barnesi*. Species with pattern 2 were the polychaetes *Streblospio benedicti*, *Marphysa sanguinea*, *Capitella capitata*, and *Cirriformia luxuriosa*, and unidentified oligochaetes. Species with pattern 3 were the polychaetes *Leitoscoloplos elongatus*, *Megalomma pigmentum*, *Armandia brevis*, and *Neanthes acuminata*; the crustaceans *Paracerceis sculpta* (isopod), *Mayerella banksia* (caprellid amphipod), and *Leptochelia dubia* (tanaid); unidentified phoronids, and the jackknife clam *Tagelus californianus*. Pattern 4 was evident for only the small marine snail *Cylichnella inculta*. Pattern 5 was present for the brittle star *Amphipholis squamata* and the clam *Macoma nasuta*.

Temporal trends in species density were also evident (Figure 21). Four basic patterns occurred; 1) higher densities in the early years of the study, 2) higher densities in the later years of the study, 3) higher densities during the middle years of the study, and 4) no obvious trend. Species showing trend 1 were *Paracerceis*, *Armandia*, *Amphipholis*, and *Marphysa*. Species with trend 2 were *Leitoscoloplos*, *Megalomma*, *Cirriformia*, *Cylichnella*, *Assiminea/Barleeia*, *Macoma*, and *Tagelus*. *Solen* was the only species showing obvious density peaks in the period from 1985 through 1988 (trend 3). The remaining species analyzed showed no obvious trend. Several of these species did show multi-year periods with lower densities: *Parasterope* in 1983 and 1984, *Neanthes* from 1982 through 1991, *Mayerella* from 1982 through 1984, and *Streblospio* from 1981 through 1984.

3.3.4.2 CORRELATION BETWEEN TIME OR ENVIRONMENTAL CONDITIONS AND SPECIES ABUNDANCE OR COMMUNITY ATTRIBUTES

Regression analyses were done with the species data being the dependent variable to selected physical variables (Table 4). All species tested showed significance against at least one of the measures of temperature. Of the three measures, the most species were significantly correlated to plant temperature. For six species, *Mediomastus*, *Armandia*, *Marphysa*, *Neanthes*, unidentified oligochaetes, and *Paracerceis*, the relationship was positive, meaning that densities of these organisms tended to increase with additional plant temperature. *Leitoscoloplos*, *Mayerella*, *Cylichnella*, *Solen*, *Tagelus*, and unidentified phoronids were negatively associated with plant temperature.

The sediment temperature deviation from intake temperature was an attempt to quantify the amount of heat attributable to power plant operation by using only the difference from the most consistent measure of ambient temperature available. Species with P values ≤0.05 and with positive association with this difference were *Streblospio*, *Capitella*, *Marphysa*, *Parasterope*, and unidentified oligochaetes. Those with negative association with this difference were *Mediomastus*, *Fabricia*, *Megalomma*, and *Mayerella.*

Comparisons with grain size suggest that some taxa were positively associated with fine sediments: Capitella and unidentified oligochaetes (silt and clay), *Streblospio* (clay), and *Cylichnella* (silt). Each of these taxa also had negative associations with sand. Several taxa had negative associations with fine sediments: *Fabricia* (silt and clay), *Parasterope* (silt and clay), and *Musculista* (clay). *Parasterope* also had a negative association with sand. The sediment association for *Fabricia* is confusing as it was negatively associated with all three sediment variables tested, suggesting that it may prefer coarser sediments than the sand component at most stations.

There were fewer associations with sediment chemistry. There were seven significant associations with COD: four positive (*Streblospio*, *Capitella*, *Paracerceis*, and unidentified oligochaetes) and three negative (*Fabricia*, *Parasterope*, and *Solen*). There two with TKN, both positive (*Solen* and unidentified phoronids).

Of the three other physical variables, distance from the plant and station depth showed some associations while annual rainfall showed none. Positive associations with distance occurred for *Mediomastus*, *Fabricia*, *Leitoscoloplos*, *Parasterope*, *Solen*, and *Musculista* while *Streblospio*, *Capitella*, *Marphysa*, unidentified oligochaetes, *Cylichnella*, and *Tagelus* showed negative associations. Three species had positive associations with depth (*Mediomastus*, *Fabricia*, and *Musculista*) while four had negative associations (*Streblospio*, *Capitella*, unidentified oligochaetes, *Cylichnella*, and unidentified phoronids).

Regression analyses comparing biomass values with values for selected physical factors showed few significant relationships (Table 4). The fine grain sizes (% silt and % clay) were negatively associated with mollusc and total infaunal biomass. The relationship was significant for both grain sizes for total infauna, and for % silt for molluscs. there was a contrasting relationship with % sand for both total infauna and mollusc biomass. Biomass of algae and marine grasses was positively associated with COD and TKN, as was Annelida and Phoronida with TKN. Significant negative relationships were present between biomass for total infauna and other phyla when compared to sediment temperature and the difference between sediment and intake temperatures. Plant temperature, however, was positively related with the biomass of algae and marine grasses, annelids and phoronids, and arthropods suggesting that biomass of these groups may be enhanced by the warmer temperature. All biomass measures except annelids and algae were positively related to distance from the plant. As occurred in the comparisons between individual species and physical variables, analyses for some of the biomass groups (annelids and algae) suggest an increase with increasing temperature (plant) while the remaining groups negatively related to temperature. Also similar to the species analyses, most of the phyletic groups (all but annelids and algae) were positively associated with increasing distance from the plant.

4. DISCUSSION

4.1 DESCRIPTION OF BASIC ASSEMBLAGES

4.1.1 COMPOSITION OF SITE GROUPS

Axis scores for the annual data from each site or for selected species were averaged for all 17 years. These average axis scores were examined through the nearest-neighbor utility of MacSpin© to establish site affinities in three-dimensional space.

In the site analysis, the sites segregated fairly clearly according to distance from the plant into near-field, mid-range, and far-field groups in a single iteration. The near-field site group comprised Stations E7 and E5; the mid-range group comprised Stations D4, E3, E4, F2, F3, and F4; and the far-field group comprised Stations N2, A3, and C3 (Figure 22).

4.1.2 COMPOSITION OF SPECIES GROUPS

Axis scores representing the relationship of each of the 58 species included in DRA to all others over the 17-year period of the study were used to establish species groups. Nearest-neighbor species in 3-dimensional space were determined using the nearest-neighbor utility in MacSpin©. A weakness of this approach is that each point in space (representing species, in this case) will be connected with at least one other point, regardless of how far away it may be. Where outliers are present, this feature may create anomalous groupings that demonstrate markedly different abundance patterns or relationships with the environmental variables. Consequently, where this occurred, the grouping based on the initial mathematical arrangement was adjusted so outliers would not be included in the groups.

This process produced 17 primary species groups ranging in size from 2 to 7 species. Axis scores for the species in each of the primary groups were averaged and the nearest-neighbor process was repeated using these averages. This process produced five larger secondary species groups. The averaging and nearest-neighbor processes were repeated; this process combined the five secondary groups into a single group. Species composition of these groups is shown in Table 5.

4.1.2.1 Comparisons of Spatial Distribution and Abundance

Average abundance of species in the species groups varied substantially by site group (Table 6). Generally, abundance at the far-field sites averaged about 75% higher than at the near-field sites; abundance at the mid-range sites averaged about 50% higher than at the near-field sites.

This pattern was generally apparent in most of the primary species groups in secondary Species Groups A, C, D, and E. Thus, most of the more abundant species were less abundant at the near-field sites and more abundant at the far-field sites. Examples of this pattern are provided by the tubicolous polychaete *Fabricia limnicola*; the burrowing polychaete *Leitoscoloplos elongatus*; the gammarid amphipod *Acuminodeutopus heteruropus*;and the ostracods *Parasterope barnesi* and *Euphilomedes carcharodonta*. (Table 7)

However, in primary Species Groups 5, 10, and 2, the opposite abundance pattern was observed, i.e., abundance of the species in the groups was highest at the near-field stations and lowest at the far-field stations (Table 7). These groups, consolidated into Tertiary

Species Group I, characterized the near-field area. Species in which this pattern was strongest include *Capitella capitata*, *Cylichnella inculta*, *Cirriformia* sp., *Typosyllis armillaris*, *Streblospio benedicti*, and *Scolelepis tridentata*. These species also declined rapidly or gradually in relative abundance from near-field to far-field sites.

In contrast, several species were generally abundant throughout the study area, for example, the polychaete *Mediomastus* sp. In secondary Species Group A, abundance patterns were relatively weak; densities were lowest at the near-field sites and highest at either the mid-range or far-field sites. Species with higher average abundance occurred in Species Group C and those with lowest abundance occurred in Species Group D (Table 6).

4.2 ANALYSIS OF STABILITY

Several temporal patterns in abundance are apparent (Table 8). The polychaete *Mediomastus* sp. was extremely stable in terms of relative abundance despite demonstrating considerable variation in real abundance at various times during the program. Although real abundance ranged from 1155 to 5369 individuals per sampling period during the program, this species was among the three most abundant species every year.

4.3 RELATIONSHIP BETWEEN DISTRIBUTION PATTERNS AND PHYSICAL AND CHEMICAL CONDITIONS

4.3.1 COMPARISONS WITH ORDINATION RESULTS

Sixteen physical, chemical, and biological variables were compared against site scores for the axes calculated using DRA using simple regression (Table 9). Correlations with the axis scores were significant for fourteen variables on Axis 1, nine variables on Axis 2, 7 variables on Axis 3, and eleven variables on Axis 4. Annual rainfall was the only variable tested that did not correlate significantly with at least one set of axis scores. Plant temperature for the month preceding annual sampling only correlated with scores for Axis 3.

The analyses summarized in Figures 23 and 24 provide indications regarding associations between the sites based on DRA scores for sites along specific axes and corresponding gradients in physical, chemical, and biological variables measured at various locations in the study area. It is clear from an examination of the various suites of variables that many are auto- or cross-correlated but no attempt has been made at this point to deal with these interactions.

Distance from plant was analyzed as a variable and exhibited the strong associations with Axes 1, 2, and 4. However, this relationship is mainly symbolic as this "variable" only represents a summation of several truly influential factors (e.g., temperature variables or particle grain size) but does not, in fact, have the ability to exert an effect on any of the factors that influence the systems reflected by axis scores.

The average site scores used in these analyses were described above and shown in Figure 17. In a comparison of Axis 1 and 2 (Figure 23), the physical variables showing the strongest associations with Axis 1 from the DRA of the comprehensive data set (those with highest correlation coefficients or coefficient of determination) include the following.

- Sediment temperature
- Percent sand
- Percent silt/clay, percent clay, and percent silt

Associations with DRA scores for sites on Axis 1 were stronger for the physical variables than for the biological attributes. However, number of species (S) and individuals (N) and evenness (J) were biological assemblage attributes that demonstrated a strong association with Axis 1.

For DRA scores for sites on Axis 2, the strongest associations were with assemblage attributes (Figure 23). They included the following.

- S
- N
- Plant temperature minus sediment temperature
- % Clay, silt, and sand
- Sediment temperature

The strongest associations with Axis 3 were Period Plant Temperature and evenness (J), a measure of biological structure (Figure 24). Other important associations included those listed below.

- Sediment temperature
- Sediment temperature minus intake temperature
- Species diversity
- COD
- Number of specimens

Sediment characteristics were poorly associated with this axis.

Of the four physical and chemical categories of variables, temperature appears to be most strongly associated with DRA scores for sites on all axes (Table 9). At least two temperature variables exhibited highly significant correlations with DRA scores for sites on all axes. In contrast, sediment and sediment chemistry variables had significant correlations with DRA scores on only three and two axes, respectively.

4.3.2 RELATIONSHIP BETWEEN DISTRIBUTION PATTERNS AND BIOLOGICAL ASSEMBLAGE ATTRIBUTES

Relationships between abiotic variables characterizing the study area and the biotic assemblage attributes in the area were examined by regressing the biotic variables against the abiotic variables. The types of abiotic factors exhibiting the strongest relationships with the biotic variables were between sediment characteristics (i.e., % clay, silt, and sand) and temperature properties (Table 10). All of the biotic variables were strongly associated with silt and sand. The relationship was inverse with silt and positive with sand. In spatial terms, since silt decreased and sand increase with greater distance away from the plant, these relationships reflect a strong trend for numbers of species, specimens, species diversity, and evenness to increase with increased distance from the plant.

The most relevant aspects of temperature were sediment temperature and the deviation between plant temperature and sediment temperature. As above, all biotic variables were strongly associated with these factors. In the case of sediment temperature, the relationship was inverse. In contrast, the biotic variables were directly associated with the difference between plant and sediment temperature. Thus, as sediment temperature became cooler, the biotic variables increased. The implication is that the biotic variables became higher with increasing distance from the plant. Thus, the biota was biologically richer (more specimens more evenly distributed among more species) at the far-field stations than at the plant and near-field stations.

4.3.3 DESCRIPTION OF LONG-TERM TRENDS IN INFAUNA WITH PHYSICAL CONDITIONS

Regression analyses for selected species showed that densities of most were significantly associated with temperature. Densities increased as temperature increased for *Mediomastus*, *Armandia*, *Marphysa*, *Neanthes*, unidentified oligochaetes, and *Paracerceis*. Thus, increases in temperature at other stations following an increase in Delta T may be expected to result in increases in the densities of these organisms. In contrast, *Leitoscoloplos*, *Mayerella*, *Cylichnella*, *Solen*, *Tagelus*, and unidentified phoronids decreased with an increase in temperature, thus their densities would be expected to decrease in areas with increased temperature.

The proportions of sediment characteristics (grain size) is usually an important factor in the distribution of infaunal species. Grain size was shown to be important in determining the distribution of *Fabricia*, *Capitella*, unidentified oligochaetes, *Parasterope*, *Cylichnella* and *Musculista* . *Capitella* and unidentified oligochaetes were positively associated with fine (silt and clay) sediments, *Streblospio* with clay, and *Cylichnella* with silt. *Fabricia* may be associated with coarser sediments than sand as it was most prevalent at stations with a consistent gravel constituent and it was negatively associated with sand, silt, and clay.

4.3.4 RELATIONSHIPS BETWEEN SPECIES GROUPS AND ENVIRONMENTAL FACTORS

Patterns in correlation between abundance of dominant species and the environmental factors were examined on the basis of species groups to obtain some indication of which factors could be influencing various groups of species (Table 11). Typically, where more than one species within a primary species group exhibited a significant correlation with an environmental factor, the direction of the correlation was the same for all, i.e., all positive or all negative. Generally, species in Tertiary Group I correlated with environmental factors in an manner opposite to that exhibited by species in Tertiary Group II. Thus, where species in one group exhibited a predominantly positive significant correlation with a variable, most species in the other group showed a negative correlation.

This analysis of the data suggests that each of the secondary species groups appears to relate to a different combination of environmental factors. Abundance of species in Group D, which included only microcrustaceans, correlated strongly with seven of the variables; correlations with silt, clay, COD, sediment temperature, and deviation between sediment and intake water temperature (sediment temperature - intake water temperature) were negative (inverse relationship between abundance and the variable) whereas correlations with sand and depth were positive. The abundance of species in Group C, the largest of the groups (thirteen polychaetes, five bivalves, three microcrustaceans), was correlated negatively with sediment temperature and positively with depth. The remaining groups each exhibited strong correlations with only a single variable. Group A, comprising two polychaetes, two bivalves, one gastropod, and four microcrustaceans, was negatively correlated with deviation between sediment and intake water temperature. Group B, comprising the ten polychaetes, one bivalve, and one gastropod that dominated at the near-field stations, was positively correlated with TKN. The environmental variables that appeared to exert the most influence over species or species groups were sediment temperature, deviation from plant temperature. silt, sand, COD, and depth.

4.4 COMPARISON OF NEAR-FIELD SITES AND FAR-FIELD SITES

Power plants can influence the composition and distribution of the infaunal biota of a site through various mechanisms. Planktonic larvae entrained in the cooling water can be damaged by thermal shock during the transit of the cooling water through the condensers. Prolonged exposure to elevated temperatures of the cooling water following discharge from the plant can effect the survival of planktonic larvae and physiological condition of juvenile and adult forms of species that filter or are otherwise exposed directly to water {Mileikovsky, 1970 #20; Naylor, 1965 #19}. Elevated sediment temperature resulting from exposure to warm water can influence survival and physiological condition of burrowing forms that are relatively isolated from direct contact with the heated effluent. Exposure to elevated temperatures in the near-field area can also modify reproductive cycles of the animals living in that area {Naylor, 1965 #19}.

Hypoxic conditions associated with elevated temperature of the effluent could also cause stress to the animals exposed to the plume {Dauer, 1992 #3}. Oxygen saturation in seawater at a temperature of 88.5°F and a salinity of 32 ppt is approximately 4.5 mg/l. The combined effects of reduced oxygen in the water and increased metabolic rate caused by elevated temperature contribute to the reduced numbers of species and individuals observed at the near-field sites {Friedrich, 1965 #18}.

Because of the configuration of the discharge channel, the South Bay Power Plant may exert a strong influence on the infaunal organisms that are able to become established in the area south of the dike. The tidal prism of this area may be small enough that it is filled mostly by effluent during the flood stage of most tide cycles. Thus, the incoming tidal wave would act like a dam and the water level behind the dike would rise primarily due to heated effluent that had passed through the plant. Colonizing species in this area therefore would be limited mainly to species that have 1) planktonic larvae with a thermal tolerance that allows them to survive the temperature regime experienced during transit through the power plant or 2) considerable dispersive capabilities as adults. Colonization in this area by species without planktonic larvae, e.g., gammarid or caprellid amphipods, isopods, and tanaids, would be limited by the ability of adults to reproduce successfully after immigrating into the area.

Based on these premises, it seems plausible to establish hypotheses that 1) species composition of the infauna in the area inside the dike will be dominated by opportunistic or invasive colonizers ("weed" species) such as the polychaete *Capitella capitata*; and 2) brooding microcrustaceans such as gammarid and caprellid amphipods, isopods, and tanaids will generally be uncommon but exhibit periodic abundance. Dominance patterns at Stations E7 and E5 appear, in large part, to comply with these hypotheses. Opportunistic species with planktonic, especially polychaetes (*Capitella capitata*, *Streblospio benedicti*, *Typosyllis armillaris*, and *Cirriformia* sp.), dominate the infauna at Stations E7 and E5 (Table 7). The nestling mussel *Musculista senhousia*, a recent invader from Japan, also appears to fit into this category. The caprellid amphipod *Mayerella banksia*, a brooder, was the only microcrustacean of importance at these sites. It occurred more than twice as frequently at Station E5 than at E7, suggesting that it was colonizing the area behind the dike from the area of the mid-range stations rather than through the power plant. The polychaete *Mediomastus* sp., the caprellid *M. banksia*, and, to a lesser degree, the gastropod *Cylichnella inculta* were all important components of the infauna throughout the study area. The abundance of *Mediomastus* and *M. banksia* was relatively depressed at Stations E7 and E5 whereas that of *Cylichnella* was relatively higher at these sites.

Assuming that abundance patterns are relatively synchronous among far-field stations, similarity in abundance patterns at near-field sites provides evidence that the abundance of a species is influenced primarily by environmental variables and that the larvae of a species are relatively unaffected by transit through the power plant. Comparison of abundance histories for near- and far-field sites for several species that were numerically dominant at the near-field sites suggests that changes in abundance were not synchronous within or between the near- and far-field sites (Figures 19 and 20). Six of the 11 species dominant at the near-field sites were generally more abundant in that area than in the far-field area; these included the polychaetes *Capitella capitata*, *Eteone lighti*, *Scolelepis tridentata*, *Streblospio benedicti*, and *Typosyllis armillaris*, and the gastropod *Cylichnella inculta*. Species that were more common at the far-field sites included the polychaetes *Mediomastus* sp. and *Neanthes acuminata*, the caprellid amphipod *Mayerella banksia*, the nestling mussel *Musculista senhousia*, and phoronids. The ubiquitous polychaete *Mediomastus* sp. displayed the strongest synchrony in temporal patterns. Most of the other species displayed a reasonable degree of similarity in temporal abundance patterns but all exhibited occasionally strong asynchrony. Most of the species exhibited strong declines in 1981 or 1982 (Figure 25). For several species, the declines occurred in 1981 at the near-field sites and in 1982 at the far-field sites. This was particularly apparent for *Mediomastus* sp., *N. acuminata*, *M. senhousia*, and *C. capitata*. At the near-field sites, substantive recovery generally occurred in one to three years after this decline (1982 to 1985) but the polychaete *S. tridentata*, which was only important at Station E5, has never recovered. In several species, the 1981-1982 declines were followed by substantial increases between 1983 and 1985 and subsequent lengthy declines that lasted until 1991 in some cases (*Mediomastus* sp., *N. acuminata*, Phoronida, *M. senhousia*, and *E. lighti*). The polychaete *Typosyllis armillaris* and the caprellid amphipod *Mayerella banksia* were absent or quite uncommon at the near-field sites until after 1984.

4.5 EVALUATION OF THE RELATIVE IMPORTANCE OF VARIOUS ENVIRONMENTAL FACTORS

A variety of biological characteristics for the infaunal assemblages in the study area indicate that the infauna in the area is responding to a stress gradient that extends outward from the power plant toward the far-field sites. Several types of characteristics indicating the occurrence of this gradient are described by {Dauer, 1993 #10}. This implies that one or more environmental factors is exerting deleterious effects on the infauna in the study area. Station E7 appears to exhibit the highest degree of stress. This conclusion is based on 1) patterns in assemblage attributes (N, S, H'), which all increased with increasing distance from the power plant; 2) the occurrence of several species commonly cited as indicators of stress (e.g., *Capitella capitata*, *Cirriformia* sp., *Typosyllis armillaris*, and Streblospio *benedicti*); 3) the tendency of the less tolerant species to increase in abundance with increased distance from the plant; and 4) the tendency of ordination to segregate the sites into distinct near- and far-field groups on the basis of species distribution and abundance patterns; and 5) the apparent instability of the near-field sites in relation to the far-field sites.

Each of the environmental variables for which measurements have been tabulated in this report could contribute to the intensity of the stress that causes the observed effects in the infauna. General categories of these variables include 1) temperature (e.g., water temperature of the effluent plume, change in temperature of the cooling water as it passes through the power plant (Δt), and sediment temperature); 2) sediment grain size characteristics (e.g., % clay, silt, or sand); 3) sediment organics (e.g., COD and TKN); 4) distance from the power plant, and 5) water depth. In addition, other unmeasured variables could be principal or contributing causes of the observed effects. Examples of potentially relevant but unmeasured variables include salinity or conductivity, turbidity, Total Organic Carbon, and eH and sulfides in the sediments.

A weakness of the measured variables with a strong seasonal component is that, while effects may be driven by a small number of extreme events (extremes in temperature or salinity, for example), the monitoring program does not record the extreme events, especially on a site-specific basis. Moreover, their patterns are characterized by a high degree of autocorrelation, i.e., while they exhibit correlatable changes in intensity, the changes are not based on a functional relationship.

While we cannot determine causality on the basis of an observational program, it is possible, through the use of available information on the response of key species and the response patterns of infaunal assemblages, to eliminate some of the environmental factors from consideration and narrow down the list of factors that must be considered.

Assemblage attributes exhibited strong positive correlations to distance of the sampling sites from the power plant (Table 12; $p < 0.0001$ in all cases). Most of the species that were more common at the far-field sites exhibited a similar correlation whereas those most common at the near-field sites exhibited a strong negative correlation with distance from the plant. While this relationship is useful in visualizing the direction of change, it is a meaningless relationship because the variable "distance", in this specific context, cannot affect any of the variables of concern. Distance is auto-correlated with most of the environmental factors and, as a consequence of summation, generally exhibits a stronger correlation with the biological variables than any single environmental variable. However, none of the environmental factors influence the infauna in the manner of a density function, e.g., logarithmic decreases in reproductive products or light with increased distance from the source and so distance is not an appropriate correlate with the biological factors in this case.

Water depth could possibly be used to assist in the description of relationships but some inconsistencies exist that eliminate it as a valid correlate. In open coast situations, silt and clay typically increase with increased depth whereas sand decreases. Where this relationship exists, it is likely that the causal mechanism involves turbulence regimes of the overlying water column and the decreasing ability of water motion to resuspend and flush fine sediment out of increasingly deeper areas [Dotsu, 1992 #2]. The principal real factor relative to infauna is turbulence as it relates to sediment instability and resuspension and movement of food particles. In reality, water depth *per se* exerts no direct influence on infaunal organisms. In this study area, the observed relationship was opposite that normally observed in open coast situations, i.e., silt and clay decline significantly at the deeper sites in the study area whereas sand increases. This pattern suggests that the distribution of sediment types in the study area is driven more by depositional patterns and proximity to sources of fine materials than by water depth, in contrast to the strong pattern generally observed between depth and the assemblage attributes in nearshore coastal situations [Dotsu, 1992 #2], [MBC, 1975 #21; Lees, MS #22] and in open ocean benthos [Buzas, 1969 #8].

Sediment grain size characteristics (e.g., % clay, silt, or sand) typically exhibit strong correlations with assemblage attributes. Generally, except where the proportions of silt or clay are very high, the assemblage attributes correlate positively with clay and silt but negatively with sand. In this data set, however, the relationships are reversed, reflecting the reversal in grain size relationships described above relative to water depth. Sediment organics (COD and TKN) exhibit the expected positive correlation with clay and silt and a negative correlation with sand ($p<0.0001$). However, in contradiction to expected patterns for organics at moderate concentrations, COD exhibited significant negative correlations with S, H', and water depth. The relationships between TKN and assemblage patterns or depth were not significant. The inconsistency in the relationships between silt, clay, sand, and COD and the assemblage attributes in open coast and shallow bay situations suggests that, in one of these cases, the importance of their effect on the infaunal organism has been overridden by other factors.

The remaining factors for which measurements are available are all related to temperature. Continuous temperature data are available for water at the intake and discharge areas of the power plant, thus providing a record of the change in temperature of the cooling water as it passes through the power plant (Δt). While this information can be useful in evaluating effects of thermal shock on larvae, it is not very helpful in the analysis of infaunal dynamics. Other direct measurements, available only for the survey periods, include surface and bottom water temperatures at the specific sites and sediment temperatures from samples collected for the infaunal analyses. The water column temperature data were omitted from analysis because of the high variability characteristic of such data over a tide cycle. Sediment temperature data are viewed as far more valuable because they are somewhat resistant to short-term variation. Values highlighting differences between sediment temperature and average temperatures from water at the intake and near the discharge for the month prior to the collection of sediment were calculated as a means of estimating the degree of exposure to the thermal plume. The latter value (average plant temperature for the month preceding sample collection minus average sediment temperature for a site) appears to be the most direct approach for estimating exposure and provides the best correlations with the assemblage attributes. Since the directions of the correlations are consistent with expected response of these attributes to temperatures in the range experienced, these relationships provide a plausible explanation of the differences observed among the sampling sites. Furthermore, based on the discussions above for the other environmental factors, the temperature variables appear to be the only suite measured that provides an explanation for the relationships observed between assemblage measured environmental factors that is consistent with relationships observed in other studies.

If the conclusion that temperature is the environmental factor that dominates the dynamics of the infaunal assemblage is valid, one must question why it is able to overpower the normal response of the infaunal organisms to factors such as grain size and sediment organics. The steepness of the temperature gradient may provide some of the answer; average temperature in sediments collected during the summer sampling period ranged from 77.1°F at Station N2 to 88.3°F at Station E7 (Table 13). An 11°F difference over a depth change of less than 10 feet is a considerable gradient. Moreover, the differences in the range of temperatures experienced at the stations indicates that thermal stress is substantially greater at the near-field stations. The observed temperature range varied from 8.6°F at Station N2 to 16.2°F and 14.9°F at Stations E5 and E7, respectively, and the standard deviations at the near-field stations were nearly twice as wide as at Station N2. In summary, if the effects of this wide range of potential sources of short- and long-term temperature effects are added together (e.g., increased mortality in larvae resulting in fewer species and lower recruitment rates, reduced fitness in recruits as a consequence of thermally induced physiological stress), the likelihood that temperature can override other environmental factors becomes easier to understand.

4.6 COMPARISON WITH CONCLUSIONS FROM PREVIOUS STUDIES

Comparisons between the results for the 17 year period, the 1980 report on the 4-year period, and the 1972-1973 results are confined to the infaunal species and sediment characteristics only as the sampling was designed for this purpose and not for collection of ancillary samples such as epibiota, floating and attached algal and plant mats, and water quality.

4.6.1 CONCLUSIONS FROM PREVIOUS STUDIES

4.6.1.1 IMPORTANT CONCLUSIONS FROM THE FOUR-YEAR REPORT

Results for abiotic variables indicated that a pattern of increasing levels of sediment temperatures, concentrations of COD and TKN, and proportions of silt and clay occurred from the station nearest the plant to the stations furthest from the plant. A complementary increase in proportion of sand also occurred.

- The station nearest the plant (E7) had significantly higher sediment temperatures and COD concentrations.
- The next station away from the plant was also significantly different for higher sediment temperatures.
- Abiotic data collected at stations located near the center of the study area (Stations D4, E3, F2, F3, and F4) were relatively similar and intermediate to values nearer the plant and further from the plant.
- Abiotic data at Station E4, also located in the center of the study area, appeared more similar to data for the stations nearest the plant, but differences were not significant.
- Abiotic data at Stations N2, A3, and C3, located furthest from the plant, were significantly different from the two stations nearest the plant. These stations had the lowest sediment temperatures, concentrations of COD and TKN, and proportions of fine sediments. The proportion of sand was highest at these stations.

Patterns in descriptive statistics calculated for the infaunal community also indicated that Stations E5 and E7 differed from the other stations.

- Number of taxa lower at E5 and E7
- Species diversity lower at E7
- Greater numbers of taxa sampled at the stations furthest from the plant

Analyses evaluating abiotic and biotic relationships consistently showed two groups: a mid-Bay grouping of Stations N2, A3, and C3, and a near-plant group of Station E7. No consistent patterns were present for the stations in-between. The most important and consistent environmental factor was a depositional gradient for 1977 through 1979 and a gravel gradient for 1980.

4.6.1.2 IMPORTANT CONCLUSIONS FROM THE 1972-1973 REPORT

Adverse effects on benthic invertebrates occurred during the late summer-early fall period of 1972 in the outer portion of the thermal plume beyond the end of the cooling channel primarily for stations in the main path of thermal effluent flow. The "adverse effects appeared to be confined primarily to the inner portion of the cooling channel" and "were relatively small, suggesting that the adverse effects apparently were mild ones."

- Lower numbers of invertebrate species including polychaetes and crustaceans
- Lower value of species diversity for all invertebrates combined

- Lack of significant differences between outer discharge and control areas during winter and spring, suggests that "mild adverse effects" were confined to summer and early fall periods
- There were adverse effects in the cooling channel on invertebrates, but not plants
- Stations within the cooling channel showed a consistent increase in number of invertebrate species from September through April
- Numbers of species in the plant mat were greater in the outer discharge area than the control area, a possible beneficial effect of the thermal plume..

Statistical comparisons of biomass indicated that biomass was usually greater in the outer discharge area compared to the control areas. Only during summer were some groups higher in the control area.

- Plants and invertebrates always greater in the outer discharge area
- Coelenterates, decapods, and gastropods greater in control area in summer
- Results of comparisons of general biomass categories between the cooling channel and control areas were not significant, except for a few categories which were lower in the cooling channel
- Biomass comparisons among three years, showed no differences for the late summer-fall period
- Biomass tended to decrease during the winter

Comparisons between years (1968, 1970, 1972) indicated that numbers of invertebrate species and all species were significantly different among years.

4.6.2 COMPARISONS WITH 17 YEAR RESULTS

The conclusions from the earlier studies generally agree with the result from this 17-year review. In all cases it was determined that the cooling channel (near-field area for this review) was impacted by the plant. In addition, stations located between the cooling channel and the control area were also affected. Ford (1975) indicated that the effects in this outer discharge area were mild and primarily limited to the stations in the thermal plume as it moved away from the cooling channel. This was also demonstrated in the 17-year results.

The species observed during the 1972-1973 period were generally the same as those present during the later monitoring surveys. Differences did exist, however, in the distribution of some species as those determined to be cosmopolitan during the early surveys were less so during the latter. For example, of the 12 cosmopolitan species during 1972-1973, only *Mediomastus* (reported earlier as *Capitita ambiseta*), *Capitella*, unidentified oligochaetes, and *Musculista* (reported earlier as *Adula diegensis*) were generally present at all stations in the 17-years of surveys. Of these four species, only *Mediomastus* showed at least a moderate abundance at all stations. In fact, *Capitella* and unidentified oligochaetes showed their highest abundances in the cooling channel as did *Marphysa*, another of the earlier cosmopolitan species. Other earlier cosmopolitan species were primarily found in the outer discharge area (e.g., phoronids, *Neanthes*, *Megalomma*, *Armandia*), present in low densities (*Diadumene*), or not reported (e.g., *Boccardia* [probably reported as another spionid during later surveys, perhaps *Polydora* or *Pseudopolydora*]) during the later surveys. The change in distribution of these species may indicate an increased plant effect from the earlier period or normal variation in distribution of the species.

One factor that may be important in the distribution and abundance of species is the effect of seasonal changes. The 1972-1973 sampling was done quarterly and provides some insight into these changes. Some species increased their range within the study area and their abundances following the late summer-early fall periods of warmer temperatures. Sampling during the 17-years of monitoring was done in either August or September to include the period during each year when the impact of the plant was most likely to be at a peak. However, there was considerable natural variation in water and sediment temperature among years (Figures 2 and 7). Thus, if a year is cooler than average (e.g., 1982, 1987, or 1989) or warmer than average (e.g., 1977, 1981, 1992), species may have considerably different distributions and abundances compared to their norm.

Based on the biomass measurements for the early study, it was suggested biomass was enhanced by the thermal effluent. This was primarily because biomass was generally higher in the outer discharge area compared to the controls during except during July when some biomass variables were higher in controls. This pattern was not as evident for the biomass data analyzed for the 17-year review. During this period, total biomass was higher at two of the control stations (N2 and A3). These stations each had a large biomass of molluscs. When infaunal biomass values were excluded, biomass of algae and marine grasses was higher at two of the stations in the outer discharge area (E4 and F2). Thus, it is possible that some enhancement at Station E4 may occur, however, it appears isolated as other stations located in the probable plume (e.g., E3, F3, D4) showed biomass levels no higher than at least one of the controls for algae and marine grasses.

4.7 CONCLUSIONS

Over the 17-year period included in this review, the infaunal assemblage exhibited considerable variation in levels of abundance (Figure 12), species richness (Figure 11) and diversity (Figure 13), and in species composition. However, patterns in these variables consistently suggest that the near-field sites (cooling channel) and, to a lesser degree, the mid-range sites (outer discharge area), are substantially influenced by heated effluent from the power plant.

Generally, the assemblage attributes varied considerably both among and within years. Number of individuals varied by as much as 50 times among sampling sites within a sampling period; number of taxa varied by as much as 8 times within a sampling period. The overriding feature in the distribution of these attributes was the occurrence of lower values at the near-field sites and higher values at the far-field sites . One notable pattern was the apparent trend for increasing species diversity at Station E7 during the early years of the review period. Species diversity at this site was considerably lower than at the other sites until 1983 but increased progressively. Since 1986, species diversity at Station E7 has not been distinguishable from diversity at the other stations.

Species composition varied considerably among the sites in any single survey and among and within sites over the period of the survey. The polychaete *Mediomastus* sp. is the only species that ranked consistently among the top three species in terms of abundance. Consistent patterns in species composition that suggest stress at the near-field sites include the dominance at those sites by opportunistic species such as the polychaetes *Capitella capitata*, *Typosyllis armillaris*, and *Streblospio benedicti*, and the paucity of microcrustaceans and echinoderms. Ordination techniques strongly demonstrated the dissimilarity among the near- and far-field sites and the higher degree of instability or variability at the near-field sites.

An examination of the relationships between and among species distribution patterns and environmental factors amplifies the suggestion that heated effluents are causing stress at the near-field sites. While the biological characteristics are strongly correlated with a wide variety of environmental factors, the types of relationships are generally inconsistent with those typically observed in infaunal assemblages or among the environmental factors themselves. Thus, while the infaunal assemblages demonstrated strong correlations with sediment grain size or organics, the direction of these relationships was opposite to expectation. Only the correlation to sediment temperature gradients was consistent with expectations based on previous studies.

One must now ask, "What is the significance of this apparent effect? Does it create a meaningful problem? Does the area still support important resources?" This review and the studies preceding it have, in addition to documenting an effect from the thermal effluent, also documented the presence of complex infaunal community in the study area. This community is characterized by a relatively stable biomass through time (Figure 15) and large numbers of organisms. The area provides important nursery resources for fish and food resources for fish, birds, and turtles. The thermal effluent from the power plant has become an integral component in determining the distribution and abundance of the infaunal species which are important to other members of the biological community in south Bay.