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Ecological Effects of the Moss Landing Powerplant Thermal Discharge

**A report submitted to the Monterey Bay National Marine Sanctuary
Sanctuary Integrated Monitoring Network (SIMoN)
and
Monterey Bay Sanctuary Foundation**

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Executive Summary

During the period 2002-2005 a study of the Moss Landing Power Plant was undertaken by Moss Landing Marine Laboratories under the auspices of the Sanctuary Integrated Monitoring Network (SIMoN) of the Monterey Bay National Marine Sanctuary. The study focused on plankton, sand beach and shallow subtidal benthos, and birds. The primary goals of the study were to identify if changes in the distribution or community structure of the plankton, benthos, and birds could be correlated with the thermal plume from the powerplant outfall, and in the case of benthos, to set a long-term baseline of the invertebrate fauna near the outfall and to compare beach fauna to a study done in 1975. In addition a database of previously performed studies on fish and benthos was compiled. The study was not designed to determine the causal factors of any observed distributional or community changes.

The mean temperature of water exiting the Moss Landing Power Plant (MLPP) outfall was 22.3 °C and dropped to 14.5 °C 100 m from the discharge site and 14.1 °C 500 m from the discharge site. Sample design of the plankton investigations provided measurements along the cooling-water flow-path, such that conditions before intake, during entrainment and after discharge into Monterey Bay could be assessed. Bacterial growth was enhanced as a result of passage through the MLPP cooling system, as evidenced from increases in bacterial colony growth, increases in the frequency of dividing cells, and increased dark respiration in water sampled at the immediate exit from the power plant. Phytoplankton were negatively impacted after passage through the MLPP cooling system as shown by reductions in photochemical quantum efficiency (F_v/F_m), increases in pheopigment/chl *a* ratios, and decreases in phytoplankton gross primary productivity at the power plant exit station. Thus, bacteria and phytoplankton were differentially impacted by once-through cooling transport. However, differential enhancement and inhibition effects on bacteria and phytoplankton, respectively, could not be detected after discharge and dilution into local Monterey Bay waters.

There were no detectable significant impacts of the MLPP outfall on intertidal and shallow subtidal faunal communities. The Outfall and MBARI intertidal stations had significantly more polychaete worms, however the total number of individuals, species, and biomass were similar along the exposure gradient (in and outside the canyon). There was no significant difference in the abundance of the intertidal total fauna, crustaceans, or polychaetes between 1975-76 and 2003-05. There were, however, significantly fewer species in 2003-05. Since the sea otters arrived in the central bay in the mid 1970's, Pismo clams have been rare on the regional beach and populations continue to be suppressed. Faunal community patterns demonstrated the depth zonation of key species within the surf zone and also an increase in the density of species from 1 m to 4 m depth.

No negative impacts on seabird abundance and distribution as a direct result of the thermal plume were observed (e.g., no species were observed actively avoiding the thermal plume). Seasonal abundance of locally resident, migratory, and wintering seabirds common in the nearshore environment of Monterey Bay was reflected in the species composition observed at

both the Plume and Reference survey sites. Some seabird species, especially cormorants, showed an increased occurrence at the Plume site, indicating potential utilization of the plume for foraging on small schooling or benthic fishes. Sea otters were regularly observed utilizing the thermal plume for grooming, resting, foraging, and interacting with other sea otters. The reasons for the otter utilization of the plume are uncertain, but may have to do with the relatively warmer water at the plume. Bat Rays (*Myliobatis californica*) aggregate at the surface in the powerplant outfall plume mostly in winter months. The reason for the aggregations is unknown, but may relate to thermoregulation.

1 Introduction

The Moss Landing power plant is California's largest power plant. It is located in Moss Landing, CA, roughly midway between Santa Cruz and Monterey (Fig. 1-1). Cooling water for the power plant is taken up within Moss Landing Harbor and discharged into Monterey Bay 200 m from shore and approximately 7 m below the sea surface. The thermal effluent temperature is approximately 13 °C higher than the intake cooling water. Both the entrainment process and the discharge of the heated water have the potential to impact benthic and pelagic ecosystems, although these effects have never before been quantitatively evaluated.

We have targeted several types of short-term and long-term indicator communities. Because of their relative lack of mobility, benthic invertebrates living in the intertidal sand beach and shallow surf zone are the best long-term indicators of potential negative impacts to the nearshore ecosystem. In contrast, marine birds are the best short-term indicators because of their ability to respond to negative impacts by changing location, while the short turnover time in the planktonic community also gives it the ability to respond quickly to change and thus act as a short-term indicator of ecosystem change. All of these communities, benthic infauna, plankton, and marine birds, were sampled at the thermal plume and at control sites outside the plume.

The sampling design permitted us to resample benthic communities that were sampled in the 1970's at the end of a cold, productive period in the CA current system. The inner, wave-exposed shelf ecosystem, which is highly sensitive to a wide variety of natural and anthropogenic disturbances, is a prime target for exploring future, long-term changes in ecosystem dynamics. We have provided the first complete baseline on nearshore planktonic communities at Moss Landing, which are likely to change as the extremely high rates of habitat erosion in Elkhorn Slough accelerate. We have also extended the first quantitative survey of nearshore marine birds from 2 to 5 years, again providing a solid baseline for assessing future ecosystem changes. We have compiled all historical community data on benthic invertebrates, plankton, marine birds, fishes, and related physical and chemical habitats conditions into the project database. Most of these historical data were collected by students and staff at Moss Landing Marine Laboratories (MLML). Since the marine lab overlooks the study site, most of the future work is also likely to be done by MLML.

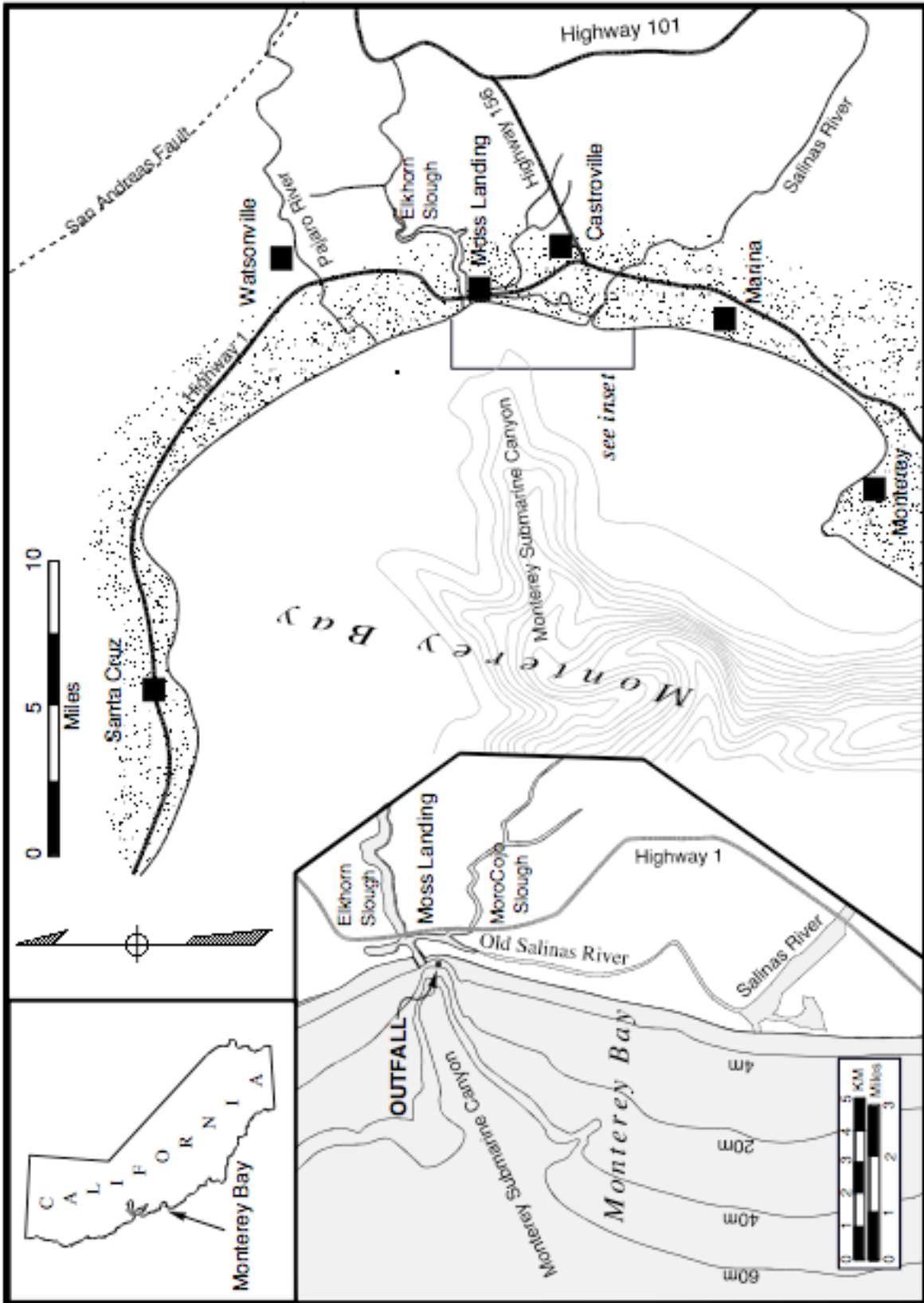


Figure 1-1. Maps showing location of study area on Monterey Bay in central California. Inset shows close-up of Moss Landing vicinity with the powerplant outfall.

2 Plankton

Prepared by Gala Wagner and Dr. Nick Welschmeyer

2.1 Introduction

Electric power plants account for 75 – 80% of the thermal pollution in the U.S. (Laws 2000). The increased use of cooling water in the electricity generating industry leads to potential impacts on estuarine and marine resources since cooling water is largely of marine origin (Laws 2000, Turnpenny and Coughlan 2003). This report describes experiments that were designed to measure impacts, if any, on planktonic organisms that are entrained and ultimately heated in cooling water that is pumped through the recently modernized Moss Landing Power Plant (MLPP) currently operated by LS Power.

Moss Landing Power Plant is the largest energy producing plant (2545 megawatts) in California (Commission 2004); it is located in Moss Landing, CA roughly midway between Santa Cruz and Monterey. Cooling water for the facility is drawn from two separate intake structures within Moss Landing harbor. Historically, cooling water from five units was discharged directly into Elkhorn Slough, one of California's largest estuaries, but this practice was discontinued in 1995 (Tenera 2000). Currently MLPP discharges thermal effluent into Monterey Bay through two subsurface conduits 200 m from shore and approximately 7 m below the sea surface (Tenera 2000, Paduan 2002). The discharge into Monterey Bay is estimated at 4.56 billion liters per day, equivalent to half the volume of Elkhorn Slough (Genz 2003). The average temperature of the intake water is 13.9 °C with a range of 12.9 °C to 18.6 °C. After a residence time of approximately 30 minutes in the power plant (Genz 2003), the temperature of the discharged water is elevated to an average of 22.3 °C with a range of 17.9 °C to 27.2 °C (Tenera 2000). Moss Landing Power Plant is permitted by the Monterey County Water Quality Resources Control Board to increase the ambient (intake) water temperature by 14.3 °C daily (Tenera 2000). Most power plants in the United States operate so that the effluent water is between 5 °C and 15 °C above ambient (Laws 2000). However, the EPA criteria specifies that the maximum acceptable increase in the weekly average temperature resulting from artificial sources is 1.0 °C during all seasons of the year (EPA 1986). The discharge plume is turbulent, producing rapid mixing with surrounding seawater, and therefore rapid cooling of the discharge water (Paduan 2002).

In 2001 the MLPP upgraded its energy production capacity to 2545 MW, compared to 1250 MW in 2000. This doubling of electrical output has doubled the volume of thermal effluent into Monterey Bay. The maximum heat loading for the modernized facility increased about 41% over present conditions to 182 million BTU/min, although the addition of the new units' cooling water to the existing discharge lowered the maximum temperature by about 2.4 °C (Paduan 2002). The present report provides an analysis of entrainment effects to lower trophic level organisms, bacteria and phytoplankton, which were not considered in previous studies of the MLPP (Tenera 2000, Paduan 2002). Recent concerns over pathogenic bacteria and harmful algal blooms provide motivation for analysis of entrainment effects on these organisms (Horner et al. 1997).

2.2 *Previous Studies*

Planktonic organisms entrained in power plant cooling water are exposed to initial thermal increase within the power plant condenser coils and may be affected (Clark 1989; Langford 1990; Laws 2000; Turnpenny and Coughlan 2003). The resulting thermal effluent that enters the surrounding marine environment may also affect planktonic and benthic organisms in the vicinity of the discharge site (Clark 1989; Langford 1990; Laws 2000).

The 1970s brought significant scientific focus to entrainment in power plant cooling water systems, subsequent thermal discharge and the potential negative effects on commercially important fish larvae, marine invertebrates, and the environment (Capuzzo 1980). From the late 1970s the number of publications declined, though the amounts of heat discharged increased, and there continues to be an increase in the building of power plants to meet new demand and replace older power plants (Langford 1990).

Studies focusing on entrainment of zooplankton and commercially important larvae found reduced survival of organisms after entrainment in the cooling system of power plants (Carpenter et al. 1974; Davies and Jensen 1975; Heinle 1976). Zooplankton losses have been reported to range from 0% - 100% loss (Clark and Brownell 1973; Langford 1983). At four power plants along the California coast, zooplankton losses were related positively with temperature increase (Icanberry and Adams 1974).

The impact of entrainment on phytoplankton is generally negative and appears to result from thermal stress and/or chlorination, but it is unclear whether cells have actually been killed or just temporarily stressed (Laws 2000). Several studies have shown that primary productivity decreases 2 to 80 % in thermal effluent from power plants (38 %, Morgan and Stross (1965); 2 – 37 %, Fox and Moyer (1973); 26 %, Suchanek (1975); 30 %, Bienfang and Johnson (1980); 22 %, Miller et al. (1976); 20 -80 %, Chang and Rossman (1985); 60 %, Servais and Billen (1989); 36 %, Martinez-Arroyo et al. (1999); 38 %, Guseva and Chebotina (2000)). Others found that entrainment of phytoplankton had minimal impact on phytoplankton productivity (Dunstall 1985; Hirayama and Hirano 1970; Socal et al. 1999). Thus, the effects of thermal discharge on phytoplankton appear to vary widely.

The impact of heated discharge water on phytoplankton seems dependent on both ambient sea temperature and the subsequent increase in temperature from the power plant (i.e. the overall effect is not dependent on ΔT alone). In the temperate northeastern Pacific and northwestern Atlantic oceans it was reported that an increase in temperature of 8 – 11 °C stimulated photosynthesis when ambient water temperatures were 16 °C or cooler, and inhibited photosynthesis when ambient water temperatures were 17 °C or warmer (Morgan and Stross 1965; Briand 1975). These findings were supported by Chang and Rossmann (1985) who found variable effects of temperature increase on phytoplankton related to the temperature differential relative to ambient natural temperature.

Temperature increases may also affect the phytoplankton assemblage by eliminating stenothermal forms and increasing remaining eurythermal species (Naylor 1965) thereby altering phytoplankton community structure. Briand (1975) found that in two southern

California coastal power plants passage through the condenser tubes enhanced the dominance of two heat tolerant phytoplankton species (*Asterionella japonica* and *Gonyaulax polyedra*) while killing less heat tolerant diatoms (45.7 % decrease in cell numbers) and dinoflagellates (32.8 % decrease in cell numbers). Rossmann et al. (1980) found that at elevated temperatures, phytoplankton assemblages exhibited a decrease in species diversity, seen as a shift from a diatom dominated assemblage to one dominated by green algae. Saravanane et al. (1998) found increased dominance of *Thalassiosira*, a diatom genus, after passage through a power plant cooling system. Touliabah and Taylor (2004) also found dominance of *Thalassiosira* in effluent at 45 °C and domoic acid producing *Pseudonitzschia pseudodelicatissima* in effluent at 50 °C. This finding is particularly relevant to the Monterey Bay ecosystem since *Pseudonitzschia* blooms are well documented locally (Scholin et al. 2000). However, it is unknown if the MLPP will affect harmful algal blooms in Monterey Bay. Corroborating laboratory studies (Ukeles 1961; Goldman and Ryther 1976) indicate that the maximum temperature for normal growth is variable among phytoplankton groups, therefore supporting the notion that temperature may result in preferential selection of tolerant species. However, field studies have also been completed showing no significant change in phytoplankton assemblages caused by thermal stress in discharged cooling water (Suchanek 1975; Martinez-Arroyo et al. 1999).

Bacteria are generally regarded as the organisms most tolerant of temperature (Brock 1985). Mesophilic bacteria have an optimal growth range of temperature between 20 and 45 °C, and thermophilic bacteria have an optimal growth range of temperature between 45 and 70 °C (Brock 1985). Shiah and Ducklow (1994) found that bacterial growth rates were positively correlated with incubation temperatures between 3 and 25 °C; they argued that marine bacterial production rates may in fact be temperature limited, not necessarily nutrient and/or food limited. At higher temperature increases the literature results are variable. High temperature (40 °C) was shown to decrease bacterial production by 9 to 39 % (Choi et al. 2002). Miller et al. (1976) and Fox and Moyer (1973) found that the numbers of bacteria increased in the discharge of power stations. Suzdaleva (1998) found bacterial populations from the intake water were significantly reduced when heated to temperatures higher than 50 °C, while others found that bacterial populations from the discharge water were not significantly reduced when heated to temperatures up to 70 °C (Rankin et al. 1974). Solski (1974) found no difference in the abundance of bacterial populations at thermal discharge sites compared with intake waters.

Clearly the expected effects of entrainment on bacteria and phytoplankton may be site specific and attempts to assess impacts may differ if assays for standing crops alone are not augmented by complementary assays for productivity and growth. Snapshot comparisons of organism concentrations before and after cooling water entrainment may be an appropriate metric to measure effects on larger organisms trapped on filters or macerated by pumps, but standing crops of smaller organisms may appear to remain relatively unchanged using conventional counting techniques while viability per se may be quite different.

2.3 Objectives

The following objectives were addressed in this study:

Determine the impact of the thermal increase and entrainment on the biomass and productivity of bacteria.

Determine the impact of the thermal increase and entrainment on the biomass, physiology, and productivity of phytoplankton.

Assess the spatial extent of the area impacted surrounding the discharge plume within Monterey Bay, California.

2.4 Methods

2.4.1 Sampling

Surface water samples were collected in triplicate in darkened 1.0 L polycarbonate bottles (rinsed three times at each station before filling) at five sites chosen to represent the path traveled from the intake source in Moss Landing Harbor to the discharge site in Monterey Bay (Fig. 2-1). The station sequence was as follows: Station 1 (Moss Landing Harbor directly in front of intake chambers), Station 2 (the surge chamber on MLPP property that represented the closest access to heated water immediately leaving the plant), Station 3 (Monterey Bay, directly over the thermal discharge site located 200 m from shore), Station 4 (Monterey Bay, 100 m west of the discharge site) and Station 5 (Monterey Bay, 500 m west of the discharge site). Temperature was measured at each sampling site using a digital thermometer (Hanna instruments) accurate to ± 0.2 °C. Samples were collected and analyzed at least monthly from March 2004 to November 2005.

2.4.2 Bacterial analysis

Biomass

The standing crop biomass of bacteria was measured using two techniques, direct bacterial counts and colony growth. For direct bacterial counting, sample water (15 ml) from each site was preserved with 1% glutaraldehyde and 1-5 ml was quantitatively filtered onto 0.02 μm Anodisc filter, backed with 0.45 μm Millipore filter. The sample was filtered to dryness and removed while the vacuum was on. The dry filter was placed on top of 100 μl of working stock SYBR Gold nuclear stain solution (Molecular Probes/Invitrogen, Inc.) on a sterile Petri dish and stored in the dark for 15 minutes (working stock was a 400-fold dilution of the 10,000x SYBR Gold concentrate distributed by Invitrogen). After the staining period, the filter was placed back on the filtration rack and rinsed with 0.02 μm filtered de-ionized water. The filter was placed on a microscope slide with one drop of Slow Fade and a glass cover slip was placed over the filter. Slides were stored in the freezer (Noble 2001) until bacteria cells could be enumerated using an epifluorescent microscope under blue light excitation (Hagstrom et al. 1979; Sherr et al. 2001); at least 100 bacterial cells were enumerated per counting grid using 1250x magnification.

Bacterial colony growth was measured using unpreserved sample water. A quantitative volume of sample (10-25 μl) was streaked onto Difco marine agar plates in triplicate with

sterile transfer loops and incubated at 25 °C for 24 hrs in the dark. The bacterial colonies were counted at the end of the incubation time (Wood 1965).

Productivity

Relative productivity of bacteria was estimated by determining the frequency of dividing cells (FDC) as described by Hagstrom et al. (1979) and Sherr et al. (2001). Bacterial cells were enumerated as explained previously, noting paired cells and single cells, to calculate FDC as a percentage. The technique provides a means to estimate relative growth rates without the need for incubations.

2.4.3 Phytoplankton analysis

Biomass and degradation

Biomass and potential degradation of the phytoplankton was measured by fluorometric chlorophyll analysis using an acidification protocol on acetone pigment extracts. Quantitative volumes of sample water (100 ml to 500 ml) from each site were filtered onto a Whatmann glass fiber filter (GF/F; 0.7 µm nominal pore size). Phytoplankton pigments were extracted by placing the filter in a 2.0 ml micro-centrifuge tube with 1.2 ml of 90 % acetone stored at -20 °C for a minimum of 24 hours in the dark. After extraction, the samples were vortexed, the filters were compressed to the bottom of the tube with a stainless steel spatula and centrifuged for approximately 1 minute in a microfuge to remove debris. The extract was quantitatively sub-sampled (100 to 500 µl) and diluted in 5 ml of acetone in a glass culture tube for biomass and degradation pigment analysis. Fluorescence was measured using a Turner Designs 112 and/or a Turner 10AU fluorometer to determine chlorophyll *a* (chl *a*) and pheophytin *a* concentrations (Strickland and Parsons 1972). The remaining extract volume was retained for later HPLC analysis of pigments to corroborate data generated by fluorescence acidification protocol.

Phytoplankton Physiology

Instantaneous measurements of photochemical efficiency based on variable fluorescence were made with a pulse amplitude modulated (PAM) fluorometer (Water PAM, H. Walz, Germany). The fluorescence ratio, F_v/F_m corresponding to photochemical efficiency, was determined using the saturation pulse technique (Schreiber et al. 1998) on dark-adapted samples. The technique is rapid, sensitive and density-independent, allowing quantitative assessment of algal physiological status from variable fluorescence properties of photosystem II (Genty 1989). Fluorescence measurements were made on triplicate samples (3 ml) from each site; sample water was returned to the laboratory for measurements within three hours of collection. The saturation pulse method provides quantitative information on photochemical efficiency (also termed photochemical yield, the fraction of absorbed photons utilized in photochemical energy conversion) calculated as:

$$\text{YIELD} = (F_m' - F)/F_m' = F_v/F_m' \quad \text{where,}$$

F_m' = maximum fluorescence

F = minimum fluorescence

F_v = variable fluorescence

F_v/F_m' = unitless ratio

The variable fluorescence ratio, F_v/F_m , produces values ranging from 0.0 to 0.7 (Genty 1989, Schreiber et al. 1998). Exponentially growing phytoplankton usually exhibit higher dark-adapted F_v/F_m values from 0.55-0.70. Decreases from the highest possible values of F_v/F_m have been shown to indicate physiological stress to the photoautotroph in both higher land plants and algae.

2.4.4 Production and Respiration

On three sampling dates (6/15/05, 9/14/05, and 11/1/05) gross primary production and dark respiration of samples from Stations 1, 2, 3 and 4 were determined using light-dark bottle incubations analyzed for oxygen exchange rates with high precision potentiometric Winkler titrations (Furuya and Harada 1995). Duplicate surface water samples were collected in 2 L clear polycarbonate bottles. Sample water from each 2 L bottle was distributed to three 300 mL biological oxygen demand (BOD) bottles with polypropylene tubing to reduce oxygen introduction. One bottle was immediately fixed with manganese chloride and alkaline iodide to determine the initial oxygen content, one bottle was wrapped in aluminum foil (dark bottle), and the third bottle was left uncovered (light bottle). The light and dark bottles were placed in an outdoor incubation tank with continuous seawater flow at 25 % irradiance for a 24 hr incubation. At the end of 24 hr each bottle was fixed with manganese chloride and alkaline iodide. Algal gross primary production rate was determined from the light bottle minus dark bottle; dark community respiration was determined from the initial oxygen level minus final dark bottle.

2.4.5 Statistical analysis

An Analysis of Covariance with a Tukey's pairwise comparisons test was used to detect differences among the stations for the following parameters: temperature, bacterial biomass, FDC, phytoplankton biomass, degradation pigments (pheopigments), photochemical yield, gross production, and community respiration (Zar 1999). Normality, equality of variances, and independence were confirmed by analysis of residuals. The correlative relationship between temperature and the above parameters were analyzed.

Absolute values of parameters on any given date provided useful comparisons of biological conditions among stations. However, during the sampling period (3/4/04 – 11/1/05) seasonal variation in biomass and production confounded useful comparisons among sampling dates. In order to remove seasonal variations in biomass and production among sampling dates, the results were normalized to Station 1 (the intake source water) for each biological parameter measured on a given date. Normalized values were scaled to 1.0 for Station 1 providing a 'snapshot' of the relative variation in parameters measured at all five stations for a given day;

mean values of the relative changes in specific parameters could then be summarized for all sampling dates.

2.5 Results

2.5.1 Temperature

The mean temperature of source water entering MLPP (Station 1) was 15.1 ± 1.8 °C (3/4/04 – 11/1/05). The power plant increased the cooling water temperature to a mean of 22.3 ± 2.3 °C in the surge chamber (Station 2), the sampling location with the highest water temperatures and most reflective of conditions at the immediate exit of the power plant. The mean temperature at the surface of the discharge site in Monterey Bay (Station 3) was 18.4 ± 2.1 °C, the mean temperature 100 m from the discharge site (Station 4) was 14.5 ± 2.0 °C, and the mean temperature 500 m from the discharge site (Station 5) was 14.1 ± 1.9 °C (Figs. 2-2 and 2-3). The maximum temperature measured at the power plant surge tank (Station 2) was 27.2 °C and at Station 3 was 24.6 °C (Fig. 2-2). The mean temperatures at Stations 2 and 3 were significantly higher ($p < 0.0001$) than all other stations and significantly different ($p < 0.001$) from each other. Due to the tidal influence of warmer shallow waters from Elkhorn and Tembladero Sloughs the source water (Station 1) was on average 0.8 °C warmer than the outer bay stations (Stations 4 and 5) but Stations 1, 4, and 5 did not differ significantly ($p \geq 0.127$). The typical range of coastal sea surface water temperature in Monterey Bay is 10 – 18 °C, during an El Niño event the typical range is increased by 2.7 °C, and during a La Niña event the typical range is lowered by 1.8 °C.

2.5.2 Bacteria

Biomass

Mean bacterial biomass from epifluorescence direct counts at the surge tank (Station 2) was significantly greater (mean = 4.2×10^5 cells/mL) than at the intake site (Station 1) (mean = 3.1×10^5 cells/mL) ($p = 0.001$) (Figs. 2-4 and 2-5). Bacterial biomass at station 2 was also significantly higher than Stations 3 ($p < 0.001$) and 4 ($p = 0.019$) but not Station 5 ($p = 0.530$). Stations 1, 4, and 5 (intake water and two outer Monterey Bay stations) did not differ significantly ($p \geq 0.803$). There was no relationship ($r^2 = 0.099$, $p = 0.090$) between average bacterial biomass and temperature (Fig. 2-6). Generally, the levels of direct count total bacteria among stations on any given date did not differ by more than a factor of two.

The colony growth assessments on bacterial agar plates showed much larger ranges in bacterial activity among stations. On average the bacterial colony biomass at the surge tank (Station 2) was more than ten times higher than at the intake site (Station 1) (Figs. 2-7 & 2-8). This indicates a significant increase in cultivable bacterial cells originating after passage through the power plant. Inactive cells could have been induced into a higher rate of reproduction as a result of temperature increases and/or a higher population of cultivable cells could have been scavenged from conduit walls within the circulation system. The surge tank (Station 2) was significantly different ($p \leq 0.001$) from all other stations. Station 3 did not significantly differ from the remaining stations ($p \geq 0.567$). Stations 1, 4, and 5 did not differ significantly from each other ($p \geq 0.547$). There was a positive relationship ($r^2 = 0.7806$, $p < 0.001$) between source temperature and cultivable bacterial colony counts (Fig.

2-6). No attempt was made to identify the bacterial taxa present in the grow-out colonies, but it is well recognized that cultivable bacteria constitute much less than 10% of the total bacterial cell population in natural marine samples (Azam 2001). The results above indicate that increases in cultivable bacteria were detectable at the immediate exit from the MLPP cooling system; however, this bacterial signal was not detectable at the Monterey Bay stations *per se*.

Bacterial Productivity

Frequency of dividing cells (FDC) provides another indicator of bacterial productivity (Newell 1981) based on total bacteria enumeration, which can be contrasted to colony growth, which only reflects activity of those cells capable of cultivation on agar growth media (Azam 2001). The results indicated by percentage that the surge tank (Station 2; mean = 29.7 ± 3.6 %) had twice as many dividing (productive) cells as the intake site (Station 1; mean = 12.9 ± 2.4 %) (Figs. 2-10 and 2-11). The FDC of Station 2 was significantly greater than all other stations ($p \leq 0.005$). The FDC of Station 3 was 18.2 ± 8.6 %, which was significantly different from Station 1 ($p = 0.003$), but did not differ significantly from Stations 4 and 5 ($p \geq 0.744$). The FDC of Station 4 was a 15.1 ± 7.4 %, and Station 5 was 14.3 ± 7.3 %; Stations 1, 4, and 5 did not differ significantly ($p \geq 0.810$). There was a positive relationship ($r^2 = 0.579$ $p = 0.000$) between temperature and FDC (Fig. 2-12). The results of bacterial productivity from FDC generally parallel those from colony growth. Both methods indicate enhanced bacterial growth by thermal increase and entrainment in the MLPP.

2.5.3 Phytoplankton

Biomass and Degradation

Relative standing stocks of phytoplankton, estimated from chl *a* determinations, were variable and indicated no clear trend among stations, possibly a result of patchy phytoplankton distributions. There was not a significant relationship ($r^2 = 0.007$, $p = 0.408$) between phytoplankton biomass (chl *a*) and temperature (data not shown).

The relative ratio of pheopigments to chl *a*, determined by the routine fluorescence acidification protocol (Strickland and Parsons 1972), did show repeatable trends along the sampling grid. The ratio of pheopigments to chl *a* represents degradation of chl *a* by phytoplankton cell death and/or grazing of cells, relative to algal cellular chl *a*; it may also indicate the presence of sediment-derived particles that are dominated by pheopigments degradation products. High pheo/chl *a* ratios can also result as an artifact of chl *b* contamination using fluorescence acidification protocol (Welschmeyer 1994); however, corroborating HPLC assays did not show relative increases in chl *b* concentrations at the surge tank (Station 2). The mean pheopigment to chl *a* ratio was 2.5 times greater at Station 2 (mean = 1.32) than at Station 1 (mean = 0.47) (Figs. 2-13 and 2-14). The surge tank (Station 2) was significantly different ($p \leq 0.002$) from all other stations. The mean ratio of pheopigments to chl *a* at Station 3 (mean = 0.77) was 1.6 times greater than Station 1 (Figs. 2-13 and 2-14). Station 3 was significantly different ($p \leq 0.007$) from Stations 1 and 4, but did not differ significantly ($p = 0.576$) from Station 5. Stations 1, 4, and 5 did not differ

significantly ($p \geq 0.956$). There was a positive relationship ($r^2 = 0.301$, $p < 0.001$) between the pheopigments-to-chl *a* ratio and temperature (Fig. 2-15). These results indicate significant phytoplankton cell death and/or the entrainment of substantial quantities of sediment that are typically dominated by pheopigments relative to chl *a*. Quantification of sediment concentration should be considered in future analyses.

Phytoplankton Physiology

The photochemical yield (F_v/F_m) measured by variable fluorescence was significantly higher ($p < 0.001$) at the intake site (Station 1; mean = 0.45 ± 0.07) than at the surge tank (Station 2; mean = 0.27 ± 0.11), indicating high stress in the phytoplankton at Station 2 (Figs. 2-16 and 2-17). The mean photochemical yield at Station 2 was significantly lower ($p < 0.001$) than all other stations. Station 3 had a higher average yield than Station 1 (mean = 0.49 ± 0.09) though not significantly different ($p \geq 0.971$) from the other bay samples (Station 4 mean = 0.52 ± 0.07 and Station 5 mean = 0.52 ± 0.08) (Figs. 2-16 and 2-17). Stations 4 and 5 did not differ significantly ($p = 0.907$). The results indicate that the physiology of the phytoplankton (photochemical energy conversion efficiency) was negatively affected by thermal stress and/or entrainment in the MLPP and could easily be detected at the surge tank exit site.

2.5.4 Gross Primary Production and Community Dark Respiration

Oxygen exchange determined in light-minus-dark experiments provides unambiguous determination of gross primary production specific to phytoplankton, while the corresponding dark oxygen depletion indicates respiration of the bulk planktonic community. On three sampling dates the chl-specific gross production rate ($\text{mg O}_2 \mu\text{g chl } a \text{ L}^{-1} \text{ d}^{-1}$) and bulk dark respiration ($\text{O}_2 \text{ mg L}^{-1} \text{ d}^{-1}$) was determined using the Winkler titration method. Average gross production was 8 times lower at the surge tank (Station 2; mean (\pm S.D.) = $0.01 \pm 0.009 \text{ mg O}_2 \mu\text{g chl } a \text{ L}^{-1} \text{ d}^{-1}$) than at the intake site (Station 1; mean (\pm S.D.) = $0.08 \pm 0.01 \text{ mg O}_2 \mu\text{g chl } a \text{ L}^{-1} \text{ d}^{-1}$) and, correspondingly, average respiration was 9 times higher at Station 2 (mean (\pm S.D.) = $3.13 \pm 1.52 \text{ O}_2 \text{ mg L}^{-1} \text{ d}^{-1}$) than Station 1 (mean (\pm S.D.) = $0.35 \pm 0.18 \text{ O}_2 \text{ mg L}^{-1} \text{ d}^{-1}$) (Figs. 2-18 and 2-19). The average gross primary production for Station 2 was significantly lower than all other stations ($p \leq 0.001$) and average respiration at Station 2 was significantly higher than all other stations ($p < 0.001$). Gross primary production at Station 3 was $0.08 \pm 0.04 \text{ mg O}_2 \mu\text{g chl } a \text{ L}^{-1} \text{ d}^{-1}$, and at Station 4 was $0.07 \pm 0.04 \text{ mg O}_2 \mu\text{g chl } a \text{ L}^{-1} \text{ d}^{-1}$. The mean (\pm S.D.) respiration at Station 3 was a $-0.28 \pm 0.13 \text{ O}_2 \text{ mg L}^{-1} \text{ d}^{-1}$, and at Station 4 was $-0.35 \pm 0.40 \text{ O}_2 \text{ mg L}^{-1} \text{ d}^{-1}$. Neither gross primary production nor community respiration at Stations 1, 3, and 4 were significantly different ($p \geq 0.129$). The significant increase in respiration at the surge chamber (Station 2) corroborates results of enhanced bacterial growth while the significant decrease in gross production at the surge chamber (Station 2) suggests negative effects on phytoplankton by thermal stress and/or entrainment in the MLPP.

2.6 Discussion

The first objective of this study was to determine the impact of thermal increase and entrainment on the biomass and productivity of bacteria. Bacterial growth was enhanced as a

result of passage through the MLPP cooling system, as evidenced from 1) increases in bacterial colony counts (Fig. 2-8), 2) increases in the frequency of dividing cells (Fig. 2-11), and 3) increased dark respiration in the surge chamber (Fig. 2-19). These results are supported by Miller et al. (1976) and Fox and Moyer (1973) who found that the numbers of bacteria increased in the discharge effluent of power stations. Shiah and Ducklow (1994) also observed increased bacterial productivity with increasing temperature between 3 and 25 °C in incubation experiments. In the present study, bacteria biomass as total direct epifluorescent counts was not a good indicator for assessing the impact of thermal stress and entrainment on bacteria, as would be expected given the short residence time (<1h) of entrained water within the power plant. We cannot reject the possibility that bacteria associated with wall growth within the conduit system contributed to the signals we detected at the surge site (Station 2). However, since significant increases in bacterial abundance at the surge site were not evident in total direct counts we must assume that total contribution of such cells was relatively small.

The second objective of this study was to determine the impact of the thermal increase and entrainment on the biomass, physiology, and productivity of phytoplankton. Phytoplankton was negatively impacted after passage through the MLPP cooling system as shown by reductions in photochemical yield (Fig. 2-14), increases in pheopigment/chl *a* ratios (Fig. 2-17), and decreases in phytoplankton gross primary productivity in the surge chamber (Fig. 2-18). Suchanek (1975) also observed an increase in pheophytin as a result of thermal increase at a power plant in Long Island. Several previous studies have shown that primary productivity decreased 2-80 % in thermal effluent from power plants (38 %, Morgan and Stross (1965); 2-37 %, Fox and Moyer (1973); 26 %, Suchanek (1975); 30 %, Bienfang and Johnson (1980); 20-80 %, Chang and Rossman (1985); 60 %, Servais and Billen (1989) and 36 %, Martinez-Arroyo et al. (1999)); our results corroborate those findings. In the present study we found roughly a five-fold decrease in chl-specific primary production determined from water samples immediately exiting the power plant at the surge tank. Phytoplankton biomass, as chl *a*, was not a good indicator for assessing the impact of thermal stress and entrainment on phytoplankton; this finding is supported by other studies which found no significant differences in phytoplankton biomass (Bienfang and Johnson 1980, Briand 1975, Chang and Rossman 1985, Martinez-Arroyo et al. 1999, Servais and Billen 1989, Suchanek 1975). To our knowledge, this is the first study to utilize PAM fluorometry to assess physiological effects of once-through cooling on phytoplankton. The technique was rapid, sensitive and density-independent; it clearly identified negative impacts of thermal stress on phytoplankton photochemical efficiency, F_v/F_m , which presumably were manifested in reduced photosynthetic rates as also found here. The fact that PAM fluorimeters can be plumbed for flow-through analysis (rather than discrete cuvet sampling) suggests this method may provide a cost-effective means for monitoring biological impacts of once-through cooling flow on a continuous basis.

A fundamental objective of this study was to determine the effects, if any, of thermal increase and entrainment on bacteria and phytoplankton passing through the Moss Landing Power Plant. Our results indicate that differential effects were indeed in place; bacteria appeared to be enhanced as a result of entrainment while phytoplankton was negatively impacted. Measurements supporting these conclusions were all based on indicators of

physiological condition and rate processes. Measurements of bulk concentrations, e.g., total direct bacteria counts and chl *a*, provided relatively little indication of impacts. This is not surprising given the potentially short (<1 h) residence time of cooling water within the power plant.

The final objective of this study was to assess the spatial extent of the area impacted surrounding the discharge plume within Monterey Bay, California. In spite of the fact that differential biological enhancement and inhibition effects were clearly evident in the cooling water flow measured at the surge tank (Station 2), the corresponding impacts in Monterey Bay (Stations 3-5) were much more difficult to detect. It appears that even at the high discharge rates that result in measurable surface temperature increases at the discharge site in Monterey Bay, the apparent biological effect is dissipated quickly within 100-500 m of the site by dilution in surrounding waters (Figs. 2-5, 2-8, 2-11, 2-14, 2-18 and 19). It is possible that bacteria and phytoplankton experienced physiological recovery back to the native biological state after reintroduction to normal ambient temperature. However, our results on negative rates of primary production do not support this possibility since the experimental productivity incubations were conducted under normal cool temperatures (13 °C) for all samples.

We generally conclude that bacterial enhancement and phytoplankton inhibition are expected to occur as a result of entrainment through the Moss Landing Power Plant. However, we were not able to document perceptible biological impacts after discharge and dilution in surrounding Monterey Bay waters.

2.7 Literature Cited

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2.8 Tables and Figures

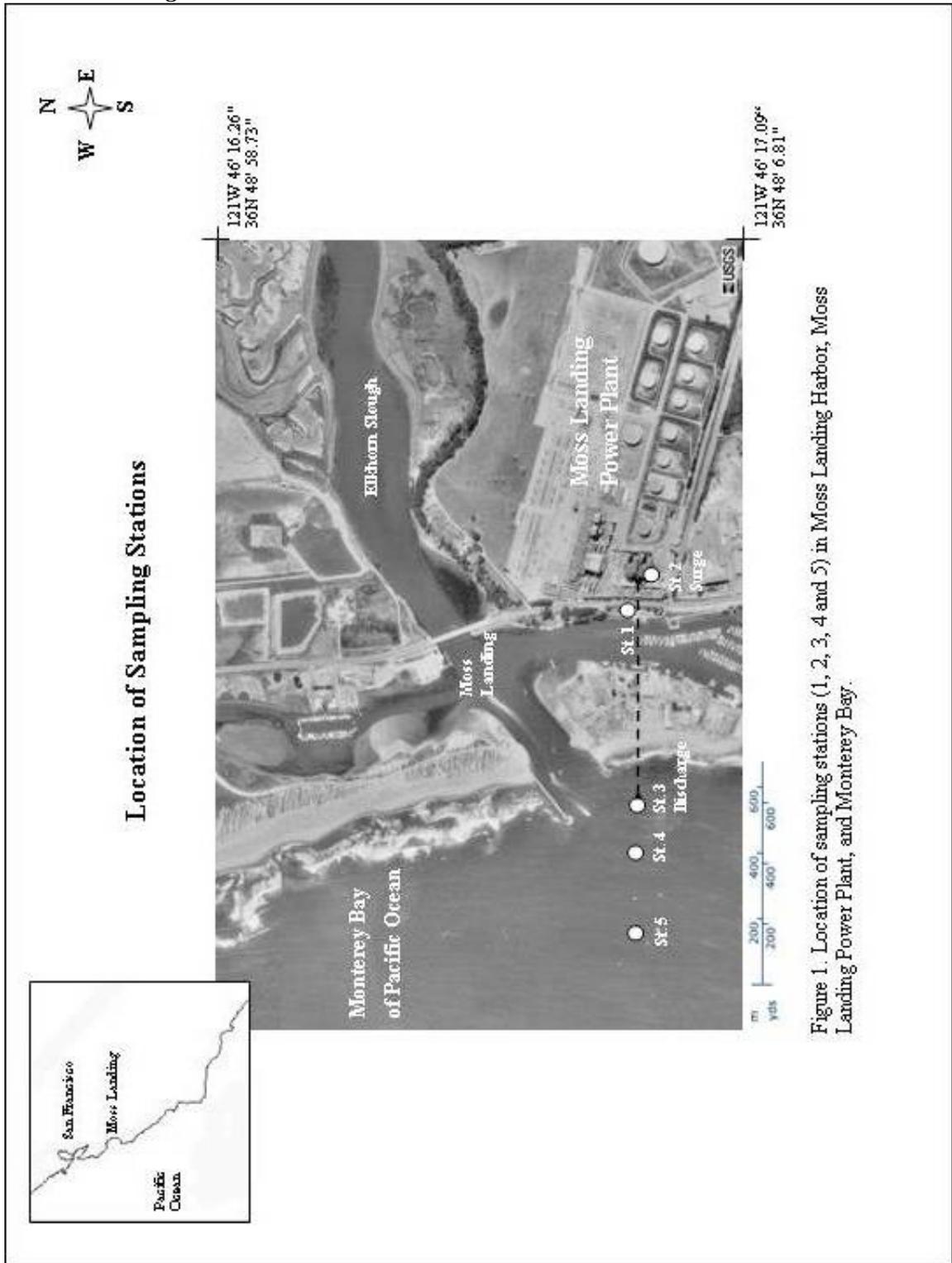


Figure 1. Location of sampling stations (1, 2, 3, 4 and 5) in Moss Landing Harbor, Moss Landing Power Plant, and Monterey Bay.

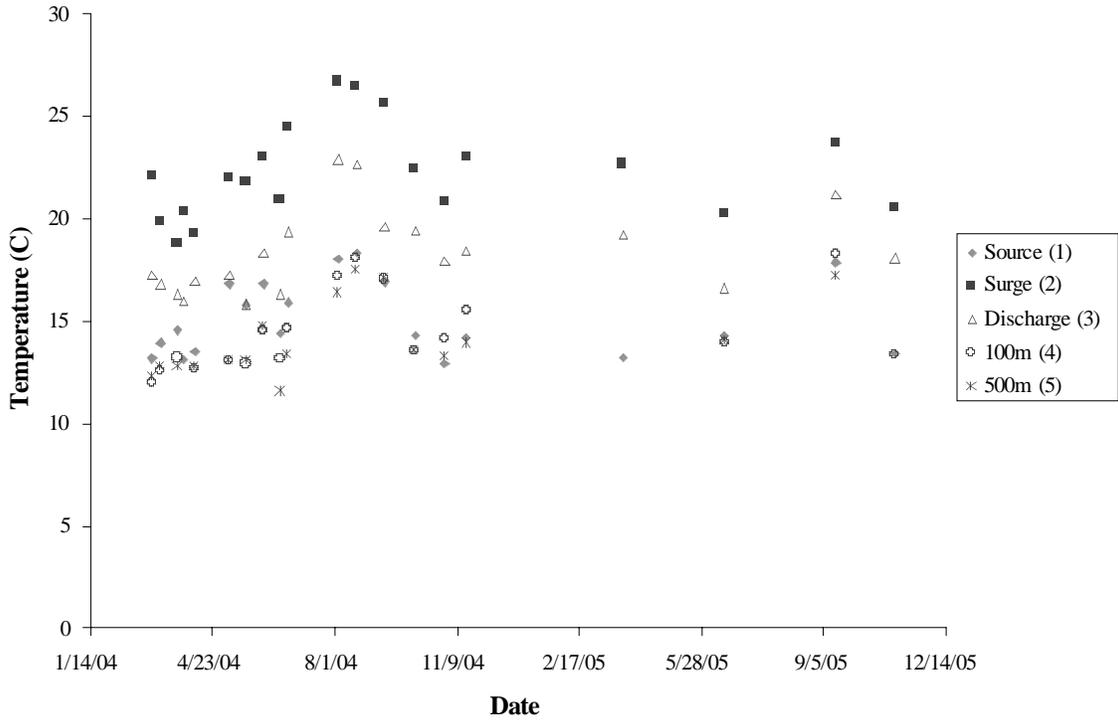


Figure 2-2. Temperature (C) for each sampling date between 3/4/04 – 11/1/05 at sampling stations (1 - 5).

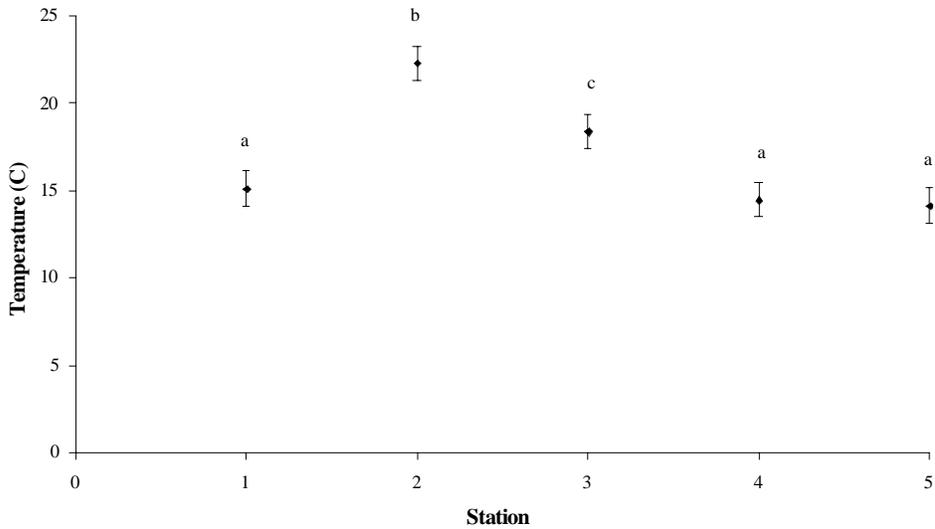


Figure 2-3. Mean temperature (C) ± SD for all sampling dates 3/4/05 – 11/1/05 (n = 20) at sampling stations (1 - 5) and results of an ANCOVA with multiple comparison Tukey tests. Different letters above symbols indicate significant differences ($p \leq 0.05$).

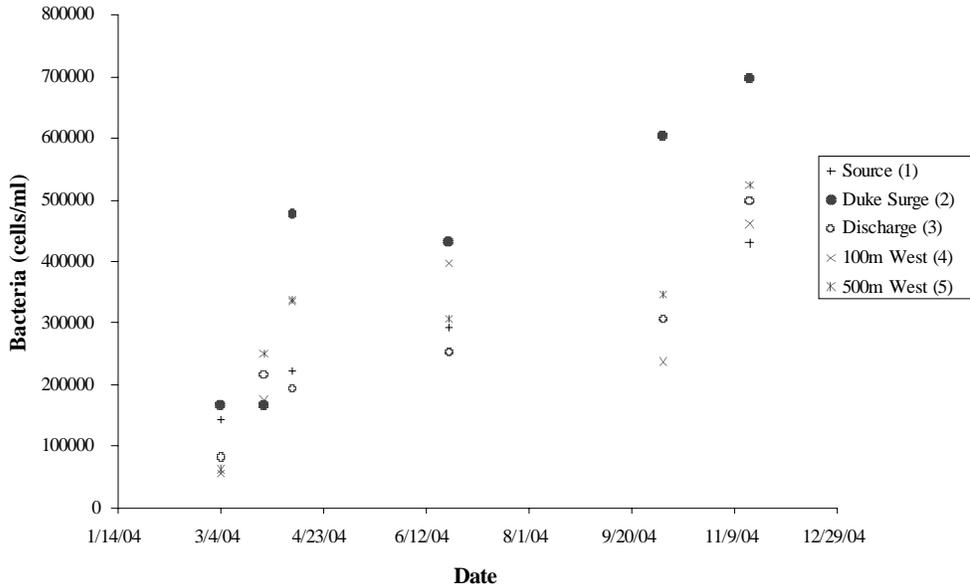


Figure 2-4. Bacteria biomass (cells/mL) for each sampling date between 3/4/04 – 11/16/04 (n = 6) at sampling stations (1 - 5).

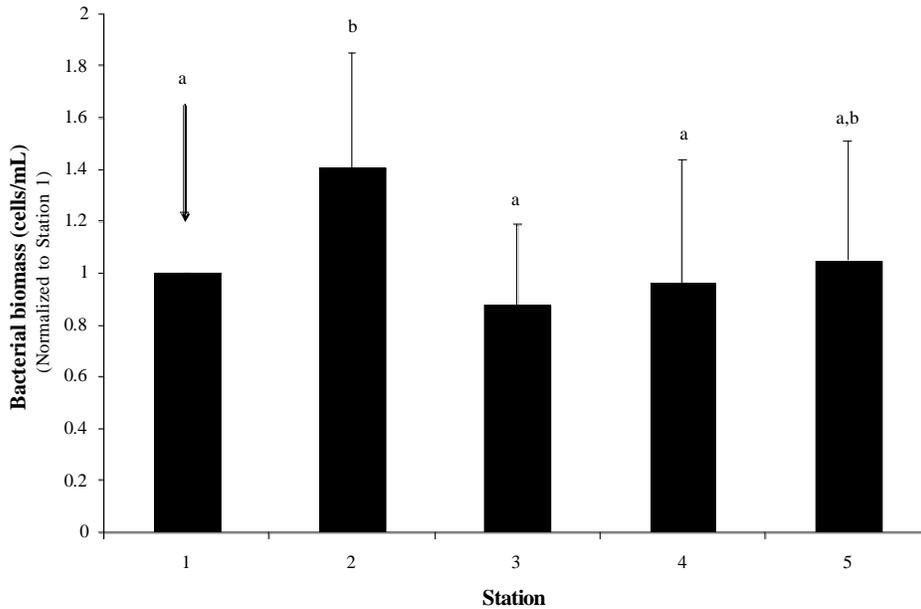


Figure 2-5. Bacteria biomass (cells/mL) \pm SD at sampling stations (1 - 5) for each sampling date between 3/4/04 – 11/16/04 (n = 6). All values normalized to 1.0 in reference to the intake site at Station 1 (identified by arrow) and results of an ANCOVA with multiple comparison Tukey tests. Different letters above symbols indicate significant differences ($p \leq 0.05$).

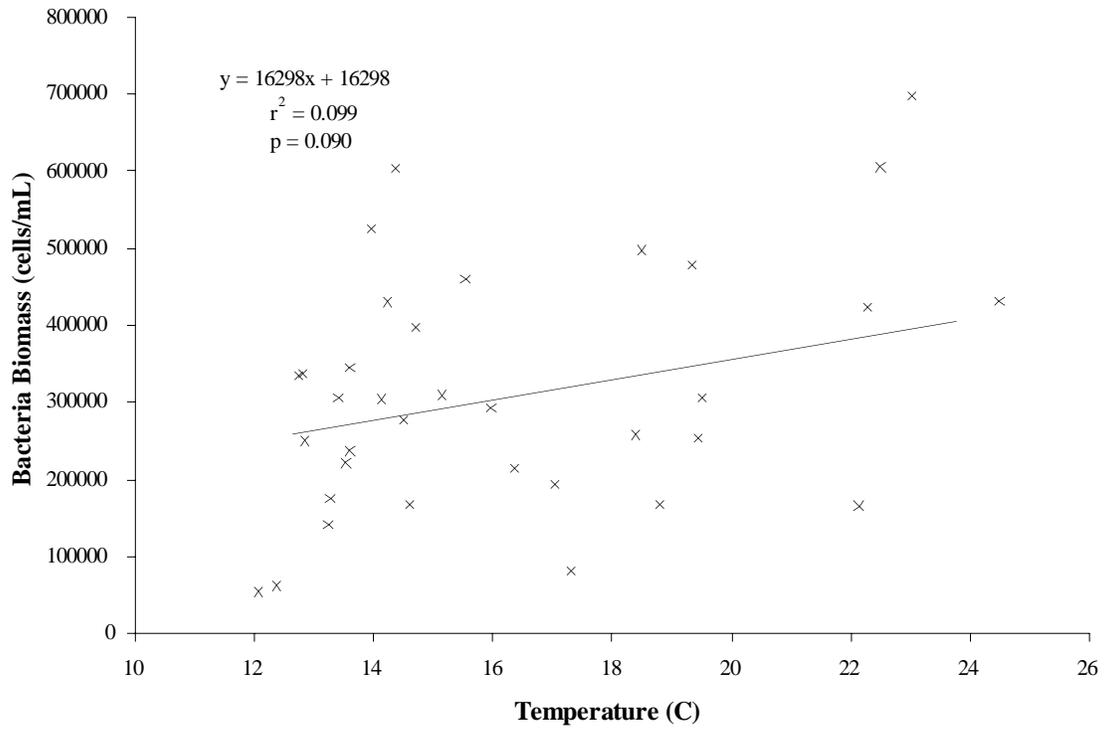


Figure 2-6. Relationship between bacteria biomass (cell/mL) and temperature. Linear regression equation is given and plotted (n = 6).

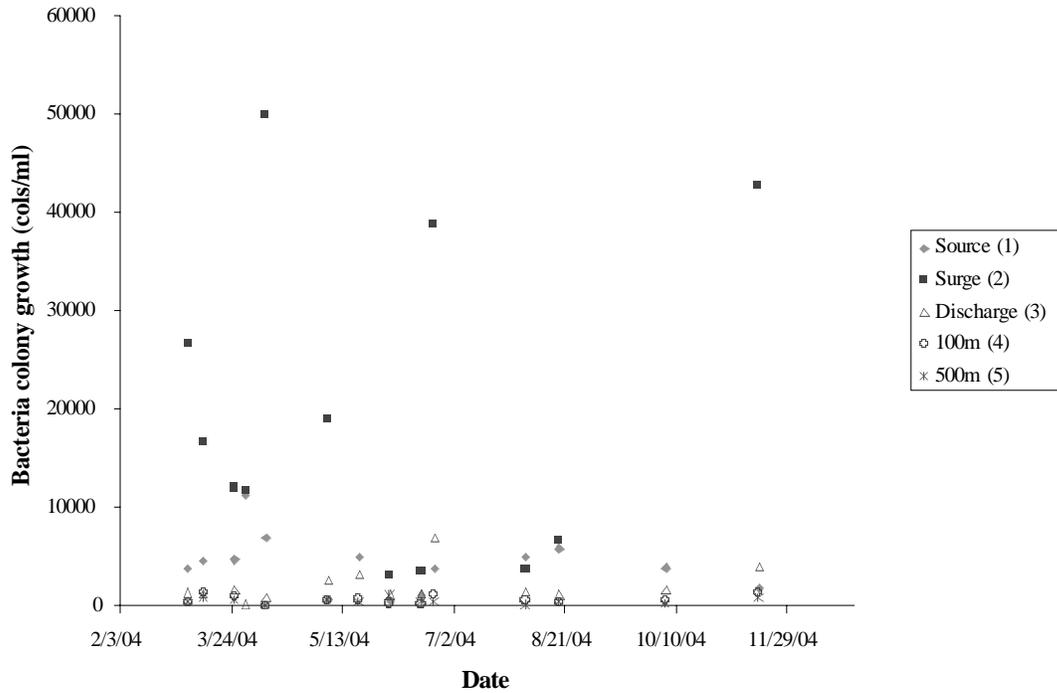


Figure 2-7. Bacteria colony growth (cols/mL) for each sampling date between 3/4/04 – 11/16/04 (n = 12) at sampling stations (1 - 5).

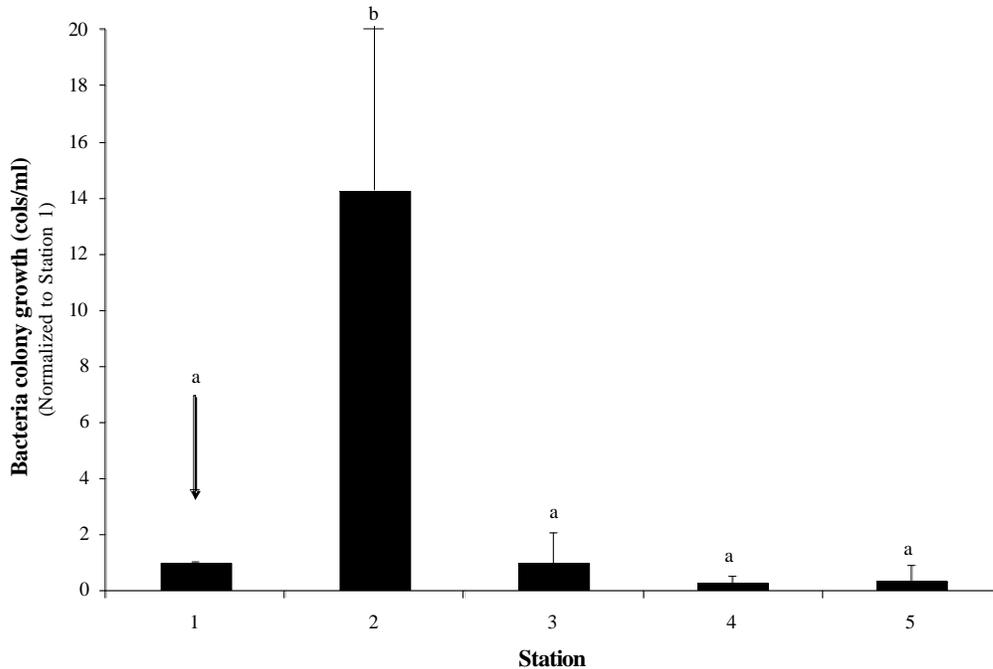


Figure 2-8. Bacteria colony growth (cols/mL) \pm SD at sampling stations (1 - 5) 3/4/04 – 11/16/04 (n = 12). All values normalized to 1.0 in reference to the intake site at Station 1 (identified by arrow) and results of an ANCOVA with multiple comparison Tukey tests. Different letters above symbols indicate significant differences ($p \leq 0.05$).

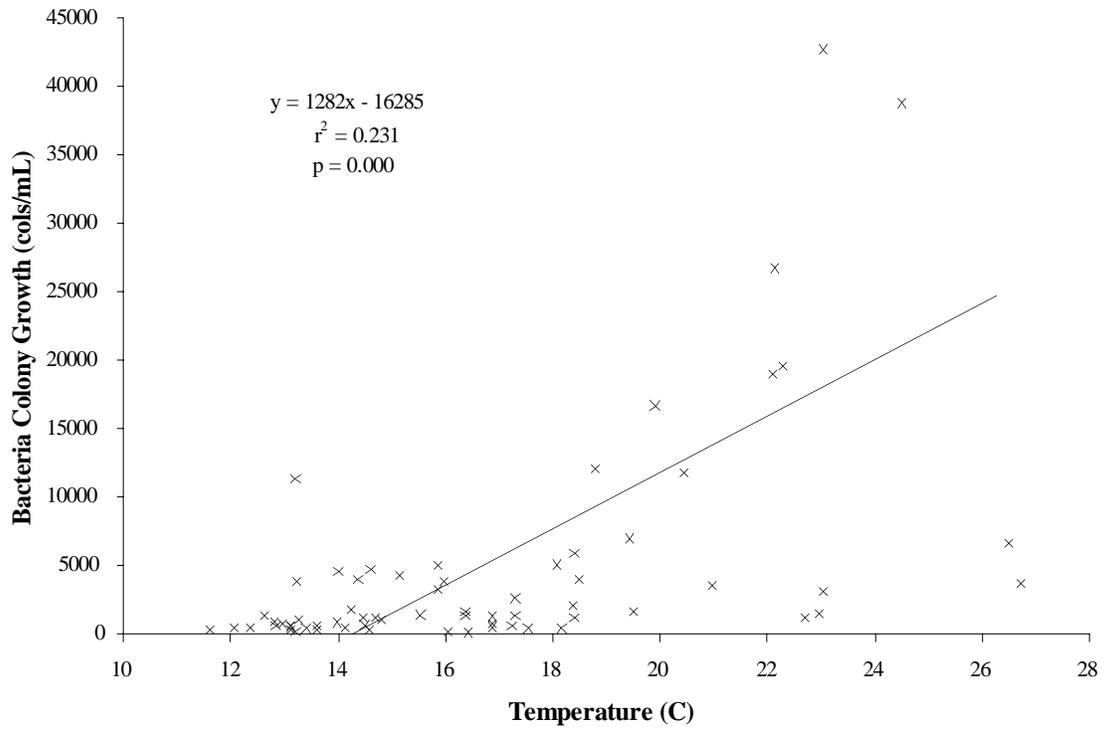


Figure 2-9. Relationship between bacterial colony growth (cols/mL) and temperature. Linear regression equation is given and plotted (n = 12).

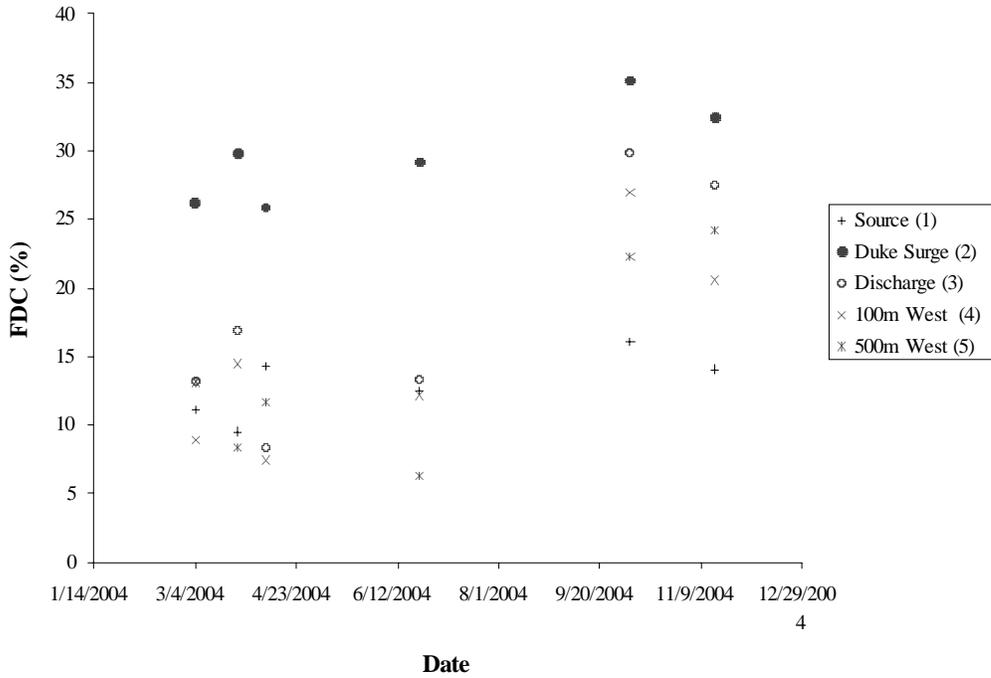


Figure 2-10. Frequency of dividing cells (FDC %) for each sampling date between 3/4/04 – 11/16/04 (n = 6) at sampling stations (1 - 5).

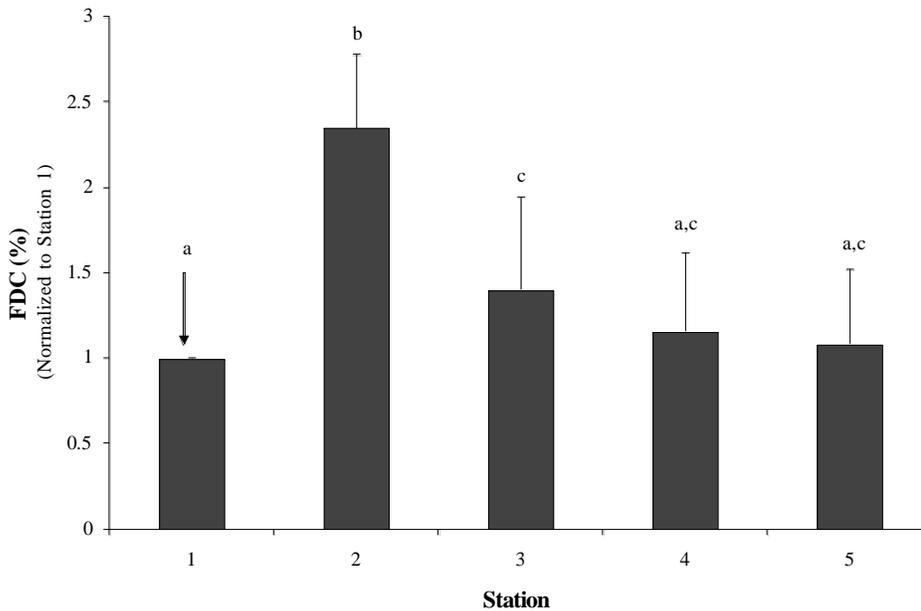


Figure 2-11. Frequency of dividing cells (FDC %) ± SD at sampling stations (1 - 5) 3/4/04 – 11/16/04 (n = 6). All values normalized to 1.0 in reference to the intake site at Station 1 (identified by arrow) and results of an ANCOVA with Tukey’s multiple comparisons test. Different letters above symbols indicate significant differences ($p \leq 0.05$).

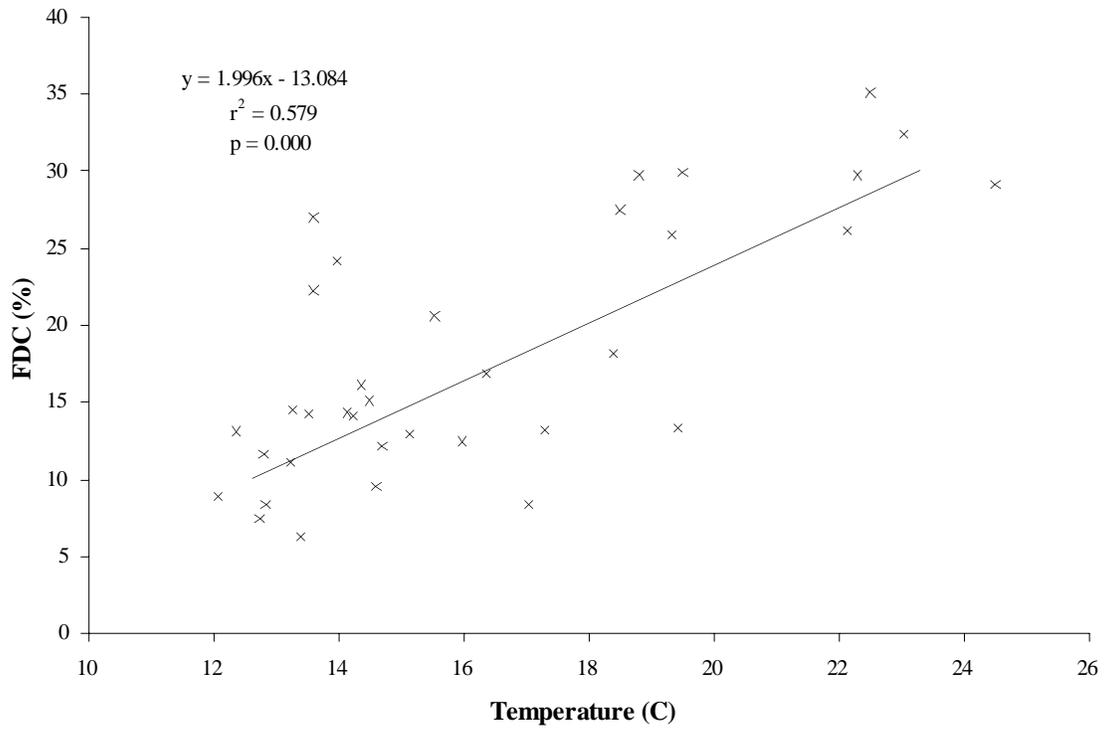


Figure 2-12. Relationship between frequency of dividing cells (FDC %) and temperature. Linear regression equation is given and plotted (n = 6).

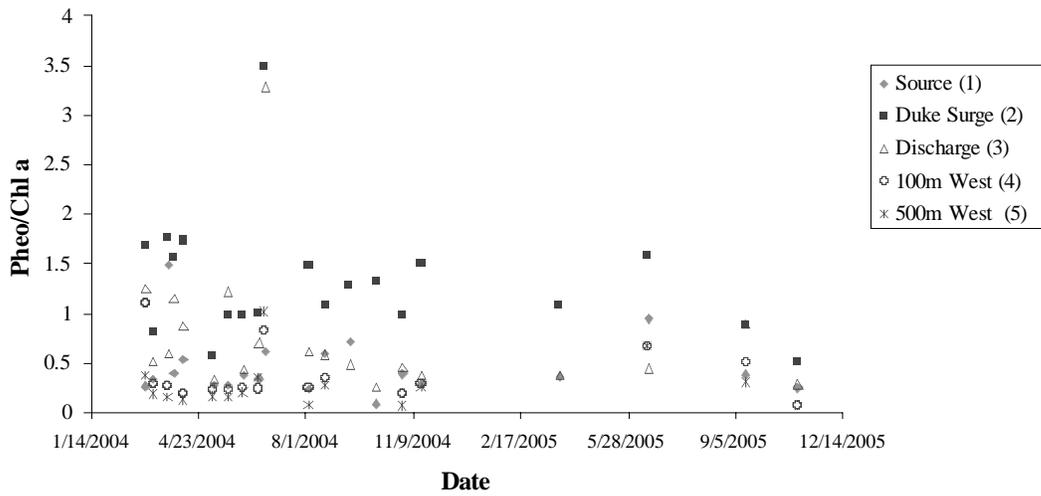


Figure 2-13. Degradation pigment ratio (pheopigment/chl *a*) for each sampling date between 3/4/04 – 11/1/05 (n = 20) at sampling stations (1 - 5).

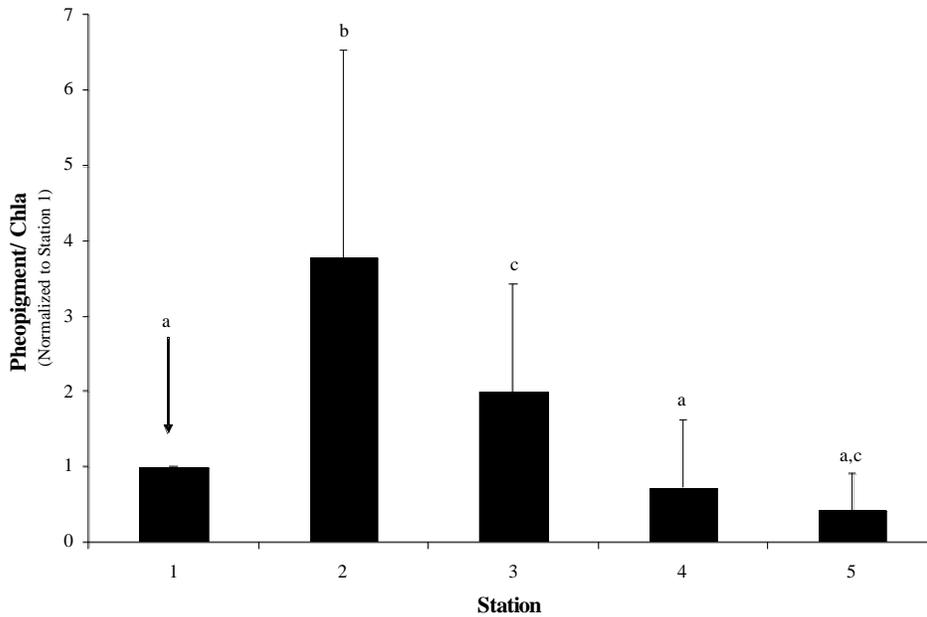


Figure 2-14. Degradation pigments (pheopigment/chl *a*) ± SD at sampling stations (1 - 5) 3/4/04 – 11/1/05 (n = 20). All values normalized to 1.0 in reference to the intake site at Station 1 (identified by arrow) and results of an ANCOVA with Tukey's multiple comparisons test. Different letters above symbols indicate significant differences ($p \leq 0.05$).

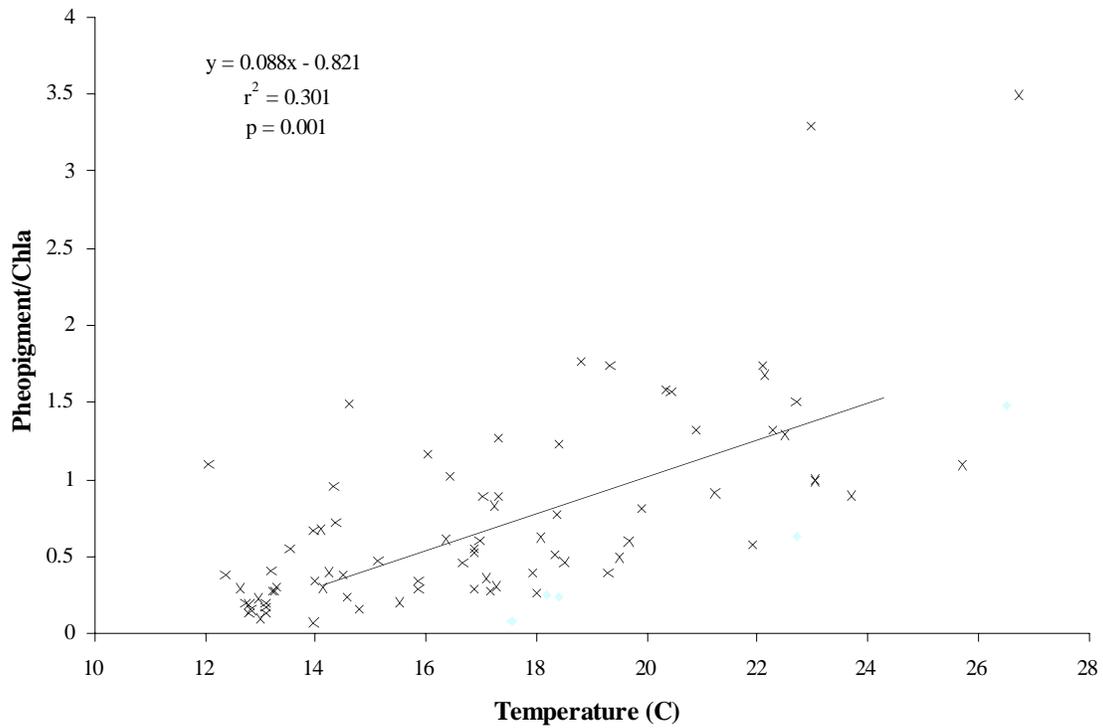


Figure 2-15. Relationship between degradation pigment ratio (pheopigment/chl *a*) \pm SD and temperature. Linear regression equation is given and plotted (n =20).

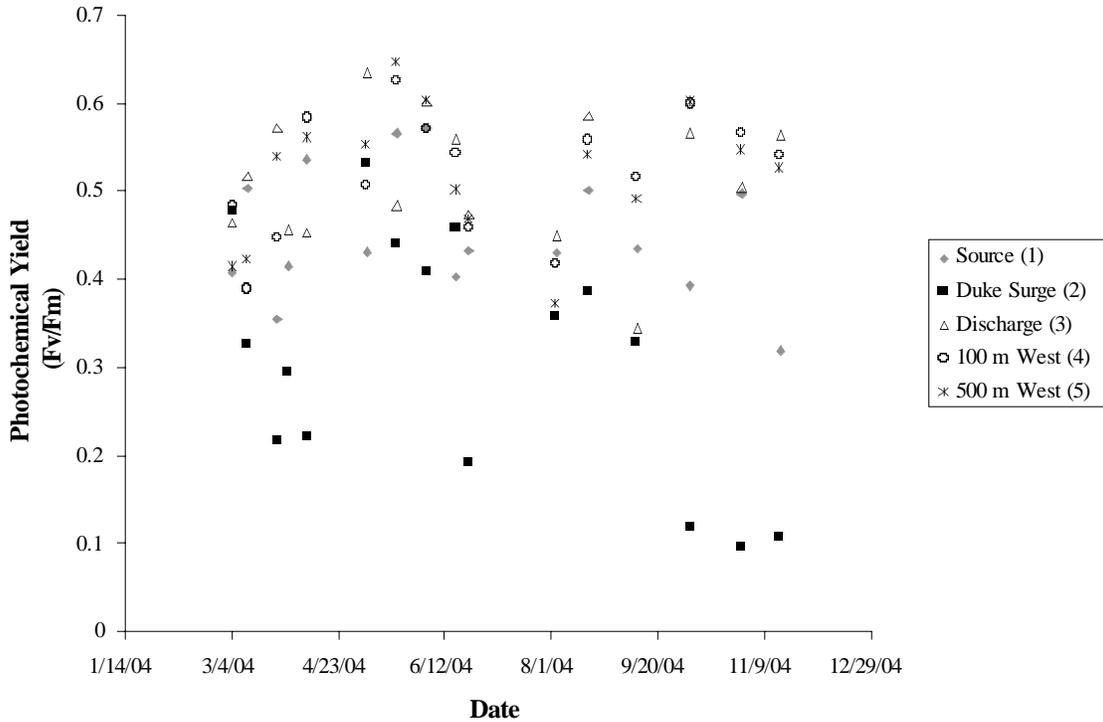


Figure 2-16. Photochemical yield (Fv/Fm) for each sampling date between 3/4/04 – 11/1/05 (n = 20) at sampling stations (1 – 5).

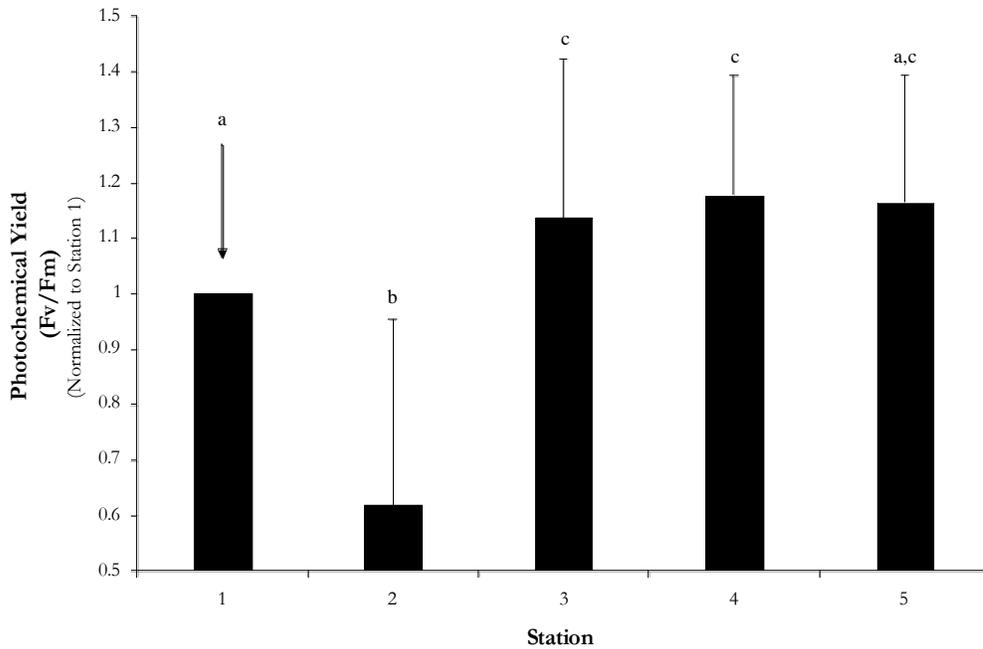


Figure 2-17. Photochemical yield (Fv/Fm) ± SD at sampling stations (1 - 5) 3/4/04 – 11/1/05 (n = 20). All values normalized to 1.0 in reference to the intake site at Station 1 (identified by arrow) and results of an ANCOVA with Tukey’s multiple comparisons test. Different letters above symbols indicate significant differences (p ≤ 0.05).

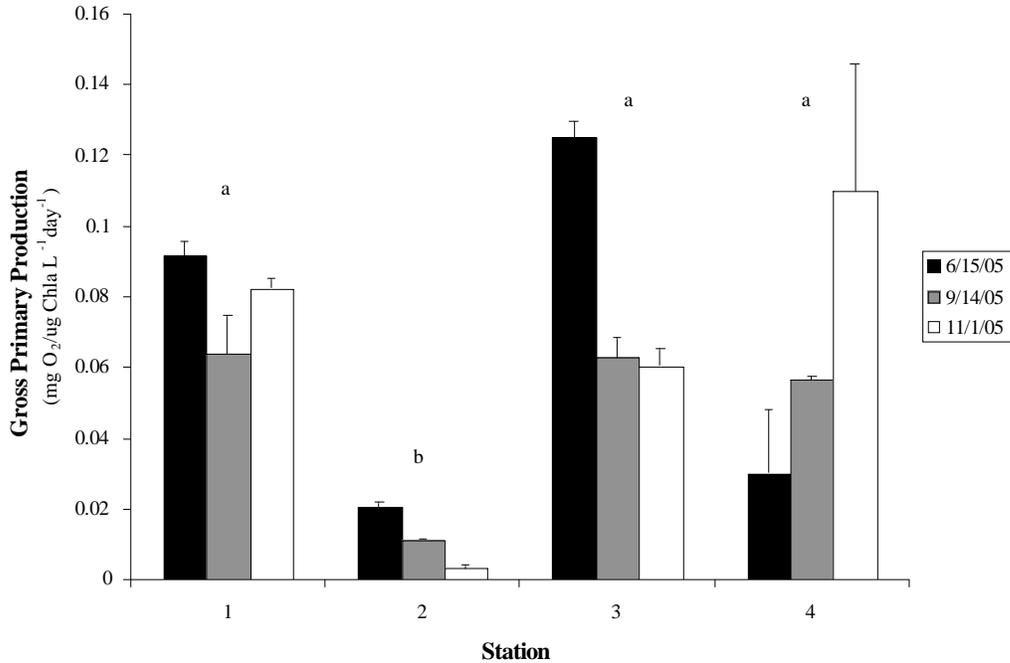


Figure 2-18. Average gross primary production (mg O₂/μg chl *a*) ± SD at sampling stations (1 - 4) for each sampling date between 6/15/05 – 11/1/05 (n = 3) and results of an ANCOVA with Tukey’s multiple comparisons test. Different letters above groups indicate significant differences (p ≤ 0.05).

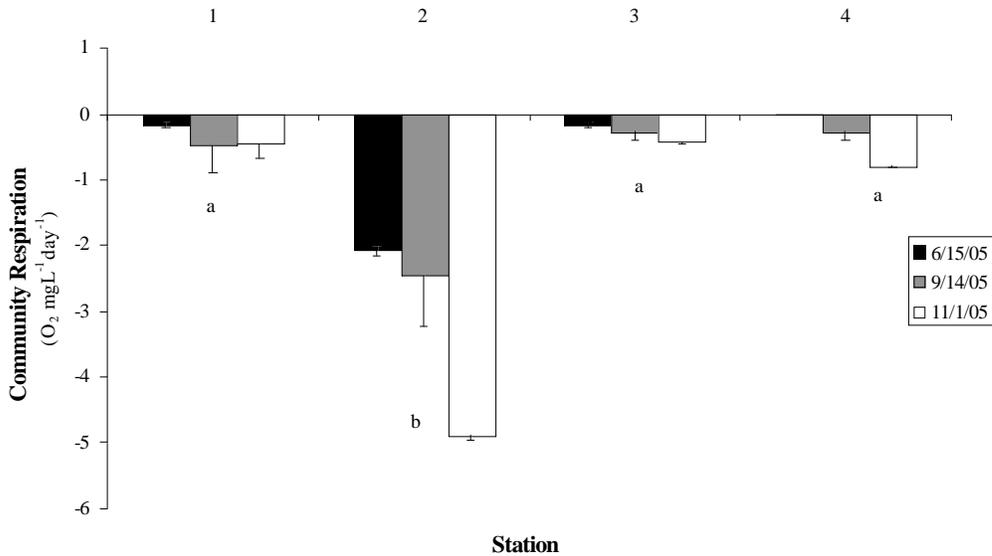


Figure 2-19. Average community respiration (O₂ mg/L) ± SD at sampling stations (1, 2, 3, 4) for each sampling date between 6/15/05 – 11/1/05 (n = 3) and results of an ANCOVA with Tukey’s multiple comparisons test. Different letters above groups indicate significant differences (p ≤ 0.05).

3 Benthos

Prepared by Dr. John Oliver, James Oakden, and Kamille Hammerstrom

3.1 Introduction

Moss Landing Power Plant has had a thermal discharge at the head of Monterey Canyon since the 1960's (Figs. 1-1 and 3-1). The warm water plume is generally 2-4° C above ambient surface water temperatures, with a maximum of 7°C above ambient at the hottest spot. The highest rise recorded at the intertidal beach has been 2°C above ambient, directly inshore from the outfall (Tenera 2000a,b). Most of the past work around the thermal discharge has been to characterize the thermal structure of the plume (Tenera 2000a,b). At high tide, the warm water from the outfall plume is a distinct feature that can be detected from the air. There are also distinct pockets of warm water in the south and north sections of Moss Landing Harbor. At low tide, these warm surface-water features are highly obscured by the extensive outflow of water from Elkhorn Slough into Monterey Bay. The outfall is adjacent to the main tidal flow from the slough. The thermal plume is a small feature compared to the turbid plume from Elkhorn Slough, which often extends over a kilometer into the bay at low tides. Both the outfall and slough plumes are present all year long. There are also net up-canyon currents that pulse deeper, colder water into the same shallow region as the thermal discharge (Breaker and Broenkow 1994). Within one day, the temperature around the canyon head, including the adjacent sand flats, can plummet from 15 to 9°C from the surface to the sea floor in over 10 m of water. Larger scale currents sweep through the entire bay episodically during the year (Breaker and Broenkow 1994).

Longshore water currents commonly flow towards Moss Landing both from the north and more strongly from the south, especially during storms and high winds (Arnal et al. 1973). Every winter the muddy, relatively warm-water runoff from the Salinas River and other watersheds covers the near shore region around Moss Landing. This giant turbid plume spreads offshore and alongshore into the northern coast of Santa Cruz towards San Francisco. Therefore, Moss Landing is a region of dynamic natural water flow, modified by the tremendous tidal flow in and out of Elkhorn Slough through the man-made entrance channel for Moss Landing Harbor. The thermal plume is subjected to mixing events tidally, seasonally, and episodically throughout the year (Tenera 2000 a,b). This is only a brief summary of the dynamic, extensive mixing processes around the head of Monterey Canyon. There are many more observations, particularly from investigators at MBARI and NPGS (See Section 2). However, this summary is adequate to set the physical stage for interpreting the ecological data from the benthos.

The intertidal beach is exposed to air temperature at low tides. On the high beach, organic debris or wrack (mostly drifting macroalgae and eel and sea grass) accumulates and harbors a unique community of beach hoppers (talitrid amphipods), insects, and worms (oligochaetes, nematodes, and insect larvae). These patches can become very warm from decay and elevated air temperatures. They are usually above the water line, and therefore they were not the focus of our benthic sampling. Our sampling began just below the wrack zone where the beach isopod, *Excirolana*, is the most abundant animal. However, the intertidal beach harbors

a group of animals subjected to more extreme temperature fluctuations (warm and cold) than those in seawater. Stress from exposure to extreme air temperatures obviously increases with higher elevation on the beach.

Moss Landing is located in the center of a coastal upwelling system, extending from Point Conception in the south to just beyond Cape Mendocino in the north (Huyer 1983). This biogeographic region has a benthic diversity hotspot along the shelf edge (at 100-200 m depth), containing the highest density of macrofaunal invertebrate species discovered so far on the planet (Oliver et al. in prep.). The high diversity is probably fueled by high primary production caused by upwelling; strong bottom currents at the shelf-slope boundary; and mixing of southern and northern species in the California current system. Just inshore of the diversity center there is a fine sediment sink from 60-100 m depth. The inner shelf (< 40 m) is heavily impacted by wave disturbance (Oliver et al. 1980). Monterey Bay is a semi-protected coastal environment with smaller waves compared to the open coast. In addition, wave disturbance increases from California to Washington, where the inner shelf ecosystem (wave-disturbed) extends to the shelf edge and there is no fine sediment sink or diversity center along the outer shelf (Lie and Kisker 1970, Oliver et al. 1980). The present study was conducted along the wave-exposed inner shelf around Moss Landing (Figure 1).

Moss Landing beach is in the center of Monterey Bay at the head of Monterey Canyon (Figure 1). The canyon head is flanked by extensive, gently sloping sand flats. Wave energy is refracted away from the canyon head and intensified along the sandflats (Oliver et al. 1980). Since waves usually arrive from the northwest, the northern sandflat has larger waves than the sandflat south of the canyon (Arnal et al. 1973, Oliver et al. 1980). Longshore currents often move towards the canyon, dumping sediment and organic debris into the canyon axis, which is flushed each year by winter storms (Oliver and Slattery 1976, Okey 1993, 1997). The thermal discharge is located along the shallow, sandy canyon wall (in about 16 m of water) between the northern and middle branches of the canyon head. The southern branch is directly off the old pier site, the middle branch is off the Monterey Bay Aquarium Research Institute (MBARI), and the northern branch is off the harbor mouth (Shepard 1948, Okey 1997). There is also a relatively flat, shallow bench (< 20 m) between the southern and middle branch of the canyon head. Although the warm water plume covers a portion of the canyon axis and deeper walls (> 20 m), potential impacts should be highest in the intertidal and shallow subtidal beach because the warm water concentrates near the sea surface.

3.2 Objectives

The following objectives were addressed in the benthic portion of this study:

- 1) Determine whether the thermal outfall is having a measurable impact on the sand beach and shallow subtidal communities in the outfall vicinity.
- 2) Determine whether significant changes in the beach community at Moss Landing have occurred since it was last sampled in 1975-76.

- 3) Characterize the previously-unsampled shallow subtidal community in the outfall vicinity and nearby areas.
- 4) Compile a historic database of previous benthic work that has been performed on the Moss Landing beach and nearby areas.

3.3 Background

3.3.1 Intertidal Ecological Background

Wave-exposed sandy beaches are often classified by morphodynamics along gradients of wave disturbance and sediment availability from dissipative to reflective (Short and Wright 1983, McLachlan 1990, Defeo and McLachlan 2005). Reflective beaches are narrow and steep with coarse sediment, and swept by smaller waves. They generally harbor invertebrate communities with lower diversity, abundance, and biomass. Dissipative beaches have the opposite characteristics (Defeo and McLachlan 2005). Many of these patterns depend on large-scale geographic comparisons from tropical to temperate latitudes, but also morphodynamic variations among beaches. There are also mesoscale patterns that occur within a single uninterrupted beach. Zonation of the fauna across the shore is well known (Ricketts and Calvin 1985, McLachlan and Jaramillo 1995), but there are significant variations at several spatial scales along shore, including animal responses to swash circulation in cusps and bays at a finer level to impacts from river outflows and differences between the central beach and the ends (McArdle and McLachlan 1992, Degraer et al. 2003, Defeo and McLachlan 2005).

Some submarine canyons cut through the continental shelf and head at sandy beaches with dramatic impacts on along shore wave energy and sediment availability. Wave energy is refracted away from the canyon head and intensified along the adjacent sand flats; beach sand is captured and transported into deeper water at the canyon head (Bascom 1964, Shepard and Dill 1966). Moss Landing Beach is in the center of Monterey Bay at the head of Monterey Canyon (Fig. 1-1), where waves are always smaller than they are along the extensive, gently sloping sand flats to the north and south (Arnal et al. 1973, Oliver et al. 1980). Beach sand is transported towards the canyon from the north and south, and into the north and south branches of the deeper canyon head (Arnal et al. 1973). The beaches at the head of the canyon receive little transported sand. They are narrow and steep, while the beaches directly adjacent to the north and south canyon rims are sand transport corridors and are broader and flatter. The exposed sandy beaches in Monterey Bay are intermediate between the reflective and dissipative beaches. However, the canyon morphology creates a distinct, persistent wave-disturbance and sediment availability gradient from more dissipative outside to more reflective beaches within the canyon head.

The Moss Landing Beach fauna is similar to sandy beach fauna throughout central California (Ricketts and Calvin 1985), and in many other parts of the world (Brown and McLachlan 1990, Peterson 1991, McLachlan and Jaramillo 1995, Dugan et al. 1999). Throughout California, there is distinct faunal zonation with tidal elevation on the beaches (Dahl 1952, Ricketts and Calvin 1985), large seasonal pulses of animal recruitment (Barnes and Wenner 1968), and considerable geographic variation from beach to beach (Dugan et al. 1999). In

general, relatively little is known about longer-term decadal variations in beach communities (but see Arntz et al. 1997, Lima et al. 2000, Defoe 2003), although these fluctuations are profound in other marine ecosystems (e.g., Dayton 1989, Roemmich and McGowan 1995, Tegner and Dayton 1996, McGowan et al. 1998, Francis et al. 1998, Chavez et al. 2003, Ainley et al. 2005). Just 25 km south of the sandy beach at Moss Landing, the rocky intertidal community at Hopkins Marine Station changed significantly since the early 1930's. In particular, there was an increase in the abundances of species ranging more to the south, and a decrease in those ranging to the north as sea surface temperatures increased (Barry et al. 1995, Sagarin et al. 1999).

This study was designed specifically to detect potential impacts of the thermal plume on the sand beach community. This was done by comparing beach species composition along four transects at increasing distances from where the thermal plume could impinge on the intertidal zone. The study design also allows the examination of several subsidiary ecological questions. This study presents a unique opportunity to explore how the sandy beach community changed since the 1970's because of a historical quantitative survey of the fauna on Moss Landing Beach (Nybakken et al. 1977). The four sites sampled for this plume study, including the historical one, are along the wave-disturbance and sediment availability gradient on the south side of Monterey Canyon (Fig. 1-1). Therefore, another study objective is to explore how sandy beach communities are structured along a canyon-head exposure gradient.

3.3.2 Shallow Subtidal Ecological Background

Intertidal sandy beaches harbor a distinct invertebrate macrofauna that often live in well-defined zones (Dahl 1952, Ricketts and Calvin 1985, Brown and McLachlan 1990, Peterson 1991, McLachlan and Jaramillo 1995). In central California, three zones are generally recognized: the supralittoral zone above the wrack line where air breathing talitrid amphipods and insects are common; the midlittoral zone characterized by cirrolanid isopods; and the sublittoral fringe with mole crabs, mysids, amphipods, polychaetes, and other marine invertebrates (Ricketts and Calvin 1985). Unlike the intertidal beach, only a few studies document the structure of benthic communities through the subtidal surf zone, especially along high-energy beaches; and these investigations were primarily done in South Africa (Field 1971, Christie 1976, McLachlan et al. 1984). McLachlan et al. (1984) provide the most comprehensive zonation scheme for this wave-controlled environment, both for intertidal and subtidal habitats. They define an inner turbulent zone including the intertidal sublittoral fringe that extends to the outer edge of the breaker zone in 2-4 m; a transition zone from here to 5-12 m around the outer limit of surf circulation cells; and an outer turbulent zone that extends into 20-40 m of water. These zones also have distinct faunal patterns (McLachlan et al. 1984). Coincidentally, the deeper limit of their outer turbulent zone (20-40 m) corresponds to the transition between the shallow crustacean and deeper polychaete zone in Monterey Bay (Oliver et al. 1980).

There are no comparable benthic studies through the subtidal surf zone in the Pacific Ocean. Just seaward of the surf zone on many high-energy beaches along the California coast, sand dollars form dense beds that move seaward with winter waves and shoreward again during

the calmer months of summer and fall (Oliver et al. 1980, Morin et al. 1985). In contrast to the subtidal surf zone, there have been a number of ecological studies of sand dollar beds (Fager 1964, Merrill and Hobson 1970, Kastendiek 1982, Cameron and Rumrill 1982, Morin et al. 1985) and the nearby, offshore sandy bottoms in the outer turbulent zone (Barnard and Zieshenne 1961, Barnard 1963, Fager 1968, Hodgson and Nybakken 1973, Davis and VanBlaricom 1978, VanBlaricom 1982, Oliver et al. 1980, 1982, in preparation, Hulberg and Oliver 1980, Slattey 1985). There are also many studies of intertidal sandy beaches in California (Nybakken et al. 1977, Ricketts and Calvin 1985, Dugan et al. 1999, 2004).

Because no studies are available for comparison, detection of possible thermal plume effects will rely on detection of changes in community structure and species composition along transects at increasing distances from the plume, and an examination of the communities nearest the outfall for signs of warm-water species. An examination of data from nearby deeper water areas and a discussion of regional climatic trends are necessary to put the results of this study into a broader ecological perspective.

3.4 Methods

3.4.1 Intertidal Methods

A quandary presented itself in trying to determine the sampling design. It was not possible logistically to collect more than about 70 samples over two days in the short sampling windows allowed by the tides, even with large field crews (our crews ranged from 9-18 people per day). When determining how to allocate these samples, we were driven by two opposing desires. In order to get an idea of within-elevation variability, and particularly to be able to locate rare species that might only be found at a particular tidal height, it was necessary to take more replicates at a fewer number of stations. On the other hand, in order to get a more complete representation of the zonation, and to have data comparable to the historical study, it was necessary to have fewer replicates at more stations.

We solved this dilemma by using two different sampling designs over the course of the study to maximize the information gained. During the first two years of the study, at each of the four locations, 6 replicates were taken at four stations corresponding to the high, mid, low, and lowest intertidal (stations A, B, C, and D). During the last year of the study, we collected 3 replicates at a larger number of stations spaced at regular (5 m or 10 m) intervals down the beach. Different transects had different numbers of samples because of variations in the width of the beach and the degree of the low tide.

Four sites were chosen to give a representative picture of the beach and nearshore subtidal (Figs. 1-1 and 3-1). These sites are located at increasing distances from the Moss Landing Power Plant thermal discharge at the canyon head. They also fall along a wave exposure gradient caused by the bathymetry of Monterey Canyon and the direction of wave arrival, and thus represent the beach conditions around the head of a submarine canyon. The 4 locations and their reference points are (from north to south):

Outfall (OF): transect starts at the final fencepost on the north side of the public access walkway by Phil's Fish Market, with a bearing directly west towards the powerplant outfall

plume and inside the canyon head. This spot is the closest point on the beach to the outfall, and presumably would be where any outfall effects would be seen if present.

MBARI (MB): starts on the edge of the sidewalk directly under the MBARI seminar room and bears due west, inside the canyon head.

Shore Lab (SL): starts at the fencepost at the south end of the former Moss Landing Lab property and bears due west, on the south rim of the canyon head within the beach transport corridor but protected from the prevailing northwest ocean swell by the canyon bathymetry. This is the same location used in Oakden and Nybakken (1976).

Potrero Rd. (PR): starts at the Hazardous Surf Warning sign near the Potrero State Beach parking lot, and bears west towards the closest surf line, outside the canyon's impact on local wave climate and representative of the sandy beaches throughout central Monterey Bay.

For each site, a permanent reference point was surveyed near the sand dunes using an RTK GPS system, which gives both horizontal and vertical accuracy to a few centimeters. Sampling dates were determined by good (minus) low tides, which severely limited the months that could be sampled. During the first two years (Surveys 1-6), 6 replicate samples were taken at four stations along an elevational gradient across the beach (stations A, B, C, and D) at each of the four sites (OR, MB, SL, PR). The highest station (A) was below the strand line in the mid-littoral zone, where cirrolanid isopods are common. Station B was at the interface between the mid-littoral and the top of the sublittoral fringe, where stations C and D were located. D was closest to the water in each survey. We did not survey the supralittoral zone, which is above the high tide and includes the strand zone, because this region was not sampled well in the 1970's survey; there is little potential for impacts from the thermal discharge; and this zone is unlikely to respond to decadal variations in oceanographic climate. During the last year (Surveys 7-8), we modified the sampling to allow more detailed comparisons with the 1970's survey (Nybakken et al. 1977). We collected 3 replicate samples at a larger number of stations spaced at regular (5 m or 10 m) intervals down the beach. Different sites had different numbers of samples because of site variations in beach width and tide level at sampling.

At the beginning of each sampling session, a theodolite was set up at the reference point and used to measure relative elevations of the 4 stations during the first portion of the study. During the third year of the study, a meter tape was used to position the stations at 5 m or 10 m intervals along each transect, and elevations were taken at each station using the theodolite. The station intervals were determined by the width of the beach, with steeper beaches having stations closer together. A core of the top 5 cm of sand was taken for grain-size analysis at each station. Replicate faunal samples from each station were taken at random within 10 m on either side of the station marker. Each sample was a 0.25 m² quadrat excavated to a depth of 10 cm. Samples were sieved on the beach, using 1 mm (Shore Lab) or 1.5 mm (other 3 stations) nylon-mesh sieves, then placed in Ziplock bags. The smaller sieve size was used for consistency with the 1976 study. Samples were preserved in buffered formalin, and transferred to isopropyl alcohol for sorting. Animals were separated from the sand in the preserved samples using an elutriation technique, followed by a quality assurance

examination of the residue. All animals were identified to the lowest possible taxon, generally species. Grain-size distribution was measured using a Beckman-Coulter LS 13 320 laser particle size analyzer.

Data were square-root transformed to meet assumptions of normality and variance homogeneity. For the first 6 surveys, a three-way analysis of variance (ANOVA) was conducted testing the main effects of survey time, site, and elevation (A, B, C, D), as well as all main effects interaction terms, on the total number of crustaceans, polychaetes, *Emerita analoga*, selected crustaceans (no *Emerita* included) and selected crustaceans and stations (no *Emerita* and no Shore Lab data included). Additional one-way ANOVAs examined the effect of site on elevation for each survey time. Tukey's studentized range test was utilized to test all pair-wise comparisons among sites. All analyses were performed in SAS v.9.1 (SAS Institute 2003).

In order to obtain estimates of the numbers of two large, rare species, the Pismo clam (*Tivella stultorum*) and the spiny sand crab (*Blepharipoda occidentalis*), we used a wheeled sieve cart that was 0.5 m high with a screen surface of 0.75 m², equipped with a nylon mesh with 2.5 mm square openings. This mesh size allowed most of the sand to move through the sieve rapidly while retaining larger animals. Samples were collected in the lowest tidal elevation (D) from 0.5 m² to 20 cm depth and placed in the cart, which was rolled into the water to wash the sand away. The screen was then examined, and the individuals rapidly counted and other observations recorded such as gravid females and clam size. Cart samples were collected on 4 June 2004 (2 at OF, 4 at MB, and 15 at SL); on 25 May 2005 (17 at SL); and on 27 May 2005 (15 at PR). The Shore Lab and Potrero sites were primary site targets because of a long history of Pismo clam collection here before the sea otters arrived (Stephenson 1977).

3.4.2 Subtidal Methods

Four sampling sites were established on the wave-exposed, sandy beach around the head of Monterey Canyon (Figs. 1-1, 3-1). They were located along a gradient away from the warm water discharge of the Moss Landing Power Plant, which is also a natural environmental gradient related to canyon bathymetry and wave disturbance (Arnal et al. 1973). Three water depths (1, 2, 4 m) were sampled at each site in the shallow subtidal zone where waves break. Historical sampling was done in the deeper subtidal environment (6 m to >20 m) directly offshore of the Shore Lab (Oliver et al. 1977, 1980), Potrero Road sites (Oliver et al. 1980, Oliver et al. in preparation), and also in the intertidal zone at the Shore Lab site (Nybakken et al. 1977). The new stations were positioned to fill in the sampling gap between the intertidal and shallow subtidal beach (6 m). Each water depth (1, 2, 4 m) was sampled at all four sites during the summer or early fall for three years (5, 30 June 2003; 5, 14 October 2004; 20, 21 October 2005). The summer and early fall were selected because this is a period of high abundance, species density, and biomass, with relatively low seasonal fluctuations from recruitment, which are greatest in the spring (Oliver et al. 1980). In addition, this is a period of lower wave action, which is critical for gaining sampling access to the surf zone. Even so, we were unable to sample from the two shallowest depths at Potrero Road in 2005 because of high wave action limiting boat operations and scuba diving. Our boat was swamped by a

large wave set, leading to the loss of the sediment sample from the 4 m station here. At each sampling period, scuba divers qualitatively surveyed the depth transect and deeper water to search for larger benthic animals such as crabs, sand dollars, and patches of gastropods (*Olivella* spp.).

Six replicate diver-held cores (area= 180 cm², 15 cm deep) were taken at each depth and time, and were washed over a 0.5 mm screen. Invertebrates were sorted from the screen residues; identified to the lowest possible taxon; and the number of individuals per taxon recorded with qualitative observations of size and reproductive condition. Surface sediments (top 2 cm) were also collected for measuring grain size distribution.

Patterns in species composition and relative abundance were displayed using a cluster analysis from PRIMER v.5 (Clarke and Gorley 2001). In addition, data were square-root transformed to meet assumptions of normality and variance homogeneity, and a three-way analysis of variance (ANOVA) was conducted testing the main effects of survey time, site, and depth, as well as all main effects interaction terms, on the total number of crustaceans, polychaetes and molluscs. Additional one-way ANOVAs examined the effect of site on depth for each survey time. Tukey's studentized range test was utilized to test all pair-wise comparisons among sites. These analyses were performed in SAS v.9.1 (SAS Institute 2003).

3.5 Results

3.5.1 Intertidal Results

Surveys 1-6

The number of individuals of macrofaunal invertebrates fluctuated by more than ten times among the sites at the highest elevation (A) and by more than 5 times at the lowest (D) (Fig. 3-2). The crustaceans dominated the variation, with polychaetes producing three significant peaks. The fluctuations among the crustaceans were caused by the sand crab *Emerita* at the three lower elevations (B-D) and by the isopod *Excirolana* at the highest elevation (Fig. 3-3). These were the two most abundant macrofauna on the beach (Table 3-1). As a result, the total number of crustaceans largely reflected the abundances of these two species, particularly *Emerita* because *Excirolana* was only abundant at A stations (Figs. 3-2 and 3-3). Since *Emerita* was abundant at all sites and at all beach elevations (Table 3-2 and Fig. 3-3), its dominance obscured site and elevation patterns that were present for the polychaetes as a group and for most of the other numerically dominant animals (Figs. 3-2 and 3-3).

Excirolana was the only numerical dominant that was most abundant at the highest elevation (station A) at each site (Fig. 3-3). It was frequently encountered at the next highest elevation as well (station B), but was not nearly as abundant here (Table 3-2, Fig. 3-3). *Excirolana* and the other numerically dominant crustaceans were most abundant at the Shore Lab site, where we collected the fauna with a 1 mm screen in contrast to a 1.5 mm screen used at the other three sites (Fig. 3-3). While *Emerita* occurred at all tidal elevations and *Excirolana* primarily at the highest, the other three numerically dominant crustaceans were most abundant at the two lowest intertidal stations (Fig. 3-3, Table 3-2). The peaks in abundance of the crustacean species were often in the spring, but not limited to this season (Figs. 3-4 and 3-5, Table 3-1). Individuals were present throughout the year.

In contrast to the crustaceans, the polychaetes generally increased in abundance from the Potrero site to the Outfall site (Fig. 3-2). They were also more abundant and frequently encountered at the lower intertidal stations (C and D) (Figs. 3-2 and 3-6, Table 3-2). Every major abundance peak in the numerically dominant polychaetes occurred at one sampling time and at one site (Fig. 3-6). The polychaetes were thus more restricted in their temporal occurrence compared to the crustaceans (Table 3-1). At these peaks (Fig. 3-6), individuals were spread throughout the replicate samples with the exception of the peak in *Nephtys* (MBARI site), which was 21 animals in on quadrat, and the secondary peak in *Saccocirrus* (MBARI site), 62 animals in one quadrat. Despite the smaller screen size used at the Shore Lab site, only one polychaete species was most abundant here, *Archiannelid* sp. B (Fig. 3-6).

There was a general increase in species from the high to the low intertidal beach at the Outfall and Shore Lab sites, but the trend was less distinct at Potrero, and not present at MBARI (Fig. 3-7).

Unlike the number of species, there were highly significant variations in the number of individuals on the beach (Figs. 3-2 and 3-7). We examined the variation in individuals using ANOVAs (Tables 3-3 and 3-4) for crustaceans, polychaetes, the most abundant animal, *Emerita*, and the other four numerically dominant crustaceans, excluding *Emerita* (*Excirolana*, *Archaeomysis*, *Americelidium*, *Mandibulophoxus*). These four crustaceans had similar patterns of abundance among the four sites, which were different from the pattern in *Emerita* (Figs. 3-4 and 3-5). Since these four species were also most abundant at the Shore Lab site, where we used a finer sampling screen throughout the study (1 mm compared to 1.5 mm at the other three sites), we also tested for site differences among only the three sites, excluding the Shore Lab (labeled selected crustacean and site in Tables 3-3 and 3-4). The three-way ANOVA showed significant variation by site, time of survey, and tidal elevation. However, all interaction terms were also highly significant (Table 3-3: the last 4 rows). Therefore, we used one-way ANOVAs to test for differences among the four sites at each time and tidal elevation (A-D). We sampled at all elevations, except D, at all six time periods.

Table 3-4 shows the number of significant ANOVAs for each metric by tidal elevation. The number of significant analyses decreased from total crustaceans, *Emerita*, the other four numerically dominant crustaceans, to the polychaetes. There was a similar pattern in the number of significant analyses when the Shore Lab site was excluded from the four-crustacean metric (compare selected crustaceans to selected crustaceans and site in Table 3-4). We did pair-wise tests on each significant ANOVA to see which sites were significantly different from each other. There was no trend for greater significance at the Outfall site, or one of the other three sites. However, there was a trend towards significant differences in pair-wise tests where there were peaks in abundance. For example, for the 23 ANOVA's done on total crustaceans (Table 3-4), 18 were significant. The Shore Lab was significantly different from all the other sites in seven tests: six times it had the highest number of crustaceans, probably because of the large number of *Excirolana* here (Figs. 3-2 and 3-3). The Outfall site was significantly different from all other sites five times: four times it was the lowest, apparently because of the low numbers of *Excirolana* and *Emerita* at the highest

elevation (station A)(Figs. 3-2 and 3-3). The MBARI and Potrero sites were each significantly different from all the other sites in three tests. They had the highest abundance in five of these six tests. The distribution of significant tests among the sites for total crustaceans was similar to that for *Emerita* and the four other numerical dominants. In contrast to the crustaceans, only 10 of the 23 tests were significant for the polychaetes (Table 3-4). Here the link to abundance peaks is easiest to show. The Outfall site was significantly different from all the other sites in six tests (always highest). The MBARI and Shore Lab sites were both significantly different from all the other sites in one test (highest), and the Potrero site in none. Each significant test for polychaetes corresponded to the peak abundances and times shown in Fig. 3-6. We only present the patterns in pair-wise tests when a site was significantly different from all of the other sites in the test. There are other combinations such as one site being different from only one or two of the others and so on. However, our primary purpose here is to show that the frequency of occurrence of significance in the pair-wise tests was highest at the Shore Lab and Outfall sites, where there were generally the greatest lows and especially peaks in abundance (Fig. 2-6).

Grain size shows a general gradient from the Outfall to the Potrero site (Table 3-4). The Outfall had the least fine-grained sand and the most coarse-grained sand. MBARI was similar. The Shore Lab and Potrero sites had more fine sand and less coarse. These patterns persisted along the entire elevation gradient from A-D among the sites. Within each site, there was a weaker trend for decreasing coarse sand from the high (A) to lower beach (D). The Shore Lab had the finest deposit among the four sites with the highest percentage of fine sand at every elevation, the highest silt fraction at 3 elevations, and the lowest quantity of coarse sand at 3 of the 4 elevations (Table 3-4). The Shore Lab and Potrero beaches were twice as wide as the Outfall and MBARI beaches, which were the steepest (Fig. 3-8: note the horizontal scale changes). March and April usually had the lowest beach profile after the winter storms.

Sieve Cart Samples

We found two immature Pismo clams at the Shore Lab in the 2004 cart samples (shell lengths: 63 and 69 mm). We collected seven invertebrate species at the Shore Lab. The olive snail *Olivella biplicata* was present in all 15 samples (mean= 5, range 1-18/sample). We collected one spiny mole crab *Blepharipoda occidentalis* in two samples. Only *Emerita* and *Nephtys californiensis* were collected at the MBARI and Outfall sites. These species were frequently collected at all sites, but were not the focus of the cart sampling. The pattern was similar at the Shore Lab in 2005, when we collected one Pismo clam (29 mm); *Olivella* in 10 of 17 samples (mean=1, range 1-3); and *Blepharipoda* in 7 of 17 samples (range 1-3). We found one Pismo clam (56 mm) and *Blepharipoda* at Potrero in 2005; and *Olivella* in 5 of 15 samples (range 1-7).

1975-76 vs 2003-05

For the comparison with the 1975-76 samples, we used the data collected in all the surveys (1-8) from 2003-05. The 1970's data are from Oakden and Nybakken (1977), and were taxonomically updated for comparison with the 2003-05 community data. A primary objective in sampling at the three additional sites in 2003-04 was to increase the mesoscale sampling along the beach to help evaluate differences between the decadal samples. Using

the entire data sets for both decades, all the species shown in Table 3-6 are significantly different between the decades in t-tests and Wilcoxon rank sum tests ($p < 0.05$), with the exception of *Excirolana* and *Nephtys*. There are also no significant differences among the decades for the total number of species, total individuals, and crustacean and polychaete individuals (Table 3-6).

Table 3-6 also shows data from only the Shore Lab site in 2003-05, which is the same beach site sampled in the 1970's. The entire data set from 2003-05 gives a better view of the community patterns along the larger beach for comparing with the 1970's. For example, *Excirolana* was most abundant at the Shore Lab site in 2003-05 (Fig. 3-3), so *Excirolana* differences between the decades are highly significant comparing just the Shore Lab sites between decades ($p < 0.0001$). However, they are not different when the others sites along the beach are considered in 2003-05 (Table 3-6). *Archaeomysis* and *Mandibulophoxus* also had abundance peaks at the Shore Lab (Fig. 3-3), so when only the Shore Lab sites are compared they are not significantly different ($p < 0.05$) between the decades, reversing the pattern when the entire 2003-05 data set is used (Table 3-6). In 2003-05, there were also highly significant variations in time and along shore in the abundances of polychaete worms (Fig. 3-6). The polychaete differences between the decades fall within the variation along the beach in 2003-05. Therefore, for these three numerically dominant crustacean species and the polychaetes, there is no compelling evidence that there were significant differences in abundance between the decades, when the site variations along the beach in 2003-05 are considered.

On the other hand, *Emerita* was abundant at all sites in 2003-05, so along shore patterns support the conclusion that there are significant differences between the decades for *Emerita* (Table 3-6). This is also true for *Grandifoxus*, *Americhelidium*, and nemertean worms (Table 3-6). In the 1970's, 103 *Grandifoxus* were captured. Only 22 were captured in 2003-05 with five times the sampling effort (equivalent to 4 instead of 103 individuals if the sampling area is adjusted to the 116 samples in 1975-76). There were no *Americhelidium* in the 1970's samples, and 353 in 2003-05 (71 adjusted to 116 samples in 1975-76). The changes in frequency of occurrence generally coincided with abundance. *Grandifoxus* decreased from 34 to 3%; and the nemerteans from 43 to 9%; while *Emerita* occurred in almost twice as many samples as it became more abundant (Table 3-6).

The species composition changed little between the two decades. There were no warm water species extending their range into the Monterey Bay. With one exception, the species that were not common to each sampling effort live in deeper water. Only a few individuals of each species were in the beach samples. Therefore, the differences in species composition between the decades can be explained by chance capture of relatively rare animals. The exception was *Archiannelida* B, which is a beach animal and was abundant in 2003-05, but not found in the 1970's.

3.5.2 Subtidal Results

Cluster analysis is effective at grouping samples with similar species composition and relative abundance patterns based on Bray-Curtis similarity coefficients, and graphically

displaying the patterns. However, the cluster analysis showed no patterns in species assemblages grouping by depth, site, or year of sampling (Fig. 3-9). The sample from the Outfall site at 1 m in 2005 (2005OF1) clustered uniquely from all other samples, because of the very high abundance of a small phyllodocid polychaete worm, *Hesionura* sp., which had a mean abundance of 96 animals per core. Five of the remaining samples from the 1 m stations closest to the canyon head clustered together (OF, MB, and SL), but three others did not, in addition to the unique sample from OF-1 m in 2005. That's only five out of nine 1 m samples in a distinct cluster, and one other sample in this 1 m dominant cluster was from a 2 m depth (2005OF2). The two samples from 1 m at Potrero Road also did not cluster with the larger group of 1 m stations (Fig. 3-9). In general, the sites, depths, and years were mixed together, indicating significant spatial and temporal variation in species composition and relative abundance as they define assemblages.

There were also significant variations in the numbers of individuals. Figure 3-10 combines the three annual samples and shows fluctuations in number of individuals at each water depth and site. The total fauna is compared to the abundance of crustaceans and to the most abundant genus of crustacean, the oedicerodid amphipods, *Americhelidium* spp. (Fig. 3-10). The error bars partially reflect large temporal variations at some depths and sites. Nevertheless, much of the general pattern in the total fauna was present in just the crustaceans; and much of the crustacean pattern was reflected in the abundance of the numerically dominant genus, *Americhelidium*. When the two species of *Americhelidium* were combined, they were more than twice as abundant as the next numerical dominant ranked for the entire data set (Table 3-7: overall). The abundance of polychaetes generally increased around the canyon head, but this pattern largely reflected the high abundance of *Hesionura* at the Outfall site (Fig. 3-11). Mollusca showed the opposite pattern, primarily because of *Olivella* increasing at Potrero Road (Fig. 3-11, Table 3-7).

The sample variation was reduced when the data were presented separately for each year (Figs. 3-12 and 3-13). The most abundant taxa accounting for significant peaks in the data were listed near the respective abundance peaks with the mean abundance shown in parentheses. The largest peak in abundance was caused by *Hesionura* at the 1 m Outfall station. The mean abundance of *Hesionura* (96/core) here was twice as much as the next most abundant taxa accounting for a large peak in the data: the phoxocephalid amphipod crustacean, *Mandibulophoxus* (46/core). With the exception of *Hesionura* and the olive snail, *Olivella biplicata*, crustaceans caused the major peaks in abundance: primarily the amphipods, *Americhelidium* spp. and *Mandibulophoxus*, but also in one case the cumacean, *Cyclaspis* sp. (Figs. 3-12 and 3-13). The six species accounting for the highest peaks in abundance were also the numerical dominants for the entire data set (Tables 3-7 and 3-8).

There were distinct changes in abundance with water depth among the numerical dominants. *Americhelidium micropleon* was most abundant at 1 m, and *A. shoemakeri* was more abundant at 2 and 4 m (Fig. 3-14). Along with *A. micropleon*, *Hesionura* was the only other numerical dominant that was clearly most abundant at the 1 m depth. However, nemertean worms were most abundant at the two shallowest depths (Table 3-7). *Mandibulophoxus* and *Olivella* increased in abundance with increasing water depth, similar to *A. shoemakeri* (Table 3-7). All the common polychaete worms, excluding *Hesionura*, increased with water depth,

including *Apoprionospio pygmaea*, *Nephtys caecoides*, *Armandia brevis*, *Scoloplos armiger*, and *Dispio uncinata*, although none were abundant (Table 3-7).

Several animals known primarily from the intertidal beach occurred in the subtidal surf zone. Only 7 individuals of the sand crab, *Emerita analoga*, were found at the 1 m stations, one animal occurred at 2 m, and none at 4 m. Nine individuals of the intertidal beach polychaete, *Nephtys californiensis*, occurred in the surf zone samples; compared with 120 *N. caecoides*, the deeper water species. We captured two of the beach mysids, *Archaeomysis graebnitski*, in addition to *Metamysidopsis elongata*, *Holmesmysis sculpta*, and *H. costata*, which were not encountered on the intertidal beach or the deeper subtidal sandflat (Oliver et al. 1980).

There were several distinct abundance patterns among the four sites. First, *Hesionura* only dominated at 1 m at the Outfall site in 2005 (Fig. 3-11 and 3-12). There were more polychaetes at all three canyon head stations compared to Potrero Road (Fig. 3-11). The total number of individuals was lowest at the Shore Lab site, particularly because of the low numbers of crustaceans (Fig. 3-10 and Table 3-7). And finally, *Mandibulophoxus* and *Olivella* were most abundant at Potrero Road (Table 3-7); and the total abundance of molluscs increased from the Outfall to Potrero Road (Fig. 3-11).

The relatively sparse nature of much of the fauna is illustrated by the number of times that no animals were collected at a station (i.e. water depth), where six replicate cores were collected each year (Table 3-8). The most frequent means were zero and one animal per core. The extreme variation was in *Hesionura*, where there was a mean of 96/core at 1 m at the Outfall in 2005; 3/core at the closest station at the same time (OF 2m); and only a few individuals at the next site (MBARI). At the spatial scale of single cores, the nemertean worms showed the greatest variation. In five single cores from three of the sites, there were more than 40 individuals/core. No other taxa showed this much variation among the six cores taken at a depth station. On the other hand, the *Americhelidium* spp., *Mandibulophoxus*, and nemerteans had the least number of stations with no animals present (Table 3-8).

We examined the variation in individuals using ANOVAs (Tables 3-9 and 3-10) for crustaceans, polychaetes, and molluscs. The three-way ANOVA showed significant variation by site, time of survey, and water depth. However, all interaction terms were also highly significant (Table 3-9: the last 4 rows). Therefore, we used one-way ANOVAs to test for differences among the four sites at each of the three times and water depths. Table 3-10 shows the number of significant ANOVAs for each metric for the three water depths. The number of significant analyses was greatest for the crustaceans, and was the same for the polychaetes and molluscs. We did pair-wise tests on each significant ANOVA to see which sites were significantly different from each other. There was no trend for greater significance at the Outfall site, or one of the other three sites. However, there was a trend towards significant differences in pair-wise tests where there were peaks in abundance. For example, when we consider cases where one site was significantly different from all of the other three sites, this occurred for the peaks at Potrero at 2 m and 4 m for June 2003; and at MBARI at 2 m for Oct 2004 and at 1 m for Oct 2005 (Fig. 3-13). For the polychaetes, several peaks are significant including the largest at the Outfall at 1 m in Oct 2005 (Fig. 3-12) and for the molluscs at Potrero 4 m (Fig. 3-11) in the first year.

The density of species showed a relatively consistent pattern of increasing with increasing water depth at all sites (Fig. 3-15 and 3-16). In addition, species number was lowest at 1 m and 2 m in 2005, but was not lowest at 4 m in 2005 (Fig. 3-16).

Qualitative observations by scuba divers revealed a bed of sand dollars (*Dendraster excentricus*) just offshore of the 4 m station at Potrero Road each year. The inshore edge of the bed was sparse (only a few animals/m²); and the first individuals were encountered about 20 m from the 4 m station. Only a few sand dollars were observed offshore from the Shore Lab site, and no distinct bed. None were observed at the two sites within the canyon head (OF, MB). On 5 June 2003, we observed a dense band of juvenile cancer crabs around the canyon head (OF, MB, SL) within the depth range of the sampling (2-4 m), but not in deeper water (6-8 m) or at any depth at Potrero Road. On 20 June 2003, we returned to the canyon head area and found no crabs in the surf zone, but many in the deeper canyon between 10-15 m. This was at the base of a steep sandy slope within the rim of the canyon where there was no wave swell. The juvenile crabs were mainly *Cancer magister* and some *C. gracilis*, with a carapace width of around 1 cm, but not greater than 2 cm. At the highest density, there were 50 to over 100 small crabs/m². We did not see any at Potrero Road or in October 2004 and 2005.

The grain size distributions were similar among sites and along the depth gradient (Fig. 3-17 and Table 3-11), with one obvious exception. The sample from 1 m at MBARI had a much larger percentage of sediment volume in the coarse sand fraction in 2004: 25% compared to less than 10% at all other stations (Table 3-11). This shows up clearly in the 2004 graph of the sample grain size (Fig. 3-17). The sediment at all the other stations was dominated by fine and medium sand, with almost no silt or clay (< 1%) at any station (Table 3-11). The percentages in fine and medium sand shifted in time and by site. The Outfall and MBARI 1 m stations had a consistently higher percentage of medium sand, with somewhat less at the 2 m stations. The Shore Lab site showed the greatest variation between the medium and fine sand fractions over time. By the 4 m depth, the percentage of fine sand was higher than medium sand at the three sites nearest to the canyon (OF, MB, SL). This pattern may be related to the canyon head topography and its impact on damping wave energy. In contrast, the most wave-exposed site at Potrero had similar percentages in fine and medium sand categories at all three depths (Table 3-11).

3.6 Discussion

3.6.1 Results of Study Objectives

- 1) The thermal plume had no detectable impact on the intertidal or shallow-subtidal benthos. See section 3.6.2: Discussion of Thermal Impacts
- 2) Significant changes in the intertidal beach community have occurred since it was last sampled in 1975-76. See section 3.6.3: Intertidal Ecology Discussion.
- 3) The shallow subtidal community was characterized. This is the first central California study to examine the shallow subtidal community. See section 3.6.4: Subtidal Ecology Discussion

- 4) A historical database of previous benthic work was compiled. See section 3.7.

3.6.2 Discussion of Thermal Impacts

In order to put the potential thermal impacts on the beach fauna in context, it is necessary to examine the temperature ranges to which the beach organisms are normally exposed, and compare that range to the maximum temperature increases that could be expected from the plume. The intertidal beach is exposed to air temperature at low tides that can range in central California from -2°C to 30°C . Stress from exposure to extreme air temperatures obviously increases with higher elevation on the beach. On the high beach, organic debris or wrack (mostly drifting macroalgae and eel and sea grass) accumulates and harbors a unique community of beach hoppers (talitrid amphipods), insects, and worms (oligochaetes, nematodes, and insect larvae). These patches can become very warm from decay and elevated air temperatures. They are usually above the water line, and therefore they were not the focus of our benthic sampling. The high intertidal animals have wider tolerances for a variety of physical parameters, including temperature and salinity, than the more strictly marine animals in the lower intertidal. Our sampling began just below the wrack zone where the beach isopod, *Excirolana*, is the most abundant animal.

The highest temperature increase caused by the warm-water discharge observed bathing the beach is 2°C (Tenera 2000). The seasonal sea surface temperature range in the offshore waters of Moss Landing is $9\text{-}17^{\circ}\text{C}$. Most of the animals that live on the beach have geographic ranges that extend into southern California, where the temperature range is broader. At the beach, we can add breaking waves to the other regional mixing processes. The presence of the warm-water plume at the beach is an infrequent event (Tenera 2000 a,b). We found no evidence of a biological response to a persistent or regular elevation of temperature on the beach from the outfall.

In the following section we consider a hypothetical worse case situation, where the warm-water plume is always at the beach and the water temperature is therefore consistently 2°C above the ambient temperature of the surrounding waters. A persistent 2°C change in temperature is unlikely to degrade the beach community, because all the beach species experience much greater temperature ranges under natural conditions throughout the year. In addition, dynamic local currents and nearshore mixing will limit drastic temperature increases. In this hypothetical case, the most likely impact of this persistent, slightly elevated local beach temperature would be a shift towards a higher frequency of warm-water species or a higher abundance of species that have distinct southern (warmer) ranges, and perhaps a decrease in species with more northerly ranges. For example, just 20 km south in the rocky intertidal habitat at the Hopkins Marine Station in Pacific Grove, as sea surface temperatures increased since the early 1930's there was an increase in the abundances of invertebrate species ranging more to the south, and a decrease in abundances of those ranging to the north (Barry et al. 1995, Sagarin et al. 1999). This is an unlikely result at Moss Landing due to the infrequent arrival of the warm-water plume at the beach. Moreover, it is much more difficult to find species with distinct northern and southern ranges in the sandy beach community (See Section 3.2). Nevertheless, this is the first potential impact to explore. The next impact concerns the degradation of the community, which might start with the loss of a temperature-sensitive species or degradation of local population structure and dynamics. Although we

cannot identify local species that are more temperature sensitive than the others, particularly to the slight increase posited here, we have looked for evidence of negative community change.

The first benthic area to explore for potential impacts from the thermal discharge is the Outfall site. This beach station was placed as close as possible to the discharge plume based on the observations from past plume monitoring. If we can detect an impact here, then we can investigate how far it might spread by looking at the other stations starting with the MBARI site. Our beach and subtidal surf zone sampling at the four sites revealed no arrival of a warm-water species assemblage at the Outfall or any of the more distant sites. In fact, no warm-water species has invaded the beach since the first quantitative surveys in 1975-76. All the species are members of the regional intertidal and subtidal fauna of central California. We were also unable to distinguish species with distinct southern and northern ranges in the sandy beach community (intertidal or subtidal) to determine if abundances changed in a manner similar to the rocky shore study to the south (Barry et al. 1995, Sagarin et al. 1999). Therefore, the most likely effects to manifest in the beach community due to the warm-water discharge were not detected in over 500 0.25m² samples taken on the beach and over 200 0.02m² cores from the subtidal surf zone. This is a large sample area, so the possibility of missing the new arrival of a warm-water species is low, unless it is extremely rare.

We found no abnormally low numbers of beach animals at the Outfall site compared to the other beach sites. For both the beach and surf zone, we performed a series of statistical analyses to determine if there was any trend towards greater population or community differences at the Outfall compared to the other sites. It was clear from examining the tables and figures that there was no trend. The statistical analysis reinforces this observation, and permits more comparisons. We did a series of three-way ANOVAs, which indicated highly significant interactions among sites, survey times, and water depths (surf zone) or tidal elevations (beach). As a result, we did one-way ANOVAs for each time and water depth or tidal elevation to evaluate just differences among the four sites. This avoids the significant interactions from the three-way test. When a one-way ANOVA was significant, we then did pair-wise tests to determine which sites were different from the others. This is a lot of multiple testing, even though all the tests were based on the starting hypothesis for the study that the Outfall site would not be different from the other sites along the beach (and further from the thermal discharge). The statistical exercise was done to look for trends in significance. The trend we observed for both the beach and surf zone was that significant differences in pair-wise tests were mostly related to peaks in abundance, and less often to lows. These peaks occurred at different sites, survey times, and water depths or tidal elevations as indicated in the figures and tables. There was no trend for the Outfall site to have significantly fewer species or individuals, which is one expectation if the site were degraded by the thermal discharge.

Although the abundances of several numerically dominant crustaceans were lowest at the Outfall along the intertidal beach (Fig. 3-3), this was not an abnormally low pattern. The total number of crustaceans, on the other hand, was similar among the four sites (Fig. 3-2). In fact, some of the crustacean species that were relatively sparse at the intertidal Outfall site were more abundant in the subtidal surf zone at the Outfall compared to the other sites, particularly

the most abundant surf zone animal, *Americhelidium mircopleon* (Fig. 3-14). The most common pattern at the Outfall site was the high number of polychaete worms, in both the intertidal (Fig. 3-6) and subtidal beach (Fig. 3-11). This is not a negative community pattern. It is positive and probably related to the changes in beach morphology in the canyon head, which creates a better interstitial habitat for interstitial polychaetes (i.e. small worms) that live in the spaces between coarse sand grains. None of the abundant polychaetes in the beach or surf zone are indicators of anthropogenic environmental stress, such as thermal stress or pollution (Grassle and Grassle 1974, Weisberg et al. 1997, Maurer et al. 1999, Karr and Chu 1999). They are more indicative of unpolluted benthic habitats.

The total number of species was the same at all sites, in the intertidal (Fig. 3-7) and subtidal habitats (Figs. 3-15 and 3-16). The density of species is the best measure of species diversity, an excellent indicator of community degradation (Weisberg et al. 1997, Maurer et al. 1999, Karr and Chu 1999, Hunt et al. 2001). It is not low at the Outfall. Although we observed no population or community impacts that can be related to the thermal discharge, there are distinct faunal patterns related to beach elevation (Figs. 3-3 and 3-6, Table 3-2), subtidal water depth (Figs. 3-14 and 3-15, Table 3-7), and the wave exposure and sediment availability gradient from Potrero Road to the canyon head and Outfall site (Fig. 3-2; Figs. 3-11 and 3-14, Table 3-7). We even found very significant differences in the beach fauna between our recent samples (2003-05) and samples collected from Moss Landing Beach in 1975-76 (Table 3-6). So the lack of ecological patterns related to the thermal discharge cannot be attributed to a general lack of faunal patterns and linkage to important processes on the beach. In summary, as might be expected from the infrequent interaction of the thermal discharge with the adjacent beach, we found no evidence of outfall thermal impacts to the beach and surf zone community nearest to the power plant discharge.

3.6.3 Intertidal Ecological Discussion

There were great spatial and temporal variations in the beach fauna, and yet distinct patterns as well. In space, there were persistent patterns across (elevation) and along the beach (site). The zonation patterns we observed with elevation have been documented before (Dahl 1952, Nybakken et al. 1977, Ricketts and Calvin 1985, Peterson 1991, McLachlan and Jaramillo 1995). Our sampling started just below the supralittoral zone, where wrack debris accumulates and talitrid amphipods and insects are common (Ricketts and Calvin 1985). The beach isopod, *Excirolana*, characterizes the high beach stations (A) of the midlittoral zone, where our sampling started (Fig. 3-3, Table 3-2). *Emerita* (mole crab) epitomizes extreme variation on the beach (Dugan et al. 1999). It can occur in narrow, dense aggregations often in response to wave wash patterns (McArdle and McLachlan 1992); had large seasonal pulses of recruitment (Fig. 3-4); and occurred at all elevations in our samples (Fig. 3-3). It was in 57% of the samples from the high beach (A), and over 80% of the samples from the three lower elevations (B-D)(Table 3-2). In contrast, the polychaete worms, mysid crustaceans, and phoxocephalid amphipods were mostly in the lower beach (Figs. 3-3 and 3-6), with the Pismo clams, *Blepharipoda* (sand crab), and *Olivella* (olive snail) that we captured with the large-area cart sampling. This is the classic zonation pattern on the high-energy sandy beaches in Central California (Ricketts and Calvin 1985).

There were also distinct faunal patterns along the beach. The four sampling sites were established along a wave-exposure and sediment availability gradient caused by the Monterey Canyon (Fig. 3-1). This is also the most well-defined gradient away from the warm water discharge from Moss Landing Power Plant (see Thermal Impacts to Benthos). Because of the steep canyon bathymetry, the canyon head beaches at the Outfall (OF) and MBARI (MB) sites are narrow and steep. These beaches also receive little long-shore sand transport, because sand moves off the beach and into the offshore canyon head to the north and south. As a result, the canyon head sites (OF, MB) have the most poorly consolidated deposits with the lowest fine sediment fractions (Table 3-5). On the other hand, in the subtidal surf zone, these same sites have the largest fraction of fine sands (See Surf Zone Section), and just beyond the surf zone the sea floor slopes steeply into the canyon where there are seasonal accumulations of muddy sediments (Oliver et al. 1980, Okey 1997, 2003). Wave energy and therefore disturbance to the intertidal beach is dramatically reduced in the canyon head (Bascom 1964, Shepard and Dill 1966, Arnal et al. 1973, Oliver et al. 1980). The Shore Lab site has a broader, less steep beach, which is still within the wave-energy shadow created by the canyon and the general northwest direction of wave arrival. Sand transport from the south moves across the Shore Lab beach into the canyon head, not onto the MBARI and Outfall sites (Arnal et al. 1973). The Shore Lab site is uniquely positioned for maximum sand transport and minimal wave disturbance. It therefore had the highest percentage of fine sediments among the sites (Table 3-5). The Potrero site is swept by large winter waves like most of central Monterey Bay; the intertidal beach (Fig. 3-8) and subtidal surf zone are the widest and the sediments in the subtidal surf zone are coarser as a result (See Surf Zone Section).

The abundance of polychaete worms increased significantly and dramatically as wave exposure decreased around the canyon head (Fig. 3-3). This is the same pattern seen along many wave-exposure gradients moving from more exposed open coastal environments to protected embayments (Ricketts and Calvin 1985, Brown and McLachlan 1990). However, along these gradients there is also a corresponding gradient in sediment grain size, from coarse to finer deposits. There is a similar wave exposure gradient along the deeper sand flat (Oliver et al. 1980). Crustaceans dominate the inner wave-swept zone, and polychaete worms characterize the deeper zone, where sediment is finer. The entire wave-exposure and sediment availability gradient around the canyon head is an exposed sandy beach; so the gradient in sediment size is more subtle than the offshore-depth and open coast to embayment exposure gradients. Moreover, instead of finer, the beach deposit is coarser because of low sediment availability and moderate wave action (Table 3-5). The polychaetes increasing along the canyon gradient are among the interstitial fauna, living in the spaces between coarse sand grains. The canyon head beach (OF & MB) has less fine sand to fill the interstitial spaces and lower wave action to disrupt them.

Apparently, the exposure gradient was not extreme enough to impact crustaceans nearly as much as the polychaetes (Fig. 3-3). The numbers of beach crustaceans were dominated by the mole crab *Emerita*, which was abundant at all sites, but is least abundant at the high elevation (A) at the Outfall (Figs. 3-2 and 3-3). The numerical dominance of *Emerita* is common on many exposed beaches (Dugan et al. 1999). Since this was also the largest abundant animal on the beach, it dominated the biomass. The numbers of *Olivella*, *Blepharipoda*, and Pismo

clams in cart samples were similar from the Shore Lab and Potrero sites. These species were not captured at the canyon head sites (MB & OF), probably because the beaches are too steep and narrow (Fig. 3-8). The other numerically dominant crustaceans, excluding *Emerita*, were all most abundant at the Shore Lab site (Fig. 3-3). These increases are expected in a more dissipative beach, broader with finer sand. However, the pattern also may reflect the finer screen size used at the Shore Lab, but the screen size change had no obvious effect on the larger *Emerita* or the large or smaller polychaetes (Figs. 3-2 and 3-6).

So, despite the tremendous variations in the beach fauna, the samples show the well-established zonation by tidal elevation as well as a distinct pattern related to wave exposure. However, the canyon head exposure gradient is unique, because it is not linked to a corresponding coarse to fine sediment gradient. Instead, there appears to be a gradient in the quality of interstitial habitat on the beach, and the polychaetes are likely responding to this structure. The gradient does fit the general physical pattern of change from dissipative to reflective beaches. The canyon head beach (OR, MB) is more reflective and is thus narrower, steeper, and coarser than the southern beach (SL, PR). However, we did not observe a decrease in faunal diversity (Fig. 3-7), or abundance (Fig. 3-2) at the reflective end of the gradient, the canyon head. Since *Emerita* dominated the biomass at all stations, there was no decrease in biomass as well. However, before the sea otters ate most of the Pismo clam population in the mid 1970's, this large clam dominated the beach biomass and was never abundant at the canyon head. The commercial fishery started on the north and south sides of the canyon (Stephenson 1977). On the other hand, the historically high biomass of Pismo clams was linked to extreme human exploitation of sea otters in the 1800's; and American Indians periodically captured sea otters and other coastal marine mammals for thousands of years along the beach, where they also collected Pismo clams (Gordon 1996).

We observed three distinct temporal patterns on the beach: seasonal, episodic, and decadal. The seasonal pattern of recruitment is exemplified best among the abundant crustaceans, particularly the mole crab *Emerita* (Figs. 3-4 and 3-5, Table 3-1). Pulses of spring recruitment are common in many benthic invertebrates (Coe 1956), and especially crustacean populations along the subtidal and intertidal beach (Barnes and Wenner 1968, Oliver et al. 1980, Slattery 1985). All the numerically dominant crustaceans were present throughout the year on the beach (Figs. 3-4 and 3-5, Table 3-1). As a result, the major peaks in abundance shown in Fig. 3-3 contain animals from most, if not all, of the 6 sampling periods. This is in stark contrast to the polychaetes, where every major peak in abundance represents a large number of animals present at only one sampling period (Fig. 3-6). Their numbers were thus patchy in both space and time. Since these individuals occurred in most, if not all, of the replicate samples from each time period when they were abundant, these peaks may be related more to episodic recruitment rather than spatial patches. Although variations in polychaete abundance among sites displayed extreme mesoscale patchiness along the beach (Fig. 3-6), one-time recruitment events within a site were more common among the polychaetes than the crustaceans. The most extreme example was the small phyllodocid polychaete, *Hesionura*, which occurred at the highest abundance recorded for any species almost exclusively at a depth of 1 m in the surf zone of the Outfall site (See Surf Zone Section).

Sea otters invaded the central bay area in the mid 1970's. A year later no large Pismo clams could be found on the beach, after decades of sport fishing here (Stephenson 1977). Four small clams were collected in the quantitative surveys in 1975-76. We collected four small Pismo clams in the large-area cart sampling targeted for this species, and another four small individuals in over 500 of the 0.25 m² samples. Similar sized shells broken by otters were seen on the intertidal beach throughout the study period. In a section of beach 100 m long, we found as many as 5 otter-cracked Pismo shells at low tides, but only several times in a year. Fresh large shells are very rare. There is thus no evidence of the recovery of the Pismo clam population on the beach, and evidence of continuing otter predation on relatively rare, small individuals.

There are no significant differences between 1975-76 and 2003-05 in the density of species and the number of individuals of the entire fauna, crustaceans or polychaetes (Table 3-6). On the other hand, abundance differences for most of the numerically dominant species are statistically significant between the decades (Table 3-6). For about half of these species, the differences between the decades can be seen in mesoscale variations along the beach in 2003-05. This is not true for *Emerita*, *Grandiphoxus*, *Americhelidium* and nemertean worms. *Emerita*, however, is known to vary tremendously over seasons and among years and also among beaches (Barnes and Wenner 1968, Wenner et al. 1987, Ricketts and Calvin 1985, Dugan et al. 1999). Therefore, although there are distinct differences between 1975-75 and 2003-05, these are likely to be short-term annual variations on Moss Landing Beach, and less likely to represent differences that persisted over decades. We know too little about the nemertean worms to say any more. However, there is evidence that the changes in *Grandiphoxus* and *Americhelidium* may be linked to interdecadal regime shifts in the California Current.

The decadal change in abundance and frequency of occurrence of the giant phoxocephalid amphipod, *Grandiphoxus*, is related to a regional pattern for this family. Throughout the 1970's, this species could be readily collected on the regional beaches, and not since then. None of the other numerically dominant beach species showed a similar qualitative trend. In addition, the subtidal populations of phoxocephalids decreased by a factor of ten from 1971-75 compared to 1997-98 (Oliver et al. in preparation). Coincidentally, so did *Grandiphoxus* from 1975-76 to 2003-05 (Table 3-6). Phoxocephalids are voracious predators (Oliver et al. 1982). In the offshore benthos, there were dramatic decadal decreases in the number of individuals, diversity (species density), biomass, and population size of many higher trophic level consumers like the phoxocephalids. Oliver et al. argue that these changes are related to the regime shift in the California Current. The 1971-75 samples were taken after 25 years of high production in a cold regime, and the 1997-98 samples at the end of a low production, warm regime. After over two decades of significantly less planktonic production, the 1997-98 subtidal community was highly degraded compared to the 1970's.

As the phoxocephalids declined, the abundance of *Americhelidium shoemakeri* increased dramatically (also by 10 times) in the same offshore habitats (Oliver et al. in preparation). We have no long-term qualitative observations on *Americhelidium* in the intertidal beach, because both species are small enough to escape detection in classroom field trips and qualitative surveys for Pismo clams and *Grandiphoxus*. Nevertheless, the quantitative and

qualitative sampling in the adjacent offshore extends throughout the two regimes, and suggests that the beach may change in a similar manner. There were no *A. microplean* in the 1975-76 beach samples and hundreds in the 2003-05 samples.

In contrast to *Grandifoxus*, the abundance of another, much smaller phoxocephalid amphipod, *Mandibulophoxus*, did not change between the decades on the beach (Table 3-6). This species primarily lives in the subtidal surf zone, not the intertidal beach (See Surf Zone Section). There is another pattern in the offshore benthos related to the oceanographic regime shift. This is an expansion of the zones of certain shallow water species into deeper water as the numbers of potential predators and competitors decreased. *Mandibulophoxus* showed this pattern. It was never encountered at offshore stations (6 and 9 m) in the 1970's, and was there in the 1990's. Perhaps it expanded into or at least persisted in the intertidal as the *Grandifoxus* decreased. As longer-term (decadal) patterns become better known, we can evaluate and either refute or accept hypotheses about regimes shifts and decadal fluctuations in plankton production and food for the benthos, expansion and contraction of faunal zones in different regimes, physical disturbance, recruitment, and key ecological indicators of these and other potentially important processes.

Finally, no warm-water invertebrates colonized the sandy beach at Moss Landing since the first quantitative sampling in 1975-76. There is also no evidence of the arrival of warm-water species before the 1970's, since the present list of species is characteristic of the sandy beach fauna observed throughout central California for many decades (Ricketts and Calvin 1985). There is also no evidence of trends in abundance for species with ranges extending more to the south or north of Monterey Bay. This result is dramatically different from the pattern documented along the rocky intertidal shore just 25 km south of Moss Landing. At Hopkins Marine Station, the abundances of southern species increased and northern species decreased between 1931-33 and 1993-94 (Barry et al. 1995, Sagarin et al. 1999). The sandy beach has many fewer species than the rocky shore, and a fauna that cannot be as easily divided into those with greater northern and southern ranges. We can also show that many of the decadal variations can be seen along the beach in a much shorter time period (2003-05). The rocky shore may simply be a better system to explore patterns related to geographical range.

3.6.4 Subtidal Ecology Discussion

This is the first quantitative study of the structure of macrofaunal invertebrate communities living in the subtidal surf zone of a high-energy sandy beach in the Pacific Ocean. The most distinct community patterns are the faunal zonation with water depth. Two groups of species are characteristic of the subtidal surf zone (Table 3-12). The first group lives almost exclusively here, but also much less abundantly in the low intertidal zone (sublittoral fringe). It has a relatively narrow zonation. The second group has a broader zonation, living primarily in the subtidal surf zone but also on the low intertidal beach and especially in deeper water. There are two other groups of relatively transient species that live in the subtidal surf zone, but primarily inhabit either the intertidal beach or deeper water, where they are much more characteristic community members (Table 3-12). The local subtidal surf zone community fits into the well-known zonation of intertidal beach fauna (Ricketts and Calvin 1985, Nybakken et al. 1977) and subtidal species just beyond the surf zone (Oliver et al. 1980).

The most characteristic macrofaunal species inhabiting the subtidal surf zone is the odocerodid amphipod crustacean, *Americhelidium micropleon* (Fig. 3-14, Tables 3-7 and 3-8). This species is most abundant at 1 m, but occurs at 2 m and 4 m. It was never encountered at stations sampled in 6 m and deeper along the sand flat (Oliver et al. 1980 in preparation, Slattery 1985, Table 3-13), but does occur much less abundantly in the low intertidal zone (See Beach Section). It is thus a surf zone species with a narrow zonation pattern (Table 3-12). *Americhelidium* is an active swimmer, a small animal about 4-5 mm long with a slender body. It burrows only into superficial sediments, and is a scavenger and predator here and in near-bottom waters (Oliver et al. 1980 in preparation). In Korea, a closely related species (*Synchelidium*) mainly eats harpacticoid copepods, while the juveniles also eat copepod nauplii and nematodes (Yu et al. 2003). The other common amphipod groups (haustoriids and phoxocephalids) on the local intertidal and subtidal beach are larger with wider bodies that are more adapted for burrowing in sediment (Slattery 1985). The other animals that are most characteristic of the subtidal surf zone are also crustaceans and fit the narrow zonation pattern (Table 3-12). They include the mysids, *Holmesmysis sculpta* and *H. costata*, and a cumacean *Cyclaspsis* sp. These crustaceans and the little phyllodocid polychaete worm, *Hesionura* sp., have been found primarily in the subtidal surf zone and much less in the lower intertidal beach, but not in deeper water.

The phoxocephalid amphipod, *Mandibulophoxus gilesi*, (Figs. 3-12 and 3-13; Table 3-7) is also characteristic of the subtidal surf zone, but occurs on the low intertidal beach and along the deeper sand flat (Table 3-12). It is a surf zone species with a broad zonation pattern. Several other species have this zonation pattern as well, including *Metamysidopsis elongata*, the Pismo clam *Tivella stultorum*, and the sand crab *Blepharipoda occidentalis* (Ricketts and Calvin 1985). Pismo clams are now rare on the low intertidal and subtidal beach because of predation by sea otters (Stephenson 1977).

There are several species that are characteristic of the intertidal beach and only occur in the surf zone infrequently and in low numbers as transients. These include the sand crab *Emerita analoga*, *Archaeomysis grebnitski*, and the polychaete worm *Nephtys californiensis* (Ricketts and Calvin 1985). There are more species that are abundant in deeper water, but also occur as surf zone transients, particularly polychaete worms (Table 3-12) with relatively opportunistic life histories (Oliver et al. 1977, in preparation, Grassle and Grassle 1974); but crustaceans as well such as *Americhelidium shoemakeri* (Fig. 3-14) and haustoriid amphipods (Table 3-12). In the present study, these deeper-water species generally increase in abundance from the 1 to 4 m depths (Fig. 3-14), but are more abundant in deeper water (Tables 3-12 and 3-13).

The faunal zonation we observe also fits the general zonation scheme proposed by McLachlan et al. (1984). Their inner turbulent zone includes the sublittoral intertidal beach and the subtidal surf zone to 2-4 m. *Americhelidium micropleon* is abundant to 1-2 m (Fig. 3-14). It is the most characteristic species of the subtidal surf zone. Offshore of our sampling area, the inner edge of the sand dollar (*Dendraster excentricus*) bed is around 5 m. It can be several meters deeper on the northern side of Monterey Canyon where wave energy increases (Oliver et al. 1980). The inner edge of the sand dollar bed is highly dispersed: the outer edge is a dense band that often ends in a sharp boundary (Merrill and Hobson 1971, Morin et al.

1985). The dense sand dollar bed defines the beginning of the outer turbulent zone, and *A. micropleon* defines the offshore side of the inner turbulent zone. This leaves a narrow transition area between 1-2 m and 5-8 m.

This general agreement in zonation is remarkable considering the large differences between the fauna found in Monterey Bay and the fauna of South Africa. Monterey Bay subtidal beaches are numerically dominated by pericarid crustaceans: cumaceans, and especially ostracods and haustoriid, phoxocephalid, and oedeceroid amphipods (Table 3-13). Polychaetes become more abundant and diverse with depth (Oliver et al. 1980). There is a dense, narrow sand dollar bed. The South African benthos includes relatively large bivalves and gastropods; many heart urchins and brittle stars; and high densities of *Callianassa* (crustaceans), which live in relatively stable burrows. All of these groups are abundant as shallow as 5 m. Sipunculid and echiuroid worms and aplacophoran molluscs are abundant at some stations (McLachlan et al. 1984). In Monterey Bay, the later groups are found only along the outer continental shelf. Tube and burrow dwellers are rare until 15-20 m at the edge of the outer turbulent zone, where polychaetes become more abundant. Monterey Bay has nothing like the high numbers of *Callianassa* found in South Africa. And the only abundant bivalves are juvenile *Tellina modesta* (several mm), which are also mostly in the polychaete zone (Oliver et al. 1980). Despite these striking faunal differences between South Africa and Monterey Bay, the wave climate divides the communities into similar physical zones.

There are numerous groups of closely related species that replace each other along the beach from the intertidal into the subtidal sand flat. *Nephtys californiensis* is most abundant in the intertidal zone (See Beach Section), *N. caecoides* peaks in 6-9 m, and *N. cornuta* is most abundant deeper than 15 m (Oliver et al. 1980, Tables 3-12 and 3-13). Among the phoxocephalid amphipods, *Grandifoxus grandis* is on the intertidal beach (Beach Section); *Mandibulophoxus* peaks in the surf zone and occurs shallower and deeper (Tables 3-7, 3-12 and 3-13); and *Rhepoxynius lucubrans* is replaced by *R. fatigans* and then by *R. abronius* with increasing water depth (Slattery 1985, Table 3-13). Among the haustoriid amphipods, *Eohaustorius washingtonianus* is on the intertidal and shallow subtidal beach, and is replaced by *E. sawyeri* and then *E. sencillus* with increasing depth (Slattery 1985, Table 3-13). The olive snail *Olivella biplicata* is in the low intertidal beach and subtidal surf zone and is replaced by *O. pycna* in deeper water (Tables 3-12 and 3-13). Sand crabs (Ricketts and Calvin 1985, Table 3-12), mysids, and cumaceans (*Cyclaspsis* species) show similar depth replacement patterns or zonation (Oliver et al. 1980, Tables 3-12 and 3-13). Finally, although there are more examples, *Americhelidium micropleon* and *A. shoemaker* co-occur in the surf zone (Fig. 3-14, Table 3-7), but only *A. shoemaker* lives along the deeper sand flat, where it is more abundant (Table 3-13). In contrast, *A. micropleon* occurs in the low intertidal zone, but in lower numbers than it does in the subtidal surf zone.

The zonation patterns presented here can change with wave exposure and other factors. For example, *Olivella biplicata* can be more characteristic of the intertidal flats that are more protected from wave exposure. Ricketts and Calvin (1985) provide a number of similar examples of the zonation of local species changing with wave exposure. Oliver et al. (1980) document a major offshore shift in the crustacean zone with an increase in wave exposure

along the subtidal sand flats on the north side of Monterey Canyon compared to the south side.

The four sampling sites were selected along a gradient away from the warm-water discharge from the Moss Landing Power Plant (Fig. 3-1). The Outfall site was closest and the Potrero site was furthest from the discharge. Potential impacts from the warm-water discharge are considered in another section.

There are few differences among the four subtidal sites we sampled, but two patterns may be related to the wave exposure gradient created by the canyon bathymetry and the direction of wave arrival (Bascom 1964, Shepard and Dill 1966, Arnal et al. 1973). *Mandibulophoxus* and *Olivella* are most abundant at Potrero Road (Fig. 3-12, Table 3-7), where the impacts of wave action are clearly the highest (Oliver et al. 1980). Compared to the other numerical dominants in the subtidal surf zone (Tables 3-7 and 3-12), these two species occur in deeper water along the subtidal sand flat, and thus may be able to move seaward more easily to avoid extreme wave disturbance. Seaward and shoreward movement in response to changes in wave action has been documented for sand dollars (Oliver et al. 1980, Morin et al. 1985), which are also more abundant at Potrero Road (Oliver et al. 1980). Although *Hesionura* dominates the polychaete abundance patterns, there is a general tendency for higher polychaete abundance at the three canyon head sites, which may be related to lower wave exposure here (Fig. 3-11). This polychaete abundance pattern is more pronounced on the intertidal beach along the same canyon-exposure gradient (See Section 3.2-) and along the wave disturbance gradient in deeper water, where a shallow crustacean zone is replaced by a deeper polychaete zone (Oliver et al. 1980).

In addition, the shallow canyon head appears to be an important recruitment region for juvenile cancer crabs, both *Cancer gracilis* and *C. magister*. We observed a narrow band of many young crabs in the surf zone, and then again two weeks later in the deeper canyon head in June 2003 (about 50-100/m²). Water clarity is low in the canyon head compared to the flanking sand flats, and the numbers of predacious fishes are lower as well. There are also patches of drift algae that can provide refuge from predators as well as prey for the young crabs (Okey 1997, 2003).

Benthic communities living in the intertidal beach and shallow subtidal habitats, including the subtidal surf zone and deeper, may be strongly limited by physical disturbance from wave-generated bottom disturbance (Oliver et al. 1980, McLachlan et al. 1984, Defeo and McLachlan 2005). Where the sediments are more stable, food may be more important in community organization (Oliver et al. in preparation). In the present study, the number of species increased at all sites with increasing water depth in the surf zone (Figs. 3-15 and 3-16). This pattern was also observed along the deeper sand flat, where the density of species increased from 6 m to 24 m (Oliver et al. 1980, in preparation). The 6 m depth has a higher number of species per core than any of the 4 m stations sampled in the present study (<10 species/core compared to >10). Therefore, the depth patterns along the sand flat suggest that wave disturbance plays an increasingly important role in controlling the density of species with decreasing water depth (Oliver et al. 1980). The pattern of increasing diversity with

depth has been documented in other sampling efforts through the wave-controlled subtidal beach (Day et al. 1971, Fields 1971, Masse 1972, Christie 1976, McLachlan et al. 1984).

In addition to wave disturbance, regional patterns of planktonic production also appear to have an important impact along the deeper sand flat, where there were radically different communities at the end of a warm, low production regime in the California Current compared to a cold, high production regime (Oliver et al. in preparation). Species density decreased significantly at all water depths (6, 9, 18, and 24 m) by the end of the warm regime, after the benthos was poorly fed for over two decades. We apparently entered into another cold regime in 1999, so the data collected in this study provide an opportunity to observe how diversity changes in the surf zone compared to deeper water, where we expect it to increase during the new high-production cold regime. In contrast, we predict that diversity will not change in the surf zone, where wave disturbance probably plays the dominant role in controlling species richness.

Another change between the cold and warm regimes was in animal zonation. By the end of the warm regime, the distribution of a number of species extended into deeper water (Oliver et al. in preparation, Table 3-13). *Americhelidium shoemakeri* is an excellent example. It was only abundant at the 6 m station in the 1970's at the end of the last cold regime. It was ten times more abundant at 6 m in the 1990's, and was also abundant at 9 m for the first time (Table 3-13). *Rhepoxynius lucubrans* characterized the 6 m station in the 1970's, and was more abundant at 9 m by the 1990's (Table 3-13). *Mandibulophoxus* occurred at the offshore stations only in the 1990's (Table 3-13). It is most abundant in the subtidal surf zone (Fig. 3-13 and Table 3-7). If these zones contract again by the end of the present cold regime, we may see this reflected in the surf zone as well, particularly in the zonation of *Americhelidium micropleon*, which may be the most characteristic macrofaunal species in the surf zone only during periods of low planktonic production in the California Current. Perhaps another species dominates when production is greater. We predict this will be *Mandibulophoxus*, since phoxocephalid amphipods were much more abundant in deeper water during the last cold regime (Table 3-13, Oliver et al. in preparation).

3.7 Historical Data

For the invertebrate fauna, reports and papers of surveys in intertidal and shallow subtidal sandy habitats near Moss Landing have been collected. The data have been entered in electronic form, and the taxonomy has been updated in some cases.

Keeping the taxonomy of historical databases up to date is a significant problem in benthic ecology, because the taxonomy is constantly changing. It can be very time consuming, and in many cases requires a bit of detective work. However, if realistic long-term comparisons are to be made, it is necessary to keep the taxonomy up to date. This is immeasurably easier if the original researchers are still alive and active (as is the case with the data presented below). We recommend updating all datasets listed below that were not updated as part of this study. There are also a number of deeper-water datasets from the Monterey Bay area that need to be compiled and updated as well.

1. "P-Data"

These were large coffee can cores from 3 depth stations (15 ft, 30 ft, and 60 ft), with 6 replicates per station. They were collected by John Oliver and Peter Slattery from 1971 through 1975. The data have been recovered and entered into the database. The taxonomy has not been updated.

2. Narine, Vidya. 1976. The Vertical and Horizontal Distribution Of the Meiofauna and some Physical Factors in a Sandy Beach in Monterey, California. Masters Arts Thesis, CSUS. 243 p.

These are meiofaunal data from the Salinas River Mouth, collected in 1974 and 1975. Data were identified to major taxonomic groups (Gastroticha, Ostracoda, Copepoda, Nematoda, Turbellaria, Nemertina, Polychaeta, Archiannelida, Oligochaeta).

3. "Preliminary Baseline Studies of the Intertidal Sandy Beach at Moss Landing" By James Oakden and James Nybakken, 1975-1976.

This is the original dataset collected from in front of the old Moss Landing Marine Labs by Jim Oakden in 1975. Two 0.25 m² replicates per station were collected at 5 m intervals along 1 transect. Samples covered most low tides (13 dates) from October 1975 through June 1976. We have updated the species names and have used these data extensively as a comparison to the data collected as part of this study.

4. Kaiser/National Refractories Outfall data

These data are from several stations around the Kaiser/National Refractories outfall as part of their NPDES monitoring program from 1971 through 1989. The data were compiled by ABA Consultants in 1994, and the names were updated then.

Another dataset from the Moss Landing beach (Steve Locey's MLML MS thesis) has no raw data, only graphs, and we were unable to figure a way to utilize it. There is also a great deal of deeper-water data from the canyon and vicinity, but it is beyond the scope of this project. There was monitoring done around the PG&E outfall, but it seems to have been only photographs, with no usable data.

The available raw data have been entered into electronic format. The historical benthic data will be included on a CD prepared for this project.

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3.9 Tables and Figures

Table 3-1. Percentage of individuals (N) of the 10 most abundant species sampled in each of the first six sampling periods.

Species	Percent of N						N
	Apr 03	May 03	Aug 03	Oct 03	Mar 04	May 04	
Spionid				100			184
<i>Pisone remota</i>	43	57					449
<i>Saccocirrus</i> sp.	32	42	25	1			281
Archiannelid			1		7	92	988
<i>Hemipodus borealis</i>	73	6	1	5	6	9	902
<i>Nephtys californiensis</i>	2	6	18	28	40	6	65
<i>Emerita analoga</i>	44	18	3	3	8	24	6085
<i>Excirolina chiltoni</i>	42	6	13	10	26	3	4518
<i>Archaeomysis grebnitskii</i>	39	9	34	9	4	5	568
<i>Americhelidium micropleon</i>	18	13	20	36	5	8	97

Table 3-2. Frequency of occurrence percentage of the 10 most abundant species, along with the mean number of individuals, the standard error and the number of samples, in the four elevations from the high (A) to the low (D) intertidal beach. (for example, 88% of the samples at Elevation A contained *Excirolana*).

Elevation	Species	Mean	SE	N	Freq of Occurrence (%)
A	<i>Excirolana chiltoni</i>	33.21	5.80	129	88
	<i>Emerita analoga</i>	8.54	1.73	129	57
	<i>Hemipodus borealis</i>	0.22	0.10	129	9
	Archiannelid	0.14	0.07	129	5
	<i>Megalorchestia columbiana</i>	0.12	0.04	129	6
	<i>Megalorchestia</i> sp.	0.11	0.04	129	8
	<i>Megalorchestia benedicti</i>	0.06	0.03	129	4
	Nemertea	0.05	0.03	129	2
	Hesionid	0.04	0.03	129	2
	<i>Saccocirrus</i> sp.	0.03	0.02	129	2
B	<i>Emerita analoga</i>	16.43	5.62	121	81
	<i>Excirolana chiltoni</i>	1.69	0.37	121	47
	<i>Hemipodus borealis</i>	1.44	0.36	121	31
	Spionid	1.10	0.71	121	4
	Archiannelid	0.79	0.41	121	10
	Nemertea	0.34	0.16	121	9
	<i>Pisone remota</i>	0.34	0.11	121	12
	<i>Archaeomysis grebnitskii</i>	0.28	0.10	121	13
	<i>Nephtys californiensis</i>	0.28	0.18	121	9
	<i>Saccocirrus</i> sp.	0.21	0.10	121	7
C	<i>Emerita analoga</i>	15.63	2.38	115	80
	Archiannelid	7.14	2.84	115	21
	<i>Hemipodus borealis</i>	5.75	1.90	115	36
	<i>Archaeomysis grebnitskii</i>	3.50	0.76	115	44
	<i>Pisone remota</i>	1.97	0.56	115	14
	<i>Saccocirrus</i> sp.	0.85	0.26	115	14
	Spionid	0.42	0.23	115	5
	<i>Mandibulophoxus gilesi</i>	0.37	0.11	115	16
	<i>Americhelidium micropleon</i>	0.33	0.10	115	16
<i>Excirolana chiltoni</i>	0.19	0.06	115	13	
D	<i>Emerita analoga</i>	15.96	3.69	75	85
	<i>Pisone remota</i>	2.43	1.43	75	5
	<i>Saccocirrus</i> sp.	2.05	1.11	75	7
	<i>Archaeomysis grebnitskii</i>	1.72	0.36	75	48
	Archiannelid	0.72	0.31	75	17
	<i>Americhelidium micropleon</i>	0.67	0.31	75	16
	<i>Hemipodus borealis</i>	0.51	0.20	75	16
	<i>Mandibulophoxus gilesi</i>	0.51	0.19	75	20
	<i>Nephtys californiensis</i>	0.24	0.08	75	15

Table 3-3. Three-way ANOVAs testing effect of elevation, station, and survey date on square-root transformed total numbers of crustaceans, polychaetes, *Emerita analoga*, selected crustaceans (no *Emerita* included) and selected crustaceans and stations (no *Emerita* and no Shore Lab data included) for surveys 1-6.

Source of variability	Total Crustaceans		Total Polychaetes		<i>Emerita analoga</i>		Selected Crustaceans		Selected Crust/Station	
	df	F	df	F	df	F	df	F	df	F
Overall Model	79	15.92	79	23.27	79	10.74	79	39.74	56	18.19
Survey	5	49.67	5	27.80	5	57.85	5	43.94	5	20.36
Station	3	25.46	3	40.46	3	1.69	3	121.57	2	50.09
Elevation	3	39.27	3	70.68	3	8.83	3	297.08	3	121.66
Interaction Terms										
Survey*Station	14	8.32	14	30.62	14	5.66	14	22.33	9	7.17
Survey*Elevation	14	8.98	14	13.33	14	14.27	14	14.80	14	9.69
Station*Elevation	9	24.73	9	14.56	9	7.83	9	41.15	6	19.76
Survey*Station*Elevation	31	11.30	31	19.99	31	5.74	31	24.94	17	7.81

Table 3-4. Summary of individual ANOVAs testing differences among sites for the numbers of individuals (as in Table -3-3) at each elevation and for each survey date. Significance was defined as any analysis with a p-value of ≤ 0.05 .

Elevation	Total Crustaceans		Total Polychaetes		<i>Emerita analoga</i>		Selected Crustaceans		Selected Crust/Station	
	Total Analyses	Significant Analyses	Total Analyses	Significant Analyses	Total Analyses	Significant Analyses	Total Analyses	Significant Analyses	Total Analyses	Significant Analyses
A	6	6	5	1	6	4	6	6	6	5
B	6	6	6	3	6	6	6	2	6	2
C	6	4	6	5	6	3	6	4	6	4
D	5	2	5	1	5	4	5	4	3	1

Table 6. Differences between sand beach communities in 1975-76 and 2003-05.

Species/Variable	1975-76 All Dates		2003-05 All Sites		2003-05 Shore Lab Only		Frequency of Occurrence (%)			
	Mean	SE	Mean	SE	Mean	SE	1975-76	2003-05	2003-05 SL	
<i>Excirolana chiltoni</i>	8.0	1.9	9.8	1.5	18.9	4.6	42	43	41	
<i>Emerita analoga</i>	2.1	0.5	15.4	2.4	12.5	2.2	43	72	71	
<i>Archannelida B</i>	0	0	2.4	0.6	5.5	2.0	0	14	13	
<i>Archaeomysis grebnitskii</i>	3.1	1.1	1.6	0.2	2.3	0.4	46	23	37	
<i>Mandibulophoxus gilesi</i>	0.7	0.2	0.2	0.04	0.6	0.1	13	7	20	
<i>Americhelidium micropleon</i>	0	0	0.6	0.2	1.2	0.5	0	10	17	
Nemertea	3.0	1.0	0.4	0.1	0.4	0.1	43	9	9	
<i>Nephtys californiensis</i>	0.1	0.03	0.2	0.05	0.5	0.1	9	10	25	
<i>Grandifoxus grandis</i>	0.9	0.1	0.04	0.01	0.1	0.03	34	3	6	
<i>Saccocirrus sp.</i>	5.3	2.7	0.5	0.2	0.1	0.05	24	5	2	
Total Individuals	27.4	4.1	35.4	2.9	42.6	5.3				
Total Crustaceans	16.4	2.2	27.9	2.9	35.7	5.1				
Total Polychaetes	5.9	2.8	7.0	0.9	6.3	2.0				
Total Species	3.4	0.2	2.5	0.1	2.8	0.1				
Number of Quadrats (n)		116		579		167				

Table 3-7. Change in abundance of the six numerically dominant taxa with water depth and at each site. Presented are means and standard errors (SE) per core. Major taxonomic groupings are crustaceans (C), polychaetes (P) and molluscs (M).

Taxa	Group	Overall		1 m		2 m		4 m		OF		MB		SL		PR	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
<i>Americhelidium shoemakeri</i>	C	3.9	1.0	0.9	0.6	5.2	2.6	5.5	1.2	2.0	1.1	6.1	3.2	2.6	0.8	5.3	1.6
<i>Americhelidium micropleon</i>	C	3.6	1.3	8.4	3.7	2.0	1.0	0.6	0.3	6.0	4.4	5.5	2.3	0.1	0.1	2.4	1.0
<i>Mandibulophoxus gilesi</i>	C	3.0	1.5	0.5	0.2	1.2	1.0	6.8	3.9	2.2	1.9	1.1	0.2	1.4	1.3	8.4	6.4
<i>Hesionura</i> sp.	P	3.0	2.8	9.0	8.7	0.2	0.2	0	0	10.9	10.6	0.4	0.4	0	0	0	0
Nemertea		2.3	0.6	2.8	1.3	2.6	1.2	1.4	0.7	2.5	1.2	3.9	1.5	0.1	0.1	2.6	1.5
<i>Olivella biplicata</i>	M	1.6	1.0	0.2	0.1	0.9	0.4	3.6	2.9	0.5	0.4	1.0	0.4	0.6	0.3	5.2	5.1
Number of Samples		204		66		72		72		54		54		54		42	

Table 3-8. Number of sample means (total = 34) occurring in five density categories for the 10 most abundant taxa.

Taxa	Group	Mean Number of Individuals per Core					
		0	> 0 to < 1	> 1 to < 2	3 to 9	10 to 15	> 15
<i>Americhelidium shoemakeri</i>	C	12	4	3	11	2	2
<i>Americhelidium micropleon</i>	C	7	13	5	6	1	2
<i>Mandibulophoxus gilesi</i>	C	9	16	5	0	2	2
<i>Hesionura</i> sp.	P	29	3	0	1	0	1
Nemertea		6	14	7	5	2	0
<i>Olivella biplicata</i>	M	17	9	5	2	0	1
Cumacea	C	12	14	6	1	0	1
<i>Olivella pycna</i>	M	22	4	3	5	0	0
<i>Nephtys caecoides</i>	P	15	16	1	2	0	0
<i>Apoprionospio pygmaea</i>	P	28	5	0	1	0	0

Table 3-9. Three -way ANOVAs testing effect of survey date, site and depth on square - root transformed total numbers of crustaceans, polychaetes, and molluscs .

Source of variability	Total Crustaceans			Total Polychaetes			Total Molluscs		
	df	F	P value	df	F	P value	df	F	P value
Overall Model	33	17.08	0.0001	33	16.19	0.0001	33	17.98	0.0001
Survey	2	26.29	0.0001	2	34.37	0.0001	2	5.16	0.0067
Site	3	34.13	0.0001	3	7.16	0.0001	3	19.45	0.0001
Depth	2	8.22	0.0001	2	7.06	0.0001	2	64.49	0.0001
Interaction terms									
Survey*Site	6	25.59	0.0001	6	22.50	0.0001	6	13.18	0.0001
Survey*Depth	4	19.52	0.0001	4	19.07	0.0001	4	10.62	0.0001
Site*Depth	6	8.30	0.0001	6	15.51	0.0001	6	16.08	0.0001
Survey*Site*Depth	10	11.09	0.0001	10	12.57	0.0001	10	17.77	0.0001

Table 3-10. Summary of individual ANOVAs testing differences among sites for total numbers of individuals (as in Table 3) at each water depth and for each survey date. Significance was defined as any analysis with a p -value of < 0.05 .

Depth (m)	Total Crustaceans		Total Polychaetes		Total Molluscs	
	Total Analyses	Significant Analyses	Total Analyses	Significant Analyses	Total Analyses	Significant Analyses
1	3	3	3	2	3	2
2	3	2	3	2	3	1
4	3	3	3	2	3	3

Table 3-11. Sediment grain size distribution along the shallow subtidal beach. The top value in each cell is from 2004, the bottom from 2005. There were no samples taken at PR 1 m, PR 2 m, or PR4 m in 2005.

Particle Size Range (μm)	1 meter depth				2 meter depth				4 meter depth			
	OF	MB	SL	PR	OF	MB	SL	PR	OF	MB	SL	PR
0 - 4 (clay)	0	0	0	0	0	0	0.06	0	0	0.03	0	0
	0	0	0	0.02	0	0	0	0	0	0.04	0.1	0.3
4 - 63 μm (silt)	0.2	0	0.7	0.4	0	0.25	0.8	0.5	0.001	0.8	0.001	0.3
	0.2	0.1	0.2	0.4	0.33	0.1	0.1	0	0	0.6	0.6	0.6
63 - 250 μm (fine sand)	27	10	65	49	20	25	72	44	65	71	67	37
	16	20	20	41	41	28	28	62	62	58	57	59
250 - 1000 μm (medium sand)	67	65	32	49	76	68	25	53	33	26	31	59
	78	70	73	56	56	68	66	38	38	39	43	3.7
1000-2000 μm (coarse sand)	5.0	25	1.6	2.0	4.2	6.8	2.0	3.2	2.4	2.2	2.3	3.7
	5.6	9.7	6.9	2.9	2.9	3.5	5.7	0	0	1.8	0	0

Table 3-12. Zonation patterns of benthic invertebrates along the high-energy sand beach in Monterey Bay focusing on the surf zone. Zonation patterns are defined as follows: surf zone/narrow band – species found almost exclusively in the surf zone; surf zone/broad band – primarily surf zone species that also occur in the intertidal and deeper water; intertidal transients – primarily intertidal species that sometimes occur in the surf zone; and subtidal transients – primarily deeper water species that also occur in the surf zone.

Surf Zone/ Narrow Band	Surf Zone/ Broad Band	Intertidal Transients	Subtidal Transients
<i>Americhelidium micropleon</i>	<i>Blepharipoda occidentalis</i>	<i>Archaemysis grebnitski</i>	<i>Americhelidium shoemakeri</i>
<i>Cyclaspsis</i> sp.	<i>Mandibulophoxus gilesi</i>	<i>Emerita analoga</i>	<i>Apoprionospio pygmaea</i>
<i>Hesionura</i> sp.	<i>Metamysidopsis elongata</i>	<i>Nephtys californiensis</i>	<i>Armandia brevis</i>
<i>Holmesmysis costata</i>	<i>Olivella buplicata</i>		<i>Dispio uncinata</i>
<i>Holmesmysis sculpta</i>	<i>Tivella stultorum</i>		<i>Eohaustorius sawyeri</i>
			<i>Eohaustorius sencillus</i>
			<i>Olivella pycna</i>
			<i>Nephtys caecoides</i>
			<i>Scoloplos armiger</i>

Table 3-13. Ten most abundant invertebrate species at 6m and 9m just offshore of the Potrero Road site at the end of a high production, cold regime in the 1970's and at the end of a low production, warm regime in the CA Current in the 1990's (mean per core, n = number of core samples). Major taxonomic groups are crustaceans (C), polychaetes (P), molluscs (M), and echinoderms (E). From Oliver et al. in preparation.

1971-75			1997-98		
6 m	Group n=139		6 m	Group n=6	
Euphilomedes longiseta	C	14.77	Americhelidium shoemakeri	C	32.25
Olivella pycna	M	5.43	Dendraster excentricus	E	6.25
Rhepoxynius lucubrans	C	5.30	Eohaustorius sawyeri	C	4.50
Eohaustorius sencillus	C	5.21	Scoloplos armiger	P	2.75
Eohaustorius sawyeri	C	4.09	Mandibulophoxus gilesi	C	2.50
Americhelidium shoemakeri	C	2.49	Syllis sp.	P	1.50
Apoprionospio pygmaea	P	1.88	Lamprops sp.	C	1.00
Scoloplos armiger	P	1.67	Armandia brevis	P	0.75
Foxiphalus obtusidens	C	1.01	Hemilamprops californica	C	0.75
Rhepoxynius fatigans	C	0.96	Pacificulodes spinipes	C	0.75
9 m	Group n=111		9 m	Group n=30	
Rhepoxynius fatigans	C	28.65	Zeugophilomedes oblongus	C	10.52
Rhepoxynius abronius	C	28.62	Eohaustorius sencillus	C	8.87
Eohaustorius sencillus	C	22.60	Americhelidium shoemakeri	C	4.27
Zeugophilomedes oblongus	C	18.56	Eohaustorius sawyeri	C	4.17
Dendraster excentricus	E	14.35	Dendraster excentricus	E	3.04
Tellina modesta	M	13.54	Rhepoxynius abronius	C	2.75
Euphilomedes longiseta	C	9.48	Apoprionospio pygmaea	P	2.63
Rochefortia tumida	M	6.96	Mediomastus californiensis	P	2.15
Armandia brevis	P	4.92	Rhepoxynius lucubrans	C	2.08
Magelona sacculata	P	4.40	Armandia brevis	P	1.38

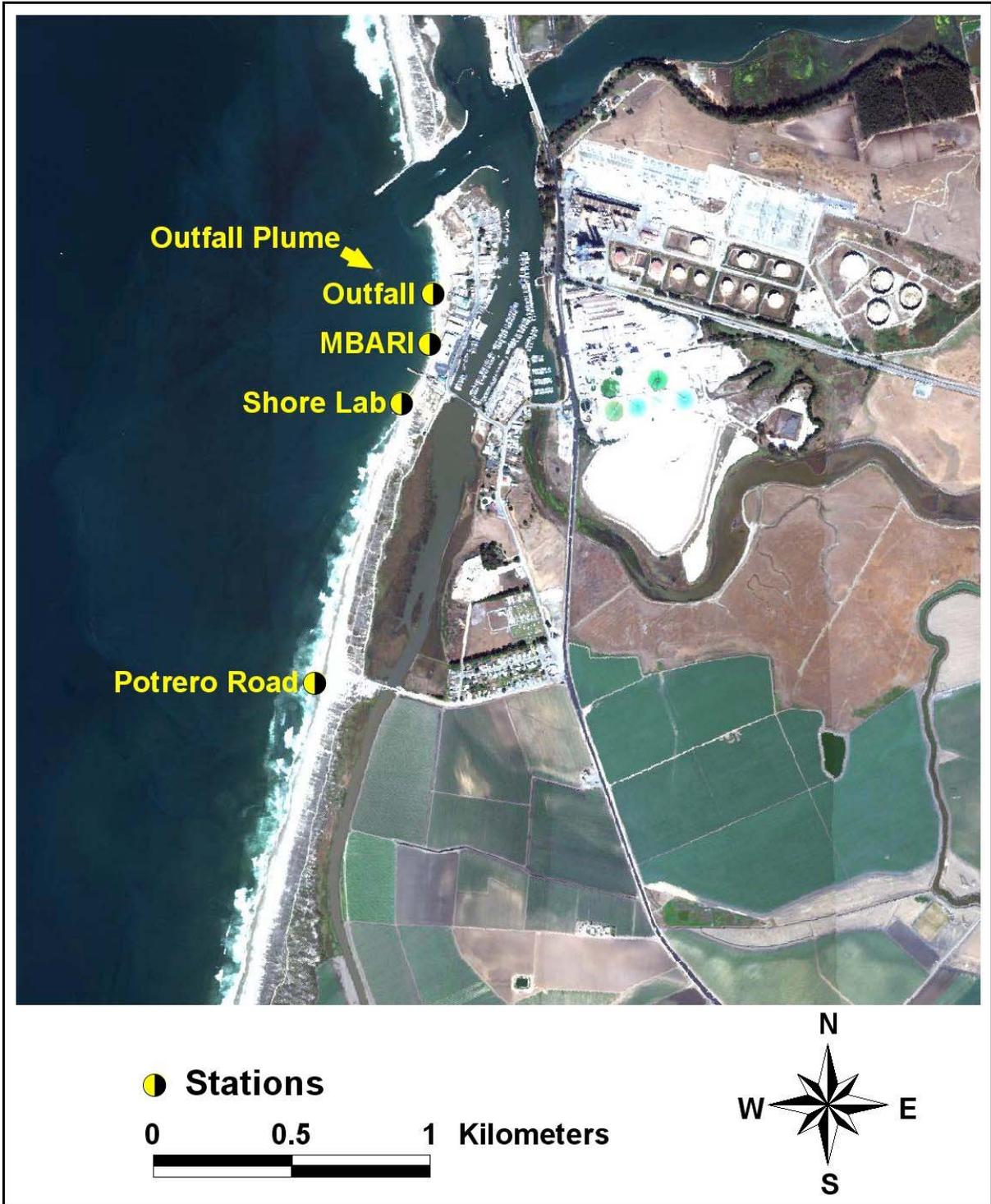


Figure 3-1. Location map. Stations for intertidal and shallow subtidal sampling are along transects indicated by the symbols. The thermal outfall plume is indicated.

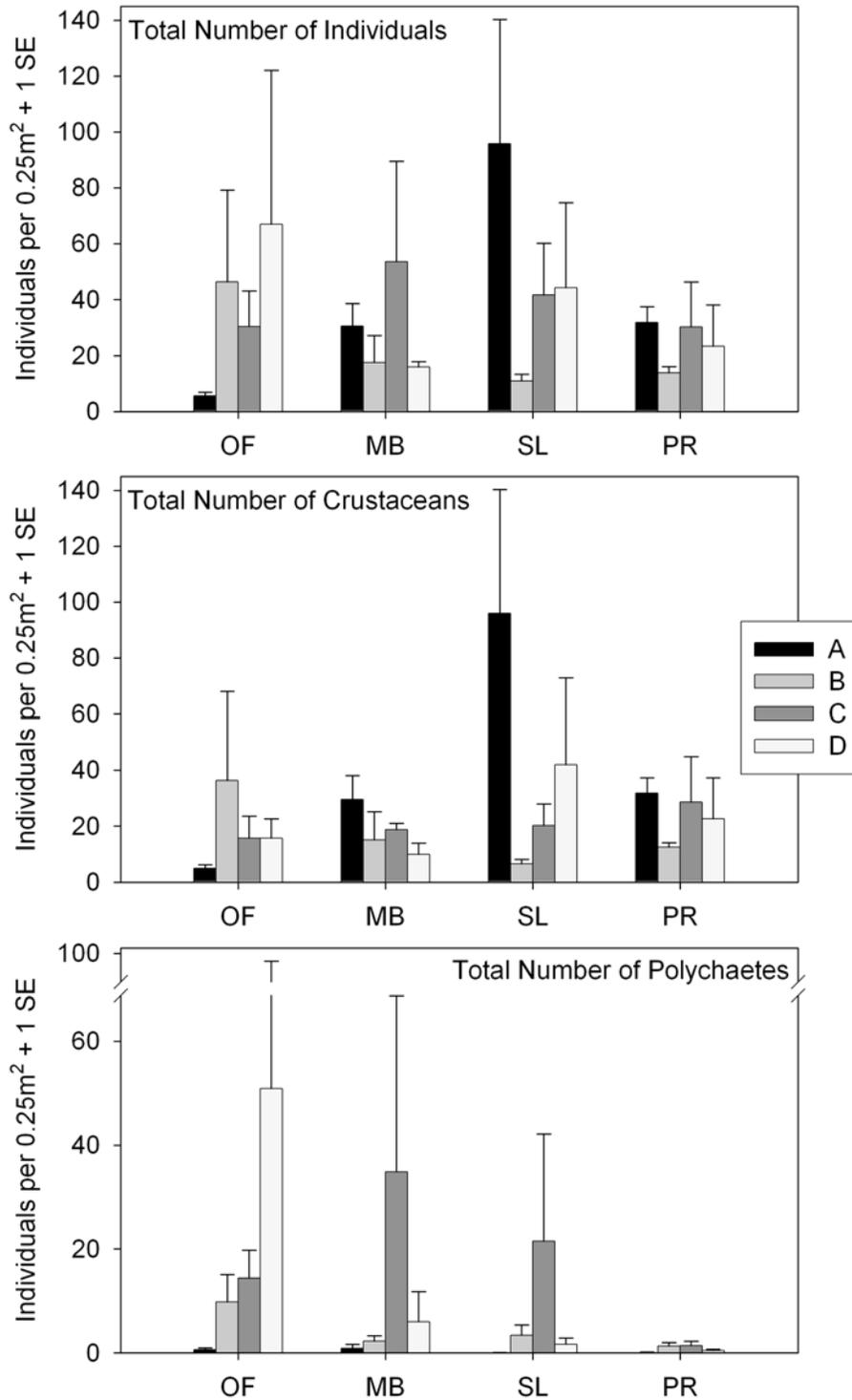


Figure 3-2. Variations in the number of individuals of all benthic invertebrates, crustaceans, and polychaete worms at the four sampling sites from the high (A) to the low intertidal (D) beach. Means and standard errors (SE) based on the following sample sizes listed by station and from high (A) to low (D) elevation: OF – 6, 6, 6, 2; MB – 5, 4, 3, 2; SL – 6, 6, 6, 5; and PR – 6, 6, 6, 5.

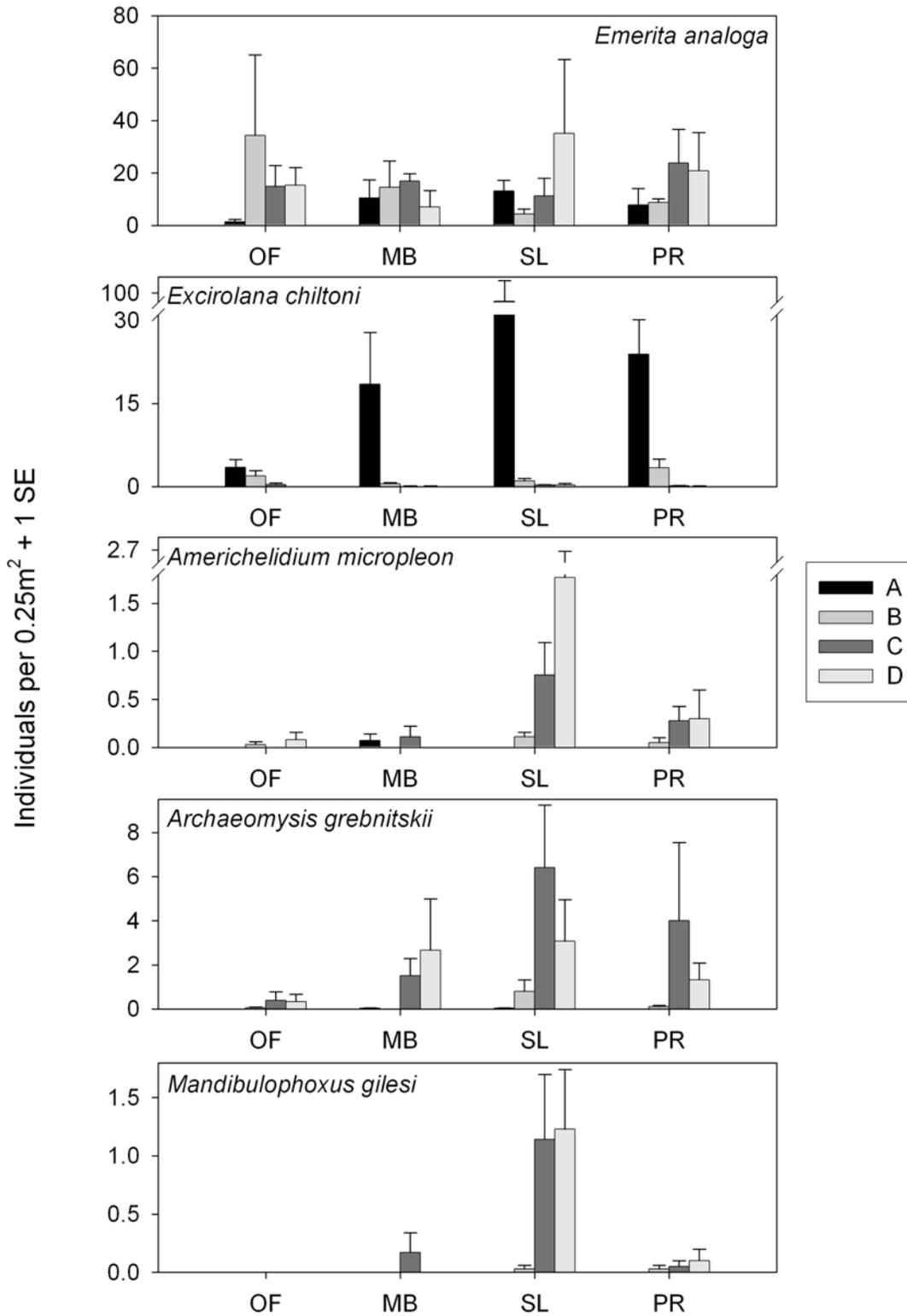


Figure 3-3. Abundance changes for the five most abundant crustacean species at the four sites from the high to low intertidal beach. Means and SE based on same sample sizes as Figure 3-2.

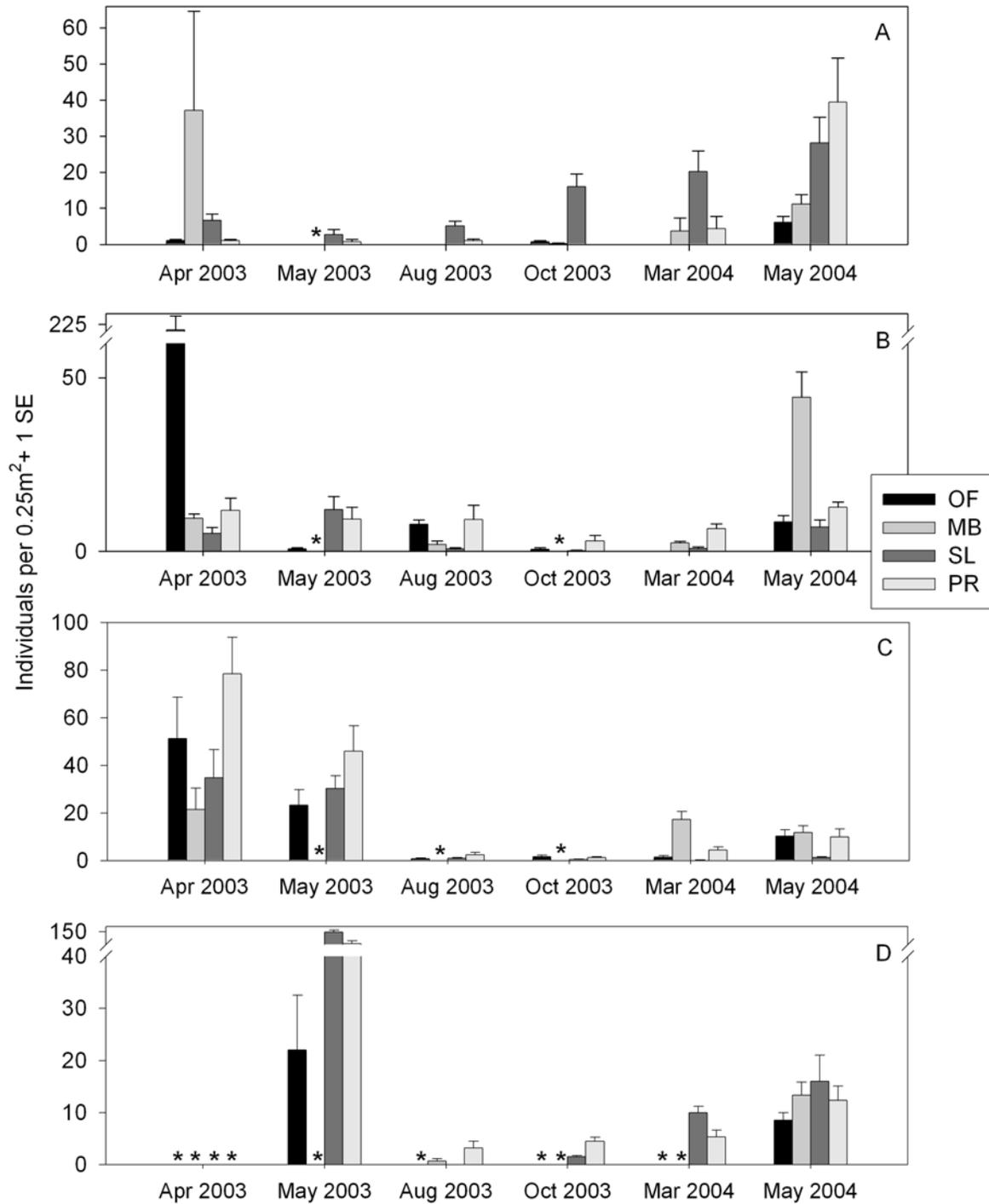


Figure 3-4. Temporal variations in *Emerita* collected during each of the first six sampling dates at the four sites from the high (A) to the low (D) intertidal beach. Asterisk indicates no samples collected. At each station, collection date, and elevation n = 6 samples, except for the following: May 2003 n = 3 samples for each station and elevation; Oct 2003 n = 5 samples for OFB, OFC, and SLC, and Mar 2004 n = 5 samples for OFB.

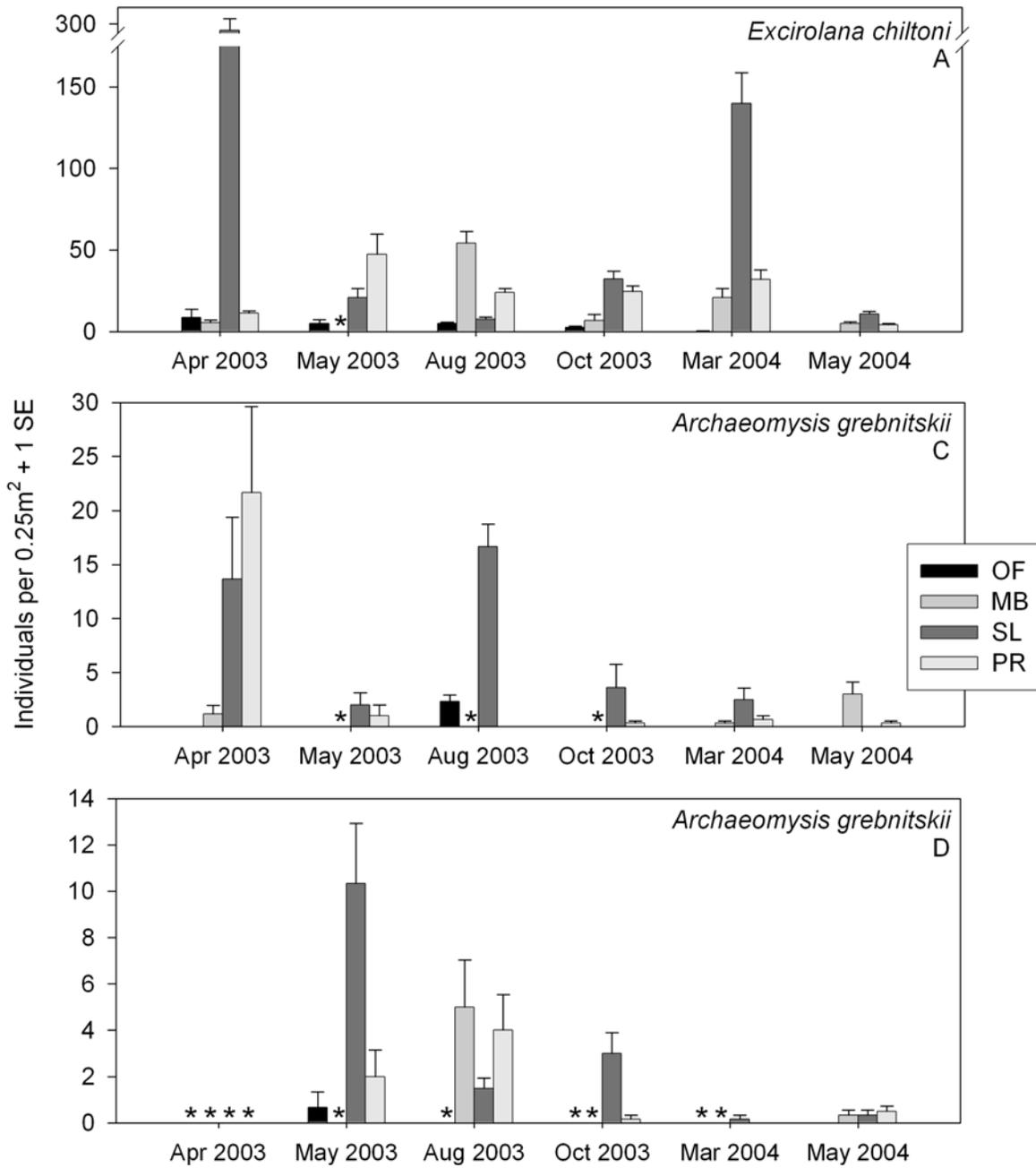


Figure 3-5. Temporal variations in *Exciorolana* on the high intertidal beach (A) and *Archaeomysis* on the low beach (C, D). Asterisk indicates no samples collected. Means and SE based on same sample sizes as in Figure 3-4.

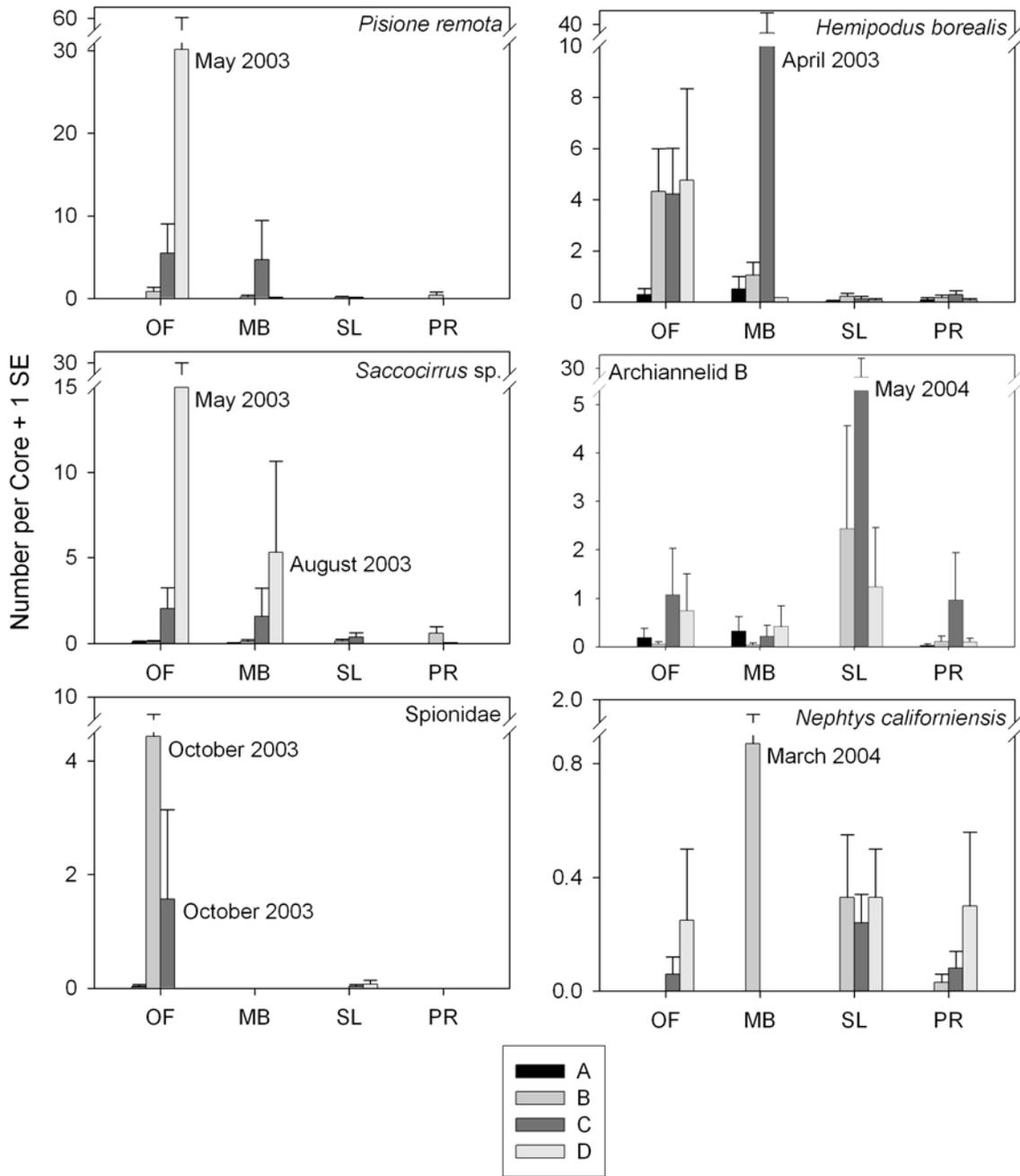


Figure 3-6. Abundance changes for the six most abundant polychaete species at the four sites from the high (A) to the low (D) intertidal beach. Means and SE based on same sample sizes as in Figure 3-2. Each major peak is from a single time period as indicated in the graph.

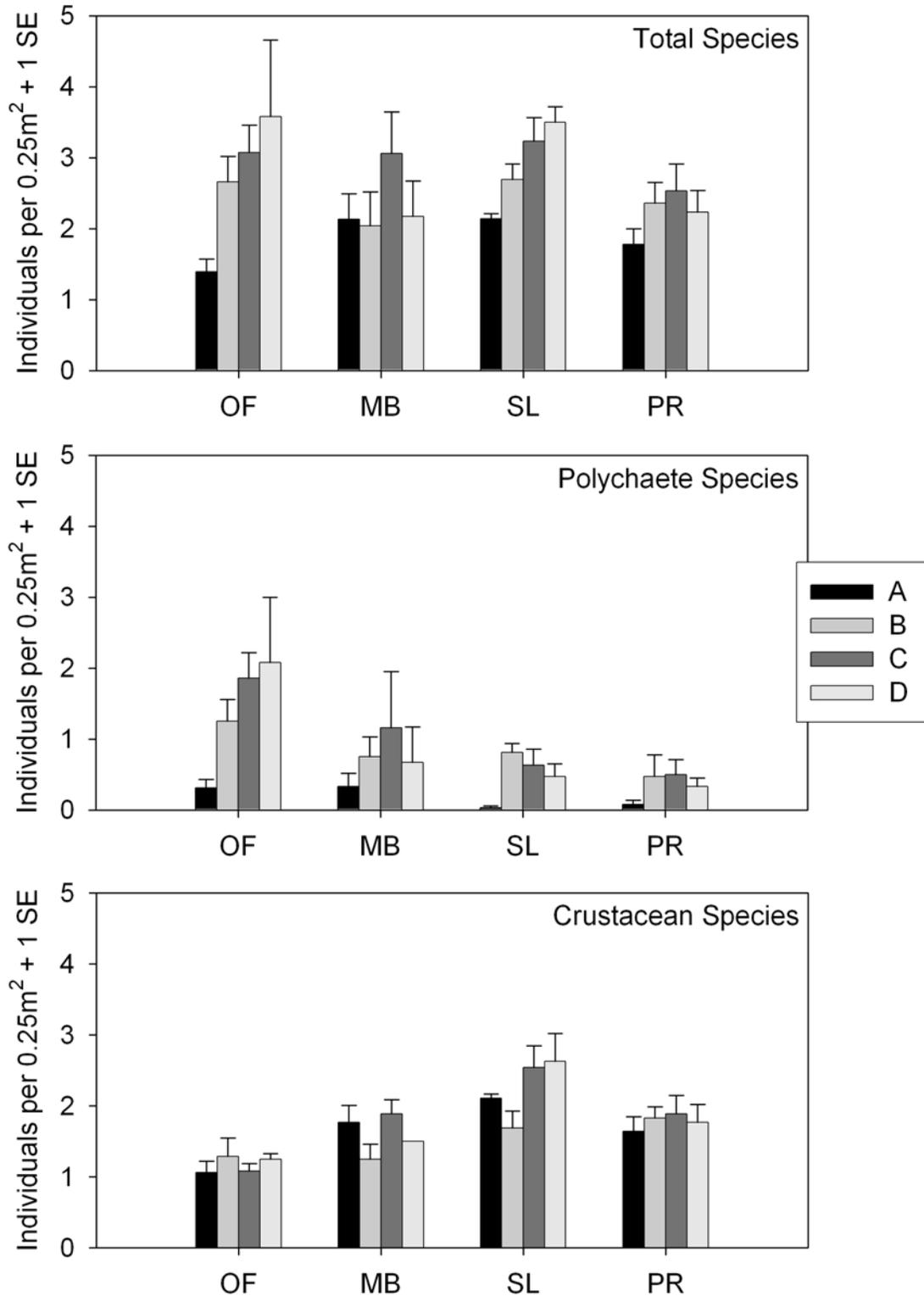


Figure 3-7. Variations in the number of species of all benthic invertebrates, crustaceans, and polychaete worms at the four sampling sites from the high (A) to the low (D) intertidal beach. Means and SE based on same sample sizes as in Figure 3-2.

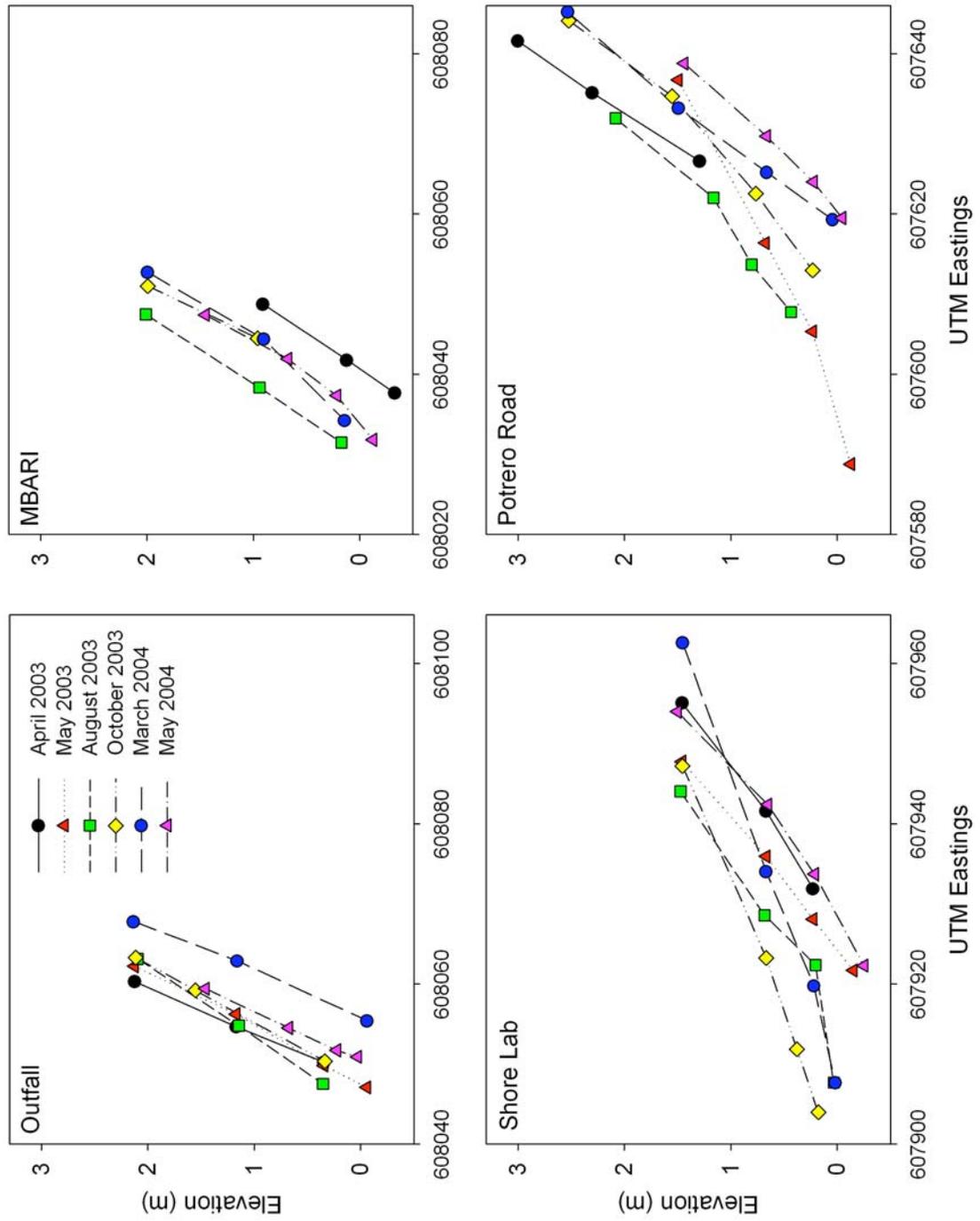


Figure 3-8. Changes in beach elevation for the first six sampling periods at each site. The Shore Lab and Potrero beaches are twice as wide as the other two and less steep.

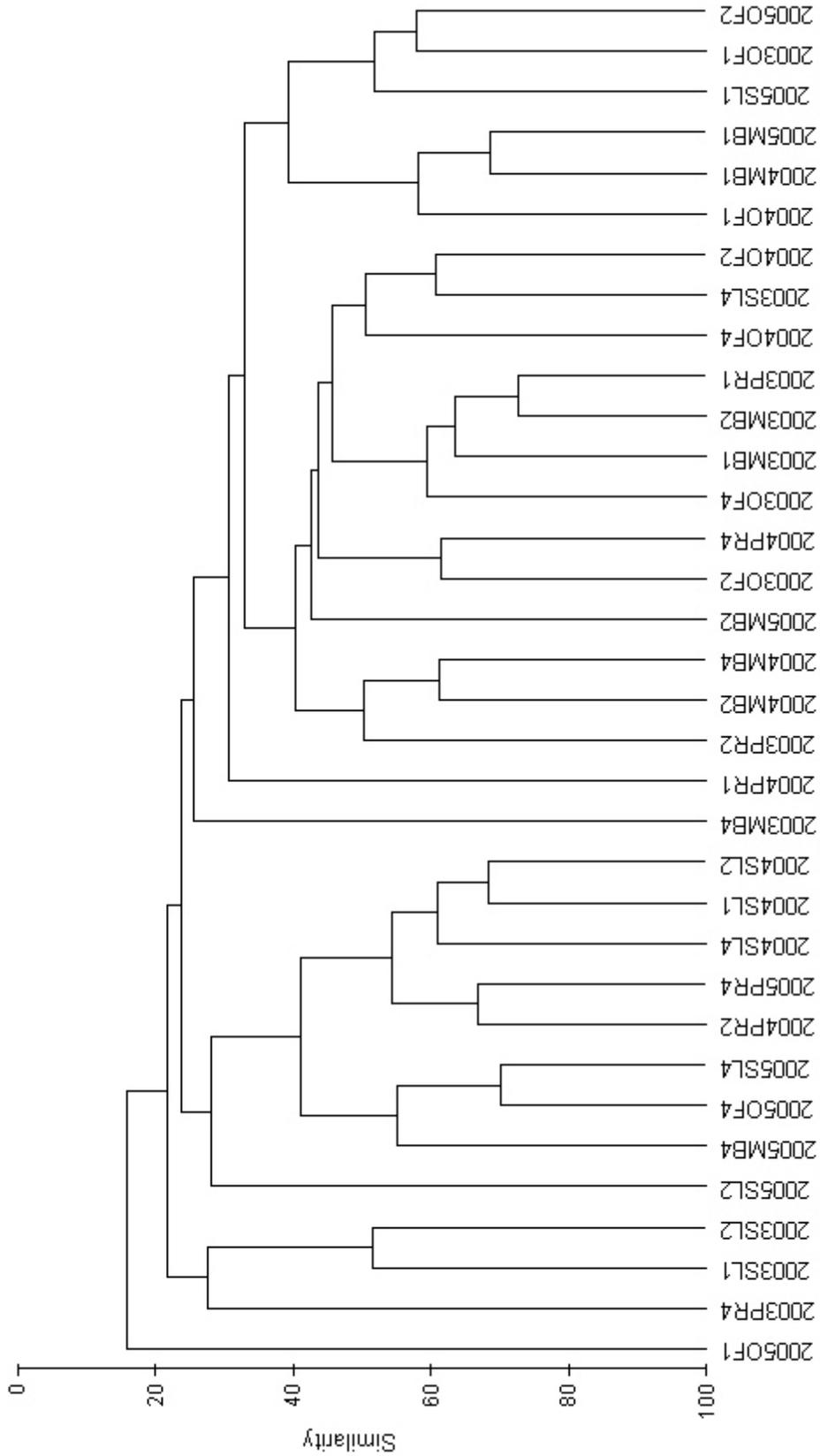


Figure 3-9. Cluster analysis showing no distinct assemblages grouping by water depth, site, or time of sampling.

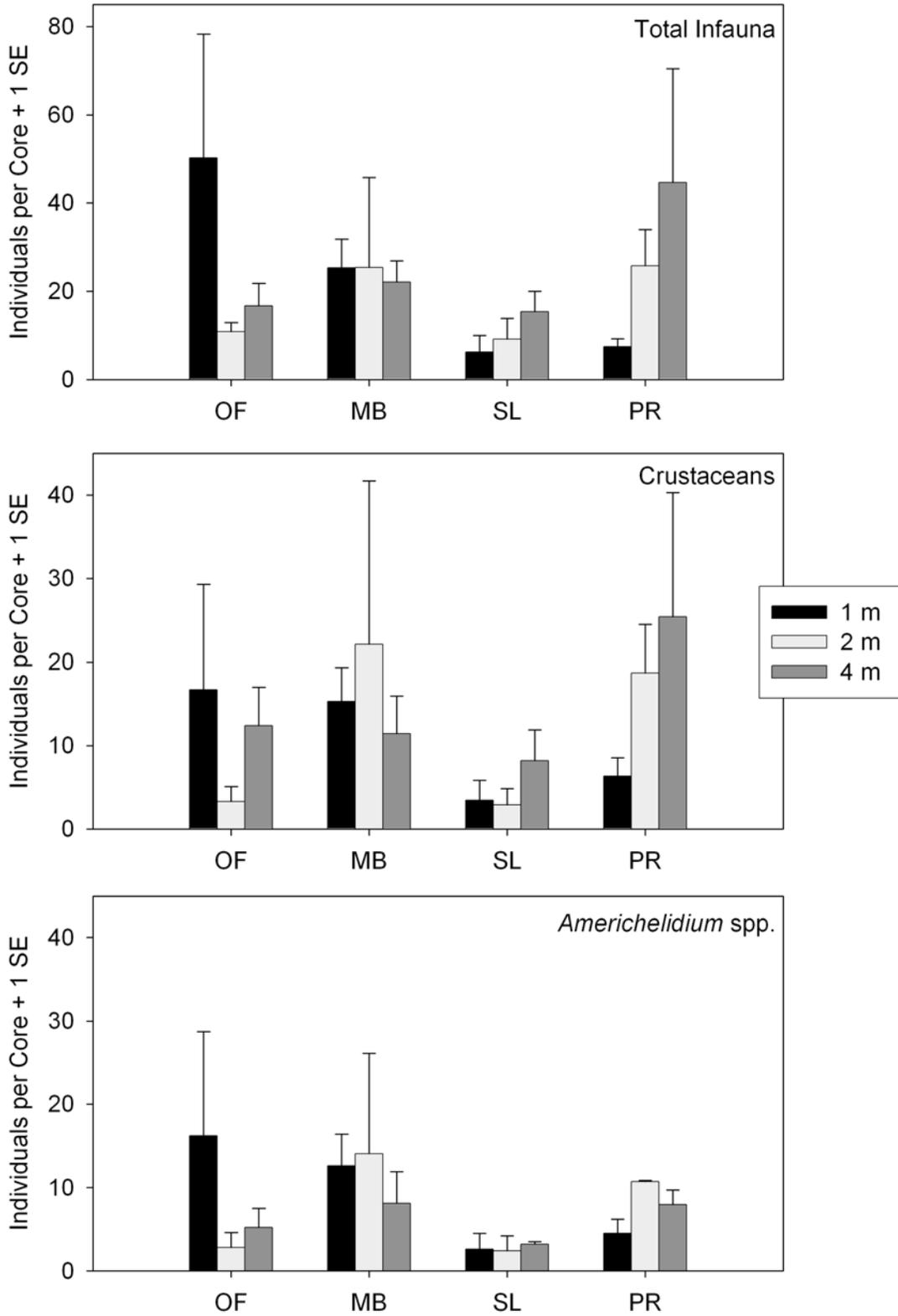


Figure 3-10. Number of individuals of all infauna, crustaceans, and *Americhelidium* spp. at the three water depths for each site (means and SE; n = 18 samples for each mean except for PR 1 m and PR 2 m where n = 12).

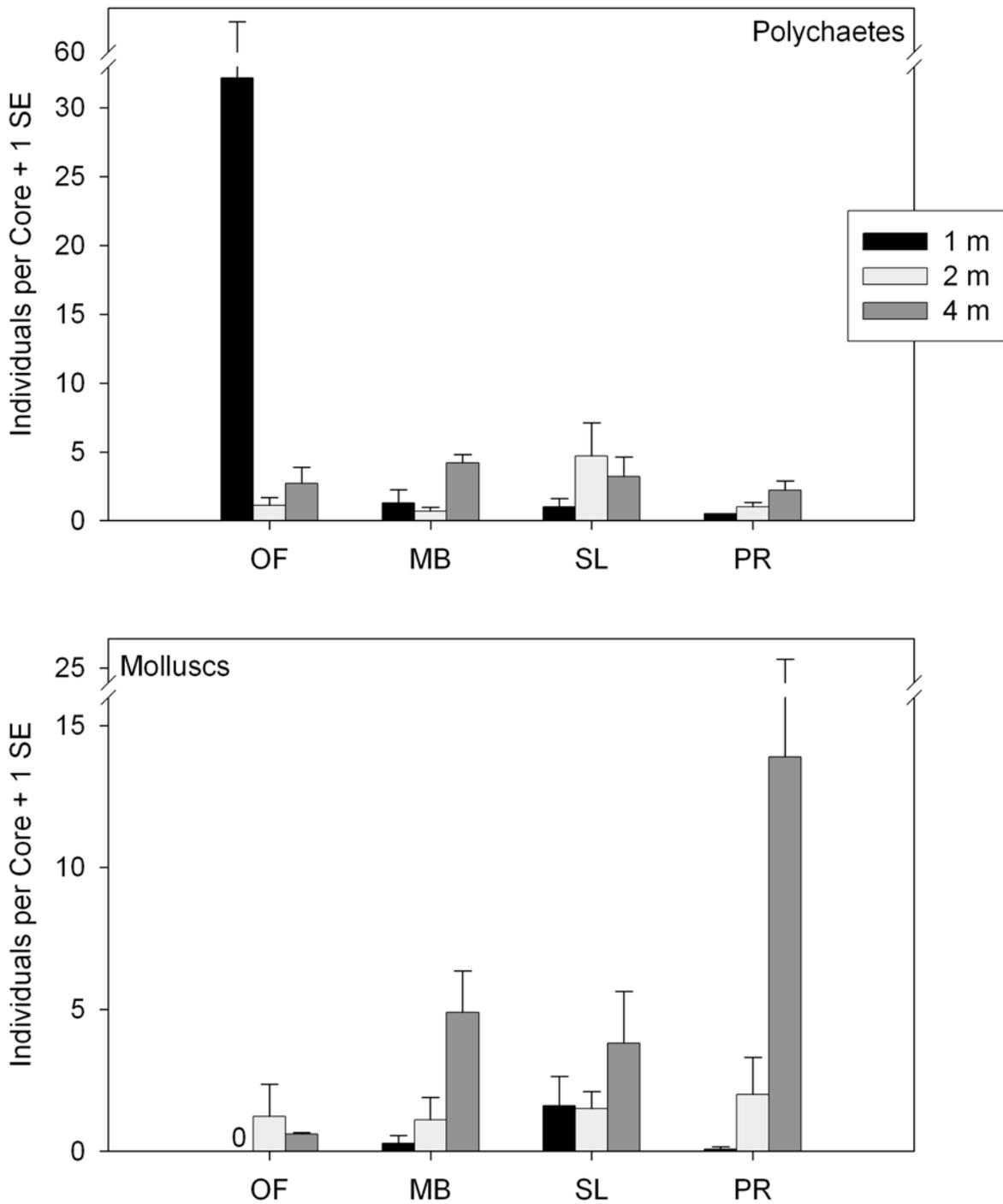


Figure 3-11. Number of individuals of polychaete worms and molluscs at the three water depths for each site (means and SE; sample sizes as in Figure 3-10).

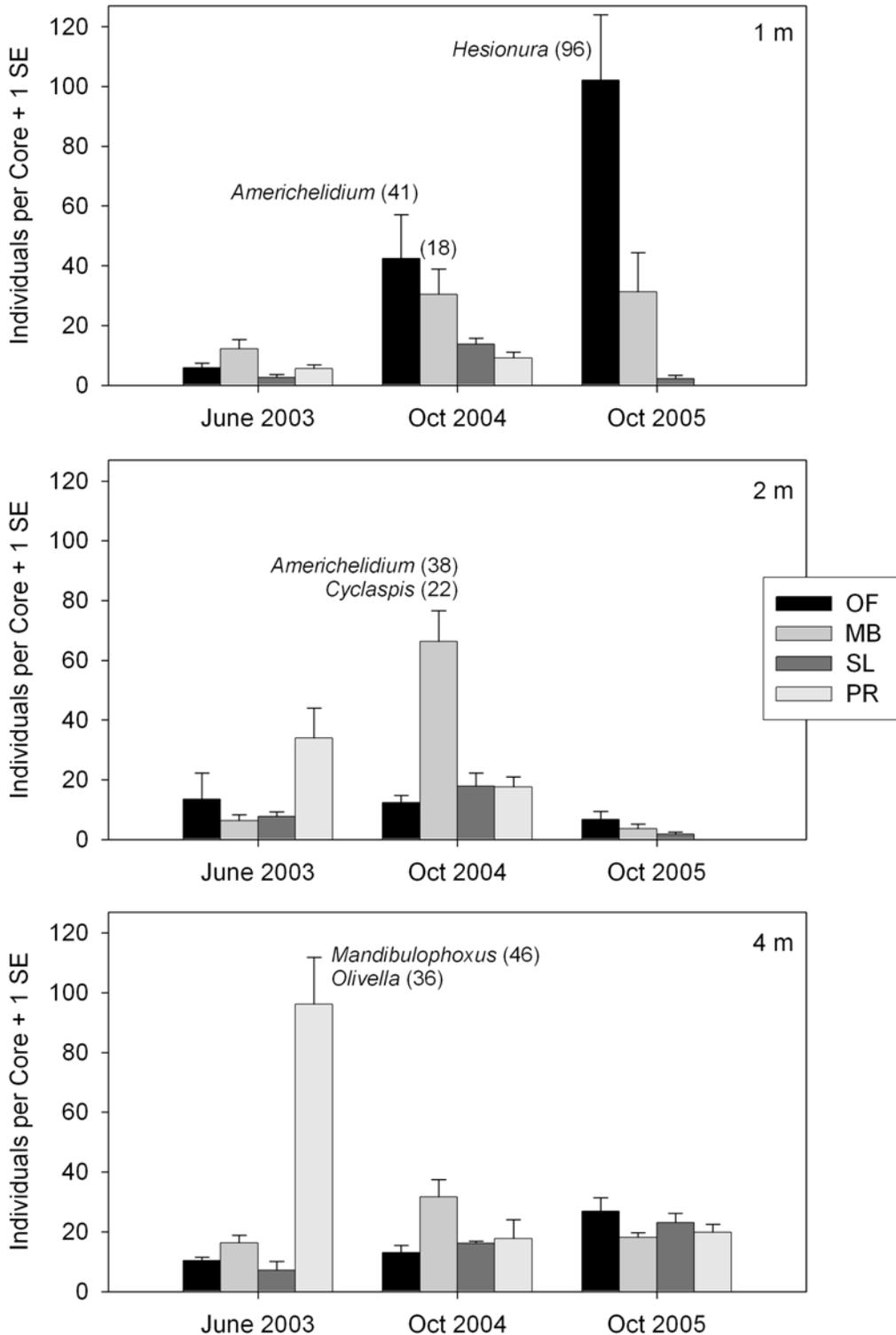


Figure 3-12. Annual changes in the total number of individuals in the shallow subtidal beach (means and SE; n = 6 samples for each mean). There were no samples taken at PR 1 m and PR 2 m in October 2005. Means of selected taxa are shown in parentheses for major peaks.

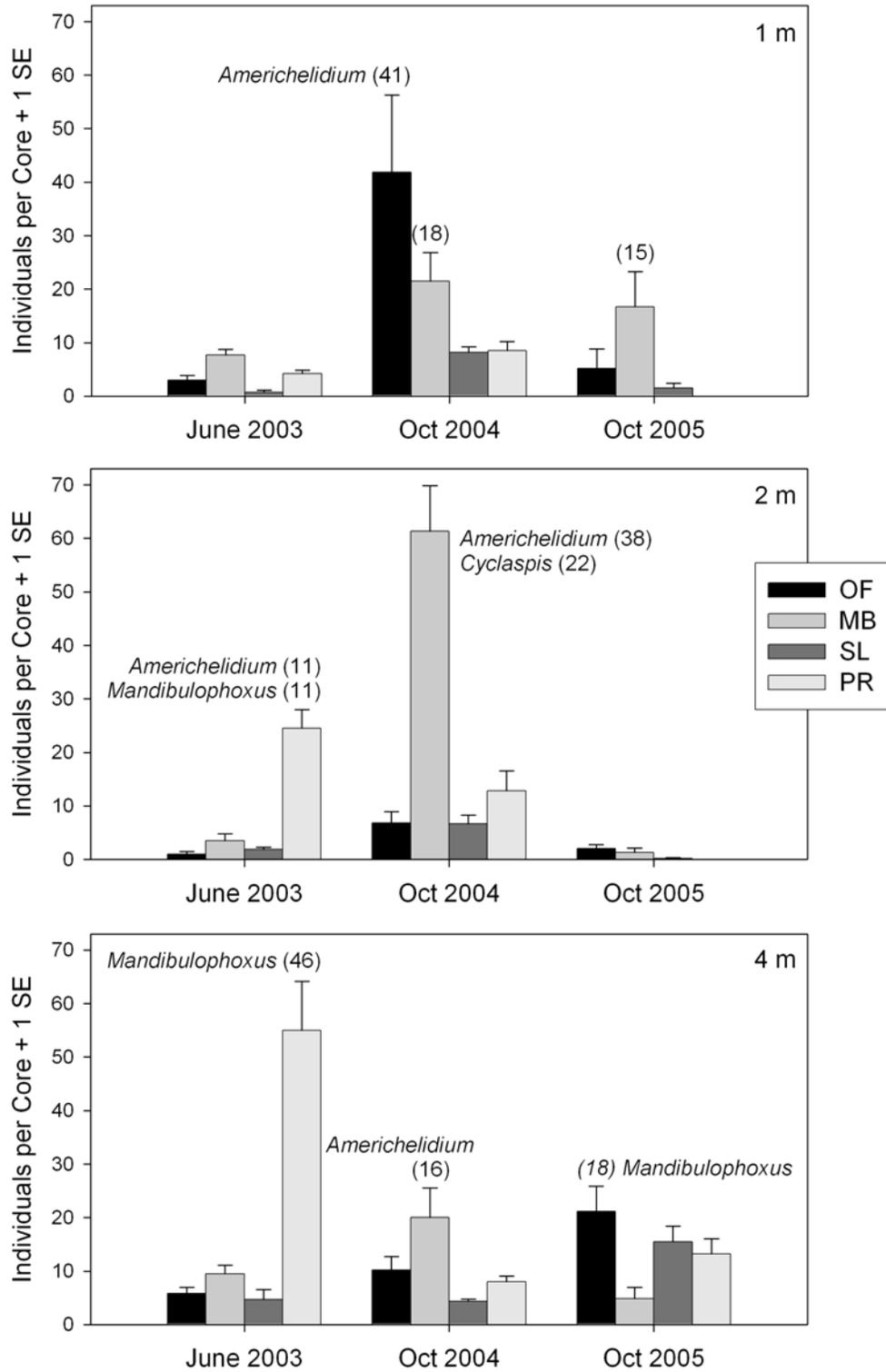


Figure 3-13. Annual changes in the number of crustacean individuals in the shallow subtidal beach (means and SE; n = 6 samples for each mean). There were no samples taken at PR 1 m and PR 2 m in October 2005. Means of selected taxa are shown in parentheses for peaks.

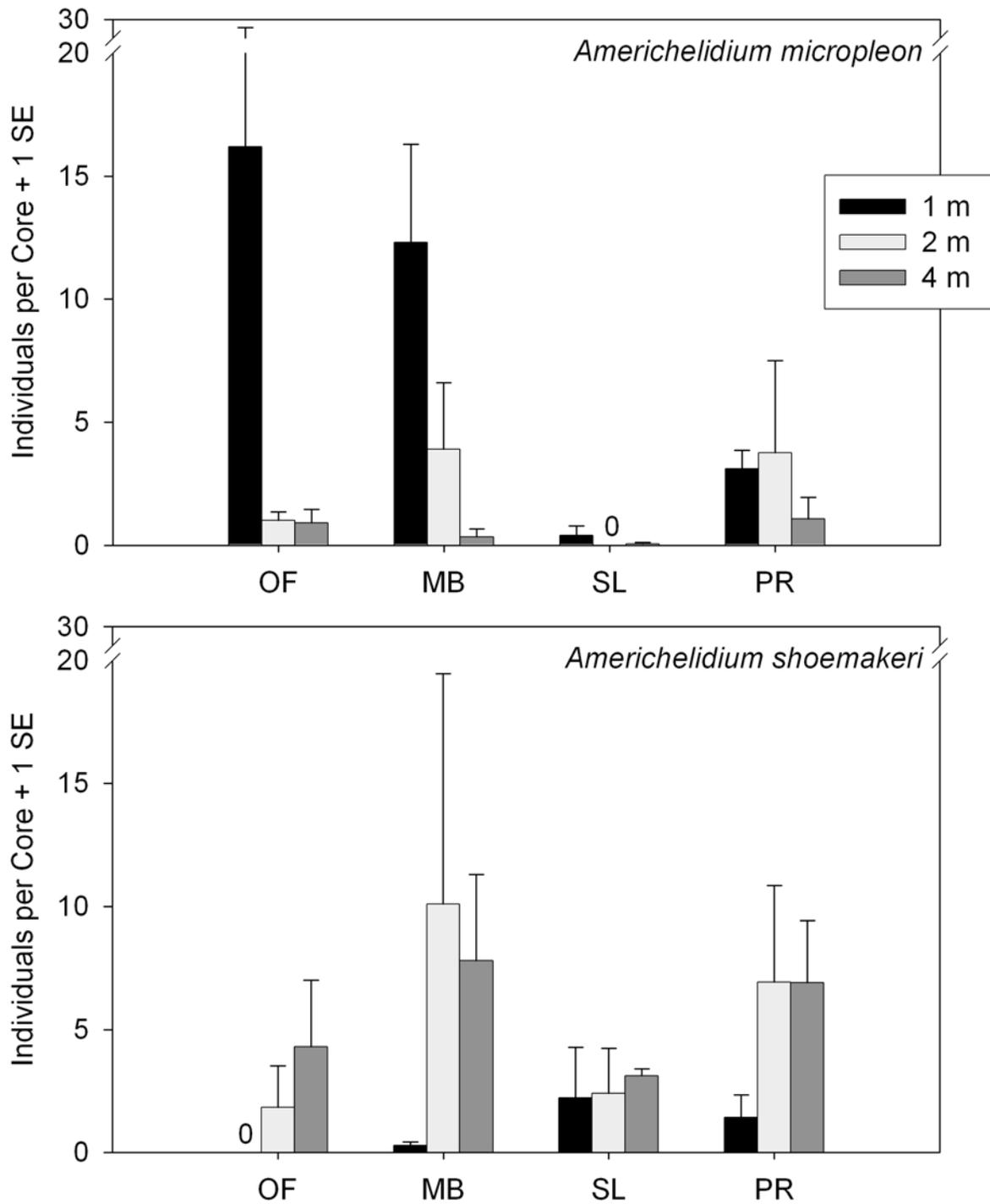


Figure 3-14. Abundance patterns in the two species of *Americhelidium*, the numerically dominant amphipod crustacean, at the three water depths for each site (means and SE; same sample sizes as Figure 3).

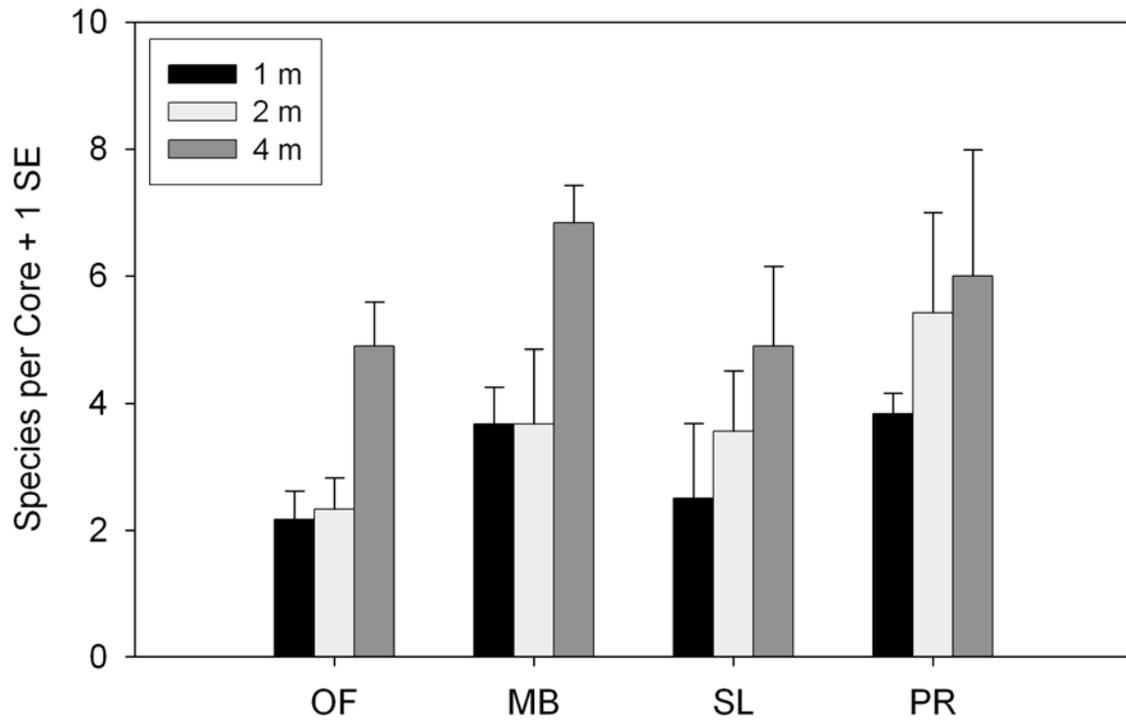


Figure 3-15. Number of species at the three water depths for each site (means and SE; same sample sizes as Figure 3).

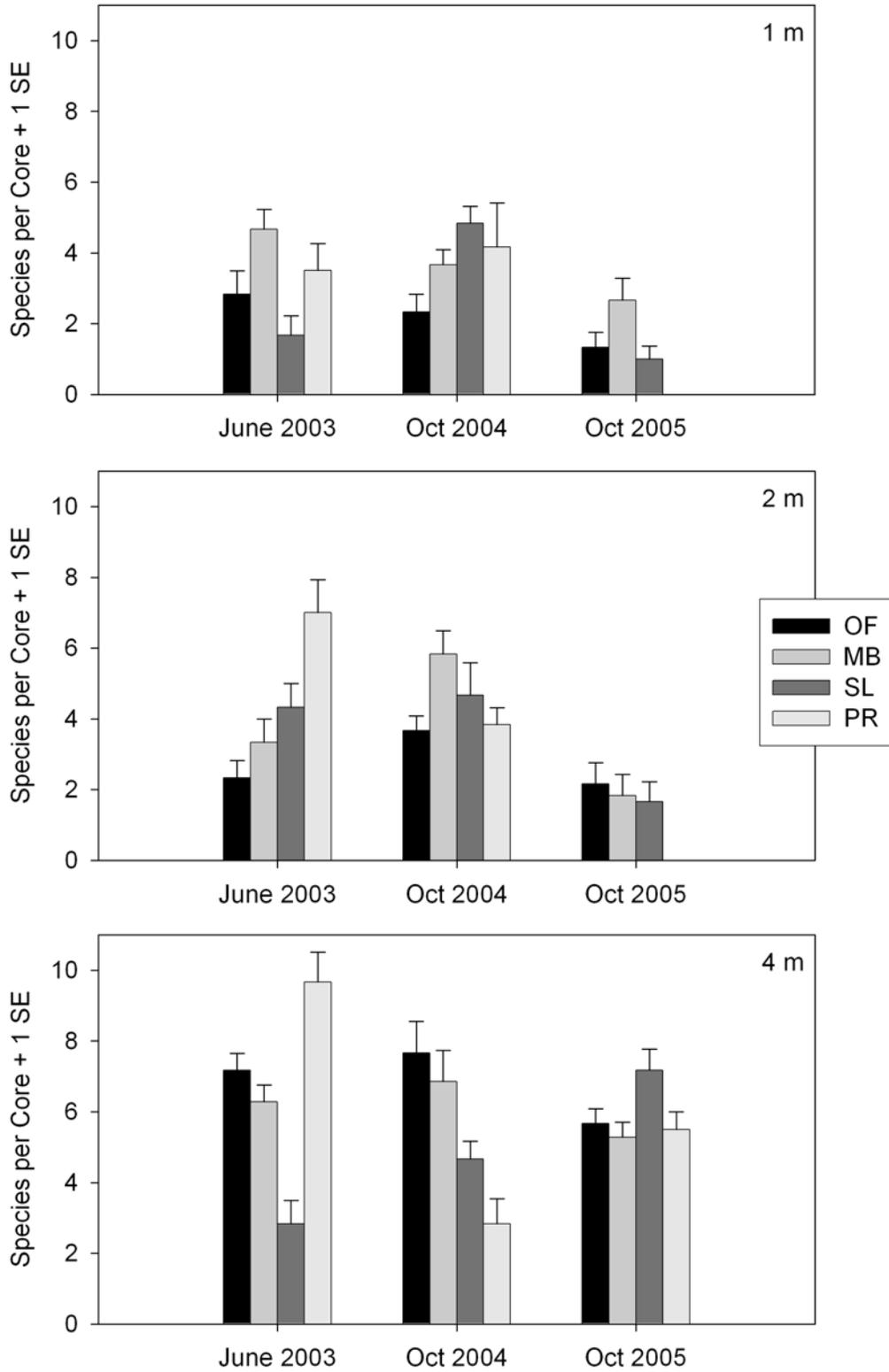


Figure 3-16. Annual changes in the number of species in the shallow subtidal beach (means and SE; n = 6 samples for each mean). There were no samples taken at PR 1 m and PR 2 m in October 2005.

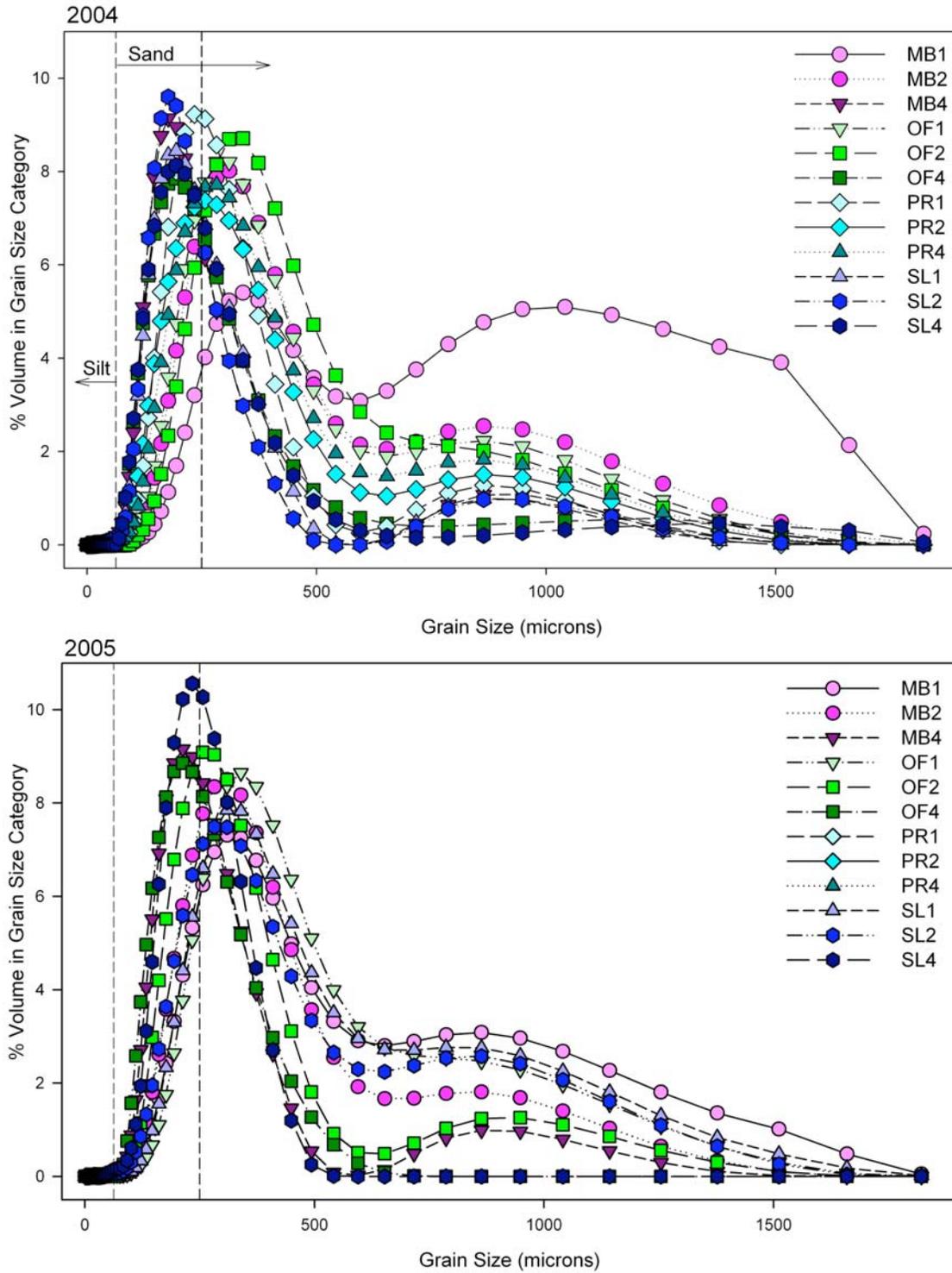


Figure 3-17. Changes in grain size patterns among water depths, sites, and years.

Fig

4 Fish

Prepared by James Oakden

4.1 Introduction

The only fish study proposed for inclusion in this project was the creation of a historical database of unpublished reports from the Moss Landing vicinity. Several fish studies have already been done on the outfall (Tenera 2000), mostly related to larval fish and entrainment. It was thought that no further fish studies were warranted at this time due to the extreme difficulty in relating fish distributions to the outfall. However, during the period of this study Bat Ray (*Myliobatis californica*) aggregations were observed in the outfall plume. It was felt that this observation should be reported, so a list of the recent bat ray observations were compiled for inclusion in this report.

4.2 Historical Data

As part of this study, a database was prepared by Aaron Carlisle and Gregor Cailliet of Moss Landing Marine Laboratories which compiles a number of unpublished studies on fish from Elkhorn Slough and the Monterey Bay waters near Moss Landing. The data were not previously collated, have generally not been included in previously published databases, and are often not in easily located archives. The main sources were Master's thesis and uncataloged reports in the MLML library, the personal archive of Gregor Cailliet, who has been the ichthyology professor at MLML since 1973, and through personal interviews with former MLML students and other Monterey Bay researchers who performed the research. The database will be included on the CD for this project. The database includes a detailed appendix which allows interpretation of the metadata associated with each entry.

Sources of Data in the Database:

The original data from the following projects have been entered into the Elkhorn Slough Historical Fish Database:

- Barry, J., 1983. Utilization of shallow marsh habitats by fishes in Elkhorn Slough, California. MS Thesis, San Jose State University. 95 pp.
- Bennett, T., 1993. Resource partitioning of two fish ectoparasites, *Lironeca vulgaris* and *Lironeca californica* (Class Isopoda, Family Cymothoidae). MS Thesis, San Jose State University. 46 pp.
- Brown, J., 2003. An evaluation of the nursery role of estuaries for flatfish populations in central California.. PhD Thesis, University of California Santa Cruz. 97p.
- Creel Census (funded by Pacific Gas and Electric), 1974-1976.

- Hall, M.A., 2000. Species composition and temporal and spatial characteristics of fish assemblages surveyed at Old Salinas River and Bennett Slough, California. Senior Thesis, Southampton College, Long Island University. 54 pp.
- Lindquist, D., 1998. The effects of erosion on the trophic ecology of fishes in Elkhorn Slough, California. MS Thesis, California State University Hayward. 65 pp.
- Moss Landing Marine Laboratories records of class field trips, class projects, and visiting groups (1964-present)
- Oxman, D., 1995. Seasonal abundance, movements, and food habits of harbor seals (*Phoca vitulina richardsi*) in Elkhorn Slough, California. MS Thesis, California State University Stanislaus. 125 pp.

Unobtained Data:

There were a number of additional studies that could potentially have sampling data that could be entered into the database. It has been very problematic to get the original data from many studies despite many attempts. Unfortunately, we were unable to obtain the original data from the following projects. It should be out there somewhere, and while we were unable to get it, it may be possible to input the original data at some point in the future.

- Ackerman, L.T., 1971. Contributions to the biology of the leopard shark, *Triakis semifasciata* (Girard) in Elkhorn Slough, Monterey Bay, California. MS Thesis, Sacramento State College, CA. 54 pp.
- Antrim, B., 1981. Habitat and food resource utilization of three species of in Elkhorn Slough, Monterey Bay, California. California State University Fresno. 83 pp.
- Appiah, J.C., 1977. Species composition and abundance of fish populations in Bennett Slough, Monterey Bay, California. MS Thesis, California State University Fresno, 63 pp.
- Cailliet, G., Species composition, abundance and ecological studies of fishes, larval fishes, and zooplankton in Elkhorn Slough. *In: Ecologic and hydrographic studies of Elkhorn Slough, Moss Landing, and nearshore coastal waters, July 1974-June 1976.* Moss Landing Marine Laboratories, Moss Landing, CA. 1977. 462 pp.

(The original data from the study above appear to be lost, hopefully it will turn up in the future)

- Kao, J., 2000. Diet, daily ration and gastric evacuation of the leopard shark (*Triakis semifasciata*). MS Thesis, California State University Hayward. 96 pp.
- Martin, L.K., 1982. Growth and reproduction of the bat ray *Myliobatis californica* Gill, in California. MS Thesis, San Jose State University, San Jose, CA. 87 pp.

- Ruagh, A., 1976. Feeding habits of silversides (family Atherinidae) in Elkhorn Slough, Monterey Bay, California. MS Thesis California State University Fresno. 60 pp.
- Talent, L., 1973. The seasonal abundance and food of elasmobranchs occurring in Elkhorn Slough, Monterey Bay, California. MS Thesis, California State University Fresno. 58 pp.

4.3 Bat Ray Observations

Jim Oakden observed aggregations of Bat Rays (*Myliobatis californica*) at the surface of the power plant outfall plume on 5 January 2004, as did Gala Wagner a few days later while doing plankton tows as part of this project. During the winter bird surveys in 2005 Elizabeth Phillips observed ray congregations from shore through a spotting scope.

Diana Steller, the current diving officer at MLML, observed the bat ray aggregation during a dive trip in late January 2004:

“January 2004 - we saw ~15-20 rays swimming in the outflow. Most of them were ~ 3-4' in 'wing' span. This observation was based on driving a whaler through the outflow and then snorkeling over the outflow numerous times for about 15 minutes. The rays were definitely actively swimming round and round to stay within the warm outflow because as we swam across the outflow, it was so strong that it pushed us out of the main path. These surface sightings occurred while motoring by the outflow for approx. 15 minutes at mid-day.”

Sporadic reports of such aggregations have been received in the past (Greg Cailliet, pers comm.), but no one has followed up on them. Table 4-1 is a compilation of the information gathered in a rapid informal survey at MLML.

4.4 Discussion

The congregation of bat rays in the outfall plume appears to be a relatively new phenomenon. John Heine, former dive officer at MLML, and John Oliver, PI on this project and longtime researcher at MLML, have made hundreds of trips over the area over the past 30 years, and did not ever observe aggregations. Jim Oakden has passed by the outfall monthly for the past 15 years, and first noticed the rays in 2004. The surface aggregations are visible from some distance away (>100 m), so it seems unlikely they would have gone unnoticed had they been present.

Bat rays are bottom feeders, which excavate clams, echinoderms, and crustaceans from sandy bottoms. The pits they leave during these excavations have been well documented, and are one of the major disturbances and causes of small-scale habitat heterogeneity in some sandy nearshore areas of California.

It seems possible that the aggregations in the warm water (up to 8°C above ambient) of the outfall plume may be related to thermoregulation. Bat rays in Tomales Bay exhibit diurnal movements that have been linked to thermoregulatory efficiency (Matern *et al.* 2000). In elasmobranchs, metabolic rates tend to increase with increasing ambient temperature. In Tomales Bay the rays move to the warmer areas of the bay to feed, taking advantage of their

higher metabolic rates in the energetically-demanding food excavating, then move to cooler areas of the Bay to rest. The situation at the power plant outfall is a bit different, in that the bottom-feeding rays seem to be resting in the warm water in winter months.

A thermoregulatory explanation similar to the Tomales Bay situation could apply at the power plant outfall. When the ambient water temperature is low (12°C) bat rays may go into the warm water to elevate their body temperatures so that they can then forage more effectively on the bottom away from the plume. This hypothesis could be tested with a straightforward series of experiments and field observations. The aggregations could also relate to reproduction, about which little is known.

4.5 Literature Cited

- Matern, S., Cech, J. and T. Hopkins. 2000. Diel movements of bat rays, *Myliobatis californica*, in Tomales Bay, California: evidence for behavioral thermoregulation? *Environmental Biology of Fishes* 58: 173–182.
- Tenera, C. (2000). Moss Landing Power Plant Modernization Project 316(b) Resource Assessment, Prepared for Duke Energy Moss Landing.

4.6 Tables and Figures

Table 4-1: Observations of Bat Rays (*Myliobatis californica*) at the surface in the Moss Landing power plant outfall plume. P=present, NP=not present

Date	Time	Present?	source	Date	Time	Present?	source
1/5/04	900	P	Oakden	2/7/05	840	P	Phillips
1/7/04		P	Wagner	2/7/05	1215	P	Phillips
1/04		P	Steller	2/7/05	1610	P	Phillips
2/5/04		P	Wagner	2/7/05	1750	P	Phillips
2/17/04	900	P	Oakden	2/15/05	900	P	Oakden
3/4/04		P	Wagner	3/14/05	900	NP	Oakden
3/8/04	900	NP	Oakden	3/24/05		P	Wagner
4/12/04	900	NP	Oakden	3/05		P	Steller
10/04		NP	Phillips	4/4/05	1000	NP	Hansen
10/04		NP	Oakden	5/9/05	1000	NP	Hansen
10/04		NP	Wagner	5/31/05	all day	NP	Phillips
11/20/04		NP	Oakden	6/1/05	all day	NP	Phillips
1/18/05	900	P	Oakden	6/4/05	all day	NP	Phillips
1/22/05	820	P	Phillips	6/6/05	1000	NP	Oakden
1/22/05	1130	NP	Phillips	6/9/05	all day	NP	Phillips
1/22/05	2535	P	Phillips	7/7/05	1100	P	Steller
1/22/05	1720	P	Phillips	7/18/05	1000	NP	Oakden
1/25/05	735	P	Phillips	8/8/05	1000	NP	Oakden
1/25/05	950	P	Phillips	9/12/05	1000	NP	Oakden
1/25/05	1345	P	Phillips	10/3/05	1000	NP	Oakden
1/25/05	1715	P	Phillips	11/7/05	1000	NP	Oakden
2/4/05	715	P	Phillips	12/12/05	1000	NP	Oakden
2/4/05	1015	P	Phillips	1/9/06	1000	P	Oakden
2/4/05	1320	P	Phillips	2/6/06	1000	P	Oakden
2/4/05	1720	P	Phillips	3/13/06	1000	P	Oakden
2/5/05	900	P	Oakden				

5 Birds

Prepared by Elizabeth M. Phillips, James Oakden, and James T. Harvey

5.1 Introduction

The waters within Monterey Bay support an incredible abundance and diversity of marine life, including 90 seabird species (Ainley and Terrill 1996). Strong upwelling events and subsequent primary production, in combination with the central location of Monterey Bay between arctic and tropical habitats, and the variety of habitats and prey available, attract large amounts of marine vertebrates. Monterey Bay has been identified as an area of biological importance for seabirds, primarily because of the strong upwelling and subsequent primary production (Ainley 1976, Briggs et al. 1987, Benson 2002). The unique bathymetry of Monterey Bay includes a deep submarine canyon that bisects the continental shelf and attracts species to the shallow, nearshore habitat, the productive shelf-edge habitat, and the deep water habitat, all within a few kilometers of shore (Ainley and Terrill 1996).

Some species of seabirds use Monterey Bay as a foraging area during winter (e.g. surf scoters), some migrate to Monterey Bay in the summer and fall to take advantage of the high productivity (e.g. sooty shearwaters), and some reside in the area year round (e.g. Brandt's cormorants). Nearly one half of the seabirds nesting in California and millions more seasonal migrants are observed in Monterey Bay at various times of the year (Briggs et al. 1987). Mean densities of birds in Monterey Bay are approximately 172.5 birds/km² and average approximately 20.5 species/month (Mason 1997). Greatest numbers of seabirds are observed nearshore in mid-fall and early spring, when there is an overlap between wintering birds and the arrival or departure of migratory species (Benson 2002, Henkel 2003). The strong upwelling events in early spring, combined with the unique bathymetry of Monterey Bay provide excellent habitat for seabirds (Ainley and Terrill 1996). Generally, seabirds in Monterey Bay can be divided into three categories, including Resident, Wintering, and Migratory species.

5.1.1 Resident seabirds

Resident seabirds are defined here as those species that breed within Monterey Bay, as well as those that breed in the areas surrounding Monterey Bay, and are present throughout the majority of the seasons. Commonly occurring resident seabirds include the Western gull, Caspian tern, pigeon guillemot, common murre, and Brandt's and Double crested cormorants (Baltz and Morejohn 1977, Ainley and Hunt 1991, Roberson 2002). The Brandt's cormorant breeds on piers, rocks and other structures and is commonly seen throughout Monterey Bay (within 50 km). The Western gull also breeds coastally on cliffs, islets and rooftops and is one of the most common and conspicuous species in Monterey Bay (Roberson 2002). Common murrens breed on islands to the north and south of Monterey Bay, and are observed year round offshore (Mason 1997).

5.1.2 Wintering birds

A number of seabirds migrate to Monterey Bay in the early fall and remain through the winter, using Monterey Bay as a rest stop and foraging area. Common species include surf

scoters, Western/Clark's grebes, California brown pelicans and Common and Pacific loons. Most of these species are much more abundant in the nearshore waters of the Bay (within 5 km), and commonly feed in shallow nearshore waters, either plunge or pursuit diving for prey (Henkel 2003).

5.1.3 Migratory seabirds

Many species of seabirds migrate to Monterey Bay in the late summer and early fall to take advantage of the high productivity in the region. Some species, such as the sooty shearwater, occur in incredibly large numbers in late summer and make up the majority of the birds encountered in Monterey Bay (Briggs et al. 1987, Ainley and Terrill 1996). Common migratory species include the shearwaters, Northern fulmars, and Heermann's gulls. Typically these birds arrive and remain in Monterey Bay for a couple of months, then make the long migration back to their breeding areas in late fall and winter.

The purpose of this study was to assess the utilization and distribution of seabirds in and around the power plant's thermal outfall just offshore of Moss Landing, California, in Monterey Bay. The study focused on quantifying bird distribution around the thermal plume in comparison to a control site. We set out to study all seabird species potentially present in Monterey Bay throughout the year, including resident, migratory, and wintering birds. In addition, data on marine mammal and other marine vertebrate (e.g. bat ray) occurrences at the two study sites were noted.

5.2 Methods

Surveys were conducted at both the thermal outfall plume ("Plume site"), readily visible from shore, and at a reference site ("Reference site") approximately 1,000 meters south of the Plume site. To minimize confounding variables, the plume and reference survey sites were of equal area (determined by the size of the thermal plume), and were equidistant from shore.

Surveys were conducted 3 times per year and corresponded to the 3 general bird assemblages, as follows: May/June surveys quantified the migratory assemblage, September surveys quantified the summer assemblage, and January/February surveys quantified the winter assemblage. Surveys were conducted on 4 randomly selected days for each of the 3 sample periods. Each daily survey consisted of 4 survey intervals corresponding to different tidal regimes: high tide, low tide, flood tide, and ebb tide. Each of the 4 daily survey periods comprised a snapshot of all of the birds and other animals present in the 2 survey areas at the survey time. The surveys occurred only during daylight hours, thus the high and low tides were either the low low tide or the high low tide, for example, depending on what low tide occurred during daylight hours.

All surveys were conducted from the second-level balcony at the Monterey Bay Aquarium Research Institute (MBARI) in Moss Landing, CA. A spotting scope and tripod was set at a known height on the balcony and leveled (tripod had internal level). Once the Plume site was found in the scope's view, the scope angle was set to that point. The center of the thermal plume was the center of the Plume site survey area, and an offshore buoy (M0) was used as a reference for the location of the Reference site, because it was approximately 90° to the south of the Plume site when the scope was swung around. The angle of the scope was not changed

when scanning between the Reference and Plume sites, to ensure that the distance from shore remained the same (Figure 5-1).

All birds within the scope's view were counted and identified to species level. In some cases when species could not be determined, the genus was noted (e.g. *Gavia* spp.). If birds entered the scope's view after surfacing from a dive, they were included in the count. Birds in flight were generally not included in the count, unless it was determined that they were interacting with the survey site (e.g. circling over the thermal plume, or landing on the surface of the water within the survey area). Marine mammals and other marine vertebrates were also identified and counted. The surveys took place for approximately 10 minutes at each site during 4 daily intervals to ensure adequate enumeration and identification of species.

Analyses focused on differences between the number and assemblage of birds and marine mammals present at the Reference and Plume sites, in addition to any patterns associated with changing tidal cycle or season. Species richness, diversity, and evenness were calculated for both sites and each season. Additionally, Chi-square analyses were conducted to quantify expected and observed proportions of birds at each site and in each season.

5.3 Results

Surveys were completed between May 2004 and September 2005 (Table 5-1). On a few occasions, all four daily surveys could not be completed, due to foggy weather. In general, all surveys were conducted in clear, relatively calm weather, and weather was not considered a factor in determining the number of birds sighted at either survey site. The general shape and width of the thermal plume varied with swell height and wind, but because the area of the plume was incorporated into the survey area for the reference site, this was not an issue. The thermal plume was detectable during all surveys, and tidal height did not affect our ability to locate the plume. We occasionally noted that the thermal plume was more "frothy" and the water in the plume seemed more turbulent, but whether this was due to changes in the current patterns and swell height or actual volume of water coming out of the plume is unknown. During these observations, we did not note any changes in behavior of any of the animals related to the turbulence of the plume.

5.3.1 Migratory season (May/June)

A total of 30 surveys were completed over the course of two migratory seasons (Table 5-1). Brandt's and Double crested cormorants were regularly seen at the Plume site (mean = 0.73 per survey; Fig. 5-2), and were often observed diving repeatedly within the plume (Table 5-3). Brandt's and Double crested cormorants were also the most common species observed at the Reference site during the Migratory period, although in fewer numbers (mean = 0.37 birds per survey) and were generally not observed actively diving. California brown pelicans, Caspian terns, cormorants, and grebes were seen at both study sites, but were sighted more frequently at the Plume site. Common murres, Pigeon guillemots, and surf scoters were seen in low numbers at both sites, whereas greater numbers of gulls were sighted at the Reference site during the Migratory period.

A total of 42 seabirds were sighted during the surveys at the Plume site, in comparison to a total of 29 seabirds at the Reference site (Table 5-2). Total species richness was greater at the

Plume site (9 species), in comparison with 6 species at the reference site. Additionally, the Shannon-Weaver Diversity Index (S) was greater at the plume site (1.96), in comparison to the reference site (1.44). However, a Chi square analysis of the six most common species indicated that there was not a significant difference between expected and observed proportions of birds at the two study sites ($\chi^2_{(5, n=59)} = 11.00, p > 0.05$), and species evenness (H') was not different between sites (0.89 vs. 0.80).

A total of five sea otters were observed at the Plume site over the course of the surveys during the Migratory period (Table 5-2), but never in high numbers (mean = 0.17 otters per survey). No other marine mammal species were observed.

5.3.2 Summer season (September)

A total of 30 surveys were completed over the course of two summer survey seasons (Table 5-1). Brandt's and Double crested cormorants were still common at the Plume site during the summer monitoring period (mean = 1.1 birds per survey, Fig. 5-2), in addition to California brown pelicans (mean = 0.13 birds per survey) and gulls (mean = 0.53 birds per survey). Other species sighted at the Plume site included Caspian terns and Heermann's gulls. Equal numbers of common murrelets were observed at each site (2 total per site). Gulls were the most common species sighted at the Reference site, and their numbers were more than double those observed at the Plume site.

In total, 63 seabirds were counted at the Plume site during summer surveys, in comparison with 54 seabirds at the Reference site (74% of which were gulls; Table 5-2). The species richness at the Plume site was double that of the Reference site (8 species vs. 4 species). Additionally, the Shannon-Weaver Index of Diversity (S) at the Plume site was 1.65, in contrast to 0.37 at the Reference site. Similarly, species evenness (H') was also greater at the Plume site (0.79) in comparison with the Reference site (0.27). A Chi square analysis of the six most common species indicated a significant difference between observed and expected proportions of seabirds at the two sites ($\chi^2_{(5, n=113)} = 28.21, p < 0.05$).

Sea otters were common in the plume, and a total of 30 otters were counted during surveys (mean = 1.0 per survey), actively foraging, grooming, fighting and resting (Table 5-3). Additionally, four California sea lions were observed (mean = 0.13 per survey). As expected, no winter species were observed.

5.3.3 Winter season (January/February)

A total of 16 surveys were completed over the course of one winter survey season (Table 5-1). Brandt's and Double crested cormorants were regularly seen at Plume site (mean = 0.44 birds per survey), in addition to high numbers of gulls (mean = 0.56 birds per survey). Surf scoters were present at both sites in low numbers, and a mean of 0.25 birds per survey were sighted at the Reference site, in comparison with 0.06 birds per survey at the Plume site. Other seabird species seen at the Plume site included a single Caspian tern, a single Common murre, and one Western grebe (Table 5-2). Three Common murrelets and one loon were sighted at the Reference site.

In total, 20 seabirds were counted at the Plume site, in comparison with 16 seabirds at the Reference site during winter surveys. The species richness at the Plume site was 9 species, in comparison with 5 at the Reference site. However, the Shannon-Weaver Index of Diversity was 0.44 at the Plume site, compared with 1.20 at the Reference site. The species evenness was also lower at the Plume site in contrast with the Reference site (0.20 vs. 0.74). A Chi Square analysis also indicated that there were no significant differences between species assemblages at either site ($\chi^2_{(5, n=34)} = 3.75, p > 0.05$).

Sea otters continued to occur commonly in the Plume site, and a mean of 0.81 otters were sighted per survey. One harbor seal was sighted in the Plume site, and no California sea lions were sighted in either survey site.

Interestingly, bat rays were observed in very high numbers at the Plume site during almost all of the winter surveys (mean = 1.9 bat rays per survey). A total of 31 bat rays were counted over the course of the 16 surveys (Table 5-2, Fig. 5-2). The bat rays were seen swimming at the surface of the thermal plume, and seemed to be actively remaining within the plume's area (Table 5-3).

5.4 Discussion

It is apparent from the data that the outfall is having an effect on local bird and mammal distribution. Some seabird species, especially cormorants, showed an increased occurrence at the Plume site, indicating potential utilization of the plume for foraging on small schooling or benthic fish. Sea otters showed an increased abundance in the plume versus the control site. In addition, no negative impacts on seabird abundance and distribution as a direct result of the thermal plume were observed (e.g. no species were observed actively avoiding the thermal plume). These observations lead us to believe that although the plume is having an effect on distribution, there is no reason to suspect that the impact is negative. However, the study was not designed to show the causal factors influencing the observed distributions. Potential causal factors could include prey distribution, thermal benefits, and/or mechanical stimulation (turbulence).

Based on our observations, seasonal abundance of local seabird species was well reflected in both the Plume and Reference study sites. Brandt's cormorants, Double crested cormorants, Western gulls, and Caspian terns are all resident seabirds that nest near Moss Landing harbor or in Elkhorn Slough. They are year-round residents commonly seen throughout the year in the nearshore environment (Baltz and Morejohn 1977, Ainley and Hunt 1991, Roberson 2002). Cormorants, gulls, and terns were observed in nearly all surveys, reflecting their local abundance in Monterey Bay. Additionally, Common murrelets, which nest to the north and south of Monterey Bay (Mason 1997), were also seen during all of the study periods, reflecting their common occurrence in the bay.

Heermann's gulls were one of the most conspicuous migratory species seen in the summer surveys, reflecting their seasonality here. They generally arrive in the mid-summer months and remain until late fall, at which point they migrate back to Baja California to breed. The winter assemblage of birds in the surveys reflected the seabird species commonly arriving in

Monterey Bay in the late fall and early winter, including surf scoters, Western/Clark's grebes, and Common and Pacific loons. Most of these species were not common in the survey sites themselves, but were locally abundant in the nearshore waters around the survey areas, reflecting their nearshore distribution and also the small area that the plume actually occupies in the nearshore environment off Moss Landing, CA. Small numbers of surf scoters and grebes were seen at the Plume and reference sites, but our analyses did not indicate a significant change in the proportions of these species at either study site, also indicating the nearshore habitat of these birds.

Monterey Bay is host to a great diversity of seabirds throughout the year, making it a biologically important area. In spite of this fact, our surveys do not indicate any sort of negative impacts on any seabird species related to the presence of the thermal plume. Most wintering and migratory seabirds were observed in low numbers at both sites, and did not appear to actively avoid the thermal plume's area. In contrast, our surveys indicate that some of the locally occurring resident seabird species may actually be utilizing the plume for foraging. Cormorants were regularly observed foraging within the Plume site. Especially during the summer survey season, we observed a significant increase in the proportion of birds at the Plume site. This is likely due to an increase in total numbers of birds within the nearshore environment, in combination with high productivity throughout Monterey Bay. Sea otters were commonly sighted in the plume, although it is unclear how they may be utilizing the plume.

Cormorants are diving seabirds, using their feet to propel them underwater and capture fish at depth before returning to the surface to consume it. We often observed them repeatedly diving within the plume site, and returning to the surface with a fish in their mouth. It is unknown which fish species the cormorants consume within the plume, but they are generally opportunistic, and will take a variety of locally abundant fish species. Although cormorants were observed repeatedly diving at both the Reference and Plume sites, the fact that on average more cormorants were seen in the Plume in all survey seasons indicates that they were utilizing the plume specifically to forage. Other seabird species were also observed foraging within the plume site, including Caspian terns and California brown pelicans, which occasionally circled above the plume and plunged into the water to capture a fish. These seabird species were probably taking advantage of fish species that became concentrated in the plume. With the exception of the cormorants, we did not observe any obvious feeding behavior by any seabirds at the Reference site.

Additionally, the regular occurrence of sea otters occupying the plume site indicated that they, too, were utilizing the thermal plume in some way. We observed nearly all of the different types of sea otter behavior commonly noted in Elkhorn Slough, including grooming, feeding, resting and fighting with other otters. Thus, it is not clear what the exact role of the plume is in the sea otter's occurrence there, but the numbers of otters concentrated in this small area suggests that it is an important area for them.

As earlier noted, bat rays were regularly noted at the surface within the plume during the winter surveys. They were discussed previously in Section 4.

5.5 *Historical Database*

The only significant historical bird data from the plume vicinity was collected by Laird Henkel as part of his thesis project (Henkel, L.A. 2003). The data are available from the author.

5.6 *Literature Cited*

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5.7 Tables and Figures

Table 5-1. Summary of survey effort including dates of all surveys, survey season, total number of surveys completed, survey duration, and total number of seabirds and marine mammals counted.

Date	Season	Number of daily surveys completed	Mean duration of survey (min)	Total number of animals counted
5/27/2004	Migratory	4	0:13	16
5/28/2004	Migratory	4	0:11	14
6/3/2004	Migratory	4	0:16	5
6/4/2004	Migratory	4	0:11	6
9/18/2004	Summer	4	0:12	26
9/20/2004	Summer	4	0:10	17
10/8/2004	Summer	4	0:10	36
10/11/2004	Summer	4	0:09	16
1/22/2005	Winter	4	0:10	28
1/25/2005	Winter	4	0:09	30
2/4/2005	Winter	4	0:10	16
2/7/2005	Winter	4	0:10	6
5/31/2005	Migratory	4	0:09	9
6/1/2005	Migratory	3 ^a	0:10	15
6/4/2005	Migratory	3 ^a	0:10	6
6/9/2005	Migratory	4	0:09	5
9/6/2005	Summer	4	0:10	16
9/13/2005	Summer	3 ^a	0:10	25
9/16/2005	Summer	3 ^a	0:10	9
9/26/2005	Summer	4	0:09	13

^a Surveys were completed for three of the four daily intervals, due to foggy conditions

Table 5-2. Summary of total number of animals counted during each survey period: Migratory (M), Summer (S), and Winter (W) at the Plume and Reference sites.

Species	Plume site				Reference site			
	M	S	W	Total	M	S	W	Total
Brown pelican	3	4		7				
Caspian tern	5	5	1	11	1			1
Common murre	1	2	1	4		2	3	5
Cormorant spp.	22	32	7	61	11	12	3	26
Gull spp.	3	16	9	28	9	40	5	54
Heermann's Gull		4		4				
Loon spp.					2		1	3
Pigeon guillemont	5			5	4			4
Surf scoter	2		1	3	2		4	6
Western/Clark's grebe	1		1	2				
Sea otter	5	30	13	48		1		1
CA sea lion		4		4				
Harbor seal			1	1				
Bat rays			31	31				
	47	97	65	209	29	55	16	100

Table 5-3. Description of most commonly observed behavior of each seabird and marine mammal species at the Plume and Reference sites.

Species	Plume site	Reference site
	Behavior	Behavior
Brown pelican	circle overhead, dive; sit	-
Caspian tern	hover and dive	hover and dive
Common murre	sit, dive	sit, preen
Cormorant spp.	dive, sit	dive, sit
Gull spp.	sit, circle overhead	sit
Heermann's Gull	sit	-
Loon spp.	-	dive, preen
Pigeon guillemont	sit, dive, eat fish	sit
Surf scoter	sit	sit
Western/Clark's grebe	dive	-
Sea otter	eat, groom, rest, fight	eat
CA sea lion	swim, bask	-
Harbor seal	swim through	-
Bat rays	swimming at surface	-

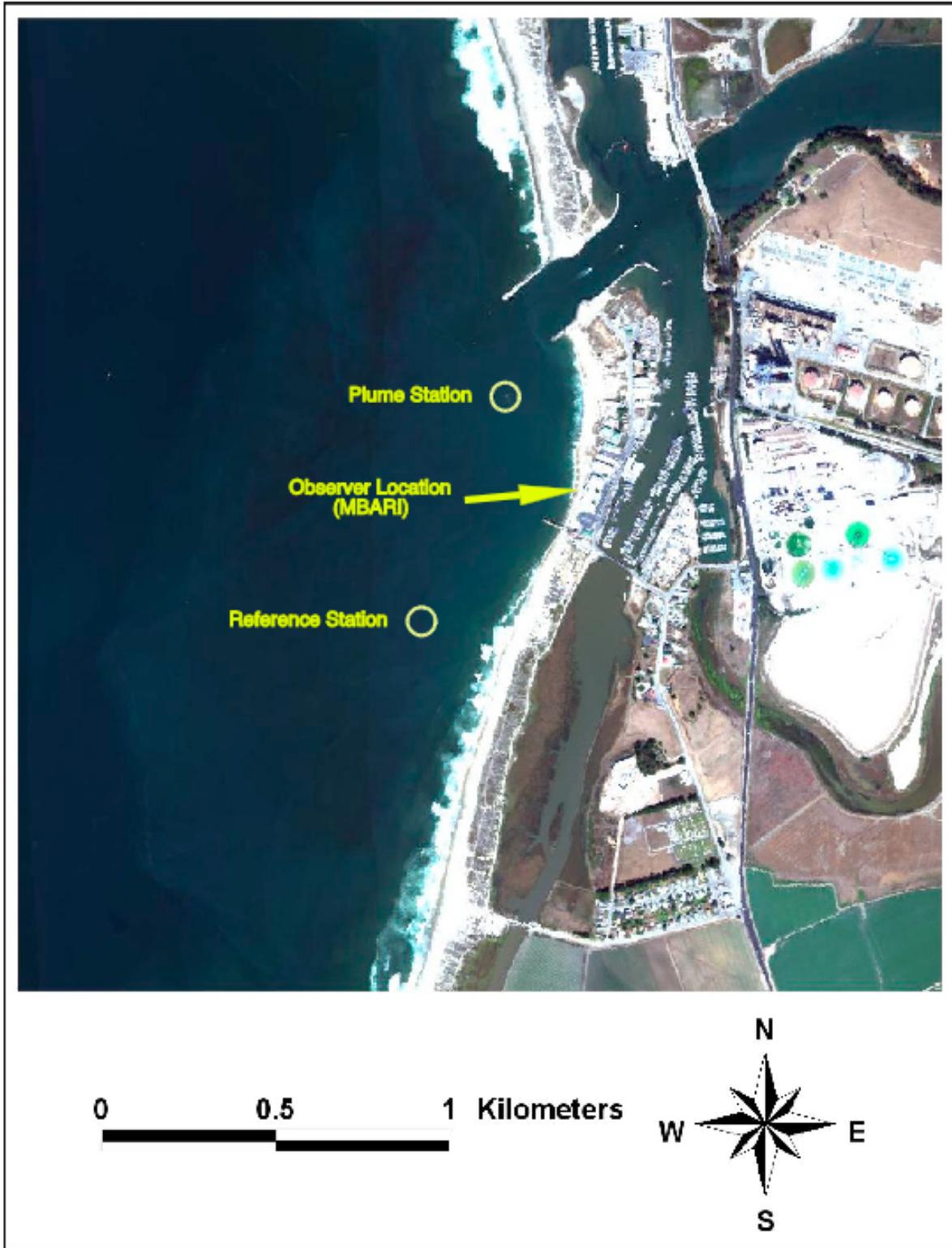


Figure 5-1. Map of Moss Landing vicinity showing location of the two bird study sites and the location where the spotting scope was set up at MBARI.

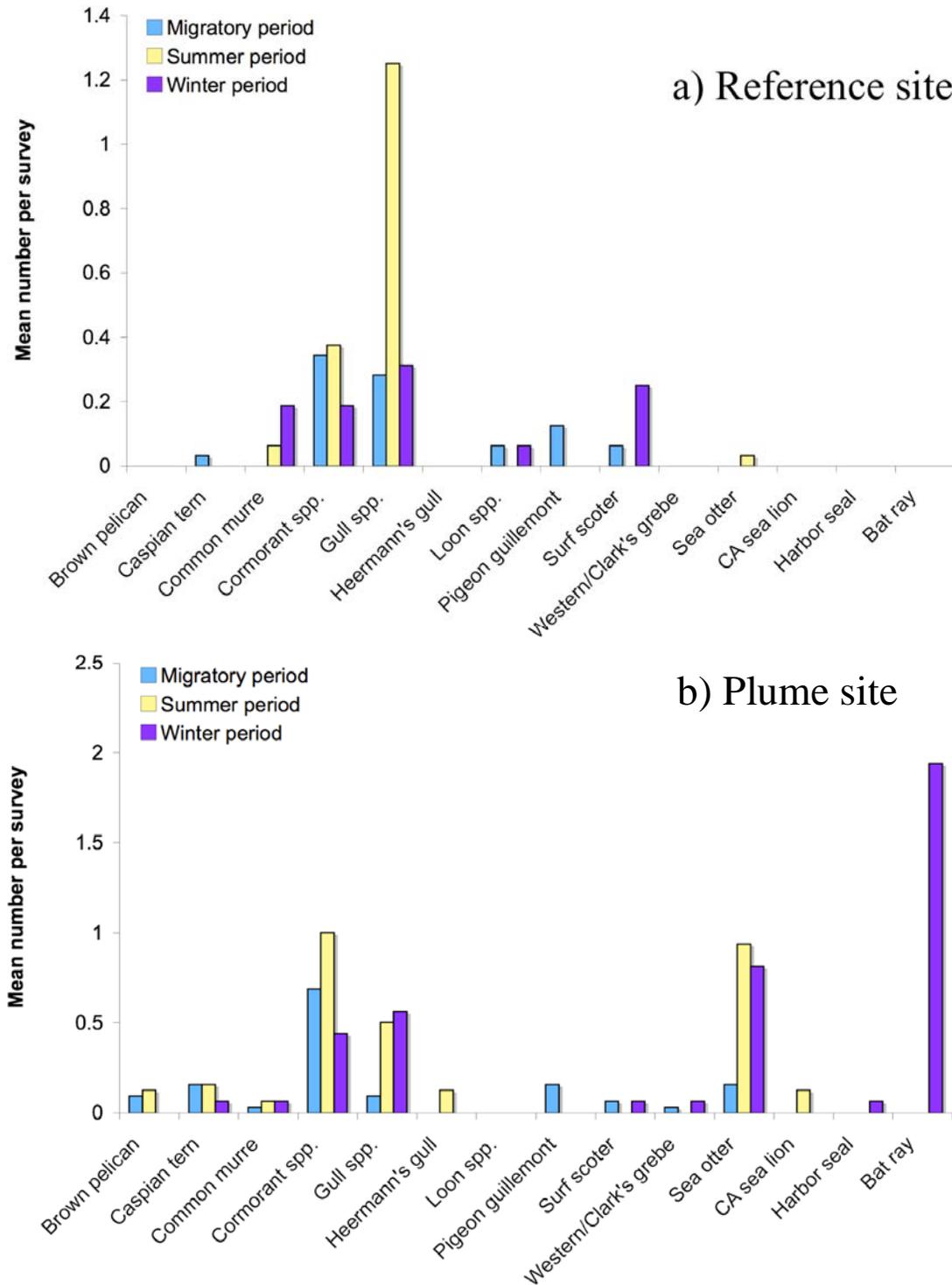


Figure 5-2. Mean number of seabirds and marine mammals occurring at the a) Reference site, and b) Plume site for each of the three sampling periods (Migratory, Summer, and Winter).

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