# An Ecological Assessment of San Diego Bay:

## *A Component of the Bight'98 Regional Survey*

***Prepared for***

**State of California**
**Regional Water Quality Control Board**
**San Diego Region**

***by***

**City of San Diego**
**Metropolitan Wastewater Department**
**Environmental Monitoring and Technical Services Division**
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**Cover:** Downtown San Diego from the Bay

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# Executive Summary

Coronado Bridge and downtown San Diego.

# Executive Summary

This assessment of environmental conditions in San Diego Bay was performed pursuant to a memorandum of understanding between the San Diego Regional Water Quality Control Board (RWQCB) and the City of San Diego. The general purpose of the study was to address concerns expressed by the San Diego Bay Interagency Water Quality Panel (Bay Panel). The Bay Panel was composed of 31 federal, state and local organizations and was formed to provide technical information and advice to the RWQCB regarding the status of various environs in the Bay. Major goals of the Bay Panel were to characterize the overall ecological state of San Diego Bay, identify long-term environmental trends within the Bay, and to address public concerns about the exposure to contaminants from eating fish captured in the Bay.

This report was designed to address the interests of the Bay Panel using data collected from San Diego Bay in conjunction with the Southern California Bight 1998 Regional Monitoring Project (Bight'98). Each of the major sampling components of the Bight'98 survey was used to characterize the state of subtidal habitats in San Diego Bay at the time. These components were sediment particle size and chemistry characteristics (see Chapter 2), macrobenthic invertebrate communities (see Chapter 3), trawl-caught fish and invertebrate communities (see Chapter 4), and contaminant levels in fish tissues (see Chapter 5).

### Sediment Quality

Sediment samples were collected at 46 stations distributed throughout San Diego Bay at depths ranging between 3 and 16 m. All samples were analyzed to determine particle size composition and concentrations of various trace metals, chlorinated pesticides, polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs). Sediment contamination was widespread in the Bay, with many of the "contaminants of concern" previously listed for San Diego Bay being present. These contaminants included the metals chromium, copper, lead, mercury and zinc, the biocide tributyltin, the pesticide chlordane, PCBs and PAHs. Chromium, copper, lead, mercury, zinc and PAHs were found in more than 70% of the sediment samples. In contrast, PCBs and tributyltin were detected much less frequently (< 26% of samples), while chlordane was not detected at all. Concentrations of various contaminants were evaluated using established sediment quality thresholds (i.e., ERL, ERM, TEL, PEL). Concentrations of nine metals, DDT and PAHs exceeded at least one of these thresholds. Sites at which multiple contaminants exceeded the thresholds typically had high percentages of fine sediments (i.e. > 60% fines) and were located near or within marinas or shipyards; this distribution pattern was similar to those described in previous studies. Compared to the other bays and harbors sampled during Bight'98, San Diego Bay ranked among the top three in average sediment contamination for only four contaminants: antimony, mercury, copper and PAHs. Additionally, the Bay ranked fourth in terms of PCB contamination, fifth for chromium, and sixth for zinc. Finally, San Diego Bay had lower levels of pesticides than any other embayment studied.

## Macrobenthic Communities

Macrobenthic community structure was summarized for each of the 46 stations described above and then compared to various environmental and sediment parameters (e.g., depth, percentage fines, total organic carbon, nitrogen, and several contaminants of concern). Additionally, ordination and classification analyses were performed to compare the similarity of the different assemblages present in the Bay. Overall, 38,187 macrobenthic organisms representing 340 taxa were identified, of which polychaetes, molluscs and crustaceans were the dominant groups. Many taxa (> 27%), however, were composed of a single rare or unidentifiable individual. Non-indigenous species were an important component of the Bay benthos, comprising at least 18 species and representing about 24% of the total macrofauna. Two species of polychaete worms, the capitellid *Mediomastus* sp (likely a species complex) and the spionid *Prionospio (Prionospio) heterobranchia*, occurred at all stations. *Mediomastus* sp was also numerically dominant, comprising 13% of all animals collected. The non-indigenous bivalve *Musculista senhousia* was the second most abundant species, followed by the sabellid polychaete *Euchone limnicola*. Hydrodynamic conditions such as tidal flushing appear to be the primary factor influencing the distribution of macrobenthic assemblages throughout the Bay, while anthropogenic impacts may represent a secondary factor.

Most of the animals common in San Diego Bay were also present in the other bays and harbors sampled during Bight'98. For example, many of the most abundant taxa in San Diego also occurred in high numbers in the other bays. Likewise, widely distributed species in San Diego Bay had similar broad distributions in the other embayments. Differences among assemblages in all bays and harbors, however, appeared to be due to multiple environmental and biological factors, including different hydrodynamic conditions, anthropogenic impact, and the presence of dominant, habitat altering species.

## Demersal Fishes and Megabenthic Invertebrates

Demersal fishes and megabenthic invertebrates were collected by otter trawl at 16 stations in San Diego Bay. Fish populations appeared healthy in the Bay, with no physical abnormalities detected on any fish. Trawl catches of fishes were relatively small, with only 16 species and 349 individuals captured. Dominant species that occurred frequently in relatively high numbers were the round stingray, spotted sand bass, barred sand bass and California halibut. Almost all of the California halibut and barred sand bass captured were juvenile fish, which supports previous findings that these two species use the Bay as a nursery.

A total of 1,172 megabenthic invertebrates, representing 43 taxa, were also collected in San Diego Bay. The bivalve *Musculista senhousia* was present in more than 70% of the samples, making it the most widely distributed trawl caught invertebrate in the Bay. Other common invertebrates that were present in at least one third of the samples included two undescribed species of sponge, Porifiera sp SD4 and Porifera sp SD5, the ascidian *Microcosmus squamiger,* the bivalve *Argopecten ventricosus*, and the gastropod *Crepidula onyx*. *Musculista senhousia* and *Microcosmus squamiger* together, both non-indigenous species, accounted for over 50% of the total catch.

The most important factor influencing the distribution of trawl-caught fishes and invertebrates in San Diego Bay appeared to be distance from the entrance to the Bay. In general, the fish and invertebrate assemblages present in the central and southern parts of San Diego Bay differed from those found near the mouth of the Bay. The species that characterized these central and southern areas in 1998 were typical of embayments in general. In contrast, assemblages found towards the entrance of the Bay and in some of the other southern California bays and harbors (e.g., LA/Long Beach Harbor) during the Bight'98 project were typically characterized by species more representative of open coastal areas.

### Bioaccumulation of Contaminants in Fish Tissues

Five species of fish were collected at 24 stations in San Diego Bay and analyzed to measure the accumulation of contaminants in their tissues. Whole fish samples of California halibut were collected at seven stations and analyzed for the presence of pesticides and PCBs. The contaminant levels present in these fish were compared to those found in whole halibut samples from the other southern California bays and harbors, as well as to predator protection limits for mammals and birds. Samples of muscle tissue were also collected from halibut and four other species of sport fish (i.e., calico bass, spotted sand bass, barred sand bass, yellowfin croaker) at the remaining 17 stations in the Bay. These muscle tissue samples were analyzed for the presence of metals, pesticides, and PCBs, and the results were then compared to human health consumption limits.

All whole fish samples of California halibut collected in San Diego Bay during 1998 contained detectable levels of PCBs and DDT. Concentrations of PCBs exceeded the predator protection limits for mammals, while DDT concentrations exceeded the protection limits for both mammals and birds. Overall, San Diego Bay ranked fourth out of the five southern California embayments sampled for whole fish in terms of total DDT. The Bay ranked first in terms of total PCBs, with the average detected value in San Diego Bay halibut being an order of magnitude higher than in fish from the other bays and harbors.

Muscle tissues contained many of the 'contaminants of concern' previously listed for San Diego Bay. For example, PCBs and the metals mercury and zinc were detected in almost all of the muscle tissue samples, while the other contaminants of concern occurred much less frequently or not at all in Bay fishes. Of the metals and pesticides for which thresholds are available, chromium and arsenic exceeded human health consumption limits in only a single sample each. Overall, PCB concentrations were very high in the muscle tissues of San Diego Bay fish, especially when compared to species of flatfish, rockfish and sand bass sampled off the outer coast of San Diego over the past several years.

## SUMMARY

Contamination remains widespread in San Diego Bay sediments and affects the tissues of various species of fish that are subject to human consumption. Contaminants previously identified to be of concern in the Bay, such as chromium, copper, lead, mercury, zinc, PCBs and PAHs continue to be present at levels that exceed one or more sediment quality criteria thresholds. This is particularly true for sites where the percentage of fine sediments is high. Such areas are typically located near or within marinas or shipyards where currents are less strong, and where various physical structures reduce tidal flow or create eddies that allow suspended particles to settle. Several of these contaminants also occurred in relatively high concentrations in the tissues of fish from the Bay. For example, mercury, zinc, PCBs and DDT occurred in over 80% of fish tissues, and both PCBs and DDT exceeded at least one of the mammal and bird predator protection thresholds.

Long-term trends in sediment and fish tissue contamination were difficult to determine for San Diego Bay due to differences between surveys in analytical methods (e.g., procedures and equipment) and species of fish analyzed. Such differences often preclude the direct comparison of data from one survey to the next. In general, however, the overall level of contamination in the Bay appears less than in previous decades. For example, concentrations of copper, mercury, tin, tributyltin and PAHs were lower in the sediments in 1998 than in previous studies. Additionally, contaminant loads of DDT, mercury and selenium in fish tissues were also less in 1998. In contrast, arsenic levels in fish tissues were slightly higher in 1998 than in previous surveys, while concentrations of chromium remained about the same. Finally, the absence of any evidence of fin erosion in fishes also suggests that conditions have generally improved since 1984 -1988 when the prevalence of fin erosion in black croaker and barred sea bass was relatively high.

Species of both macrobenthic and megabenthic invertebrates as well as bottom-dwelling fishes encountered in San Diego Bay were similar in 1998 to those reported previously. The composition and structure of these assemblages typically varied with distance from the entrance to the Bay, and these differences generally paralleled local hydrodynamic conditions. Anthropogenic impacts, including the deposition of contaminants and the presence of invasive or non-indigenous species, may represent a secondary factor that influences the distribution of assemblages in the Bay.

The 1998 survey of San Diego Bay provides valuable data against which future changes in fish and invertebrate communities may be measured. For example, being able to monitor population densities of non-indigenous species such as the bivalve *Musculista senhousia* may be vital to understanding any changes that take place in these communities. Finally, since impact assessments require thorough knowledge of the natural processes that influence community structure, further investigations into the relationship between hydrodynamics and resident fish and invertebrate assemblages will be central to the proper management of a healthy ecosystem in San Diego Bay. Such studies will provide a more detailed understanding of this unique and valuable ecosystem, upon which to base future management decisions.

# General Introduction

Bait barge with sea lions near the entrance of San Diego Bay, along the inside of Point Loma Peninsula.

# *Chapter 1*
# General Introduction

San Diego Bay is one of few natural deepwater harbors on the Pacific Coast. The Bay is located in the Southern California Bight (SCB) just north of the Mexican/United States border, and is sheltered by the overlapping peninsulas of Point Loma and Coronado. San Diego Bay is an important commercial port that accommodates substantial military holdings as well as a commercial and recreational fishing fleet. The Bay also harbors several types of important natural resources, including salt marches, tidal flats, bird nesting and foraging sites, and essential fish habitats such as eelgrass beds. Many of these resources are located within two National Wildlife Refuges, the Sweetwater Marsh National Wildlife Refuge (316 acres) and the South San Diego Bay National Wildlife Refuge (3,940 acres). Additionally, nine federal and state listed endangered or threatened species are found in various habitats scattered about the Bay (Port of San Diego 2003).

In 1987, the San Diego Bay Interagency Water Quality Panel (Bay Panel) was formed by legislation (California Law Chapter 1087) to gain a better understanding of the environmental conditions of the Bay (see San Diego Bay Perspective 2003). This legislation was designed to encourage agencies responsible for stewardship of San Diego Bay and its resources to coordinate their efforts and to provide technical information and advice to the San Diego Regional Water Quality Control Board (RWQCB). The Bay Panel was composed of 31 member organizations, including federal, state and local agencies such as the National Fish and Wildlife Service, the County of San Diego Department of Health Services, the California Department of Fish and Game, the United States Environmental Protection Agency, and so forth (see San Diego Bay Perspective 2003 for complete list of agencies). Some of the goals of this panel were to characterize the ecological state of San Diego Bay, identify long term environmental trends within the Bay (e.g., trends in sediment contaminant levels), and to address public concerns about the exposure to contaminants from eating fish captured in the Bay. The mission of the panel was passed on to the RWQCB when the Bay Panel disbanded in 1997.

This report was created in accordance with a memorandum of understanding between the RWQCB and the City of San Diego designed to address the interests of the Bay Panel using data collected for San Diego Bay as part of the Southern California Bight 1998 Regional Monitoring Project (Bight'98). Bight'98 was part of an effort to provide an integrated assessment of the SCB through regional-scale EMAP style stratified random sampling (see Bight'98 Steering Committee 2003). In addition to addressing the Bay Panel's interests, the results of this study are put into context with the U.S. Navy's Integrated National Resources Management Plan for San Diego Bay (USDoN, SWDIV and SDUPD 2000), a recent publication that provides a historical review of data collected in San Diego Bay. The Navy's Management Plan outlined several "contaminants of concern for the San Diego Bay Region," which included chlordane, chromium, copper, lead, mercury, tributyltin, zinc, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated byphenols (PCBs). The report also describes several sources for these and other contaminants, and includes a thorough biological assessment of the flora and fauna of the Bay (e.g., macroalgae, eelgrass, plankton, invertebrates, fishes, birds, marine mammals).

Each of the major sampling components of the Bight'98 survey was used to characterize the state of the subtidal habitats in San Diego Bay. These components include sediment particle size and chemistry characteristics (Chapter 2), macrobenthic invertebrate communities (Chapter 3), trawl-caught fish and megabenthic invertebrate communities (Chapter 4), and contaminant levels in fish tissues (Chapter 5). A summary of the stations and type of sampling conducted at each site is listed in Appendix A.1. Sediment toxicity samples were also collected by the City of San Diego during the course of this survey, but the Southern California Coastal Water Research Project (SCCWRP) analyzed these samples. All of the sediment toxicity results for Bight'98, including an evaluation of samples from San Diego Bay, are reported in the Bight'98 Sediment Toxicity Report (Bay et al. 2000).

The study described herein was unique in its comprehensive coverage of San Diego Bay. First, it includes the first random survey of fish and invertebrate populations in the Bay. Second, it provides an assessment of contaminants in the tissues of fishes in order to address human health concerns and ecological impacts (e.g., muscle tissue vs. whole fish samples). Finally, this report also provides the first comprehensive comparison of conditions in San Diego Bay to other bays and harbors in the SCB. Such comparisons were possible because these areas were sampled at the same time using the same Bight'98 sample design.

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# Sediment
# Quality

NASSCO Shipyards, located south of downtown San Diego

# *Chapter 2*
# Sediment Quality

## INTRODUCTION

The quality of sediments in San Diego Bay has historically been altered by human activity (USDoN, SWDIV and SDUPD 2000). Major anthropogenic disturbances have included the removal and displacement of sediments by channel dredging, and the direct input of sewage, industrial wastes and pesticides. For example, the use and disposal of petroleum products (e.g., oils, paint sludge, diesel fuel, and creosote) throughout the Bay introduced high levels of polycyclic aromatic hydrocarbons (PAHs) into the sediments. Moreover, various metals have been released to the water and sediments through the leaching of hull paints, and from the disposal of industrial wastes.

Many of the above contaminants have accumulated within shipyards and marinas where fine sediments often accumulate. Fine particles tend to sorb and transport biological wastes, organic chemicals, gases, and other pollutants because of their chemical make-up and physical structure (i.e., high surface area per unit weight volume) (Manahan 2000). Consequently, elevated levels of pollutants are often correlated with the distribution of fine sediments. Sediment distribution within bays is, in turn, affected by a complexity of factors, such as tidal influence, current velocity, sedimentary input, the presence or absence of large structures (e.g., piers or docks), channel dredging, and breakwaters (USDoN, SWDIV and SDUPD 2000). The analysis of contaminant loads as well as percentages of silt and clay provides useful information on sediment conditions, which also influences the distribution of organisms living within the Bay.

This chapter presents summaries and analyses of sediment grain size and chemistry data collected in San Diego Bay in conjunction with the Bight'98 regional survey. The major objectives of this chapter are to describe the physical sediment characteristics within the Bay, and to assess overall sediment quality with respect to the presence and distribution of various chemical contaminants. In addition, sediment conditions in San Diego Bay are compared to those of the other bays and harbors sampled during the Bight'98 survey.

## MATERIALS & METHODS

### Field Sampling

Sediment samples were collected at 46 randomly selected stations within San Diego Bay during July and August of 1998 (Figure 2.1). The stations ranged in depth from 3.0 to 15.6 m and encompassed an area extending from the Ballast Point Naval Facility at the bay entrance to the Coronado Cays Marina located in the back region of the Bay. Samples for sediment chemistry and particle size analyses were obtained using a modified 0.1 $m^2$ chain-rigged van Veen grab. These samples were taken from the top 2 cm of the sediment surface and processed according to procedures described in the Bight'98 field manual (FSLC 1998).

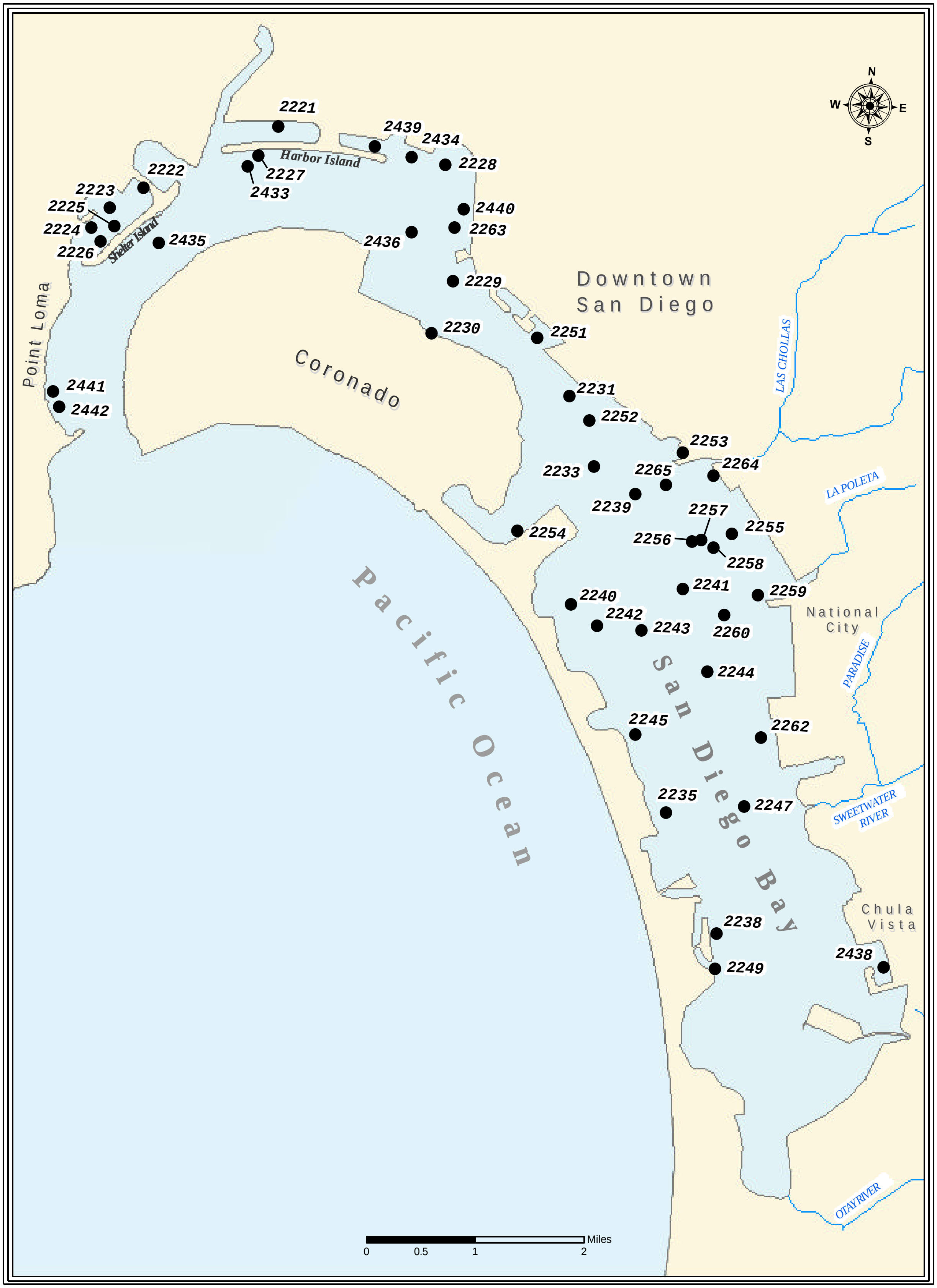



**Figure 2.1**

Sediment quality stations sampled in San Diego Bay during 1998.

## Laboratory Analyses

Analyses of sediment particle size and the presence of chemical constituents were performed by the City of San Diego Wastewater Chemistry Laboratory, the City of Los Angeles Hyperion Wastewater Laboratory, and the Southern California Coastal Water Research Project. Each sediment sample was analyzed for the presence of two indicators of organic loading, 18 metals, 24 polycyclic aromatic hydrocarbons (PAHs), 41 polychlorinated biphenyl compounds (PCBs), a biocide, and 28 chlorinated pesticides (see Appendix B.1). Details of the analytical techniques employed are available in Noblet et al. (2002). Samples for grain size analysis were first sieved through a 1.0 mm mesh screen in order to separate the coarse and fine sediment fractions. The fraction of coarse sediments (e.g., coarse sand, gravel, and shell hash) in each sample was determined by measuring the weight of particles retained on the sieve (i.e., > 0 phi), and was expressed as the percent weight of the total sample. Analysis of the fine fraction was performed using either: (1) a Horiba LA-900 laser analyzer, which measures particles from zero to10 phi in size (i.e., 1.0 - 0.00098 mm in diameter); or (2) a Coulter LS230 particle size analyzer that measures particles from -1 to12 phi (i.e., 2.0 - 0.00024 mm in diameter). Sand was defined as all particles ranging in size from zero to 4 phi, while fine sediments included all particles > 4 phi.

## Data Analyses

### *San Diego Bay*

The sediment grain size composition at each station was characterized by calculating median and mean phi size, the sorting coefficient (i.e., standard deviation), and the percent fines (i.e., percent of silt and clay combined). Most of these parameters were calculated using the normal probability scale described by Folk (1968) based on whole phi sizes; however, percent fines were calculated using half phi sizes. Patterns in the sediment chemical composition were analyzed using area means and quartile plots generated for the following parameters: total nitrogen (TN), total organic carbon (TOC), metals, PAHs, PCBs, and pesticides. The concentration of many of these compounds, however, fell below laboratory method detection limits (MDLs). Any concentration reported at less than the MDL was set to zero for the calculation of mean values. In contrast, such concentrations were omitted from the quartile ranks. Covariance among the above parameters was tested using Pearson correlation coefficients. Levels of sediment contamination in San Diego Bay were further evaluated by comparing the results of this study to several previously established sediment quality guidelines. These guidelines include the Effects Range-Low (ERL) and Effects Range-Medium (ERM) of Long et al. (1995), and the Threshold Effects Level (TEL) and Probable Effects Level (PEL) of MacDonald (1994).

### *Comparison of San Diego Bay to Other Embayments*

Sediment samples were collected from 114 stations distributed among San Diego Bay and eight other bays and harbors during Bight'98. From north to south these embayments were Ventura Harbor, Channel Islands Harbor, Marina Del Rey, Los Angeles/Long Beach Harbor, Anaheim Bay, Newport Bay, Dana Point Harbor, Mission Bay, and San Diego Bay. Differences in the sediment conditions among these embayments were evaluated by comparing particle size composition (i.e., percent fines) and concentrations of TOC, TN, various metals, total PCBs (tPCBs), total PAHs (tPAHs), and pesticides (i.e., total DDT, chlordane). Means, standard deviations, and confidence intervals were determined for detected values of these parameters. In order to address the inherent differences in analytical techniques and instrumentation among the different participating agencies, the highest MDL for each chemical constituent was used in all inter-bay comparisons

## RESULTS

### San Diego Bay

***Sediment Grain Size***
The percentage of fine sediments at a station in San Diego Bay ranged from 10 to 91%, with the median phi size ranging between 2.3 and 6.0 (Appendix B.2). Sites with the highest percent fines were usually located near or within small boat marinas or shipyards for large vessels (Figure 2.2). These include two sites near Naval Station San Diego (stations 2257, 2264), one site near the 10$^{th}$ Avenue Marine Terminal (station 2251), three sites within Shelter Island Yacht Basin (stations 2222, 2223, 2226), and two sites near Naval Submarine Base San Diego, located at Ballast Point near the mouth of the Bay (stations 2441, 2442). The finest sediments occurred at station 2226 within the Shelter Island Yacht Basin. In contrast, the coarsest sediments were typically found at sites in the middle of the Bay. An exception to this pattern occurred at station 2230, which is an exposed area located along the east side of Coronado Island and where the coarsest sediments were found.

***Indicators of Organic Loading***
Concentrations of total nitrogen (TN) and total organic carbon (TOC) in San Diego Bay sediments ranged from about 0.03 to 0.24% and 0.20 to 2.01%, respectively (Appendix B.2). These indicators were strongly correlated with each other ($r = 0.92$, $p < 0.05$) and had similar patterns of distribution within the Bay. Concentrations of TN and TOC were also strongly correlated with percent fines ($r > 0.84$, $p < 0.05$), and their distribution patterns were consistent with that described above for percent fines (see Figure 2.2). The highest concentrations of both TN and TOC were found at one site near the southeast entrance to Las Chollas Creek (i.e., station 2264), one site near the 10$^{th}$ Avenue Marine Terminal (i.e., station 2251), one site in the Shelter Island Yacht Basin (i.e., station 2226), and at two sites near Naval Submarine Base San Diego where storm drains and a bait barge are located (i.e., stations 2441, 2442). The lowest concentrations of both organic indicators were located primarily in the central portions of the Bay where channel dredging has occurred.

***Metals***
Metal contamination was widespread in San Diego Bay sediments, with every station containing measurable quantities of at least 15 different metals. Antimony and thallium were detected at less than half the stations, and tin was not detected at all (Appendix B.3).

The highest concentrations of metals were found where the percent of fine sediments was high. These included sites near Naval Station San Diego (i.e., stations 2264, 2257, 2258) and within or near small boat marinas and commercial piers (i.e., stations 2222, 2226, 2263, 2251). The concentrations of several metals (i.e., aluminum, arsenic, barium, chromium, copper, iron, manganese, nickel, zinc) were strongly correlated with the percentage of fine sediments ($r > 0.69$, $p < 0.01$). Aluminum and iron are naturally occurring elements in silt and clay bearing minerals and are considered to be normalizers. Normalizers can be used to account for natural mineralogical variations and provide baseline relationships with which to assess metal enrichment (Schiff and Weisberg 1998). In this survey,

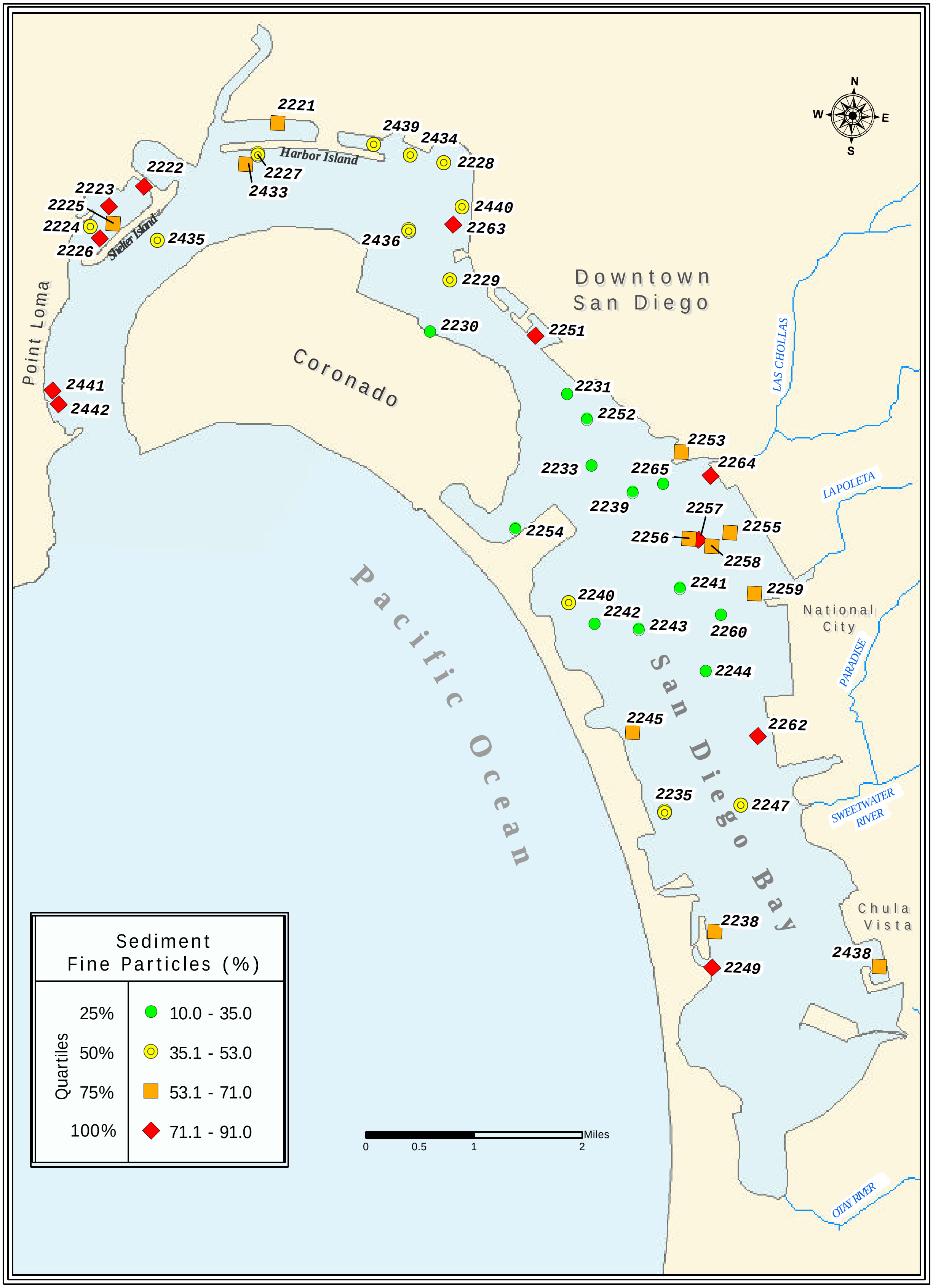



**Figure 2.2**

Quartile distributions of percent fine sediments for San Diego Bay during 1998.

**Table 2.1**

Summary of sediment contaminant loads for San Diego Bay during 1998 compared to available sediment screening criteria developed by the State of Florida (TEL/PEL: MacDonald 1994) and NOAA (ERL/ERM: Long et al. 1995). N = 46, except for cadmium and silver where n = 40; % Exceed = percent of detected values that exceeded threshold values (TV).

| | Metals (ppm) | | | | | | | | | | tPAH | tDDT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **As** | **Sb** | **Cd** | **Cr** | **Cu** | **Pb** | **Hg** | **Ni** | **Ag** | **Zn** | **(ppb)** | **(ppt)** |
| # Detected | 46 | 19 | 38 | 45 | 46 | 46 | 45 | 44 | 36 | 46 | 34 | 7 |
| **TEL** | | | | | | | | | | | | |
| %Exceed | **35** | **–** | **0** | **24** | **96** | **43** | **91** | **32** | **22** | **59** | **21** | **14** |
| (TV) | 7.24 | na | 0.676 | 52.3 | 18.7 | 30.24 | 0.13 | 15.9 | 0.733 | 124 | 1684 | 3890 |
| **ERL** | | | | | | | | | | | | |
| %Exceed | **22** | **100** | **0** | **0** | **91** | **17** | **91** | **2** | **11** | **39** | **9** | **57** |
| (TV) | 8.2 | 2 | 1.2 | 81 | 34 | 46.7 | 0.15 | 20.9 | 1 | 150 | 4022 | 1580 |
| **PEL** | | | | | | | | | | | | |
| %Exceed | **0** | **–** | **0** | **0** | **35** | **2** | **9** | **0** | **0** | **4** | **0** | **0** |
| (TV) | 41.6 | na | 4.21 | 160.4 | 108.2 | 112.18 | 0.7 | 42.8 | 1.77 | 271 | 16771 | 51700 |
| **ERM** | | | | | | | | | | | | |
| %Exceed | **0** | **100** | **0** | **0** | **0** | **0** | **9** | **0** | **0** | **2** | **0** | **0** |
| (TV) | 70 | 2.5 | 9.6 | 370 | 270 | 218 | 0.7 | 51.6 | 3.7 | 410 | 44792 | 46100 |

the range of concentrations of iron and aluminum within the Bay had similar distributions to most of the other metals.

Fairly et al. (1996) concluded that five metals (i.e., chromium, copper, lead, mercury, zinc) should be considered contaminants of concern in San Diego Bay based on their concentrations in sediments or their potential for causing detrimental effects. Stations with the highest concentrations of these five metals occurred near naval shipyards and marinas (Figures 2.3-2.7). Copper, mercury, and zinc were the most prevalent of these metals in the Bay and also occurred in the highest concentrations.

Four sediment quality criteria (TEL < ERL < PEL < ERM) were available for 10 of the 18 metals listed in Appendix B.1 (see Table 2.1). Of these metals, all except cadmium were detected at concentrations that exceeded at least one of the four sediment quality criteria thresholds. Exceedences of the lower-level criteria (i.e., TEL and ERL) ranged from 22 to 96% and from 2 to 100%, respectively. Moreover, many stations contained concentrations of metals that exceeded the TEL/ERL for three or more metals (Table 2.2). Two metals of concern, copper and mercury, exceeded these criteria at over 90% of the sites. Fewer metals exceeded the higher level PEL and ERM screening thresholds at which toxic effects are likely (Table 2.1). For example, the PEL was exceeded by copper, lead, mercury, and zinc in 2-35% of the sediment samples, while the ERM was exceeded by antimony, mercury, and zinc in 2-100% of the samples. Although antimony was detected at less than half the stations sampled, it was found in relatively high concentrations (i.e., >5.0 ppm) that exceeded the ERM 100% of the time.

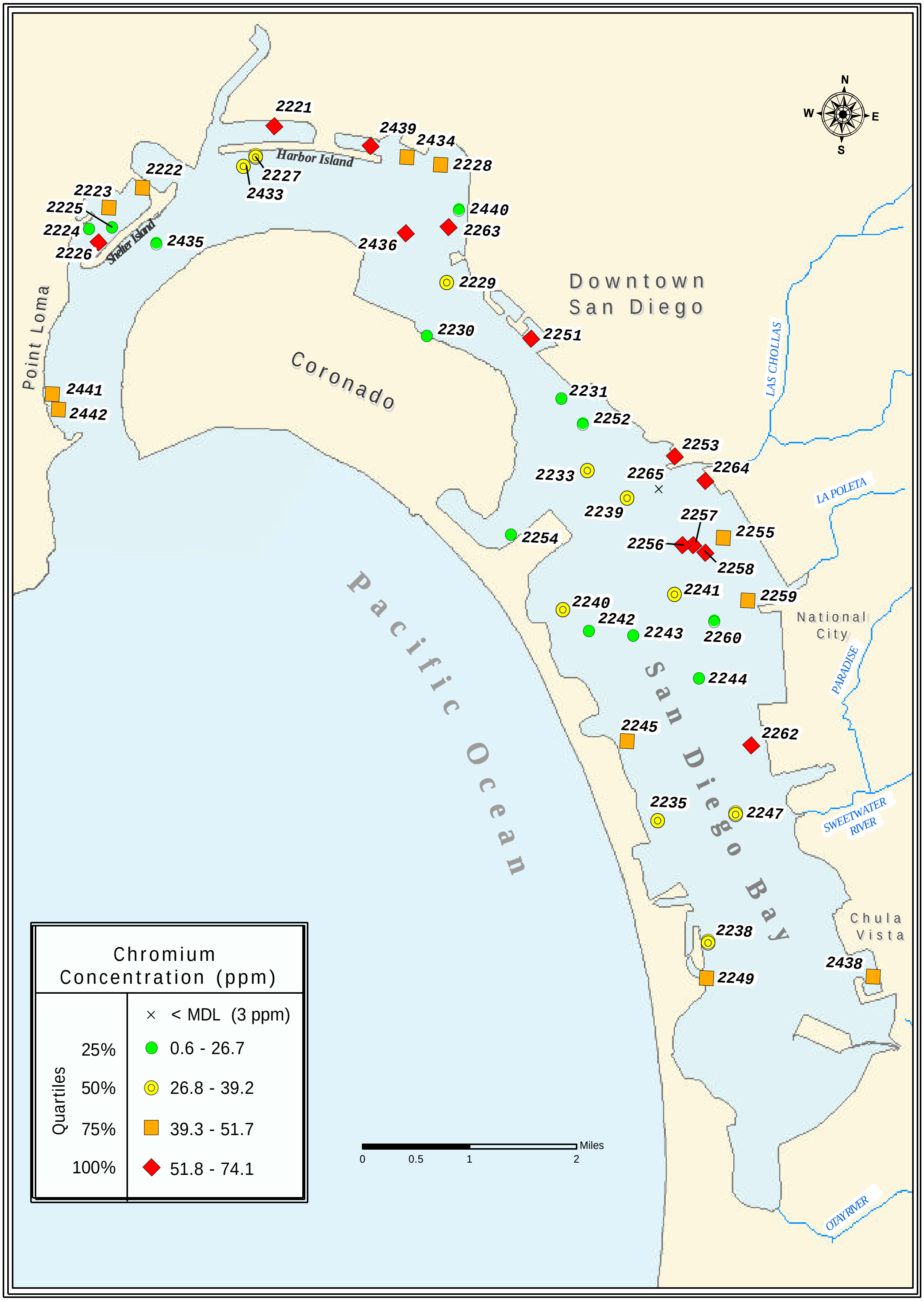
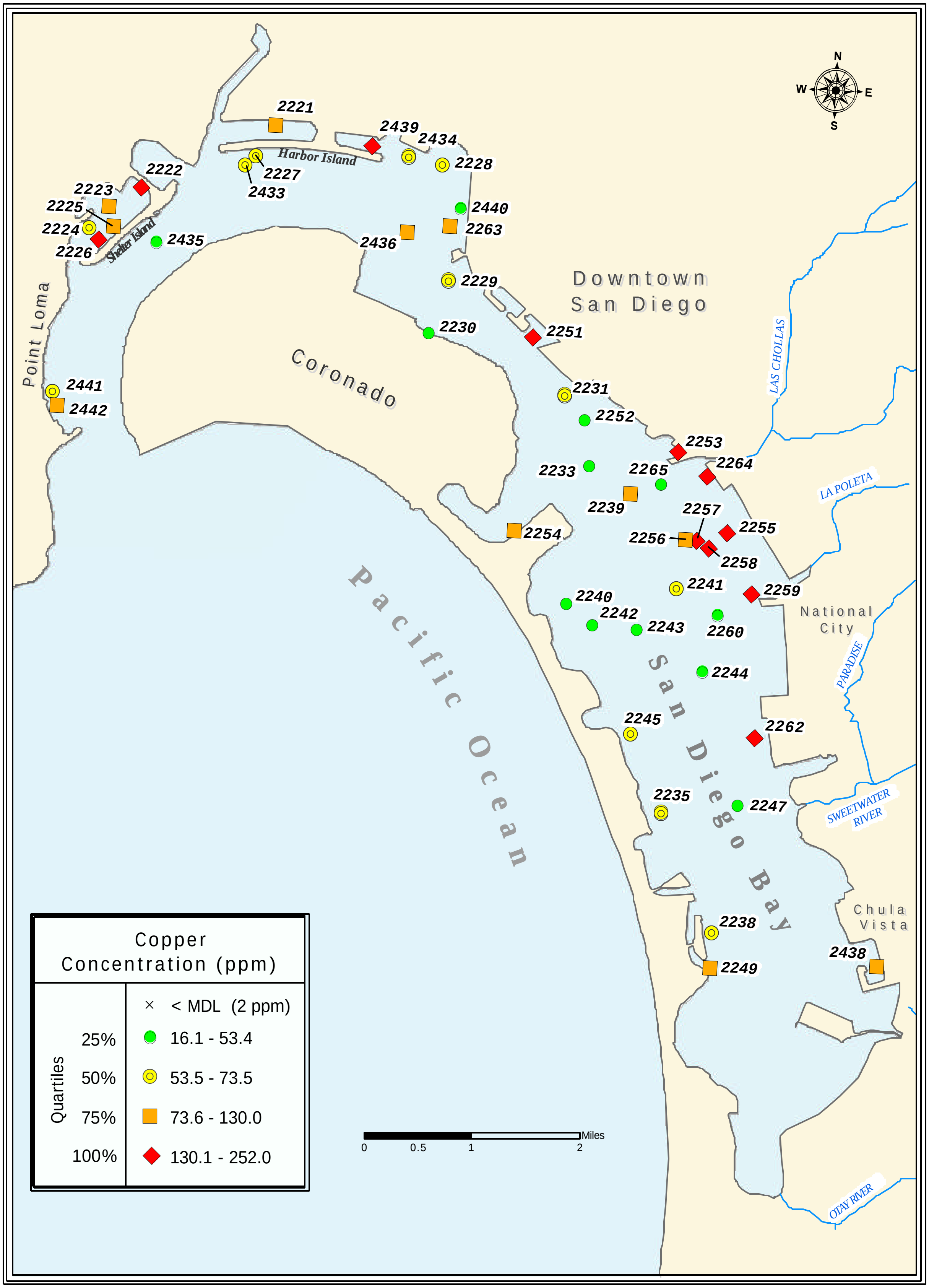



**Figure 2.3**

Quartile distributions of chromium concentrations (ppm) in San Diego Bay sediments during 1998.




# Figure 2.4

Quartile distributions of copper concentrations (ppm) in San Diego Bay sediments during 1998.

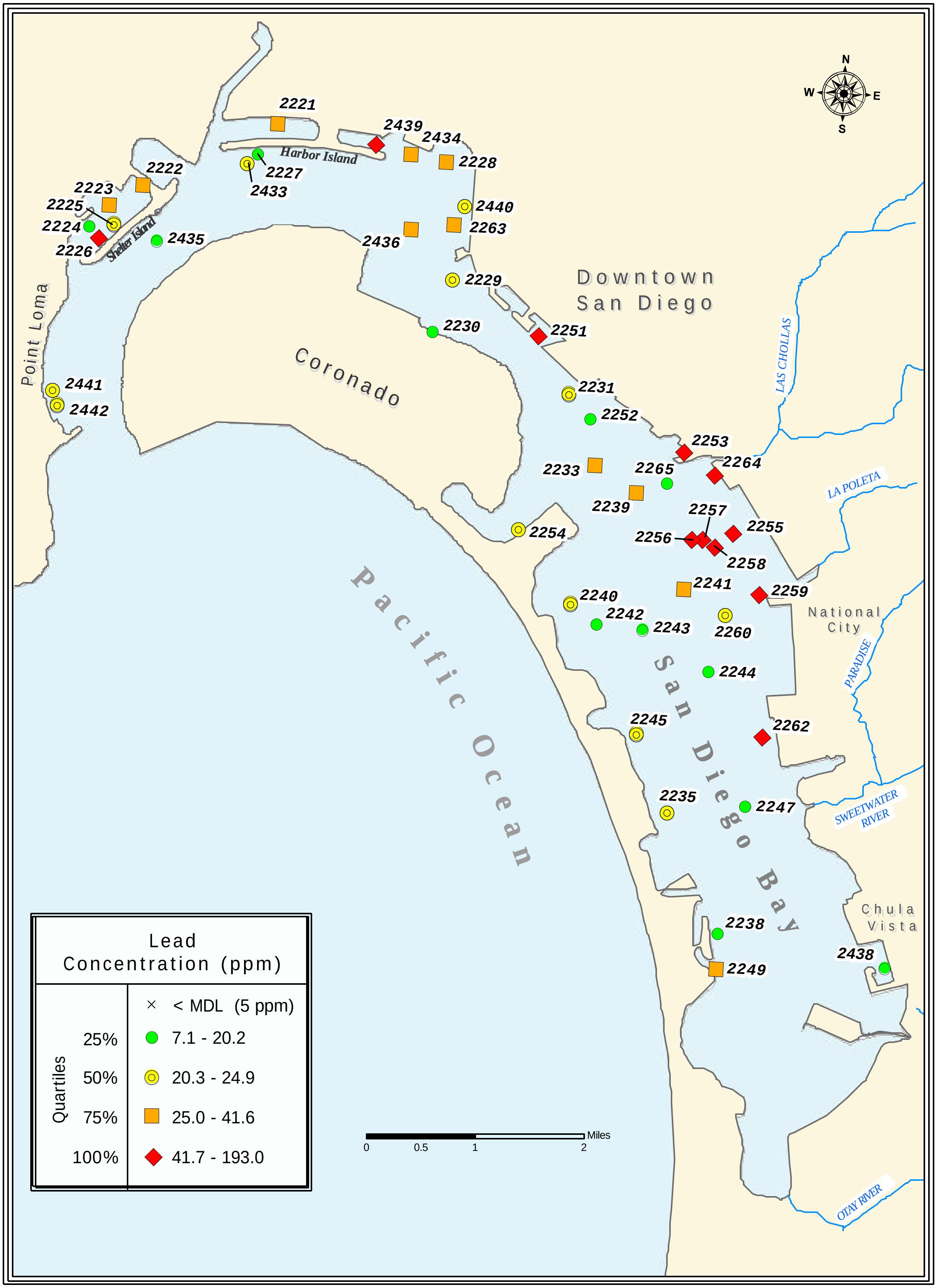



**Figure 2.5**
Quartile distributions of lead concentrations (ppm) in San Diego Bay sediments during 1998.

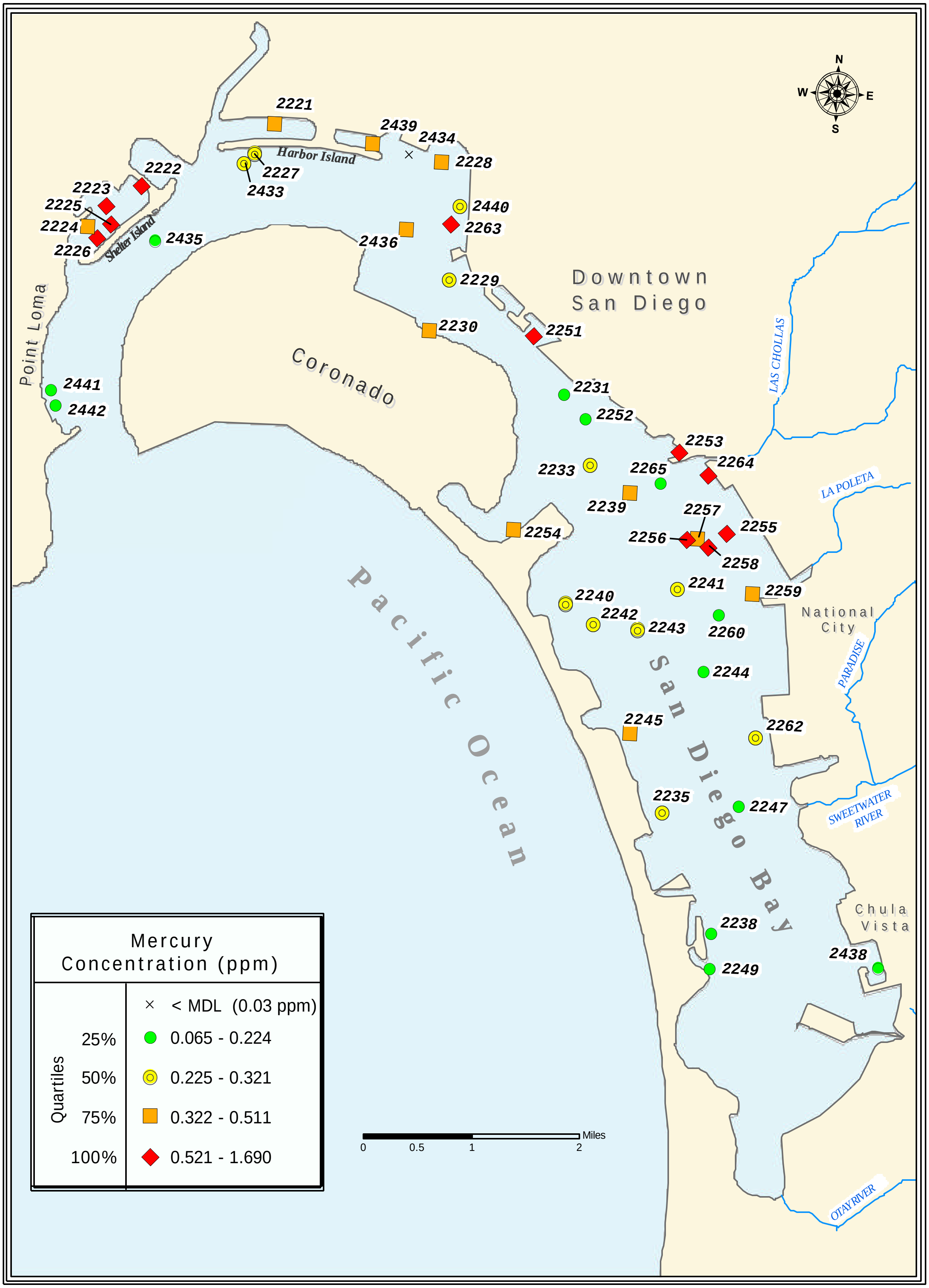
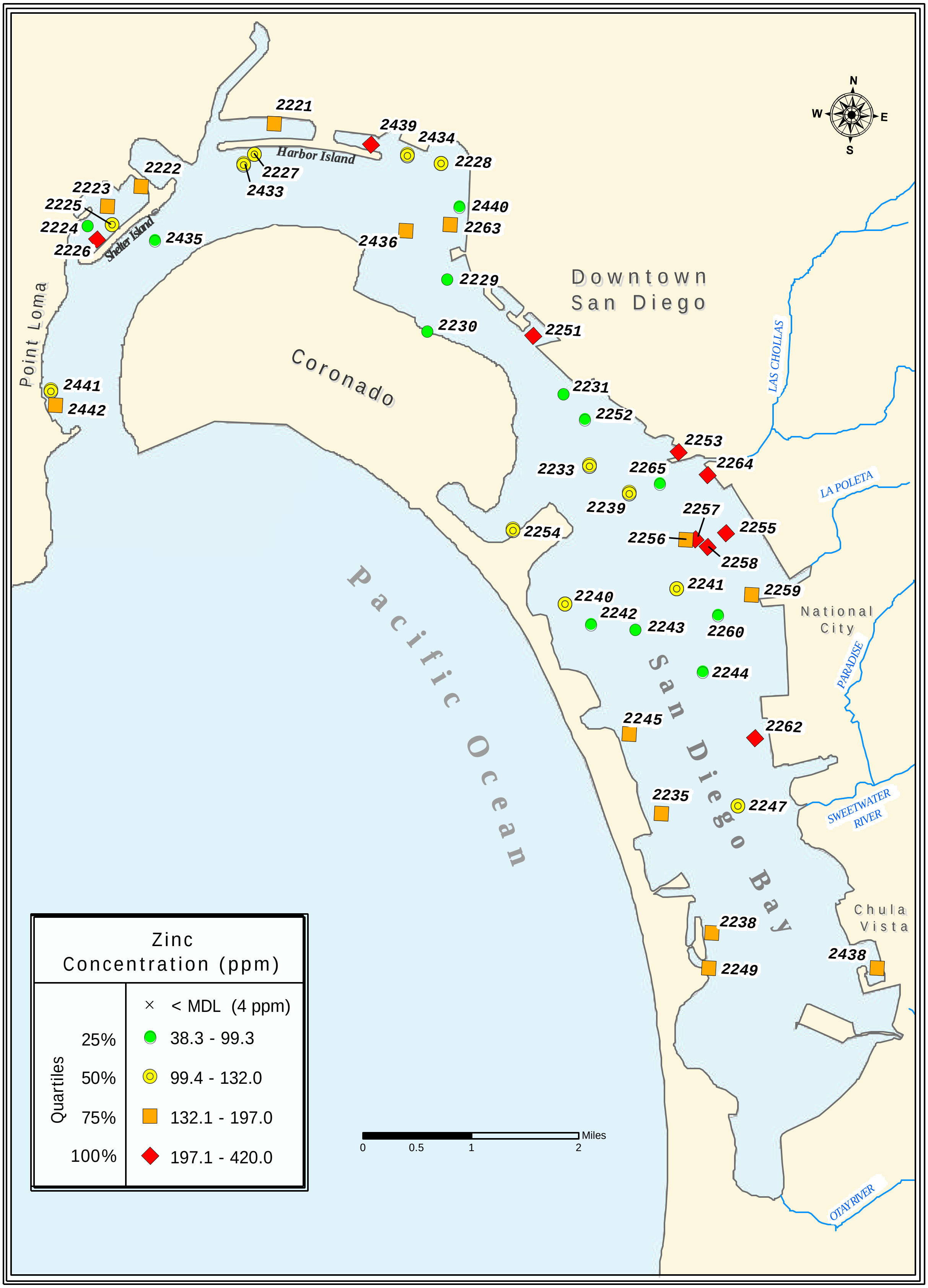



**Figure 2.6**

Quartile distributions of mercury concentrations (ppm) in San Diego Bay sediments during 1998.




## Figure 2.7

Quartile distributions of zinc concentrations (ppm) in San Diego Bay sediments during 1998.

***Polycyclic Aromatic Hydrocarbons (PAHs)***

PAHs were detected in the sediments at 34 of the 46 stations sampled in San Diego Bay. Total PAH concentrations ranged from 16 to 10,768 ppb, with the highest concentrations occurring primarily within naval installations and large shipyards (Figure 2.8, Appendix B.4). For example, the highest concentrations were found in sediments located near the naval submarine station at Ballast Point (i.e., station 2442) and within the naval shipyard for small vessels in Glorietta Bay (i.e., station 2254). In contrast, the lowest PAH concentrations generally occurred in sediments in open areas of the Bay where tidal flushing is relatively strong. This distribution pattern is similar to that shown for both fine sediments and metals. In addition, most stations that exceeded the lower-level ERL and TEL sediment screening thresholds for tPAH occurred among naval facilities or small boat marinas (Table 2.2).

***Polychlorinated Biphenyl Compounds (PCBs)***

PCBs were detected in sediments at 12 of the 46 stations sampled. These stations were located primarily in large shipyards, naval facilities, and along downtown waterfronts (Figure 2.9). Total PCB levels ranged from 1,500 to 123,800 ppt (Appendix B.5). The highest concentrations were found near the NASSCO shipyard (i.e., station 2253), the mouth of Las Chollas Creek (i.e., station 2264), and in Harbor Island East Basin near the mouth of Convair Basin, a PCB toxic cleanup site (i.e., station 2439).

The levels of PCB contamination reported during this survey were less than those detected previously for San Diego Bay (e.g., Fairey et al. 1996, USDoN, SWDIV and SDUPD 2000). The apparent decline in reportable values may reflect differences in the methods used to quantify PCB levels rather than an actual reduction of PCB contamination in the Bay. Factors that may affect MDLs and reported PCB concentrations include: (1) Sample size - larger samples produce higher concentrations of target analytes, increasing the potential for detectable quantities; (2) Detection limits used to qualify data – a Practical Quantification Limit produces fewer detected values and false positives than a statistical Quantification Limit; and (3) Tertiary Mass Spectrometry (TMS) confirmation - a third level of qualitative confirmation that differentiates between various congeners but with less sensitivity than the primary and secondary Electron Capture Detectors (ECD). Because PCB congeners are particularly vulnerable to false positive readings due to the regularity of their molecular weight and structure, City of San Diego staff used TMS to confirm each result that indicated the detection of a specific PCB on the two ECDs. The target analyte in question must have been above the detection limit of the TMS to be considered a reportable value. The use of TMS to confirm the presence of each detected PCB likely created the discrepancy in reported values between this and previous San Diego Bay surveys. Never-the-less, data reported herein are consistent with patterns of contamination found in previous studies (e.g., SAIC 1998).

***Pesticides and Biocides***

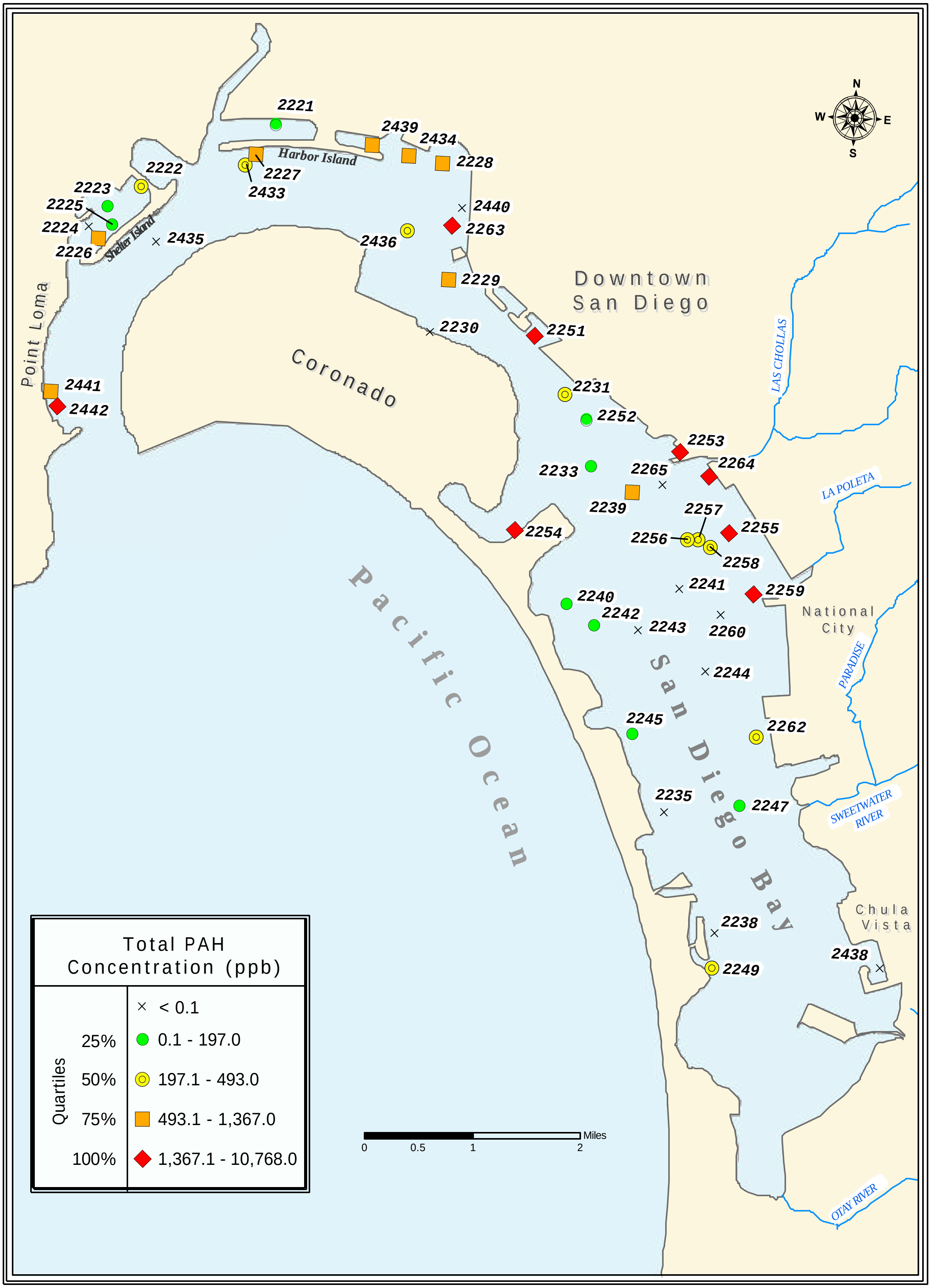
DDT was the only pesticide detected in San Diego Bay sediments in 1998. It occurred at only seven of the 46 San Diego Bay stations. Total DDT (tDDT) concentrations ranged from 780 to 7,300 ppt (Appendix B.6), and four stations exceeded the lower level ERL/TEL sediment screening criteria (Tables 2.1 and 2.2). These four sites were in the central portion of the Bay located near the NASSCO shipyard (i.e., station 2253), Las Chollas Creek (i.e., station 2264), Naval Station San Diego (i.e., station 2255), and near the Naval Amphibious Base at Glorietta Bay (i.e., station 2242). The station near the mouth of Las Chollas Creek had the highest tDDT concentration. Chlordane was not detected in any sediment sample during the 1998 survey, although this pesticide had been considered a contaminant of concern (e.g., Mearns et al. 1991, Fairey et al. 1996).

## Table 2.2

Summary of the San Diego Bay stations with three or more contaminants that exceeded sediment screening criteria: TEL (B) < ERL (△) < PEL (C) < ERM (▲). SIYB = Shelter Island Yacht Basin; HIWB = Harbor Island West Basin; HIEB = Harbor Island East Basin.

| Station | As | Sb | Cd | Cr | Cu | Pb | Hg | Ni | Ag | Zn | tPAH | tDDT | Field observations/site description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2221 | B | ▲ | | B | C | B | △ | B | | △ | | | small boat marina (HIWB) |
| 2222 | B | ▲ | | | C | B | ▲ | B | | △ | | | small boat marina (SIYB)* |
| 2223 | △ | ▲ | | | C | B | ▲ | | | △ | | | small boat marina (SIYB)* |
| 2224 | | ▲ | | | △ | | △ | | | | | | small boat marina (SIYB)* |
| 2225 | | ▲ | | | C | △ | B | | | | | | small boat marina (SIYB)* |
| 2226 | | ▲ | | | C | △ | ▲ | B | | △ | | | small boat marina (SIYB)* |
| 2227 | | ▲ | | | △ | | △ | | | | | | anchorage off Harbor Island |
| 2228 | | | | | △ | B | △ | | B | B | | | anchorage near Embarcadero tuna fleet* |
| 2235 | | | | | △ | | △ | | | B | | | north of Crown Cove - sandy shore |
| 2238 | | | | | △ | | △ | | | B | | | near Coronado Cays Yacht Club |
| 2239 | | | | | △ | B | △ | | | | | | dredged channel |
| 2241 | | ▲ | | | △ | B | △ | | | B | | | dredged channel |
| 2242 | | | | | △ | | △ | | | △ | | | near Naval Amphibious Base |
| 2244 | | ▲ | | | △ | | △ | | | | | | dredged channel |
| 2245 | | ▲ | | | △ | | △ | | | B | | | near small boat marina (Navy Yacht club) |
| 2249 | B | ▲ | | | △ | | △ | B | | △ | | | small boat marina (Coronado Cays) |
| 2251 | △ | | | B | C | △ | △ | B | △ | △ | △ | | shipyard near 10th Ave. Marine Terminal* |
| 2253 | △ | | | B | C | △ | ▲ | B | | C | | △ | NASSCO Shipyard* |
| 2254 | | ▲ | | | △ | | △ | | | | △ | | small boat marina (Naval vessels) |
| 2255 | | ▲ | | | C | △ | △ | | △ | △ | B | △ | Naval Station SD* |
| 2256 | B | | | B | C | △ | △ | | △ | △ | | | dredged channel, near Naval Station SD |
| 2257 | △ | | | B | C | △ | △ | B | △ | △ | | | dredged channel, near Naval Station SD |
| 2258 | B | | | B | C | △ | △ | B | B | △ | | | dredged channel, near Naval Station SD |
| 2259 | | | | | C | B | △ | | B | △ | B | | Naval Station SD / 7th St. Channel* |
| 2260 | | ▲ | | | △ | | △ | | | | | | dredged channel |
| 2262 | △ | | | B | C | B | △ | B | | △ | | | near 24th St. Marine Terminal* |
| 2263 | B | | | B | C | B | △ | B | B | △ | B | | downtown (Broadway & Navy Piers)* |
| 2264 | △ | | | B | C | C | △ | △ | | ▲ | B | B | Naval Station SD, near Las Chollas Crk* |
| 2433 | △ | ▲ | | | △ | | △ | | | B | | | anchorage off Harbor Island |
| 2434 | | ▲ | | | △ | B | | | | B | | | near Coast Guard facility |
| 2436 | △ | ▲ | | B | △ | B | △ | B | | △ | | | dredged channel |
| 2439 | | | | B | C | B | △ | | | △ | | | small boat marina (HIEB) |
| 2440 | | ▲ | | | △ | | △ | | | | | | downtown (B St. Pier)* |
| 2441 | △ | ▲ | | | △ | | △ | B | | | | | Ballast Point Naval Submarine Base* |
| 2442 | △ | | | | △ | | △ | B | | B | △ | | Ballast Point Naval Submarine Base* |

* = Areas previously identified as having elevated contaminant loads or toxicity levels by the State Water Resources Control Board (CRWQCB-SDR 1997).




## Figure 2.8

Quartile distributions of detected tPAH concentrations (ppb) in San Diego Bay sediments during 1998.

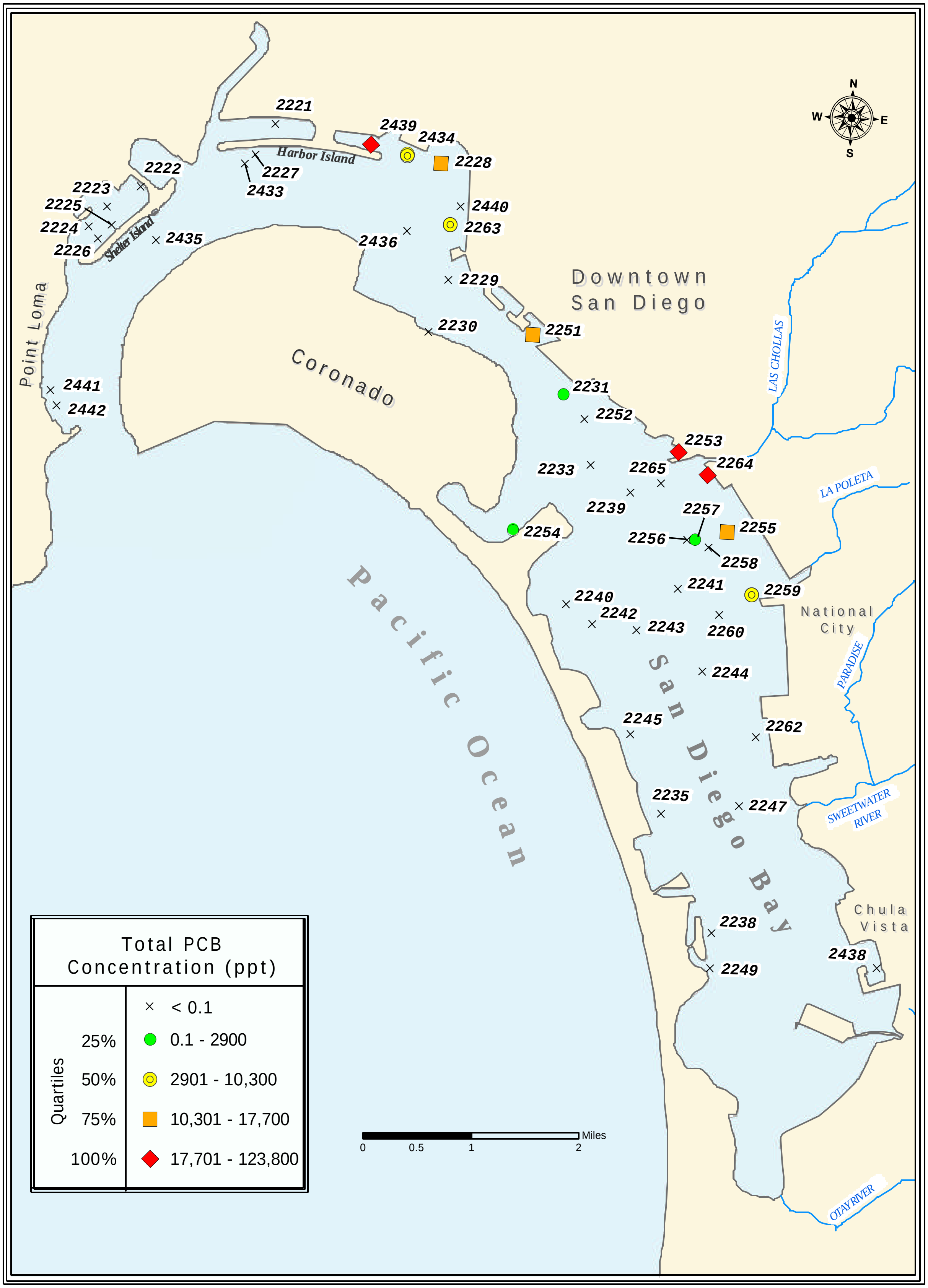



**Figure 2.9**
Quartile distributions of detected tPCB concentrations (ppt) in San Diego Bay sediments during 1998.

The biocide tributyltin (TBT) was detected in sediments at only two sites in San Diego Bay. These included a concentration of 89 ppt at station 2222 in the Shelter Island Yacht Basin and a value of 160 ppt at station 2253 located near the NASSCO shipyard. TBT is the active agent of antifouling paints that degrades naturally into tin, a metal that was not detected in any of the bay sediment samples.

***Comparisons of San Diego Bay to Other Embayments***

Generally, the sediment sites in San Diego Bay grouped consistently with sites located in other bays and harbors from the southern portion of the Southern California Bight (SCB) (i.e., Orange and San Diego counties). These southern embayments, with the exception of Newport Harbor, generally had lower levels of organic indicators and lower concentrations of contaminants than the more northern embayments of Los Angeles and Ventura counties (Table 2.3 and Appendix B.7). The lower contaminant loads may reflect the fact that these southern sites contained fewer fine particles. For example, San Diego Bay, Mission Bay, Anaheim Bay, and Dana Point Harbor averaged less than 60% fines and had the lowest overall concentrations of metal and pesticides. In contrast, all of the more northern bays and harbors averaged over 60% fine particles and were first or second in average concentration for all 19 reported contaminants. Nonetheless, San Diego Bay had the highest mean value for antimony, the second highest value for mercury, and the third highest value for copper. The highest values for tPAH were found in Mission Bay, followed by Los Angeles/Long Beach Harbor, San Diego Bay, and Anaheim Bay. All contained mean values greater than 1,000 ppt with individual values that exceeded the TEL sediment screening criteria. San Diego Bay ranked fourth in PCB contamination, below LA/LB Harbor, Marine del Rey, and Newport Harbor. Finally, San Diego Bay had the lowest overall pesticide contamination. DDT was the only pesticide detected in San Diego Bay and the average tDDT concentrations were well below those of the other bays and harbors. The highest concentrations of tDDT in sediments were found in Ventura and Channel Island Harbors, while total chlordane was highest in Channel Island Harbor and Marina Del Rey. However, the absence of chlordane from San Diego Bay sediments may have resulted from differences in analytical techniques and instrumentation employed by the various laboratories. For example, the MDLs for chlordane-*a* among agencies participating in the Bight'98 survey were 14 and 7.6 times higher in Los Angeles County and San Diego Laboratories, respectively, than those established by the Orange County Laboratory.

## SUMMARY & DISCUSSION

The results of the 1998 survey for sediment particle size and sediment chemistry suggest that the highest levels of pollutants in San Diego Bay were widely distributed among commercial shipyards, naval installations, and small vessel marinas where fine sediments were often most concentrated. The potential for fine particles to sorb contaminants and settle in areas of reduced water flow, such as shipyards and marinas, may explain this pattern. For example, stations with the greatest number of contaminants that exceeded recognized sediment screening criteria (i.e., TEL/PEL, ERL/ERM) tended to have the highest percentage of fine sediments (i.e., $\geq$ 60% fines) (Figure 2.10).

The distribution of fine sediment particles appears to reflect, in part, the circulation patterns within the Bay (see Sutton 2002). Fine particles were more prevalent in shipyards and marinas where currents were less strong and the presence of various structures reduce tidal flow or create eddies

## Table 2.3

Comparison of various sediment grain size and sediment chemistry parameters among the nine bays and harbors sampled during Bight'98.

| | Ventura Harbor | Channel Is. Harbor | Marina Del Rey | LA/LB Harbor | Anaheim Bay | Newport Harbor | Dana Pnt Harbor | Mission Bay | San Diego Bay |
|---|---|---|---|---|---|---|---|---|---|
| **N** | 1 | 3 | 7 | 36 | 3 | 11 | 3 | 3 | 46 |
| ***%Fines*** | | | | | | | | | |
| **Mean** | 87 | 81 | 69 | 71 | 59 | 75 | 48 | 39 | 52 |
| **95% CI** | — | 8 | 10 | 6 | 38 | 12 | 25 | 34 | 6 |
| ***%TN*** | | | | | | | | | |
| **Mean** | 0.176 | 0.202 | 0.125 | 0.110 | 0.129 | 0.130 | 0.097 | 0.168 | 0.102 |
| **95% CI** | — | 0.075 | 0.024 | 0.014 | 0.091 | 0.032 | 0.051 | 0.161 | 0.013 |
| ***%TOC*** | | | | | | | | | |
| **Mean** | 1.736 | 2.085 | 1.529 | 1.429 | 1.751 | 1.323 | 0.927 | 1.626 | 0.987 |
| **95% CI** | — | 0.795 | 0.291 | 0.216 | 1.456 | 0.274 | 0.489 | 1.897 | 0.141 |
| ***Metals (ppm)*** | | | | | | | | | |
| **Chromium** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 |
| **Mean** | 38.0 | 43.5 | 46.0 | 53.9 | 27.4 | 51.6 | 33.1 | 19.4 | 39.8 |
| **95%CI** | — | 5.0 | 13.3 | 6.3 | 14.1 | 9.4 | 16.4 | 17.7 | 4.6 |
| **Copper** | | | | | | | | | |
| **%Detect** | 100 | 67 | 100 | 92 | 100 | 100 | 100 | 100 | 100 |
| **Mean** | 131.0 | 63.3 | 171.9 | 71.3 | 48.1 | 52.4 | 85.3 | 34.1 | 95.1 |
| **95%CI** | — | 65.0 | 76.0 | 12.2 | 36.2 | 28.2 | 104.3 | 50.1 | 17.3 |
| **Mercury** | | | | | | | | | |
| **%Detect** | 0 | 100 | 86 | 89 | 33 | 100 | 100 | 67 | 98 |
| **Mean** | — | 0.063 | 0.567 | 0.283 | — | 0.271 | 0.028 | 0.056 | 0.415 |
| **95%CI** | — | 0.018 | 0.276 | 0.076 | — | 0.288 | 0.020 | 0.028 | 0.088 |
| **Zinc** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Mean** | 205 | 154 | 245 | 153 | 179 | 145 | 104 | 65 | 148 |
| **95%CI** | — | 57 | 76 | 23 | 130 | 39 | 77 | 69 | 21 |
| ***Total PAHs (ppb)*** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 97 | 100 | 91 | 100 | 33 | 74 |
| **Mean** | 177.6 | 389.7 | 675.5 | 1541.8 | 1101.8 | 832.2 | 121.2 | 2291.3 | 1283.8 |
| **95%CI** | — | 156.9 | 374.4 | 817.1 | 1022.5 | 390.0 | 66.8 | — | 722.7 |
| ***Total PCBs (ppt)*** | | | | | | | | | |
| **%Detect** | 100 | 67 | 100 | 94 | 100 | 100 | 100 | 0 | 26 |
| **Mean** | 2.1 | 4.3 | 80.6 | 55.2 | 18.0 | 27.2 | 14.3 | — | 23.4 |
| **95%CI** | — | 2.9 | 40.4 | 27.0 | 16.8 | 20.9 | 21.5 | — | 19.4 |

that allow suspended particles to settle (Valkirs et al. 1991, USGS 1994, USDoN, SWDIV and SDUPD 2000, Knox 2001). In contrast, coarse sediments were most prevalent in the central portion of the Bay where the current flow is high and dredging is practiced regularly. A review of the cumulative history of dredge and fill activity in the Bay showed that those stations with less than 36 percent fines were located within areas of the Bay where dredging has exposed sandier sediment layers (USDoN, SWDIV and SDUPD 2000).

Metal contamination in San Diego Bay continues to be widespread. Every station had measurable quantities of at least 15 metals in 1998, and many stations exceeded the lower level sediment quality thresholds for multiple metals. Copper, mercury, and zinc were the most prevalent metals of concern and frequently exceeded available sediment quality guidelines. Antimony, although not considered a contaminant of concern, is associated with shipyard activity (e.g., solder, metal bearings and castings, adhesives) and exceeded the more stringent ERM sediment threshold 100% of the time. The contamination levels of some metals appears to be in decline, however. For example, although tin has been found in high concentrations in San Diego Bay (Mearns et al. 1991), it was not detected in any sediment samples collected in 1998. Additionally, San Diego Bay had the third highest average copper concentration in the present study in spite of being listed by Dailey et al. (1993) as having the highest copper contamination of all SCB embayments.

PAH contamination was also prevalent in Bay sediments, but in relatively low concentrations. Although 74% of the stations had measurable quantities of PAHs, only seven exceeded the lower level sediment screening criteria, and these were concentrated among naval facilities and small boat marinas. Overall, it appears that PAH concentrations in San Diego Bay have fallen over time because PAH inputs to the environment have declined. In San Diego Bay, creosote leaching from pier pilings was thought to be one of the main sources of PAH contamination, followed by in-place sediments introduced to the water column (Katz 1998; USDoN, SWDIV and SDUPD 2000). At the Naval facility, half of the pier pilings treated with creosote and copper have been removed, and the discharge of bilge water into gravity separators located in the Bay has ceased (Katz 1998). As a result, PAH inputs to the environment have declined.

PCB congeners were mostly undetected in San Diego Bay sediments during 1998 even though Fairey et al. (1996) previously found PCBs to be widespread. The low detection rates presented herein may reflect, in part, differences in instrumentation and confirmation techniques as discussed previously (see Results section). In spite of these differences, however, PCB-contaminated sediments were distributed among areas previously identified as having elevated PCB contamination, such as large shipyards, naval facilities, and the downtown waterfronts (e.g.,

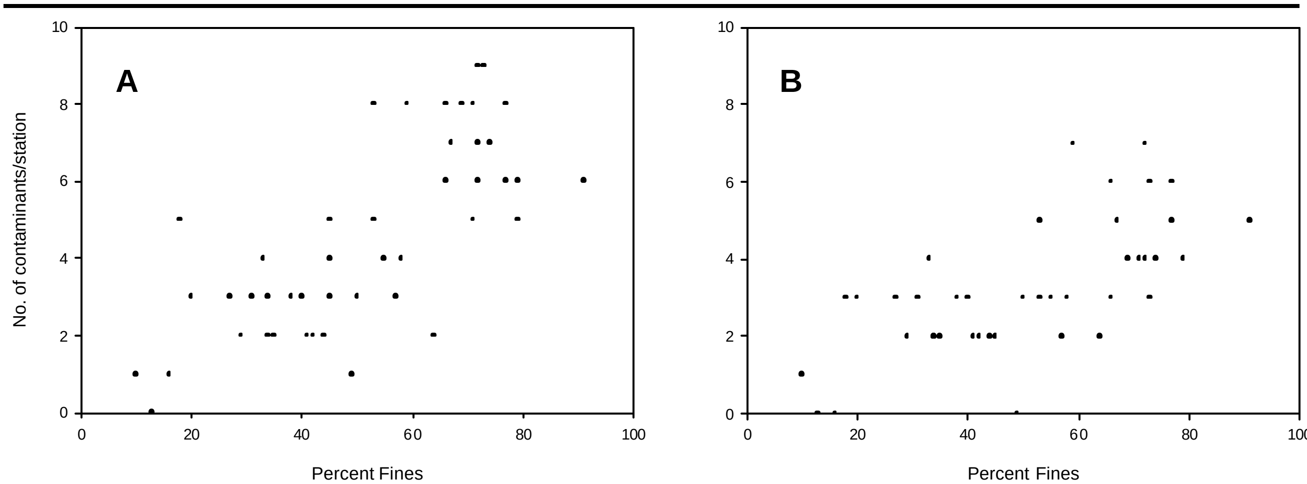



**Figure 2.10**

The number of instances per station that (A) TEL and (B) ERL sediment screening criteria were exceeded plotted against the percentage of fine sediments per station.

Fairey et al. 1996, SAIC 1998, CRWQCB-SDR 2001). The high stability of PCBs and the extent of their use in paints, electronics, and plastics has contributed to their widespread dispersion and accumulation in the environment (Manahan 2000). Moreover, most PCBs in the sediments exist in anaerobic conditions where degradation via anaerobic bacteria requires a very long residence time. Additional surveys using similar detection techniques should help determine whether or not PCB contamination is in decline.

Pesticide and biocide contamination was found in such high concentrations throughout San Diego Bay that chlordane and tributyltin (TBT) were considered chemicals of concern by Mearns et al. (1991) and Fairey et al. (1996). However, DDT was detected at only seven stations in 1998, TBT was detected at only two stations, and chlordane was not detected at all. The apparent reduction in chlordane contamination may result from differences in analytical techniques and instrumentation as discussed above (see Results section). On the other hand, the decline in TBT likely reflects a reduction in usage of TBT within the United States. TBT has been linked to endocrine disruption in shellfish, oysters, and snails (Manahan 2000) and was banned from antifouling paint for ship hulls by the Organotin Antifouling Paint Control Act of 1988. The affect of this legislation was to limit the use of TBT to Navy ships and larger commercial vessels. Finally, mean concentrations of tDDT in sediments from San Diego Bay were the lowest among the nine bays sampled during Bight'98.

Overall, the results of this study are in keeping with previous investigations for toxic hot spots (see Fairey et al. 1996, CRWQCB-SDR 1997, MESO 1998, CRWQCB-SDR 2001). The areas of concern continue to be the naval shipyards and various marinas, including the Naval Submarine Base San Diego, Shelter Island Yacht Basin, the downtown waterfront (i.e., anchorage off Grape Street and B Street Pier), Switzer Creek outlet and the Tenth Avenue Marine Terminal, NASSCO shipyard, Naval Station San Diego, Las Chollas and La Paleta Creeks (including the Seventh Street Channel), and the 24th Street Marine Terminal. These areas reflect zones of heavy industrial/naval use and point source discharges, such as storm drains and creek mouths. In comparison to other bays and harbors in the SCB, however, San Diego Bay has relatively low levels of widespread contamination and has considerably less contamination than in decades past.

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# Macrobenthic Communities

Shelter Island Yacht Basin

# *Chapter 3*
# Macrobenthic Communities

## INTRODUCTION

Benthic macroinvertebrates are important members of marine ecosystems, serving vital functions in wide ranging capacities. For example, many species that live within or on the surface of the sediments (i.e., infauna and epifauna, respectively) provide the prey base for fish and other marine predators, while other species decompose organic material as a crucial step in nutrient cycling. In addition, correlations between environmental factors and benthic community structure often provide useful measures of anthropogenic impact (Pearson and Rosenberg 1978). For this reason, the characterization of macrobenthic communities has long been recognized as an integral component of marine ecological assessments.

Macrobenthic communities in San Diego Bay are influenced by many physical, chemical, and biological factors. These include the various attributes of the bottom waters (e.g., temperature, salinity, dissolved oxygen, current velocity) and sediments (e.g., particle size distribution, sediment chemistry), as well as biological factors such as food availability, competition, and predation. These factors are controlled by both natural processes and human activities, which ultimately determine the structure of the Bay's benthic communities. For example, differences in tidal flushing, evaporation, and freshwater input create unique hydrodynamic regions throughout the Bay (see Largier 1995), while human activities such as dredging and shipbuilding affect the physical environment through habitat alteration or the deposition of toxic compounds (USDoN, SWDIV and SDUPD 2000). Most previous studies of the San Diego Bay benthos have focused on anthropogenic impacts from known point sources. A comprehensive survey of the bay's macrofauna, with adequate coverage to address both natural and anthropogenic influences on community structure, has not been done prior to this study.

This chapter presents an assessment of macrobenthic communities sampled throughout San Diego Bay in the summer of 1998. Included is a discussion of the factors that may influence the composition and distribution of the various assemblages. In addition, this chapter presents a comparison of the San Diego Bay macrofauna to that occurring in the other bays and harbors sampled during the Bight'98 regional survey of the Southern California Bight (SCB). These data will provide a baseline against which to measure future trends, monitor populations of indigenous and nonindigenous species, and assess the overall ecological condition of the Bay.

## MATERIALS & METHODS

### Collection and Processing of Samples

Benthic samples were collected at 46 stations in San Diego Bay during July and August of 1998 (Figure 3.1). These stations were randomly located throughout the Bay and ranged in depth from 3.0 to 15.6 m. One sample was collected at each site using a 0.1 $m^2$ modified van Veen grab. Criteria established by the United States Environmental Protection Agency to ensure the consistency of grab samples were followed with regard to sample disturbance and depth of penetration (see USEPA 1987). All samples were sieved through a 1.0 mm mesh screen and processed aboard ship. Organisms retained on the screen were relaxed for approximately 30


## Figure 3.1

Macrobenthic stations sampled in San Diego Bay during 1998.

minutes in a magnesium sulfate solution. The samples were then fixed with buffered formalin for a minimum of 72 hours, rinsed with fresh water, and transferred to 70% ethanol. All of the organisms were sorted from the debris into major taxonomic groups, after which they were identified to species or the lowest taxon possible and enumerated. Complete details regarding the project's experimental design, randomized station location procedures, field sampling methods and sample processing protocols are available in the Bight'98 field manual (FSLC 1998).

### Data Analyses

The following community structure parameters were calculated for each station: species richness (number of species per grab); abundance (number of individuals per grab); Shannon diversity index (H' per grab); Pielou's evenness index (J' per grab); Swartz dominance index (minimum number of species accounting for 75% of the abundance in each grab).

Ordination (principal coordinates) and classification (hierarchical agglomerative clustering) analyses were performed to examine spatial patterns in the overall similarity of the macrobenthic assemblages. These analyses were performed using Ecological Analysis Package (EAP) software (see Smith 1982, Smith et al. 1988). Prior to analysis the abundance data were square root transformed and the data set was reduced by excluding any taxon represented by only one animal.

Environmental correlates to the biological distribution patterns were investigated by overlaying rank-ordered values for the various environmental parameters onto plots of stations distributed in ordination space (see Field et al. 1982). The parameters used for these comparisons included station depth, percent fines (silt and clay sediment fraction), total organic carbon (TOC), total nitrogen (TN), several trace metals (i.e., copper, mercury, zinc and lead), total DDT (tDDT), total polycyclic aromatic hydrocarbons (tPAH) and total polychlorinated biphenyls (tPCB). The above chemical parameters were identified as contaminants of concern by either Fairey et al. (1996) or USDoN, SWDIV and SDUPD (2000), and were detected during this study in concentrations exceeding the Effects Range-Low (ERL) guidelines developed by NOAA (Long et al. 1995).

### Comparison of San Diego Bay to Other Embayments

In addition to San Diego Bay, the macrobenthos from eight other southern California bays was sampled during Bight'98. From north to south these embayments are Ventura Harbor, Channel Islands Harbor, Marina Del Rey, Los Angeles/Long Beach Harbor, Anaheim Bay, Newport Bay, Dana Point Harbor, and Mission Bay. Including San Diego Bay stations, a total of 114 sites were surveyed by 11 participating agencies. Methodologies and protocols for the collection and processing of these samples were the same as for those outlined previously. Data analysis, however, was limited by the differences in sampling effort among the embayments. For example, Ventura Harbor was represented by a single station with only 11 species, and therefore was not included in comparisons of the dominant taxa in southern California bays. Ordination and classification analyses were performed on a dataset including all 114 stations, following methods described above.

## Table 3.1

Summary of abundance (Abun) and species richness (SR) for major taxa (Polychaeta, Crustacea, Mollusca, Other Phyla combined) collected in San Diego Bay during 1998. Data are expressed as means per sample (no./0.1 $m^2$). Ranges of values for individual samples are shown in parentheses.

| | Polychaeta | Mollusca | Crustacea | Other Phyla | Total |
|---|---|---|---|---|---|
| **Abun** | 545<br>(74-2145) | 164<br>(11-1187) | 103<br>(2-839) | 17<br>(1-91) | 830<br>(102-3149) |
| **SR** | 23<br>(14-48) | 9<br>(3-26) | 9<br>(2-21) | 6<br>(1-14) | 47<br>(25-96) |

# RESULTS

## Community Structure

In total, 38,187 macrobenthic organisms representing 340 taxa were identified from the 46 San Diego Bay samples. The dominant higher taxonomic groups were polychaetes, molluscs and crustaceans (Table 3.1). Polychaetes averaged 545 individuals and 23 taxa per 0.1 $m^2$ grab sample. Molluscs and crustaceans averaged 164 and 103 individuals per sample respectively, and each about nine taxa per sample. All of the remaining taxa combined (e.g., echinoderms, nemerteans, cnidarians, etc.) averaged 17 individuals and less than six taxa per grab. A conservative estimate identified 18 species that are considered not native to San Diego. These nonindigenous species represented 24% of the total macrofauna in the Bay.

A small number of species (< 5%) accounted for over 80% of the individual animals collected from San Diego Bay. These numerically dominant taxa also tended to be widely distributed throughout the Bay. The majority of taxa, however, occurred in low numbers, with over 25% being represented by single individuals. Although some of the many taxa with low to moderate abundances were widely distributed, most were not. In total, only 22 species were found at more than half the stations. Hence, the benthos was dominated by relatively few species in terms of both abundance and distribution.

The dominant macrofauna in San Diego Bay are listed in Table 3.2. A capitellid polychaete, *Mediomastus* sp (a species complex), was the most abundant organism. This worm was present in every sample, with populations varying from 2 to 521 per 0.1 $m^2$. Another polychaete, the spionid *Prionospio heterobranchia*, was also found at all stations. The second most abundant animal was the nonindigenous bivalve *Musculista senhousia*, which occurred in densities exceeding 1100 per $m^2$. This ecologically important mussel was also found at more than 95% of the stations. Two other nonindigenous species that were also widespread and abundant were the spionid polychaete *Pseudopolydora paucibranchiata* and the bivalve *Theora lubrica*. Finally, a crustacean, the tanaid *Synaptotanais notabilis* (=*Zeuxo normani* in Fairey et al. 1996), was highly abundant at a small group of stations, most of which were located within the Shelter Island Yacht Basin.

There was considerable variation in the overall structure of the macrobenthic assemblages distributed throughout the Bay (see Appendix C.1). Species richness varied among stations, ranging from 25 to 96 species per 0.1 $m^2$ grab (mean = 47/grab). In general, there were higher numbers of species at stations located

## Table 3.2

Dominant macroinvertebrates at San Diego Bay benthic stations sampled during 1998. Included are the 10 most abundant taxa overall and per occurrence, and the 10 most widely occurring taxa. Data are expressed as: MS = mean number per 0.1 $m^2$ over all samples; MO = mean number per 0.1 $m^2$ per occurrence; and PO = percent occurrence.

| Species (Taxa) | Higher Taxa | MS | MO | PO |
|---|---|---|---|---|
| Ten Most Abundant | | | | |
| 1. *Mediomastus* sp | Polychaeta: Capitellidae | 108.2 | 108.2 | 100% |
| 2. *Musculista senhousia* [1] | Mollusca: Bivalvia | 85.5 | 89.3 | 96% |
| 3. *Euchone limnicola* | Polychaeta: Sabellidae | 84.7 | 99.9 | 85% |
| 4. *Pseudopolydora paucibranchiata* [1] | Polychaeta: Spionidae | 72.0 | 89.5 | 80% |
| 5. Lumbrineridae [2] | Polychaeta: Lumbrineridae | 44.0 | 54.8 | 80% |
| 6. *Amphideutopus oculatus* | Crustacea: Amphipoda | 31.8 | 39.6 | 80% |
| 7. *Synaptotanais notabilis* | Crustacea: Tanaidacea | 31.6 | 145.2 | 22% |
| 8. *Prionospio heterobranchia* | Polychaeta: Spionidae | 31.5 | 31.5 | 100% |
| 9. *Lumbrineris* sp C | Polychaeta: Lumbrineridae | 28.8 | 29.4 | 98% |
| 10. *Leitoscoloplos pugettensis* | Polychaeta: Orbiniidae | 28.6 | 30.6 | 94% |
| Ten Most Abundant per Occurrence | | | | |
| 1. *Synaptotanais notabilis* | Crustacea: Tanaidacea | 31.6 | 145.2 | 22% |
| 2. *Mediomastus* sp | Polychaeta: Capitellidae | 108.2 | 108.2 | 100% |
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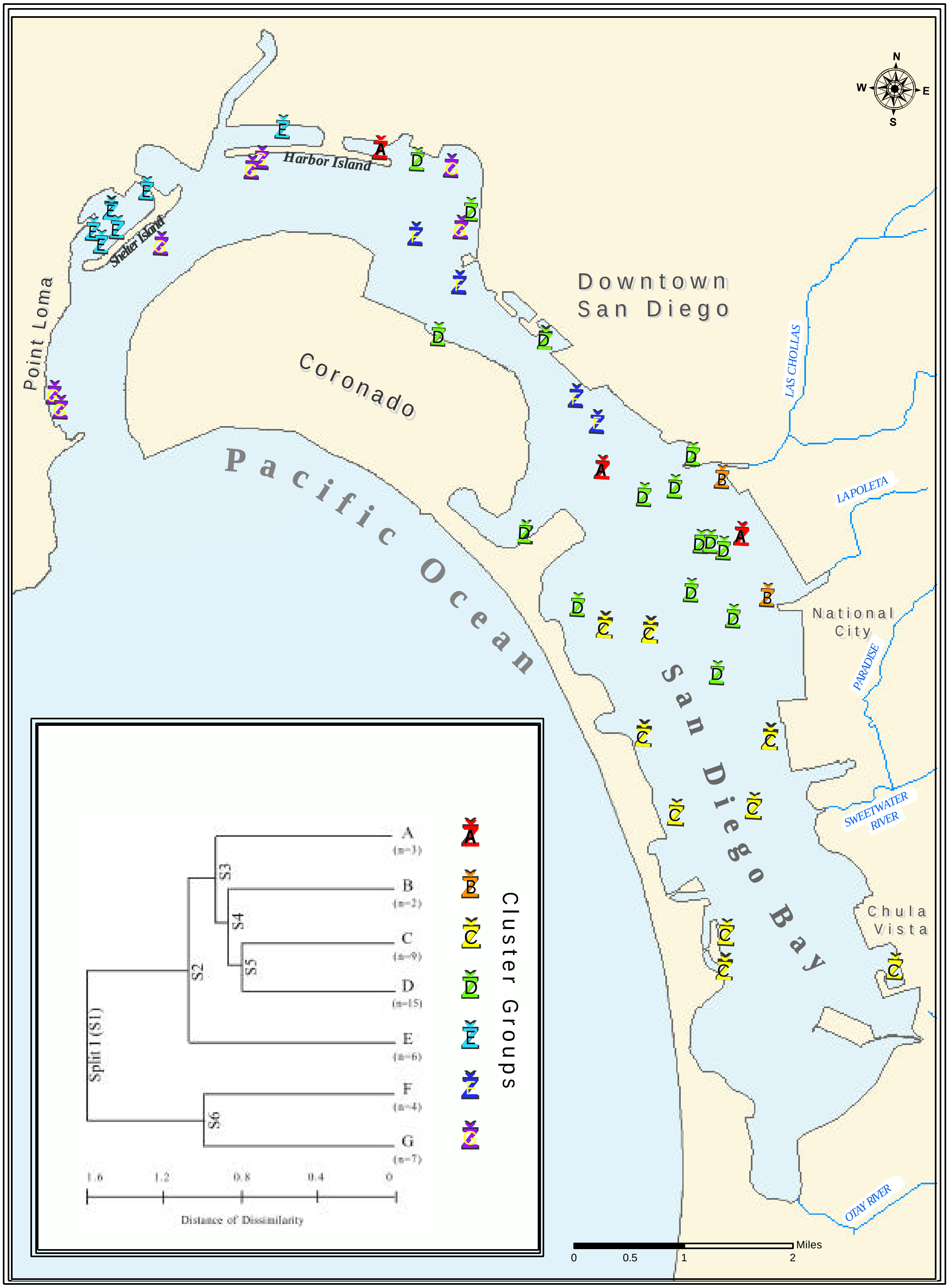
| 5. *Musculista senhousia* [1] | Mollusca: Bivalvia | 85.5 | 89.3 | 96% |
| 6. Lumbrineridae [2] | Polychaeta: Lumbrineridae | 44.0 | 54.8 | 80% |
| 7. *Fabricinuda limnicola* | Polychaeta: Sabellidae | 21.0 | 46.1 | 46% |
| 8. *Amphideutopus oculatus* | Crustacea: Amphipoda | 31.8 | 39.6 | 80% |
| 9. *Exogone lourei* | Polychaeta: Syllidae | 28.5 | 33.6 | 85% |
| 10. *Prionospio heterobranchia* | Polychaeta: Spionidae | 31.5 | 31.5 | 100% |
| Ten Most Widespread | | | | |
| 1. *Mediomastus* sp | Polychaeta: Capitellidae | 108.2 | 108.2 | 100% |
| 2. *Prionospio heterobranchia* | Polychaeta: Spionidae | 31.5 | 31.5 | 100% |
| 3. *Lumbrineris* sp C | Polychaeta: Lumbrineridae | 28.8 | 29.4 | 98% |
| 4. *Musculista senhousia* [1] | Mollusca: Bivalvia | 85.5 | 89.3 | 96% |
| 5. *Pista agassizi* | Polychaeta: Terebellidae | 27.4 | 28.7 | 96% |
| 6. *Leitoscoloplos pugettensis* | Polychaeta: Orbiniidae | 28.6 | 30.6 | 94% |
| 7. *Theora lubrica* [1] | Mollusca: Bivalvia | 25.6 | 29.4 | 87% |
| 8. *Glycera americana* | Polychaeta: Glyceridae | 3.8 | 4.4 | 87% |
| 9. *Euchone limnicola* | Polychaeta: Sabellidae | 84.7 | 99.9 | 85% |
| 10. *Exogone lourei* | Polychaeta: Syllidae | 28.5 | 33.6 | 85% |

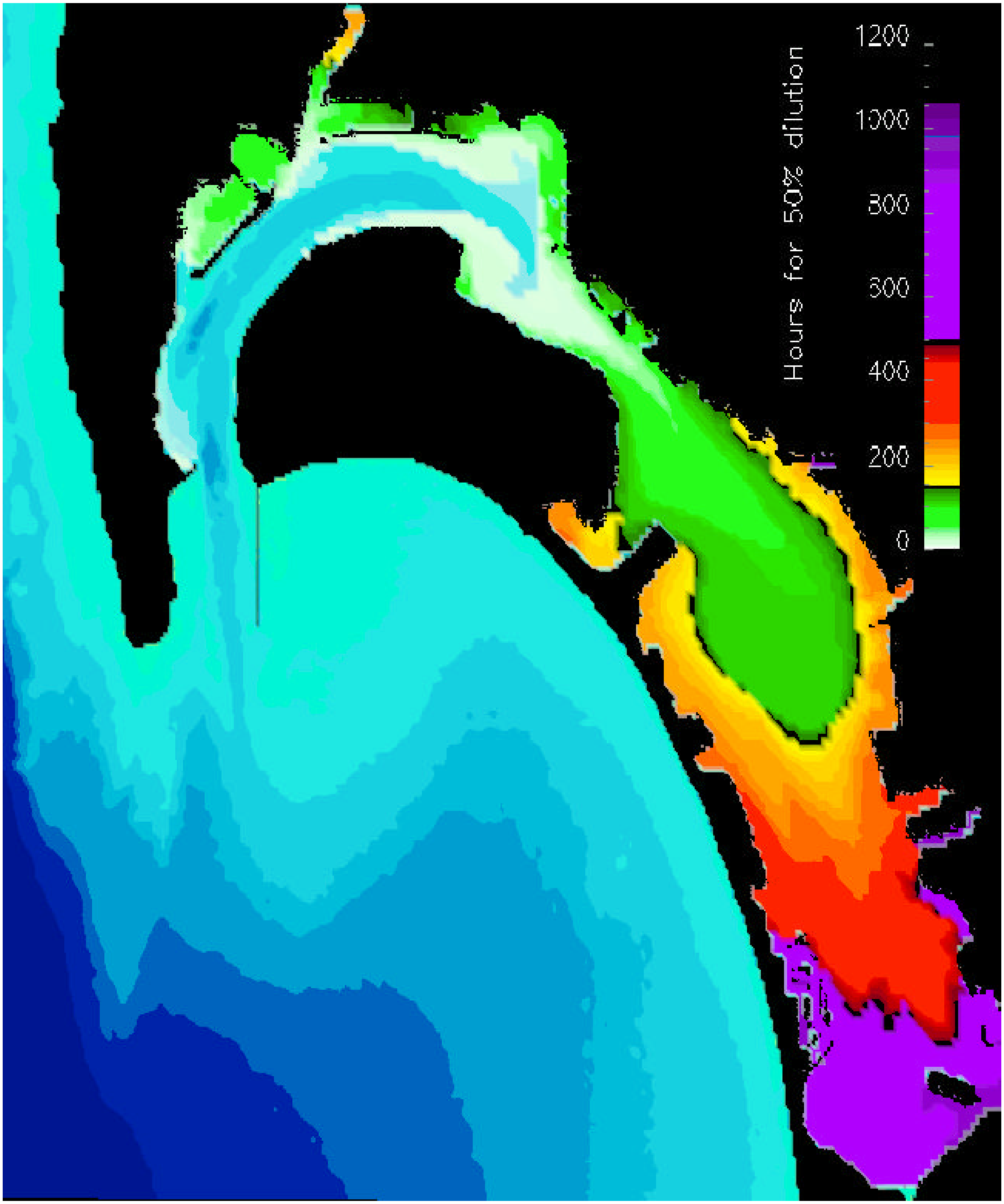
1 = nonindigenous species
2 = unidentified juveniles and/or damaged specimens

near the mouth of the Bay, and fewer taxa at sites towards the backwaters. Macrofaunal abundance was also highly variable, ranging from 102 to 3,149 animals per grab and with an average density of 830 animals per sample. Species dominance was expressed as the minimum number of species composing 75% of a community by abundance, with lower values indicating higher dominance (Swartz 1978). These values varied from 3 to 16 species per station, with the lowest dominance typically occurring at sites nearer the mouth of the Bay. Similarly, species diversity was highest near the Bay's mouth, with H' values ranging between 1.7 and 3.4 (mean = 2.5) at the various stations.




## Figure 3.2

Summary of results of classification analysis of macrofaunal abundance data from the 1998 survey of San Diego Bay. Major station cluster groups are color-coded on the map to reveal spatial patterns in the distribution of benthic assemblages.




## Figure 3.3

Tidal flushing simulation for San Diego Bay representing the number of hours for water in the Bay to be diluted or exchanged by 50% at a 100 cm tidal amplitude. Average tidal amplitude was 85 cm with a maximum spring tide of 270 cm (Sutton and Helly 2002). Graphics provided courtesy of John Helly of the San Diego Supercomputer Center.

## Table 3.3

Summary of environmental parameters and contaminants of concern for San Diego Bay sediments corresponding to macrofaunal cluster groups A-G. Data are expressed as group averages for those stations with detected values. Depth=m; Fines =% silt+clay; trace metals = parts per million; tDDT and tPAH= parts per billion; tPCB = parts per trillion; nd = not detected. ERL=Effects Range-Low; ERM=Effects Range-Median (Long et al. 1995). Ranges of values for individual samples are shown in parentheses. Highest group averages for contaminants of concern are in bold type.

| Cluster Group | Depth | Fines | Cu | Hg | Zn | Pb | tDDT | tPAH | tPCB |
|---|---|---|---|---|---|---|---|---|---|
| A | 7.5 | 50 | 110 | 0.49 | 172 | 42 | 2060 | 834 | **33150** |
| | (3.0-10.6) | (38-60) | (52-146) | (0.32-0.70) | (106-206) | (27-53) | (nd-2060) | (17-1934) | (nd-49800) |
| B | 10.5 | 71 | **196** | 0.51 | **300** | **119** | **7300** | **2675** | 17050 |
| | (10.1-10.9) | (69-73) | (145-247) | (0.40-0.62) | (180-420) | (44-193) | (nd-7300) | (2347-3003) | (9900-24200) |
| C | 4.3 | 54 | 78 | 0.23 | 143 | 24 | 1337 | 194 | nd |
| | (3.0-10.3) | (33-75) | (39-200) | (0.10-0.33) | (81-232) | (17-46) | (nd-2100) | (nd-457) | |
| D | 6.8 | 43 | 92 | 0.40 | 143 | 36 | 3200 | 2183 | 30640 |
| | (3.3-11.2) | (12-78) | (18-252) | (nd-0.79) | (38-314) | (11-83) | (nd-3200) | (nd-10768) | (nd-123800) |
| E | 4.2 | 68 | 139 | **0.89** | 160 | 32 | 780 | 283 | nd |
| | (3.6-4.8) | (41-91) | (58-220) | (0.40-1.69) | (83-216) | (13-47) | (nd-780) | (nd-735) | |
| F | 11.6 | 37 | 61 | 0.28 | 103 | 24 | nd | 548 | 1500 |
| | (10.9-13.1) | (17-56) | (31-95) | (0.11-0.46) | (64-157) | (14-37) | | (nd-1285) | (nd-1500) |
| G | 11.0 | 64 | 70 | 0.30 | 125 | 24 | nd | 1929 | 13250 |
| | (5.2-13.3) | (46-80) | (28-118) | (0.12-0.69) | (64-180) | (7-42) | | (nd-5925) | (nd-16200) |
| ERL | . | . | 34 | 0.15 | 150 | 46.7 | 1580 | 4022 | 22700 |
| ERM | . | . | 270 | 0.70 | 410 | 218.0 | 46100 | 44792 | 180000 |

### Classification of Benthic Assemblages

Ordination and classification analyses separated the San Diego Bay stations into seven major cluster groups or types of assemblages based on differences in species composition and the relative abundances of specific taxa (see Figure 3.2). These cluster groups appeared to separate along gradients of tidal flushing and anthropogenic impact (see Figures 3.2 and 3.3, Table 3.3).

Cluster group A represented samples collected from three stations located in different regions of the Bay, but which may be linked by similar histories of human impact (see Fairey et al. 1996). For example, relatively high levels of contaminants were measured in the sediments at these sites, including the highest average value for PCBs (see Table 3.3). Polychaete worms were the dominant taxa in this assemblage, although the bivalve *Musculista senhousia* was also common (Table 3.4). The most abundant polychaetes included juveniles and unidentified members of the family Lumbrineridae, followed by the capitellid *Mediomastus* sp, the spionid *Prionospio heterobranchia*, and the syllid *Exogone lourei*.

Cluster group B represented samples from sites located in a region where human impact has been documented previously (e.g., Fairey et al.1996, USDoN, SWDIV and SDUPD 2000), and where sediments averaged the

## Table 3.4

Numerically dominant taxa composing cluster groups A-G from the 1998 benthic survey of San Diego Bay. Data are included for the 10 most abundant taxa in each group and are expressed as mean abundance per sample (no./0.1m$^2$). The three most abundant taxa per cluster group are shown in bold type.

| Species (Taxon) | Higher Taxa Code * | Cluster Groups A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| *Lumbrineris* sp[1] | A | . | 12.5 | 35.0 | 7.5 | 2.7 | . | 8.6 |
| ***Exogone lourei*** | A | **46.0** | 2.5 | 11.1 | 24.0 | **112.3** | 6.0 | 1.3 |
| ***Pseudopolydora paucibranchiata*** [2] | A | 4.3 | . | 4.4 | 91.5 | **300.8** | 4.3 | 9.1 |
| *Oligochaeta* [1] | A | 14.3 | 1.0 | 4.3 | 1.4 | 7.0 | 0.3 | 3.9 |
| ***Musculista senhousia*** [2] | M | 37.3 | 10.5 | **114.1** | **155.7** | 61.2 | 6.3 | 6.1 |
| ***Mediomastus* sp**[1] | A | **65.7** | **22.0** | **196.2** | **162.3** | 14.3 | 32.0 | 46.0 |
| ***Prionospio heterobranchia*** | A | **46.0** | **19.0** | 30.2 | 32.9 | 18.0 | 61.8 | 21.7 |
| ***Lumbrineris* sp C** | A | 22.7 | **21.5** | **67.3** | 15.0 | 16.3 | 11.5 | 34.0 |
| *Pista agassizi* | A | 3.3 | 16.5 | 24.0 | 43.1 | 22.5 | 13.5 | 23.9 |
| ***Leitoscoloplos pugettensis*** | A | 2.3 | 6.0 | 26.8 | 20.7 | 56.2 | 6.5 | **54.4** |
| *Euphilomedes carcharodonta* | C | 18.7 | 12.0 | 1.7 | 10.6 | 7.2 | 18.3 | 0.4 |
| ***Euchone limnicola*** | A | 18.0 | 1.5 | 37.6 | **175.7** | 48.2 | **107.0** | 21.0 |
| ***Lumbrineridae*** [1] | A | **87.7** | . | 42.8 | 45.3 | 38.5 | 33.3 | 47.9 |
| *Fabricinuda limnicola* | A | 1.3 | 1.0 | 1.8 | 61.7 | 0.5 | 4.0 | 0.3 |
| *Solen rostiformis* | M | 0.3 | . | 11.8 | 4.2 | . | 8.5 | 11.8 |
| ***Synaptotanais notabilis*** | C | 8.7 | . | . | 0.8 | **235.7** | . | . |
| ***Theora lubrica*** [2] | M | 1.0 | 12.0 | 8.1 | 20.5 | 16.2 | 29.5 | **79.1** |
| *Diplocirrus* sp SD1[2] | A | . | 6.5 | 2.7 | 3.7 | 25.0 | 1.8 | 21.3 |
| ***Amphideutopus oculatus*** | C | 3.3 | . | 3.3 | 30.3 | 26.2 | **115.5** | **50.1** |
| ***Lyonsia californica*** | M | 1.7 | 1.5 | 2.0 | 8.4 | 10.3 | **99.5** | 24.6 |
| *Crucibulum spinosum* | M | 8.0 | . | 0.3 | 0.3 | . | 37.0 | . |
| *Tagelus subteres* | M | . | 1.0 | 0.1 | 2.8 | 1.2 | 19.5 | 25.1 |

*A = Annelida  C = Crustacea  M = Mollusca
1 = unidentified juveniles and/or damaged specimens; 2 = nonindigenous species

highest concentrations of many contaminants of concern during the present study (see Chapter 2 and Table 3.3). Overall, the group B assemblage was characterized by fewer species and lower abundances than found elsewhere in the Bay (Table 3.5). *Mediomastus* sp was the most abundant taxon at these sites, followed by two other polychaetes, *Lumbrineris* sp C and *Prionospio heterobranchia* (Table 3.4).

Cluster group C included samples from nine south-bay stations that had the lowest exposure to tidal flushing. Largier (1995) referred to this part of San Diego Bay as the "Estuarine Region;" where the waters are subject to occasional freshwater inputs, and are characterized by residence times that can exceed one month. *Mediomastus* sp and *Musculista senhousia* were by far the two most abundant taxa in this group (Table 3.4).

Cluster group D comprised samples from 15 stations that were generally located in a hydrodynamic region of the Bay described as seasonally hypersaline (Largier 1995). In addition, a number of stations within this group had sediments containing relatively high levels of contaminants (see Chapter 2). Therefore, the benthic community characteristic of these sites may reflect the combined influences of lower exposure to tidal flushing and a history of human impact. The three numerically dominant species were the polychaetes *Euchone limnicola* and *Mediomastus* sp, and the bivalve *Musculista senhousia* (Table 3.4).

## Table 3.5

Summary of major benthic community parameters for San Diego Bay cluster groups A-G. Data are expressed as means (no./0.1 $m^2$) and include: species richness (SR); abundance (Abun); diversity (H'); evenness (J'); Swartz dominance (Dom). Ranges of values for individual samples are shown in parentheses.

| Cluster Group | SR | Abun | H' | J' | Dom |
|---|---|---|---|---|---|
| A (n=3) | 37 (31-44) | 441 (391-536) | 2.4 (2.1-2.7) | 0.7 (0.6-0.7) | 7 (5-9) |
| B (n=2) | 28 (25-30) | 170 (102-237) | 2.7 (2.6-2.7) | 0.8 (0.8-0.8) | 8 (8-8) |
| C (n=9) | 36 (28-50) | 701 (384-1117) | 2.3 (1.8-2.7) | 0.6 (0.5-0.7) | 5 (3-8) |
| D (n=15) | 46 (28-76) | 1030 (237-2263) | 2.4 (1.7-3.3) | 0.6 (0.5-0.8) | 7 (3-15) |
| E (n=6) | 51 (40-79) | 1146 (383-3149) | 2.5 (1.8-2.9) | 0.6 (0.5-0.8) | 7 (3-10) |
| F (n=4) | 60 (38-78) | 783 (327-1502) | 2.9 (2.8-3.1) | 0.7 (0.6-0.8) | 11 (8-14) |
| G (n=7) | 62 (44-96) | 680 (251-1672) | 3.1 (2.8-3.4) | 0.8 (0.7-0.8) | 12 (9-16) |
| Overall | 47 (25-96) | 830 (102-3149) | 2.5 (1.7-3.4) | 0.7 (0.5-0.8) | 8 (3-16) |

Cluster group E included samples from six stations located in marinas in the northern portion of the Bay. These marinas likely represent a unique habitat, reflecting influences such as human impact and hydrodynamic conditions. For example, sediments here had relatively high levels of mercury (see Chapter 2 and Table 3.3). In addition, tidal flushing is reduced in these areas (see Figure 3.3). The most abundant species in this assemblage were the nonindigenous polychaete *Pseudopolydora paucibranchiata*, the tanaid *Synaptotanais notabilis*, and the polychaete *Exogone lourei* (Table 3.4). The high numbers of *S. notabilis* in these marinas are especially notable, since this animal was nearly absent elsewhere in the Bay.

Cluster group F represented the assemblage present at four mid-channel stations in the north-central region of the Bay. This area receives relatively frequent tidal flushing as illustrated by the model in Figure 3.3. The amphipod *Amphideutopus oculatus* was the numerically dominant species in this assemblage, followed by the polychaete *Euchone limnicola*, and the bivalve *Lyonsia californica* (Table 3.4).

Cluster group G represented the macrobenthic assemblage most directly influenced by tidal flushing. This assemblage was characterized by the highest species richness, the highest diversity, and the lowest dominance of any in the Bay (Table 3.5). The nonindigenous bivalve *Theora lubrica* was the most abundant species in this group, followed by the polychaete *Leitoscoloplos pugettensis*, and the amphipod *Amphideutopus oculatus* (Table 3.4).

**Table 3.6**

Comparison of San Diego Bay with other SCB embayments in terms of abundance and occurrence of the dominant benthic organisms collected during 1998. SD=San Diego Bay; N=Newport Bay; MDR=Marina Del Rey; LALB=Los Angeles/Long Beach Harbor; MB=Mission Bay; CI=Channel Island Harbor; DP=Dana Point; A=Anaheim Bay; p = taxa present in bay, though not among the ten most abundant. n = total number of stations sampled per embayment.

| **Ten Most Abundant** | **Rank Abundance per Embayment** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SD | MB | DP | N | A | LALB | MDR | CI |
| Species (Taxa) | (n=46) | (n=3) | (n=3) | (n=11) | (n=3) | (n=36) | (n=7) | (n=4) |
| *Mediomastus* sp | 1 | p | p | 6 | 1 | p | 3 | 7 |
| *Musculista senhousia* [1] | 2 | 10 | . | 4 | p | p | p | . |
| *Euchone limnicola* | 3 | p | 5 | 1 | 5 | p | 2 | 5 |
| *Pseudopolydora paucibranchiata* [1] | 4 | 6 | 1 | 5 | 9 | 1 | 1 | 4 |
| Lumbrineridae | 5 | p | 7 | 10 | 4 | 9 | p | p |
| *Amphideutopus oculatus* | 6 | p | p | p | p | 3 | 10 | p |
| *Synaptotanais notabilis* | 7 | 9 | 4 | p | . | 8 | p | 3 |
| *Prionospio heterobranchia* | 8 | p | p | p | 8 | p | 5 | p |
| *Lumbrineris* sp C | 9 | p | p | p | 7 | p | 9 | 10 |
| *Leitoscoloplos pugettensis* | 10 | p | 6 | 2 | 6 | p | 8 | p |

| **Ten Most Widespread** | **Percent Occurrence per Embayment** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SD | MB | DP | N | A | LALB | MDR | CI |
| Species (Taxa) | (n=46) | (n=3) | (n=3) | (n=11) | (n=3) | (n=36) | (n=7) | (n=4) |
| *Mediomastus* sp | 100% | 67% | 67% | 91% | 100% | 64% | 57% | 75% |
| *Prionospio heterobranchia* | 100% | 100% | 67% | 91% | 67% | 11% | 86% | 25% |
| *Lumbrineris* sp C | 98% | 67% | 100% | 91% | 100% | 11% | 71% | 75% |
| *Musculista senhousia* [1] | 96% | 100% | 0% | 82% | 33% | 3% | 29% | 0% |
| *Pista agassizi* | 96% | 100% | 67% | 64% | 67% | 44% | 14% | 0% |
| *Leitoscoloplos pugettensis* | 94% | 100% | 100% | 91% | 100% | 64% | 100% | 75% |
| *Theora lubrica* [1] | 87% | 100% | 67% | 91% | 66% | 100% | 43% | 25% |
| *Glycera americana* | 87% | 67% | 0% | 18% | 33% | 69% | 0% | 0% |
| *Euchone limnicola* | 85% | 33% | 67% | 91% | 67% | 33% | 71% | 50% |
| *Exogone lourei* | 85% | 100% | 67% | 36% | 33% | 8% | 0% | 50% |

1 = nonindigenous species

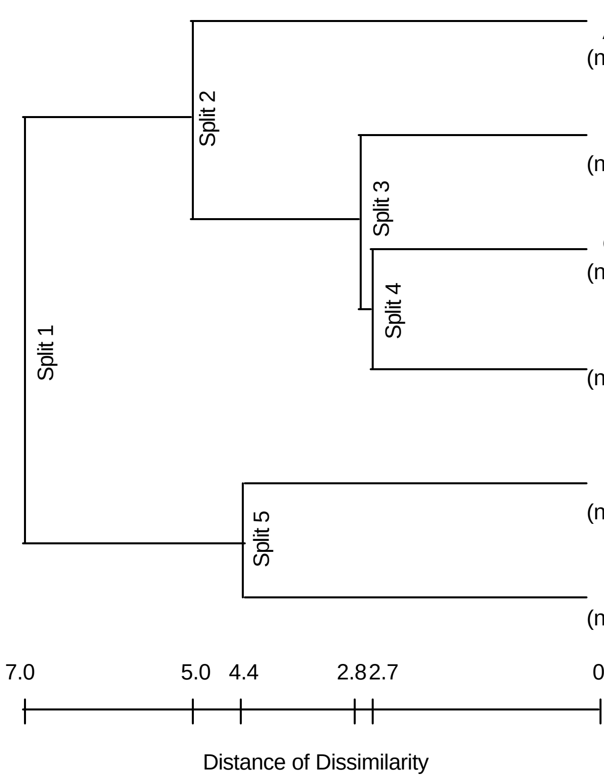
## Comparison of San Diego Bay to Other Embayments

Most of the animals common in San Diego Bay were also present in all other bays sampled during Bight'98 (Table 3.6). In addition, many of the most abundant taxa in San Diego were also found in high numbers in the other bays. For example, the nonindigenous polychaete *Pseudopolydora paucibranchiata* was the most abundant species in three embayments (Dana Point Harbor, Los Angeles/Long Beach Harbor, Marina Del Rey) and among the numerically dominant animals in the other bays as well. Furthermore, species that were widespread in San Diego Bay had similar broad distributions in the other embayments. Such species included *Leitoscoloplos pugettensis*, *Mediomastus* sp, and *Theora lubrica*, all of which occurred at around 80% of stations sampled throughout the SCB.

Ordination and classification analyses separated the SCB bay macrofauna into six major types of assemblages (see Figure 3.4, cluster groups A-F). None of these assemblages was restricted to any single embayment, and most bays had more than one assemblage type present (see Figure 3.5). Cluster groups A-D included some stations from every bay sampled during the survey. These groups all had relatively high abundances of the polychaete *Pseudopolydora paucibranchiata*. All of the San Diego

Bay stations were associated with cluster group C, which represented a macrobenthic community characterized by high numbers of the nonindigenous bivalve *Musculista senhousia.* This community was also present at three stations in Newport Bay and one station in Mission Bay. Cluster groups E and F were primarily composed of stations located in Los Angeles/Long Beach (LA/LB) Harbor, and were dominated by the nonindigenous bivalve *Theora lubrica*.

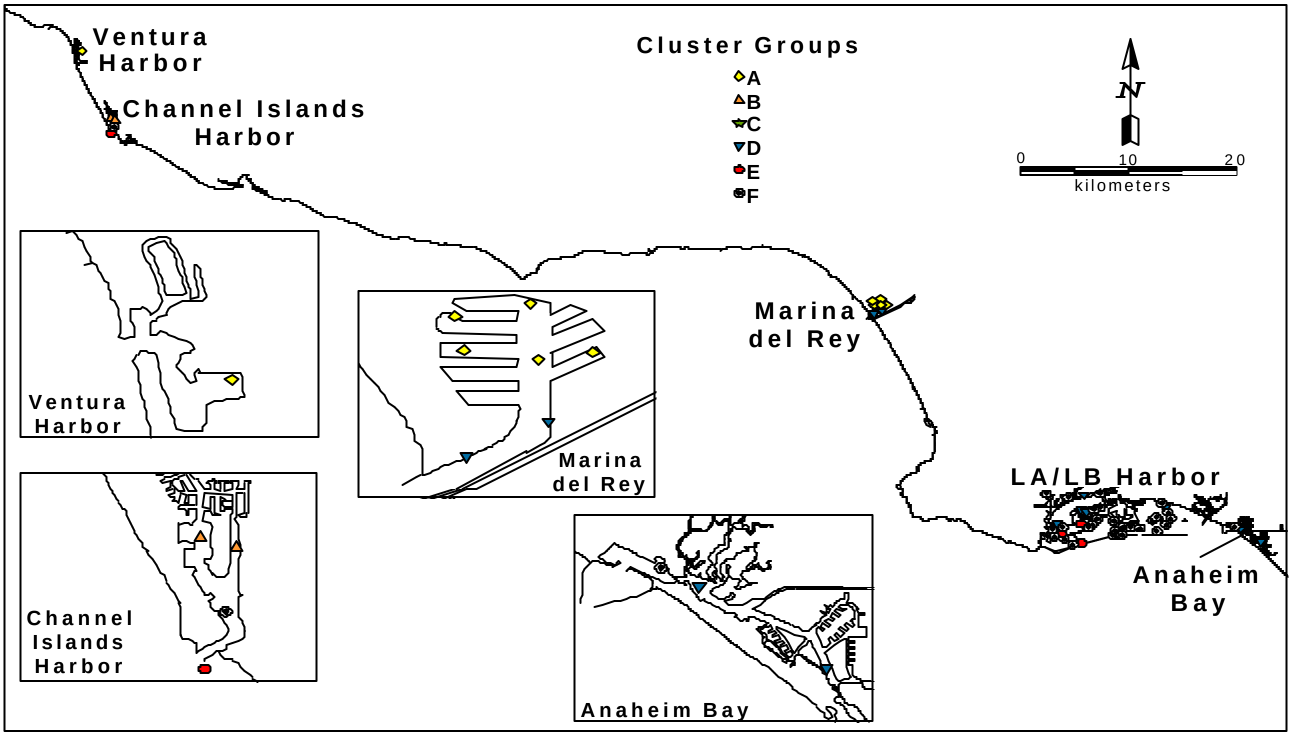
The cluster groups appeared to separate based on multiple environmental and biological factors, including different hydrodynamic conditions, anthropogenic impact, and the presence of dominant, habitat altering species. For example, two stations located near the mouth of Marina Del Rey clustered together with stations from a similar hydrodynamic region in Newport Harbor (see Figure 3.5). Classification analyses of these individual bays revealed a distinct zonation of assemblages along gradients from the open ocean to the headwaters of both Marina Del Rey and Newport Harbor. The separation of cluster groups A and E may be explained by anthropogenic impacts. Group A was characterized by the highest average values for most contaminants of concern, while group E included three sites in LA/LB Harbor that were dredged just prior to sampling. These groups had low abundances and low diversity, with each averaging fewer than 80 individuals and less than 12 taxa per grab.

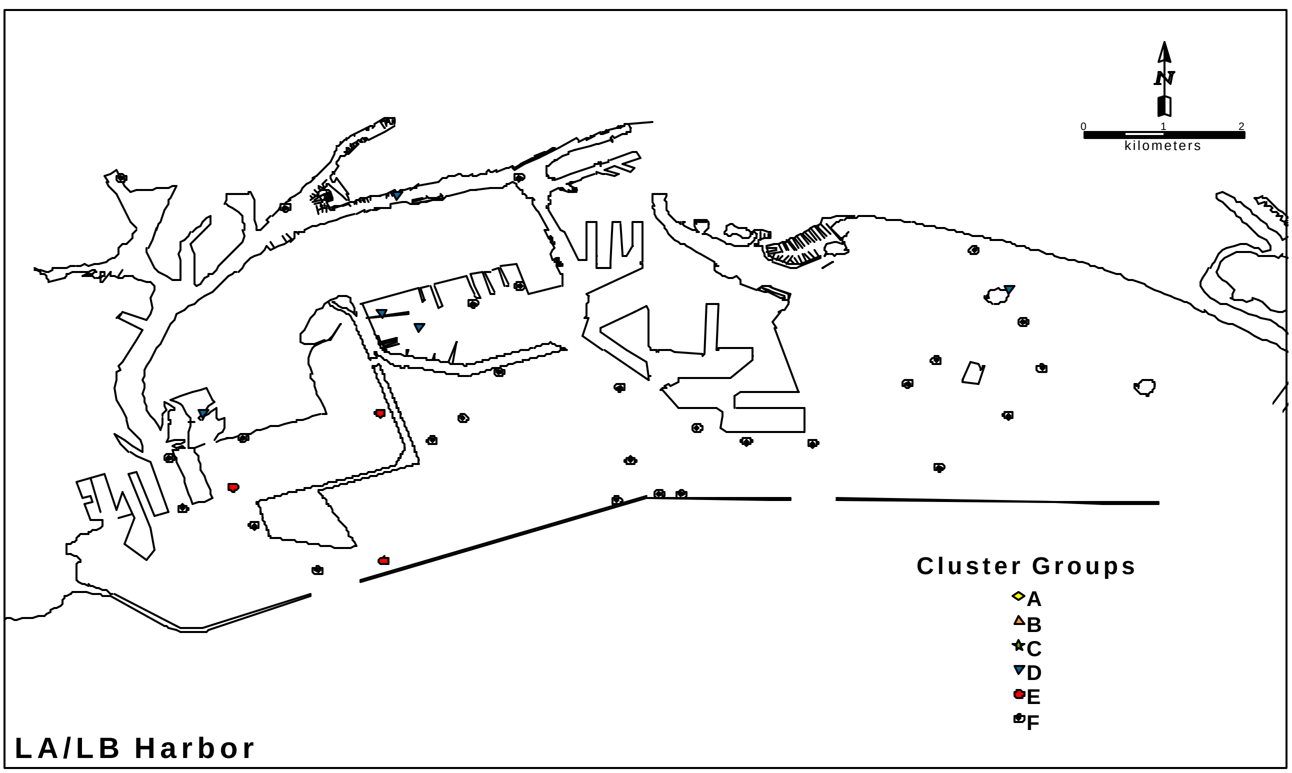



| Cluster Group | Bays | Top Three Taxa |
|---|---|---|
| A (n=6) | Ventura Harbor (n=1)<br>Marina del Rey (n=5) | *Pseudopolydora paucibranchiata* *<br>*Aphelochaeta* sp<br>*Leitoscoloplos pugettensis* |
| B (n=7) | Channel Islands Harbor (n=2)<br>Dana Point Harbor (n=3)<br>Mission Bay (n=2) | *Caecum californicum*<br>*Barleeia subtenuis*<br>*Pseudopolydora paucibranchiata* * |
| C (n=50) | Newport Bay (n=3)<br>Mission Bay (n=1)<br>San Diego Bay (n=46) | *Mediomastus* sp<br>*Musculista senhousia* *<br>*Euchone limnicola* |
| D (n=17) | Marina del Rey (n=2)<br>LA/LB Harbor (n=5)<br>Anaheim Bay (n=2)<br>Newport Bay (n=8) | *Pseudopolydora paucibranchiata* *<br>*Euchone limnicola*<br>*Mediomastus* sp |
| E (n=4) | Channel Islands Harbor (n=1)<br>LA/LB Harbor (n=3) | *Theora lubrica* *<br>*Capitella capitata*<br>*Rhepoxynius lucubrans* |
| F (n=30) | Channel Islands Harbor (n=1)<br>LA/LB Harbor (n=28)<br>Anaheim Bay (n=1) | *Theora lubrica* *<br>*Cossura candida*<br>*Amphideutopus oculatus* |

## Figure 3.4

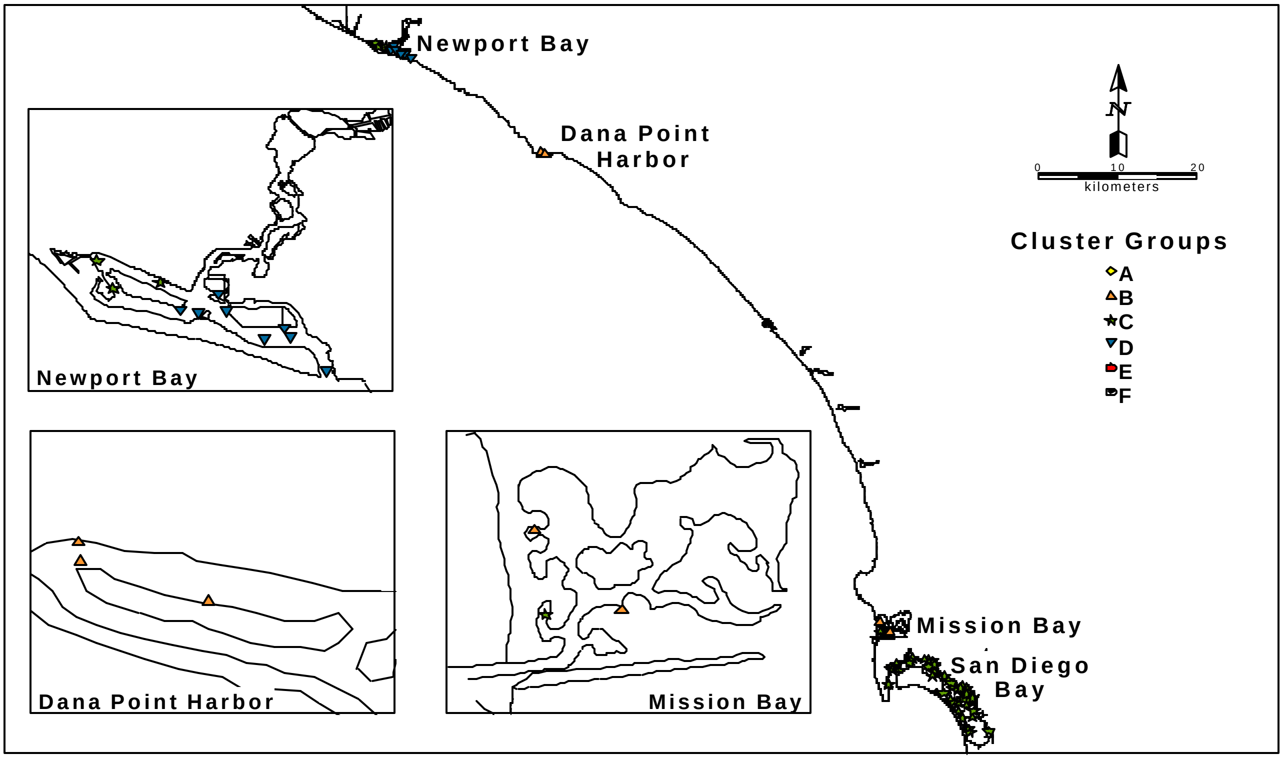
Cluster results of macrofaunal abundance data for Bight'98 embayment stations sampled during July and August, 1998. Included are the major cluster groups chosen to represent benthic assemblages, the bays in which each assemblage occurred and the top three taxa by mean abundance per $0.1m^2$ for each assemblage (n = # of stations). Nonindigenous species are indicated by an *.




## Figure 3.5

Benthic station locations for the nine embayments sampled during the Bight'98 survey. Stations are color-coded to represent affiliation with macrofaunal clusters.



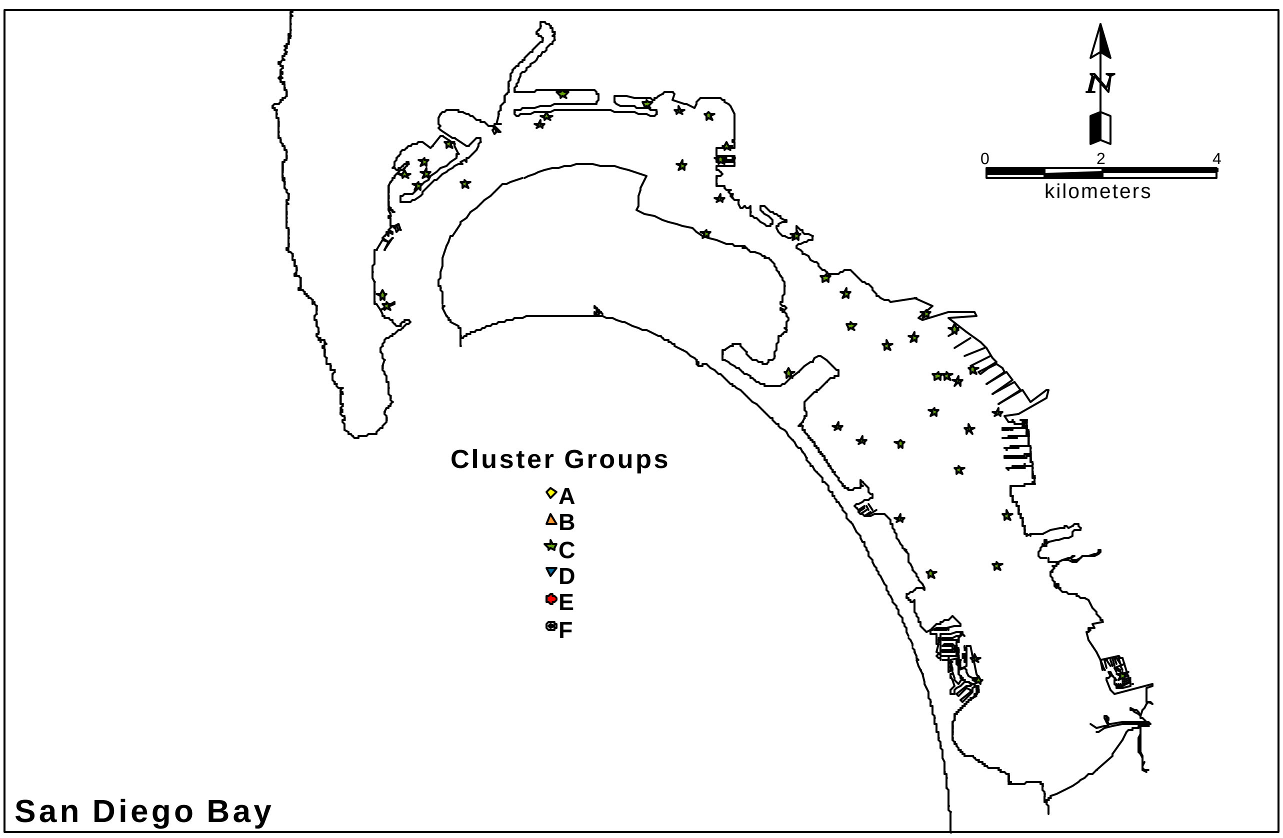




**Figure 3.5 (continued)**

## SUMMARY & DISCUSSION

The macrobenthic community of San Diego Bay consisted of several unique assemblages distributed throughout different regions of the Bay. Most of the animals composing these assemblages belonged to a relatively small number of species, which reflects the unstable habitat typical of many embayments (Sumich 1992). Polychaete worms were the most abundant taxa followed by molluscs and crustaceans. These three taxa often dominate marine macrobenthic assemblages. Polychaetes were also the most diverse and widely occurring animals in the Bay.

Hydrodynamic conditions appeared to be the primary factor influencing the distribution of macrobenthic assemblages in San Diego Bay. For example, the distribution of assemblages found during 1998 resemble models of tidal exchange described previously by Largier (1995) and Sutton and Helly (2002). In addition, there was a pattern of increasing numbers of species (i.e., species richness) when moving from the backwaters towards the mouth of the Bay. This biological “zonation” was also apparent when considering populations of certain individual species. Some animals such as the bivalve *Musculista senhousia* and the polychaete *Mediomastus* sp were far more abundant in parts of the Bay where tidal flushing was less frequent, while others such as the bivalve *Theora lubrica* and the amphipod *Amphideutopus oculatus* were more common in areas of high tidal flushing. Similar patterns relative to hydrodynamic gradients have been reported for Mission Bay (Dexter and Crooks 2000), and are typical of estuarine benthic communities in general (Sumich 1992).

Anthropogenic impact may represent a secondary factor that influenced the distribution of the benthic macrofauna. For example, species richness was typically low in regions of the Bay that have well-documented histories of anthropogenic impact (e.g., see Fairey et al.1996, USDoN, SWDIV and SDUPD 2000). One such region is near the NASSCO shipyard, located between Las Chollas Creek and La Poleta Creek, where the macrobenthic assemblage (cluster group B) was characterized by few taxa and low abundance. This assemblage was only present at two sites, one of which had some of the highest concentrations of contaminants of any station in the Bay (i.e., station 2264).

Some evidence suggests that the overall composition of San Diego Bay’s macrofauna has been affected by anthropogenic impacts. For example, several of the dominant species collected during this survey are not native to southern California. These nonindigenous species were probably introduced to the Bay through human activities, and are now among the most ecologically important members of the benthic community. One such animal, *Musculista senhousia*, was the second most abundant species collected during this survey. This exotic bivalve builds habitat-altering mats, and can have considerable influence on the species composition of benthic communities (Crooks 1996).

The various embayments sampled throughout southern California during 1998 generally had similar benthic communities. Results from multivariate analyses revealed that the benthos of the individual bays typically included multiple types of macrobenthic assemblages. As in San Diego Bay, these assemblages varied along environmental gradients. Although the same assemblage rarely occurred throughout a single embayment, all assemblage types were found in more than one bay. This zonation was such that the assemblages present in one region of a bay were often more similar to assemblages occurring in other bays than to those in adjacent regions of the same bay.

San Diego Bay was also similar to other bays in terms of dominant taxa. Earlier studies have shown similar results, with a small group of taxa dominating most bay assemblages throughout the SCB (Dexter 1983, Thompson et al. 1993). For example, Dexter (1983) found that three of the 13 most abundant species collected in Mission Bay were also reported from six other bays in southern California and northern Baja California. Six other species were also found in at least 50% of the bays. The presence of these ubiquitous organisms reflects the similarity of conditions in SCB bays and harbors. In contrast, most of the dominant species from San Diego Bay are not common on the mainland shelf off San Diego (see City of San Diego 2001). Despite the general similarity among SCB bays, however, the benthic community in San Diego Bay could be distinguished from most other embayments. This was mainly due to the large numbers of *Musculista senhousia* that were found in San Diego. Although *M. senhousia* is not dominant throughout the other southern California bays, other nonindigenous species were represented among the dominant taxa in all bays sampled.

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# Demersal Fishes and Megabenthic Invertebrates

Hotels located along the north end of the Silver Strand, Coronado Island

# *Chapter 4*
# Demersal Fishes and Megabenthic Invertebrates

## INTRODUCTION

Bays and estuaries are important nursery and refuge areas for many fish species (Cross and Allen 1993) and provide suitable habitats to large populations of megabenthic invertebrates (i.e., large epibenthic species) as well. However, human development has altered or degraded many embayments in southern California with few still serving all of their original functions. San Diego Bay is the largest naturally occurring marine embayment between San Francisco and Scammon's Lagoon in central Baja California, Mexico. As such, it forms an essential habitat for many ecologically and commercially important species. Consequently, the fishes of San Diego Bay have been studied extensively in order to better understand this important ecosystem (see review in USDoN, SWDIV and SDUPD 2000). Of the 86 species reported from the Bay, the most common are the California halibut, spotted sand bass, barred sand bass and round stingray. In contrast to fishes, invertebrate assemblages have been studied much less extensively. For example, little is known about many of the megebenthic species that inhabit the Bay, including populations of various sponges, gastropods, bivalves and decapods (see USDoN, SWDIV and SDUPD 2000).

The City of San Diego and SPAWAR surveyed the demersal fish and megabenthic invertebrate populations of San Diego Bay as part of the Bight'98 regional survey. The purposes of the study were to add to the existing body of knowledge on fish and invertebrate communities in the Bay, describe their structure, and provide insight into the effects associated with anthropogenic and natural influences on these communities. This chapter presents analyses and interpretation of data collected by otter trawl during the summer of 1998. The San Diego Bay assemblages are also compared to those from other bays and harbors sampled during Bight'98.

## MATERIALS & METHODS

### Sampling

Demersal fishes and megabenthic invertebrates were collected at 16 randomly selected stations in San Diego Bay during the summer of 1998 (Figure 4.1). The methodology for locating stations and trawling are described in the Field Manual for the Bight'98 project (FSLC 1998). A 7.6 m Marinovich otter trawl with a 1.3 cm cod-end mesh was towed at each station along a predetermined heading for five minutes at approximately 2.5 knots. Trawl catches were brought on board for sorting and inspection. Fishes and invertebrates were identified to the lowest taxon possible and enumerated aboard ship. However, sponges were recorded only as "present" because their tendency to fragment prevented accurate enumeration. Animals that could not be identified in the field were set aside and returned to the laboratory for further identification. Fish were inspected for the presence of external parasites and physical anomalies (e.g., tumors, fin erosion, discoloration) and measured (or size-classed) to the nearest centimeter according to protocols described in the field manual (FSLC 1998). The biomass (wet weight, kg) were recorded for each fish species, while

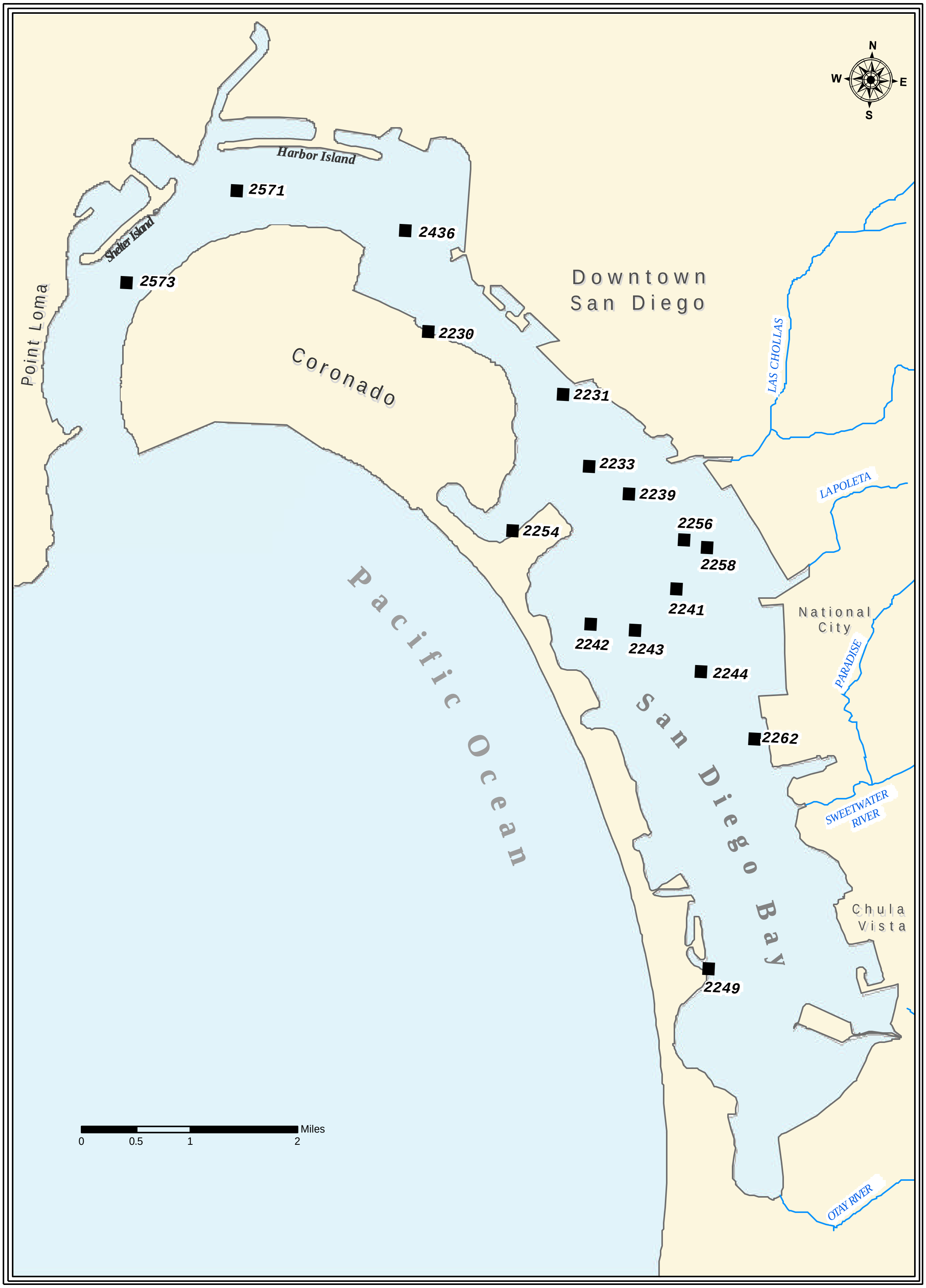



**Figure 4.1**
Otter trawl station locations sampled in San Diego Bay during 1998.

invertebrate biomass was measured as a composite weight of all species combined. The type and amount of any debris associated with each haul was also identified (see Appendix D.1).

### Data Analyses

Fish and invertebrates communities were summarized by calculating (1) the mean abundance per occurrence (MO = number per species/total number of trawls), (2) percent abundance (PA = number per species/total number caught), and (3) frequency of occurrence (FO = number of occurrences for each species/total number of trawls). In addition, the following parameters were calculated by station for both fishes and invertebrates: (1) species richness (number of species); (2) abundance (number of individuals); (3) Shannon diversity index (H'); (4) biomass (wet weight, kg.).

Ordination (principal coordinates) and classification (hierarchical agglomerative clustering) analyses were performed separately for fishes and invertebrates to examine spatial patterns among assemblages occurring in San Diego Bay. All analyses were performed on total abundance per trawl for each species using Ecological Analysis Package (EAP) software (see Smith 1982, Smith et al. 1988). The abundance data were square-root transformed prior to analysis.

### Comparison of San Diego Bay to Other Embayments

In addition to San Diego Bay, nine other southern California bays were sampled by trawl during Bight'98. From north to south these embayments are Ventura Harbor, Channel Islands Harbor, Marina Del Rey, King Harbor, Los Angeles/Long Beach Harbor, Alamitos Bay, Newport Bay, Oceanside Harbor, and Mission Bay. Including San Diego Bay stations, a total of 55 sites were surveyed by 11 participating agencies. Methodologies and protocols for the collection and processing of these samples were the same as for those outlined previously. Ordination and classification of total abundance data from all 55 stations was performed to evaluate spatial patterns among the ten embayments. The distribution of fish and megabenthic invertebrates were considered separately.

## RESULTS

### Fishes in San Diego Bay

***Community Description***

Trawl catches from San Diego Bay during the summer of 1998 were fairly small in terms of the abundance and diversity of fish. Three hundred forty-nine individuals, representing 16 species of fish were collected from 16 stations (Table 4.1, Appendeces D.2 and D.3). Generally, the small size of each haul was reflected in the low abundance, species richness, diversity and biomass values (Table 4.2). For example, the average trawl included only 22 individual fish with a diversity (H’) of 1.4. Despite the small size of the hauls, fish populations in San Diego Bay appeared to be healthy, with no physical abnormalities (i.e., fin rot) detected on any fish. In addition, only one instance of parasitic infestation was observed on a barred sand bass collected from Glorietta Bay (i.e., station 2254).

The four most widely occurring species were the round stingray, spotted sand bass, barred sand bass and California halibut (Table 4.1). Each of these species was present in more than 75% of the trawls and represented

## Table 4.1

Demersal fish species collected in 16 trawls from San Diego Bay during 1998. Data for each species are expressed as: frequency of occurrence (FO); percent abundance (PA); and mean abundance per occurrence (MAO).

| Species | FO | PA | MAO |
|---|---|---|---|
| Round stingray | 79 | 25 | 8 |
| Spotted sand bass | 100 | 18 | 5 |
| Barred sand bass | 100 | 15 | 4 |
| California halibut | 86 | 13 | 4 |
| California tonguefish | 21 | 5 | 6 |
| Spotted turbot | 50 | 5 | 3 |
| Slough anchovy | 14 | 4 | 8 |
| Black croaker | 43 | 4 | 2 |
| Diamond turbot | 57 | 4 | 2 |
| Specklefin midshipman | 14 | 3 | 5 |
| White croaker | 14 | 2 | 3 |
| California lizardfish | 21 | 1 | 1 |
| Diamond stingray | 14 | 1 | 1 |
| Pacific seahorse | 14 | 1 | 1 |
| California butterfly ray | 7 | <1 | 1 |
| Shovelnose guitarfish | 7 | <1 | 1 |

## Table 4.2

Summary of demersal fish community parameters sampled in San Diego Bay during 1998. Number of species (SR) is expressed as total number of species. Abundance, diversity (H') and biomass (kg, wet weight) are expressed for each station.

| STATION | SR | ABUND | H' | BM |
|---|---|---|---|---|
| 2230 | 3 | 7 | 1.0 | 0.6 |
| 2231 | 6 | 20 | 1.6 | 3.9 |
| 2233 | 7 | 24 | 1.7 | 5.5 |
| 2239 | 7 | 22 | 1.8 | 13.6 |
| 2241 | 5 | 47 | 1.1 | 12.8 |
| 2242 | 7 | 24 | 1.5 | 3.4 |
| 2243 | 6 | 32 | 1.4 | 5.3 |
| 2244 | 3 | 13 | 1.0 | 2.5 |
| 2249 | 3 | 5 | 1.1 | 0.3 |
| 2254 | 4 | 15 | 1.3 | 1.5 |
| 2256 | 8 | 24 | 1.7 | 9.1 |
| 2258 | 4 | 15 | 1.3 | 3.1 |
| 2262 | 4 | 17 | 0.8 | 0.9 |
| 2436 | 9 | 43 | 1.9 | 3.3 |
| 2571 | 9 | 31 | 1.9 | 7.2 |
| 2573 | 5 | 10 | 1.5 | 1.0 |
| **Survey Mean** | **6** | **22** | **1.4** | **4.6** |
| **Survey STD** | **2** | **12** | **0.4** | **4.1** |

between13 and 25% of the total fish abundance. Diamond and spotted turbots and black croaker also occurred quite frequently (i.e., 40 – 60% of the hauls), but in fairly low numbers ($\leq$ 3 fish per haul). The round stringray and slough anchovy had the highest numbers per occurrence (i.e,. 8 fish per haul).

Ordination and classification of sites discriminated among three assemblages (SG1-SG3) within San Diego Bay (Table 4.3, Figure 4.2). SG1 comprised 56% of all samples analyzed (i.e., 9 stations) and represents the dominant assemblage in the central region of the Bay. This assemblage was characterized by relatively large numbers of round stingrays and spotted sand bass per trawl. Other species typical of southern California embayments, such as barred sand bass and California halibut, were also common in this assemblage. SG2 consisted of four stations located along the margins of central and southern San Diego Bay. This assemblage included many of these same species found in SG1, but with lower numbers of round stingrays and spotted sand bass. This group had the lowest average abundance and number of species of the three groups. In contrast, SG3, which included three relatively deep stations located close to the entrance of the Bay, had the highest average species richness and abundance. This assemblage was characterized by relatively high abundances of species frequently associated with shallow coastal communities, such as those located just outside of San Diego Bay. For example, three species unique to SG3 (specklefin midshipman, California tonguefish, and California lizardfish) are commonly collected on the coastal shelf off Point Loma and Imperial Beach (City of San Diego 2001a, 2001b).

***Size Distribution***

The fishes captured in San Diego Bay ranged in length from 4 to 79 cm (Appendix D.2). Only the four most abundant species (round sting ray, spotted sand bass, barred sand bass, California halibut) provided enough data to evaluate life history traits. Almost all of the barred sand bass and California halibut were juveniles, indicating that they use the Bay primarily as a nursery (Figure 4.3). For example, the average barred sand bass from San Diego Bay was 14 cm long with a maximum length of 21 cm, well below the size at which they are considered mature (i.e., 27 cm; Love 1996). California halibut also averaged 14 cm in length, far below the size at which they typically become mature (30 cm and 58 cm for males and females, respectively; Love 1996). On the other hand, round stingrays and spotted sand bass had multi-modal length distributions, representing both juvenile and adult life stages. Round stingrays ranged from 15 to 36 cm in lenght, with an average of 25 cm. According to Love (1996), round stingrays become sexually mature around 25 cm. Therefore, approximately 56% of the round stingrays collected in San Diego Bay would be classified as adults. Similarly, 30% of the spotted sand bass captured were considered sexually mature. These fish ranged in length from 11 to 29 cm, with an average length of 21 cm. Female spotted sand bass mature at one year old or at a length of about 25 cm, and males mature slightly later (and larger) at about three years old (Love 1996).

## Megabenthic Invertebrates in San Diego Bay

A total of 1,172 megabenthic invertebrates, representing 43 taxa, were collected in San Diego Bay during 1998 (Table 4.4, Appendix D.4). The non-indigenous bivalve *Musculista senhousia* was present in over 70% of the samples and was the most widely distributed trawl-caught invertebrate. Other frequently occurring species that were present in at least 33% of the samples included two unidentified sponges, Porifiera sp SD4 and Porifera sp SD5, the ascidian *Microcosmus squamiger*, the bivalve *Argopecten ventricosus*, and the gastropod *Crepidula onyx*. *Musculista senhousia* and *Microcosmus squamiger,* both introduced species, together accounted for over 50% of the total catch.

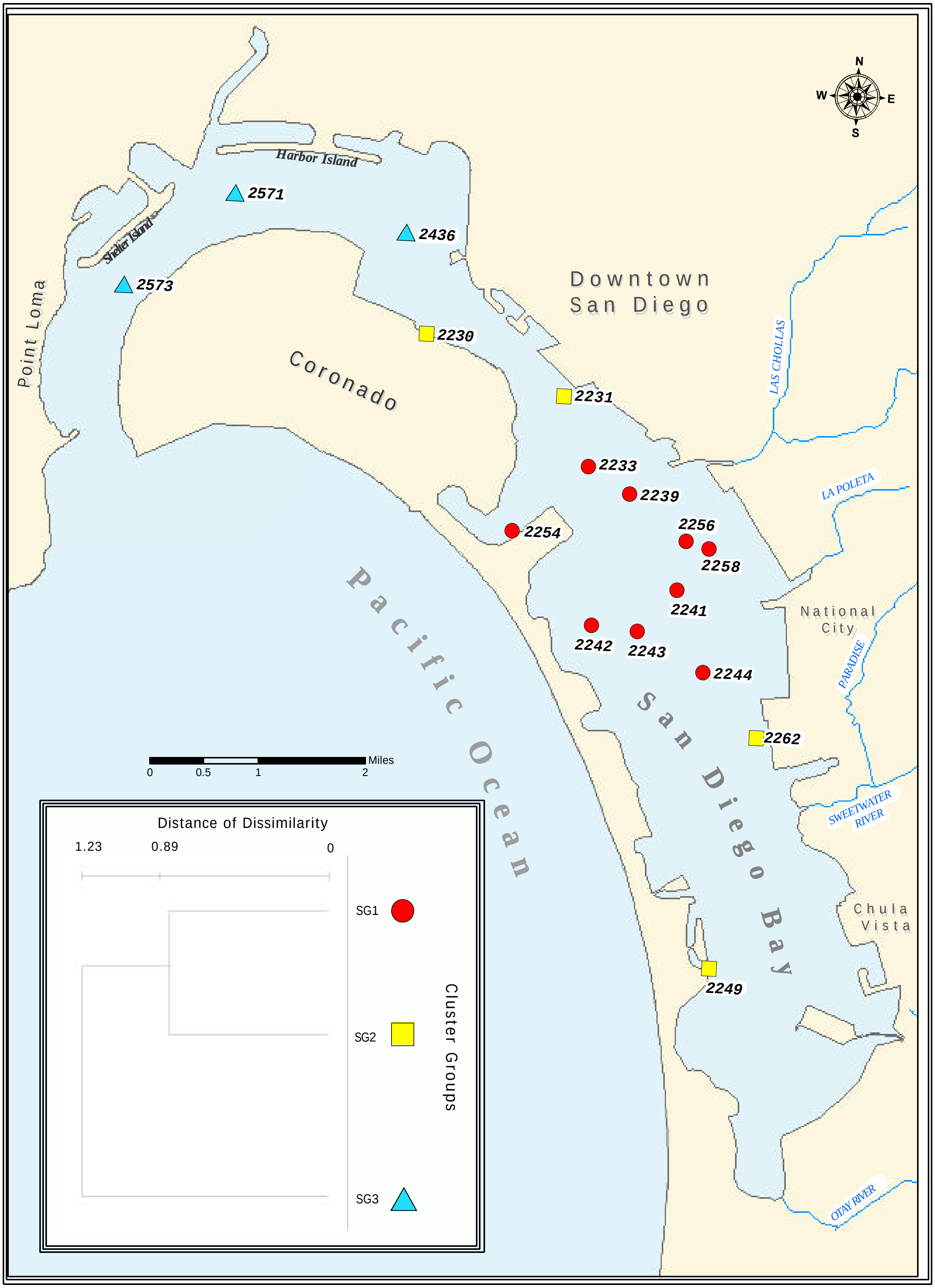


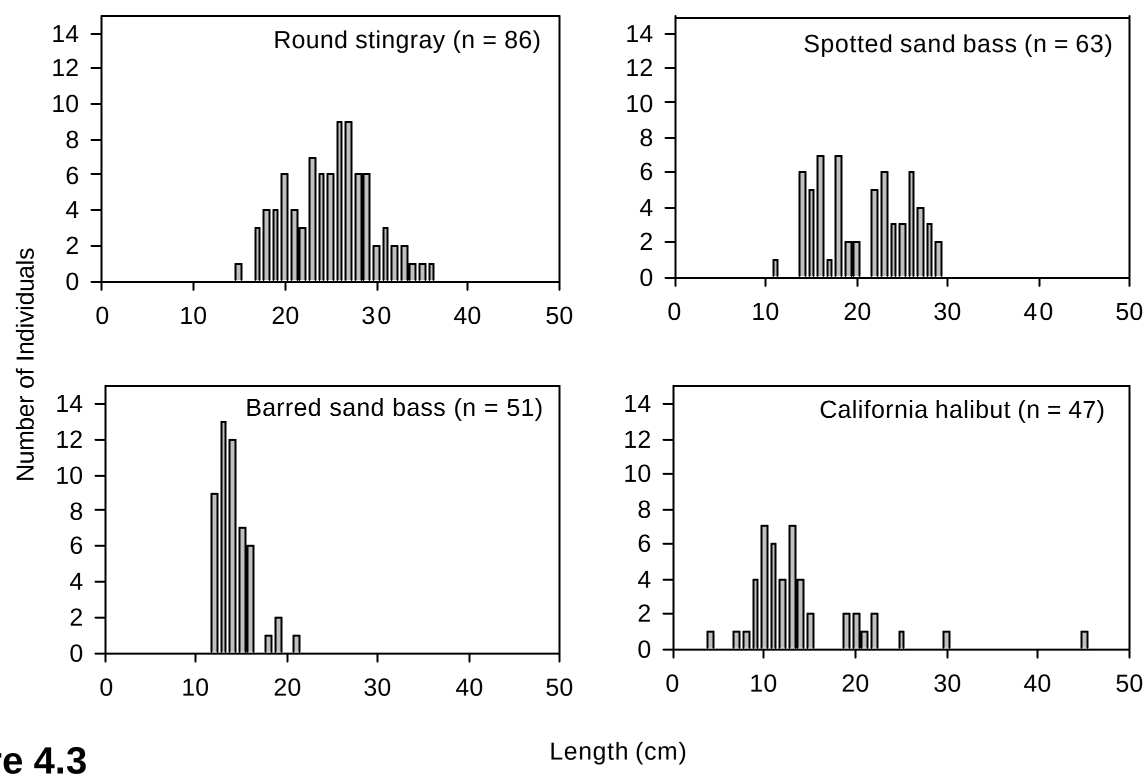

**Figure 4.2**

Summary of results of classification analysis of demersal fish collected in San Diego Bay during 1998.

## Table 4.3

Distribution of the abundant and frequently occurring fish species among the main station cluster groups for San Diego Bay. '—'= not present. The three most abundant species per group are shown in bold type.

| | SG1 | SG2 | SG3 |
|---|---|---|---|
| Number of hauls | 9 | 4 | 3 |
| Mean depth per haul (m) | 7 | 8 | 13 |
| (Range) | (3-11) | (3-11) | (10-15) |
| Mean No. of Species | 6 | 4 | 8 |
| (Range) | (3-8) | (3-6) | (5-9) |
| Mean No. of Individuals | 24 | 12 | 28 |
| (Range) | (13-47) | (5-20) | (10-43) |
| **Species** | | **Mean Abundance** | |
| **Round stingray** | **9.2** | 0.3 | 0.7 |
| **Spotted sand bass** | **5.8** | **2.3** | 0.7 |
| **Barred sand bass** | **3.9** | **2.5** | 2.0 |
| **California halibut** | 2.9 | **3.3** | **2.7** |
| Black croaker | 0.6 | 1.3 | 1.0 |
| **Spotted turbot** | 0.3 | 1.8 | **2.7** |
| Diamond turbot | 0.3 | 1.0 | 2.0 |
| **Specklefin midshipman** | 0.1 | — | **2.7** |
| **California tonguefish** | — | — | **6.0** |
| **Slough anchovy** | — | — | **5.0** |
| California lizardfish | — | — | 1.3 |




## Figure 4.3

Length frequency plots for the top four most abundant fish captured in San Diego Bay during 1998.

## Table 4.4

Megabenthic invertebrate species collected in 16 trawls from San Diego Bay during 1998. Data for each species are expressed as: mean abundance per occurrence (MAO); percent abundance (PA); and frequency of occurrence (FO).

| Species | Taxa | FO | PA | MAO |
|---|---|---|---|---|
| *Musculista senhousia* | Mollusca | 71 | 42 | 50 |
| Porifera sp SD 4* | Porifera | 50 | 1 | 1 |
| *Microcosmus squamiger* | Ascidiacea | 43 | 16 | 32 |
| *Argopecten ventricosus* | Mollusca | 43 | 1 | 1 |
| *Crepidula onyx* | Mollusca | 36 | 7 | 15 |
| Porifera sp SD 5* | Porifera | 36 | <1 | 1 |
| *Ostrea sp* | Mollusca | 29 | 7 | 20 |
| *Nassarius tiarula* | Mollusca | 29 | 6 | 17 |
| *Bulla gouldiana* | Mollusca | 29 | 6 | 17 |
| *Styela plicata* | Ascidiacea | 29 | 2 | 5 |
| *Pteropurpura festiva* | Mollusca | 29 | 1 | 3 |
| Ascidiacea | Ascidiacea | 29 | <1 | 1 |
| *Crucibulum spinosum* | Mollusca | 14 | 5 | 31 |
| *Penaeus californiensis* | Crustacea | 14 | 1 | 5 |
| *Lophopanopeus frontalis* | Crustacea | 14 | <1 | 3 |
| Porifera* | Porifera | 14 | <1 | 3 |
| *Pyromaia tuberculata* | Crustacea | 14 | <1 | 3 |
| *Ciona sp* | Ascidiacea | 14 | <1 | 2 |
| *Diaulula sandiegensis* | Mollusca | 14 | <1 | 2 |
| *Styela montereyensis* | Ascidiacea | 14 | <1 | 2 |
| *Synalpheus lockingtoni* | Crustacea | 14 | <1 | 2 |
| Porifera sp SD 2* | Porifera | 14 | <1 | 1 |
| Actiniaria sp SD 1 | Cnidaria | 7 | 1 | 15 |
| *Limaria hemphilli* | Mollusca | 7 | <1 | 2 |
| *Loligo opalescens* | Mollusca | 7 | <1 | 2 |
| *Acanthoptilum sp* | Cnidaria | 7 | <1 | 1 |
| *Asterina miniata* | Echinodermata | 7 | <1 | 1 |
| *Crangon nigromaculata* | Crustacea | 7 | <1 | 1 |
| *Doriopsilla albopunctata* | Mollusca | 7 | <1 | 1 |
| *Haminoea vesicula* | Mollusca | 7 | <1 | 1 |
| *Leptopecten latiauratus* | Mollusca | 7 | <1 | 1 |
| *Leucilla nuttingi* | Porifera | 7 | <1 | 1 |
| *Lophopanopeus bellus* | Crustacea | 7 | <1 | 1 |
| *Loxorhynchus sp* | Crustacea | 7 | <1 | 1 |
| *Navanax inermis* | Mollusca | 7 | <1 | 1 |
| *Panulirus interruptus* | Crustacea | 7 | <1 | 1 |
| Porifera sp SD 1* | Porifera | 7 | <1 | 1 |
| Porifera sp SD 10* | Porifera | 7 | <1 | 1 |
| Porifera sp SD 6* | Porifera | 7 | <1 | 1 |
| Porifera sp SD 7* | Porifera | 7 | <1 | 1 |
| Porifera sp SD 8* | Porifera | 7 | <1 | 1 |
| *Pugettia producta* | Crustacea | 7 | <1 | 1 |
| *Synidotea harfordi* | Crustacea | 7 | <1 | 1 |

* Sponges identified as present/absent (abundance always =1)

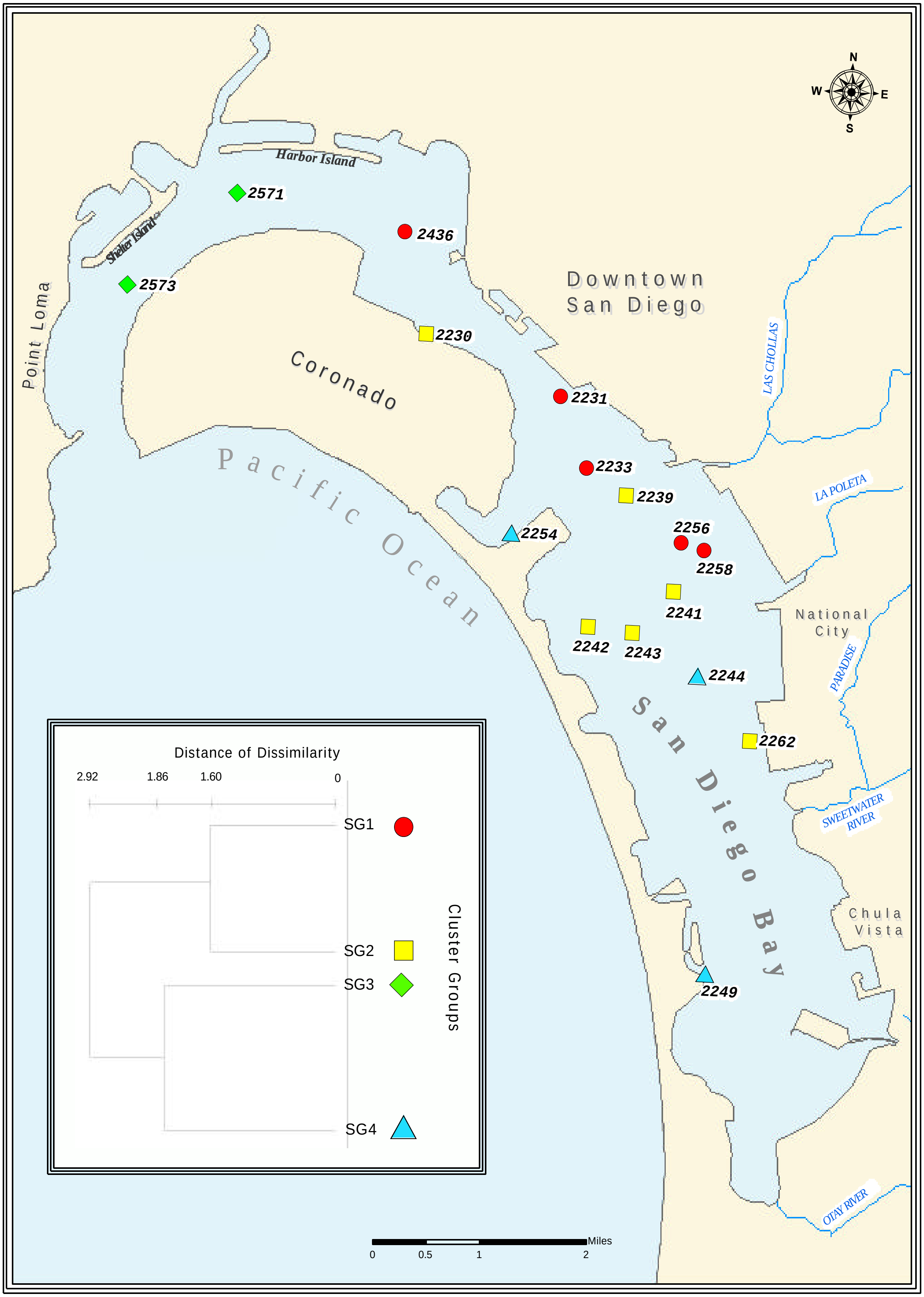
## Table 4.5

Megabenthic invertebrate community parameters sampled in San Diego Bay during 1998. Number of species (SR) is expressed as total number of species. Abundance (ABUND), diversity (H') and biomass (BM) (kg, wet weight) are expressed for each station. P-BM = average sponge biomass per station (subset of total).

| STATION | SR | ABUND | H' | BM | P-BM |
|---|---|---|---|---|---|
| 2230 | 3 | 11 | 0.6 | 0.1 | - |
| 2231 | 11 | 18 | 2.2 | 4.0 | 2.6 |
| 2233 | 13 | 20 | 2.4 | 0.3 | 0.2 |
| 2239 | 5 | 58 | 0.5 | 1.5 | 1.4 |
| 2241 | 5 | 167 | 0.7 | 5.8 | 5 |
| 2242 | 3 | 20 | 0.9 | 4.4 | 4.2 |
| 2243 | 7 | 32 | 1.4 | 24.9 | 24.8 |
| 2244 | 4 | 5 | 1.3 | 5.3 | 5.2 |
| 2249 | 4 | 7 | 1.2 | 14.1 | 14 |
| 2254 | 10 | 24 | 1.9 | 0.6 | - |
| 2256 | 9 | 294 | 0.8 | 0.3 | - |
| 2258 | 9 | 387 | 1.6 | 62.7 | 61 |
| 2262 | 6 | 70 | 1.0 | 1.1 | 1 |
| 2436 | 10 | 46 | 1.3 | 4.5 | 4.2 |
| 2571 | 2 | 10 | 0.3 | 1.1 | - |
| 2573 | 3 | 3 | 1.1 | 0.1 | - |
| **Survey Mean** | **7** | **73** | **1.2** | **8.2** | **11.2** |
| **Survey STD** | **3** | **113** | **0.6** | **15.9** | **18.0** |

Although the contribution of marine sponges to the total trawl catch was significant, abundance estimates were not possible since these animals tended to fragment upon collection. Consequently, the importance of sponges to the megabenthic invertebrate community can only be inferred from their biomass and frequency of occurrence, which is only represented in the raw data (Appendix D.5). For example, Porifera sp SD4 and Porifera sp SD5 were collected in what appeared to be large mats. The overwhelming contribution of these sponges to a station's total biomass (e.g., 97% at station 2258) was indicative of their dominance, as well as their contribution as a substrate for other organisms.

The structure of the trawl-caught invertebrate assemblages was highly variable (Table 4.5). For example, the number of species per trawl ranged from 2 at station 2571 near the entrance to the Bay to 13 at station 2333 located near the middle of the Bay. Abundance per trawl averaged from 3 near the mouth of the Bay (i.e., station 2573) to 387 individuals near the middle of the Bay (i.e., station 2258). The highest invertebrate abundances occurred at sites near the Naval Station San Diego (i.e., stations 2241, 2256, 2258) located towards the middle of the Bay. These sites included large numbers of the ascidian *Microcosmus squamiger* and the bivalve *Musculista senhousia*. Average biomass also ranged widely, ranging from 0.1 to 62.7 kg depending upon the amount of sponge material collected. For example, when present, sponges frequently accounted for 65-97% of the total invertebrate biomass. The three stations with the highest sponge biomass occurred in the central and southern sections of the Bay (i.e., stations 2243, 2249, 2258). Stations with the lowest species richness, abundance, and biomass values tended to occur towards the northern portion of the Bay (i.e., 2230, 2571, 2573).




## Figure 4.4

Summary of results of classification analysis of megabenthic invertebrates collected in San Diego Bay during 1998.

## Table 4.6

Distribution of the abundant and frequently occurring megabenthic invertebrate species among the main station cluster groups for San Diego Bay; '—'= not present. The three most abundant species per group are shown in bold type.

| | SG1 | SG2 | SG3 | SG4 |
|---|---|---|---|---|
| Number of hauls | 5 | 6 | 2 | 3 |
| Mean depth per haul (m) | 10 | 7 | 15 | 4 |
| (Range) | (8-11) | (3-11) | (15-15) | (3-4) |
| Mean No. of Species | 10 | 5 | 3 | 6 |
| (Range) | (9-13) | (3-7) | (2-3) | (4-10) |
| Mean No. of Individuals | 153 | 60 | 7 | 12 |
| (Range) | (18-387) | (11-167) | (3-10) | (5-24) |

| **Species** | **Mean Abundance** | | | |
|---|---|---|---|---|
| ***Musculista senhousia*** | **54.6** | **36.0** | — | **3.0** |
| ***Microcosmus squamiger*** | **37.6** | 0.2 | — | 0.3 |
| ***Ostrea* sp** | **15.6** | — | — | 0.3 |
| *Crepidula onyx* | 14.8 | — | — | 1.0 |
| *Crucibulum spinosum* | 12.4 | — | — | — |
| ***Nassarius tiarula*** | 6.4 | **6.2** | — | — |
| ***Styela plicata*** | 2.0 | 0.8 | — | **1.3** |
| Porifera sp SD 4 | 1.0 | 0.5 | — | — |
| *Argopecten ventricosus* | 0.6 | 0.7 | — | — |
| ***Penaeus californiensis*** | 0.2 | — | **4.5** | — |
| ***Bulla gouldiana*** | — | **11.2** | — | 0.3 |
| Actiniaria sp SD 1 | — | 2.5 | — | — |
| Ascidiacea | — | 0.3 | — | 0.7 |
| ***Synidotea harfordi*** | — | — | **0.5** | — |
| ***Pugettia producta*** | — | — | **0.5** | — |
| **Porifera** | — | — | — | **1.7** |
| ***Panulirus interruptus*** | — | — | **0.5** | — |
| ***Crangon nigromaculata*** | — | — | **0.5** | — |

Ordination and classification of sites discriminated among four main invertebrate assemblages (SG1-SG4) within San Diego Bay (Figure 4.4 and Table 4.6). Two assemblages (SG1 and SG2) occurred along the shipping channel in the north and central portions of the Bay. SG1 consisted of five relatively deep stations located along the east half of the Bay. This section of San Diego Bay included the most dense and diverse invertebrate populations. *Musculista senhousia*, *Microcosmus squamiger*, *Ostrea* sp, *Crepidula onyx*, and various sponges (Porifera species SD4 and SD5) were common members of this assemblage (see Appendix D.3). SG2 consisted of six stations that were slightly shallower and located more centrally within the Bay than SG1. These sites averaged fewer species and fewer numbers of individuals, and had lower abundances of *M. squamiger*, *Ostrea* sp, *Crepidula onyx*, *Crucibulum spinosum*. SG2 also differed from those stations along the east side of the bay (SG1) by the presence of *Bulla gouldina*, a gastropod that was one of the dominant taxa. The other two assemblages represented sites that were located in relatively deeper waters near the entrance to the mouth of the Bay (SG3), or shallow, muddy habitats located towards the back of the Bay (SG4). With the exception of station 2254 located in Glorietta Bay, species richness and overall abundances were low at the locations comprising these two station groups. SG3 was represented by species typically found in the shallow, off-shore coastal areas of San Diego, such as the decapods *Penaeus californiensis*, *Pugettia producta*, *Crangon nigromaculata* and *Panulirus interruptus*, and the isopod *Synidotea harfodi*. In contrast, SG4 comprised sites containing many species common to the main assemblage in the northern and central portion of the Bay (i.e., SG1 and SG2), but in significantly lower abundances.

## Comparison of San Diego Bay to Other Embayments

### *Fish Assemblages*

Ordination and classification of all 55 Bight'98 embayment sites discriminated between five major clusters, each consisting of similar types of demersal fish assemblages (SG1 – SG5) (Figure 4.5 and 4.6). The stations generally clustered according to the size and structure of the bay. For example, most of the stations of San Diego Bay and Los Angeles/Long Beach Harbor separated into their own respective groups, while some of the smaller embayments (e.g., Marina Del Rey, Alamitos Bay, Channel Islands, Oceanside, and Ventura Harbors) tended to group together.

SG1 consisted of two shallow water sites, one each from Newport Harbor and Marina Del Ray. These stites were unique in that each was represented by a single species collected: one California halibut was collected in Newport Harbor, and three anchovies were collected in Marina Del Rey.

Stations from central San Diego Bay formed SG2. These thirteen stations averaged the second lowest species richness and abundance, and included relatively large numbers of round sting rays and spotted sand bass, as well as barred sand bass. These interior stations of San Diego Bay reflect the community described previously as SG1 (see Fishes in San Diego Bay, Community Description). One additional site from this group was located in Mission Bay, close to the Kendall Frost Marine Reserve, the only remaining estuarine area of Mission Bay.

The SG3 assemblage comprised most of the sites in Marina Del Ray, all of the sites in Alamitos Bay, and three sites in north and south San Diego Bay. This assemblage included barred sand bass, California halibut, and diamond turbot as the dominant fish. Overall abundances at SG3 were higher than SG1 and SG2, but lower than the other two assemblages (SG4 and SG5).

Assemblages from Los Angeles/Long Beach Harbor formed SG4 and averaged the highest mean abundance per haul, with the greatest range (i.e., 4 to 1,051 fish/haul). The assemblage was characterized by relatively large numbers of several schooling species, such as white croaker, northern anchovy, Pacific sardine, and queenfish (Table 4.7). California tonguefish were also prominent members of this assemblage. These fishes were also collected in large numbers close to the mouth of San Diego Bay (i.e., station 2573) and inside the breakwater at King Harbor (Figure 4.6). These species are common in shallow, open coastal communities (versus true estuary or bay habitats), and their large numbers may reflect the proximity of these sites to the open coast.

The SG5 assemblage comprised sites from several of the smaller harbors (Channel Island Harbor, Oceanside Harbor, Ventura Harbor), as well as one site each from Mission Bay and Los Angeles/Long Beach Harbor (Figure 4.6). These sites averaged the second highest abundance of fish (79 individuals/haul) and species richness (6 species/haul) of the five cluster groups (Table 4.7). This assemblage was also dominated by schooling species (i.e., white croaker and deepbody anchovy), but included higher numbers of fish that favor piers, pilings, and rocks as preferred habitats (e.g., spotfin croaker, shiner and black perch, and white

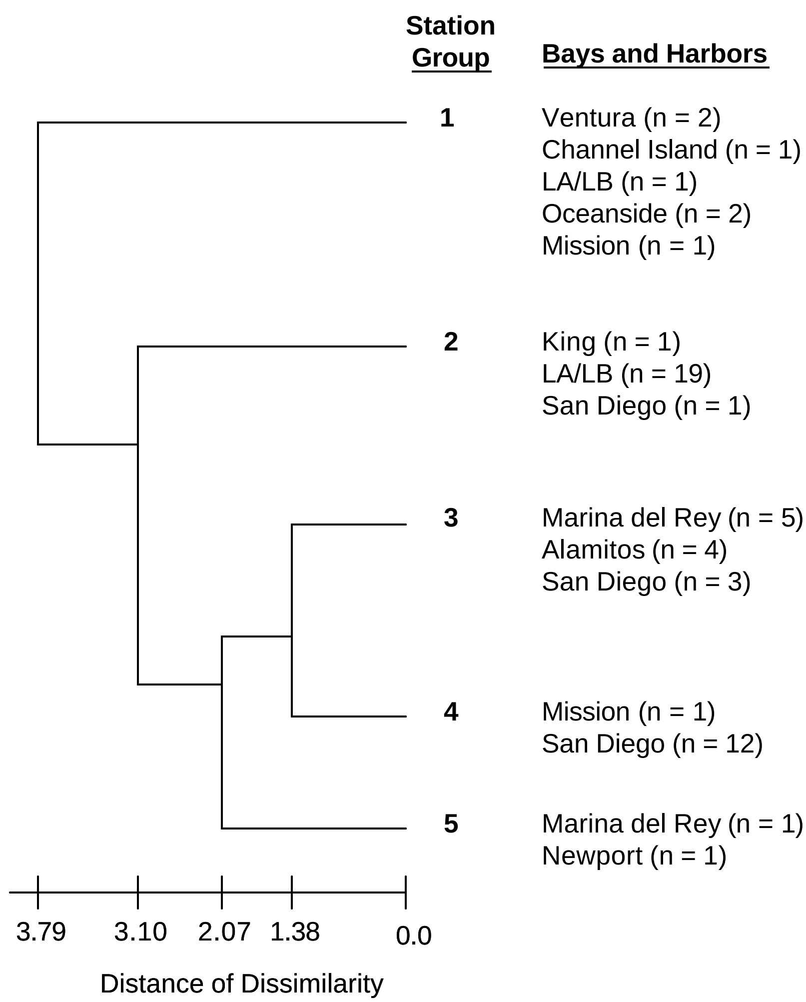
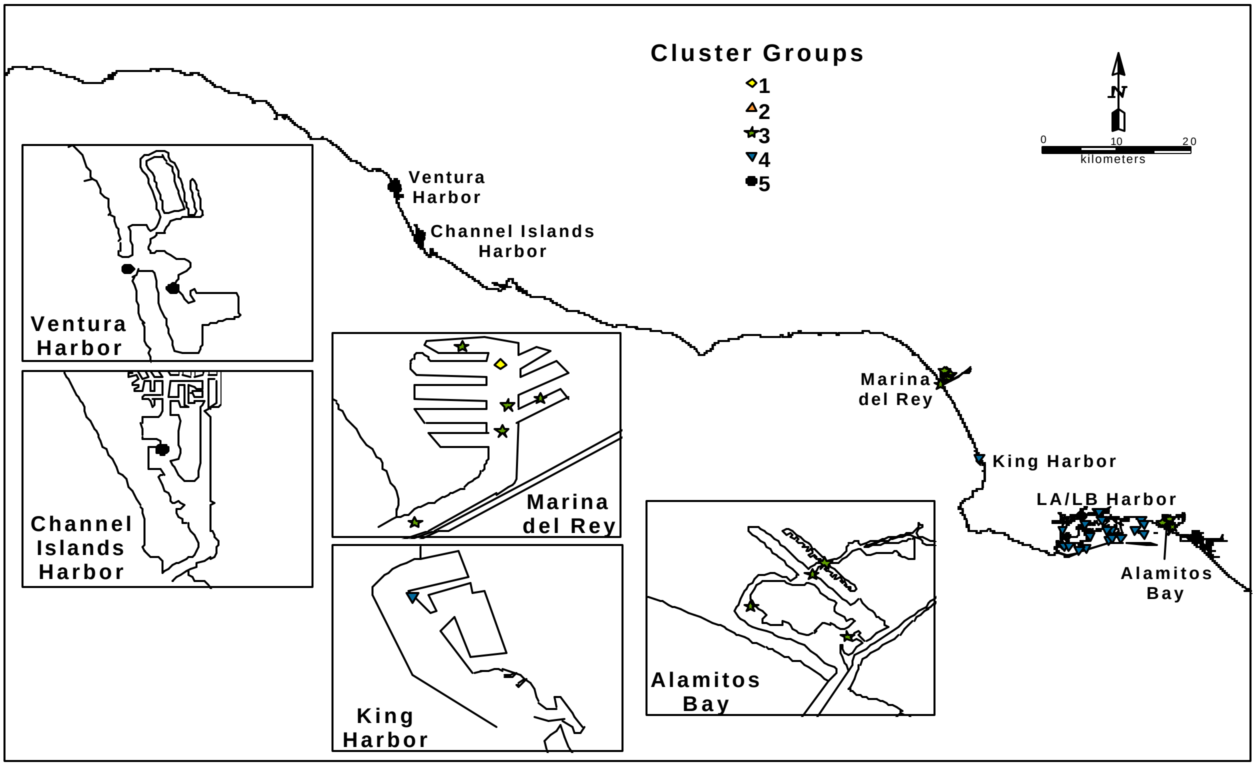
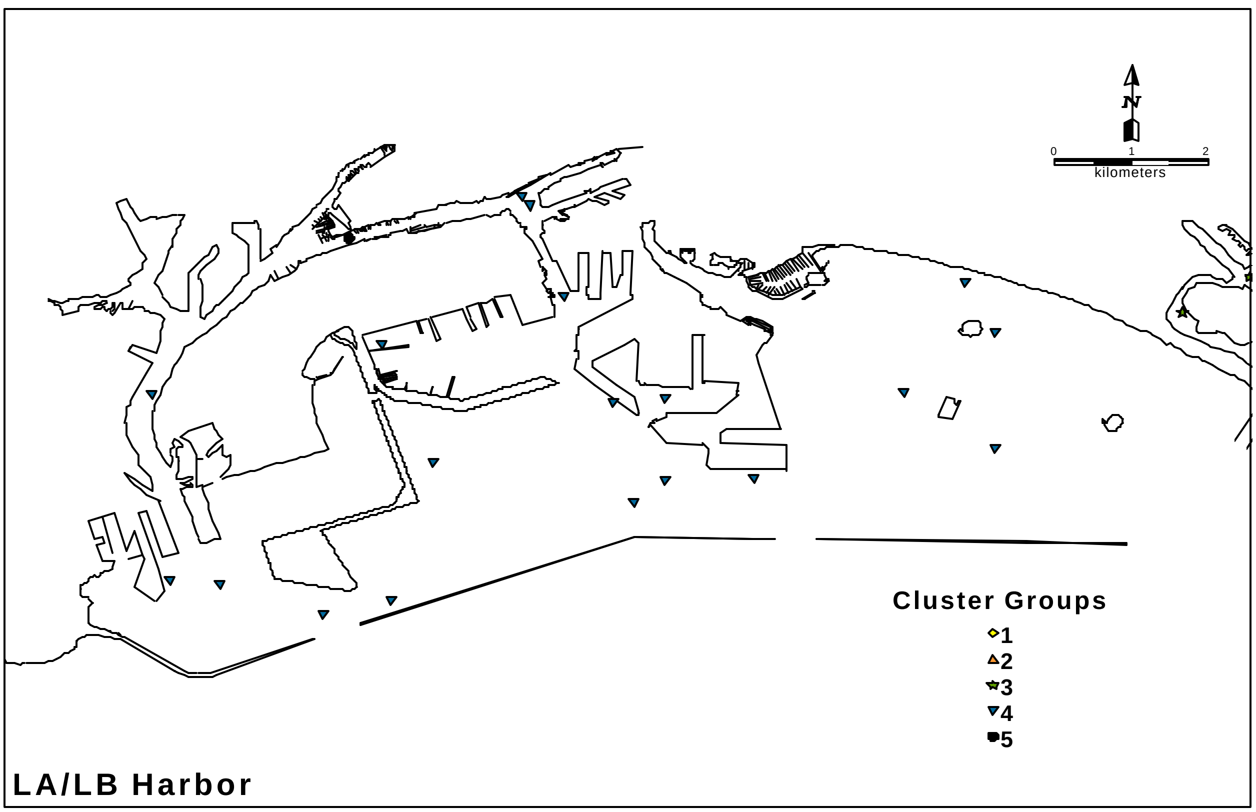



**Figure 4.5**

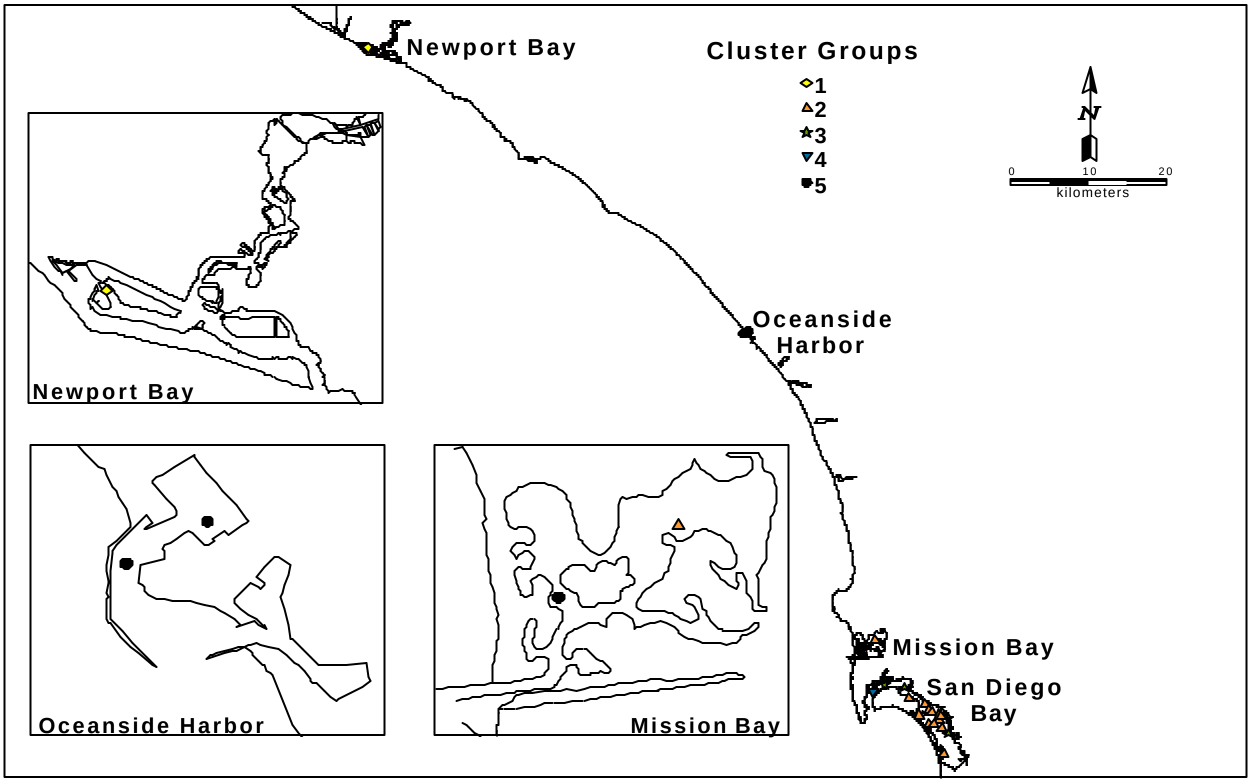
Results of classification analysis of demersal fishes collected from all bays and harbors sampled as part of Bight'98.




# Figure 4.6

Distribution of station groups from classification analysis of fishes collected from all bays and harbors sampled as part of Bight'98.



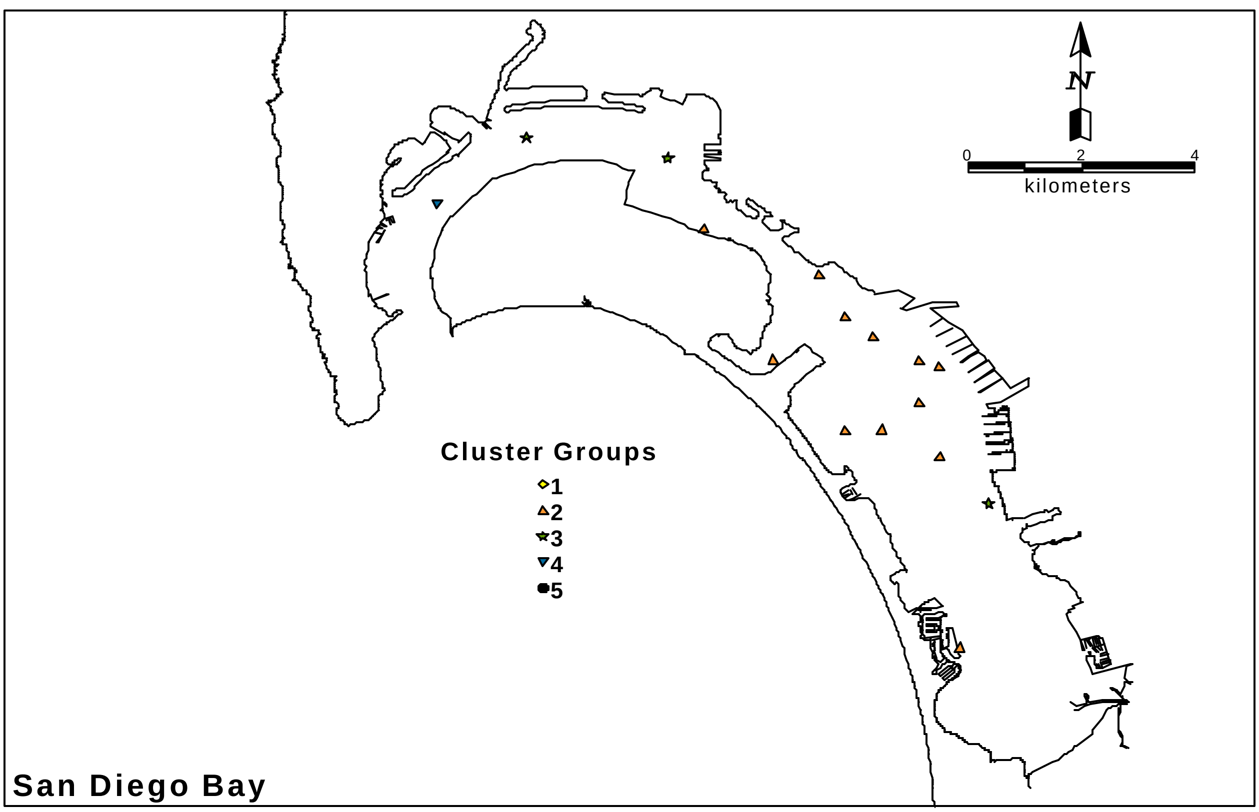




**Figure 4.6 (continued)**

## Table 4.7

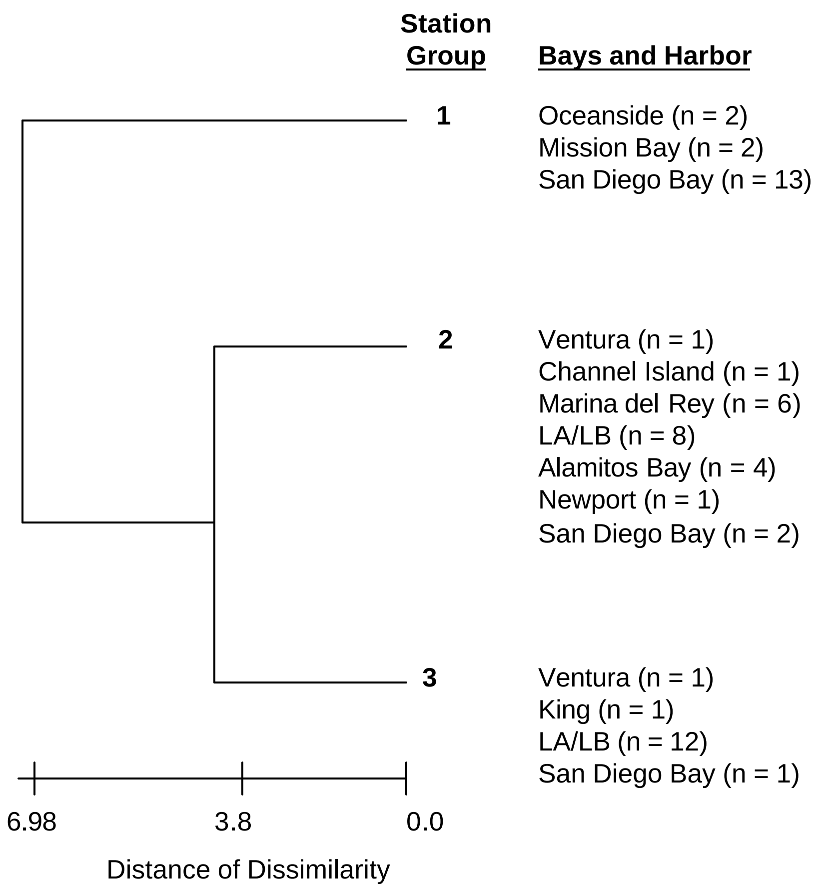
Distribution of the abundant and frequently occurring fish species among the main station cluster groups for all bays and harbors sampled as part of Bight'98. '—'= not present. The three most abundant species per group are shown in bold type.

| | SG1 | SG2 | SG3 | SG4 | SG5 |
|---|---|---|---|---|---|
| Number of hauls | 7 | 21 | 12 | 13 | 2 |
| Mean No. of species per haul | 6 | 7 | 7 | 5 | 1 |
| (Range) | (1-11) | (3-10) | (4-11) | (2-8) | (1-1) |
| Mean No. of individuals per haul | 79 | 241 | 34 | 19 | 2 |
| (Range) | (1-232) | (4-1051) | (13-55) | (3-47) | (1-3) |
| Mean depth per haul (m) | 6 | 16 | 6 | 6 | 3 |
| (Range) | (3-14) | (7-27) | (3-15) | (2-11) | (3-3) |
| **Species** | | | **Mean Abundance** | | |
| **Round stingray** | — | — | 0.3 | **6.5** | — |
| **Spotted sand bass** | — | — | 0.3 | **4.6** | — |
| Black croaker | — | 0.1 | 0.3 | 0.8 | — |
| **Diamond turbot** | 0.3 | — | **2.8** | 0.5 | — |
| **Slough anchovy** | — | — | 2.4 | — | **1.5** |
| **Barred sand bass** | 0.4 | 1.4 | **8.9** | **3.5** | — |
| **California halibut** | 0.7 | 1.2 | **5.9** | 2.0 | **0.5** |
| Spotted turbot | — | 0.9 | 1.0 | 0.8 | — |
| Pacific sardine | — | 6.0 | — | — | — |
| **Northern anchovy** | — | **64.0** | 0.2 | — | — |
| **California tonguefish** | 0.1 | **8.0** | 1.5 | — | — |
| California lizardfish | 0.1 | 2.2 | 0.2 | — | — |
| Queenfish | 2.6 | 7.5 | 0.9 | — | — |
| **White croaker** | **24.9** | **143.7** | 2.1 | 0.2 | — |
| **Deepbody anchovy** | **31.0** | — | 1.8 | — | — |
| Spotfin croaker | 3.3 | — | 0.3 | — | — |
| Shiner perch | 5.7 | 1.6 | 1.9 | — | — |
| **White seaperch** | **6.6** | 1.2 | — | — | — |
| Black perch | 0.9 | — | — | — | — |

seaperch).This assemblage may reflect the presence of various physical structures in the vicinity of the trawl locations.

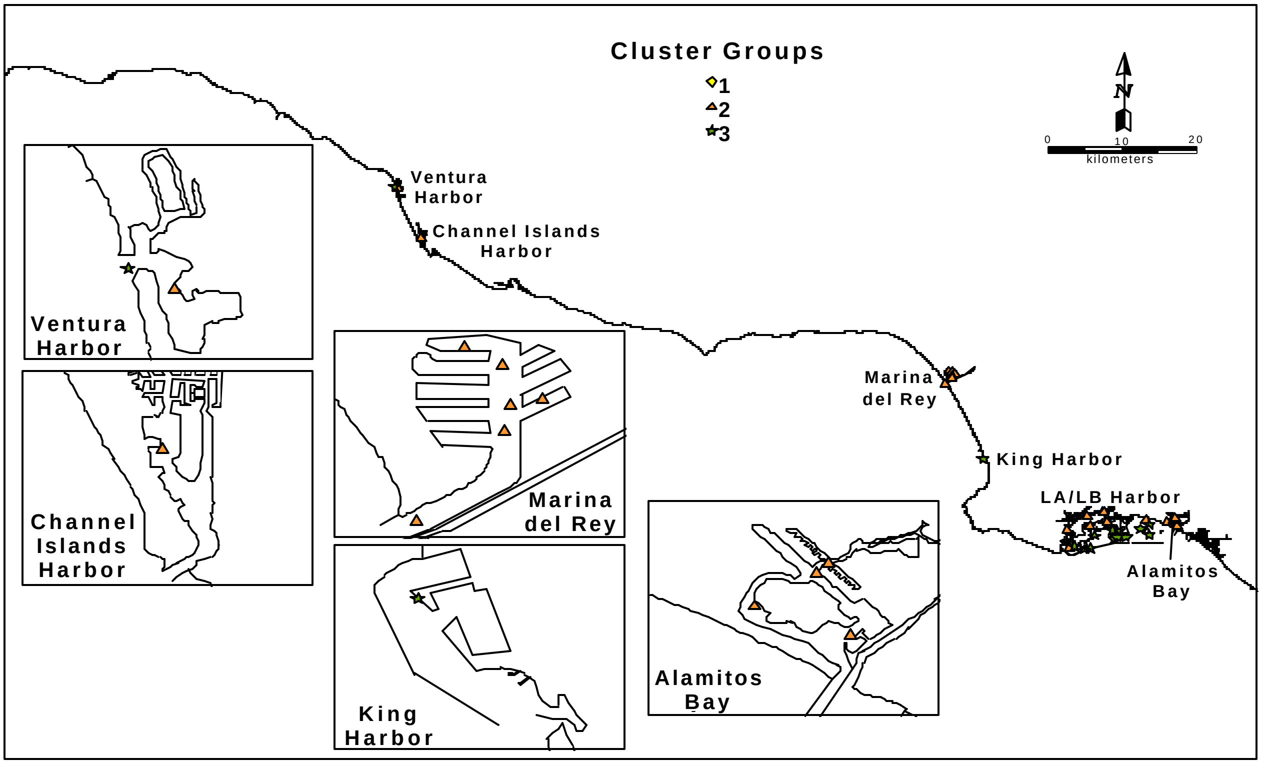
### *Megabenthic Invertebrate Assemblages*

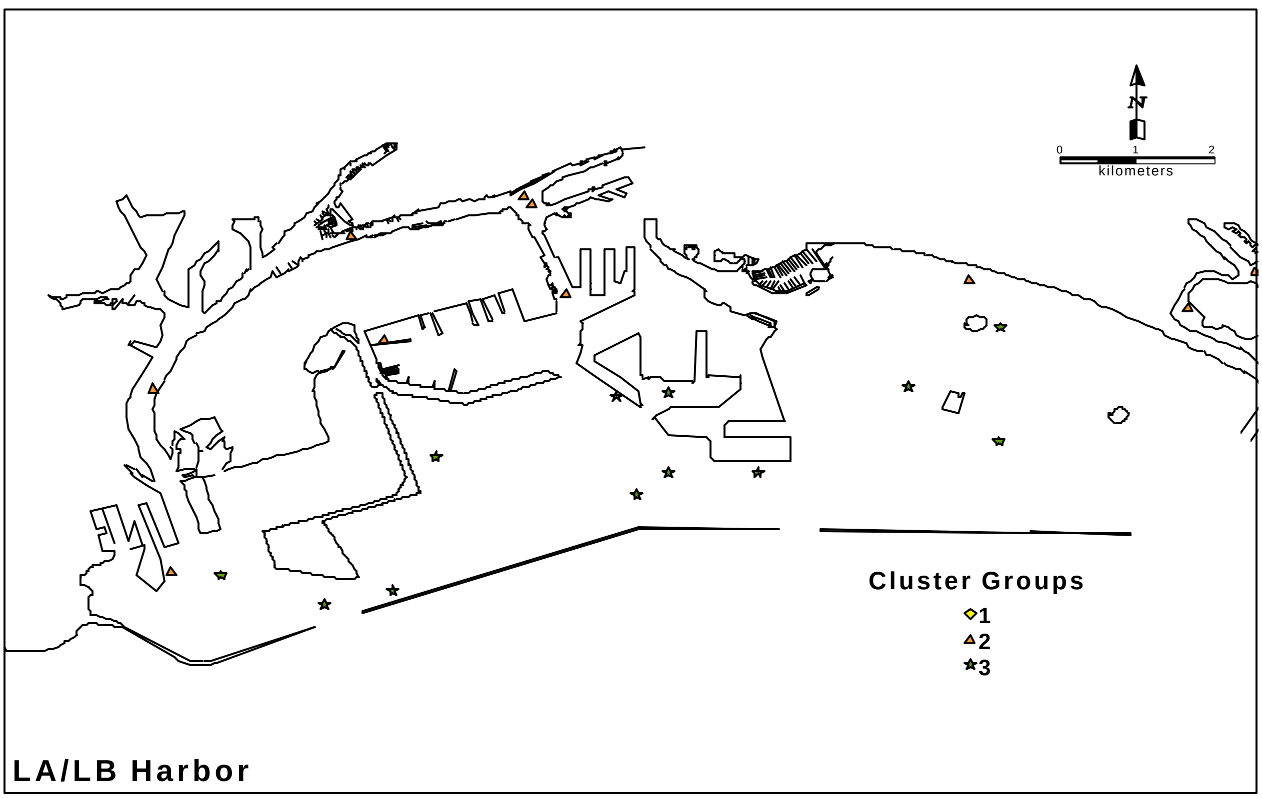
Ordination and classification of the Bight'98 embayment sites discriminated between three major station groups (SG1 – SG3) (Figures 4.7 - 4.8, Table 4.8). The groups reflect differences between assemblages typical of bays versus coastal communities. SG1 represents a distinct southern bay community that was limited to the San Diego region (San Diego Bay, Mission Bay, and Oceanside Harbor). This assemblage was distinguished by relatively large populations of *Musculista senhousia* and *Microcosmus squamiger*, and a paucity of decapod crustaceans. Other widespread members of this station group included various sponges (e.g., *Porifera* sp SD4 and SD5) whose abundances were significantly under estimated, and several ascidians (e.g., *Styela* spp.). SG2 represented a mix of coastal and bay communities characterized by such widespread and abundant taxa as the crab *Pyromaia tuberculata*, the shrimp *Penaeus californicus*, the gastropod *Bulla gouldiana*, and the bivalve *Mytilus galloprovincialis*. SG3 consisted of relatively deep water sites that were located primarily in Los Angeles/Long Beach Harbor. This assemblage of megabenthic invertebrates was characterized by low numbers of a few coastal species such as the gastropod




## Figure 4.7

Results of classification analysis of megabenthic invertebrates collected from all bays and harbors sampled as part of Bight'98.




## Figure 4.8

Distribution of station groups from classification analysis of megabenthic invertebrates collected from all bays and harbors sampled as part of Bight'98.

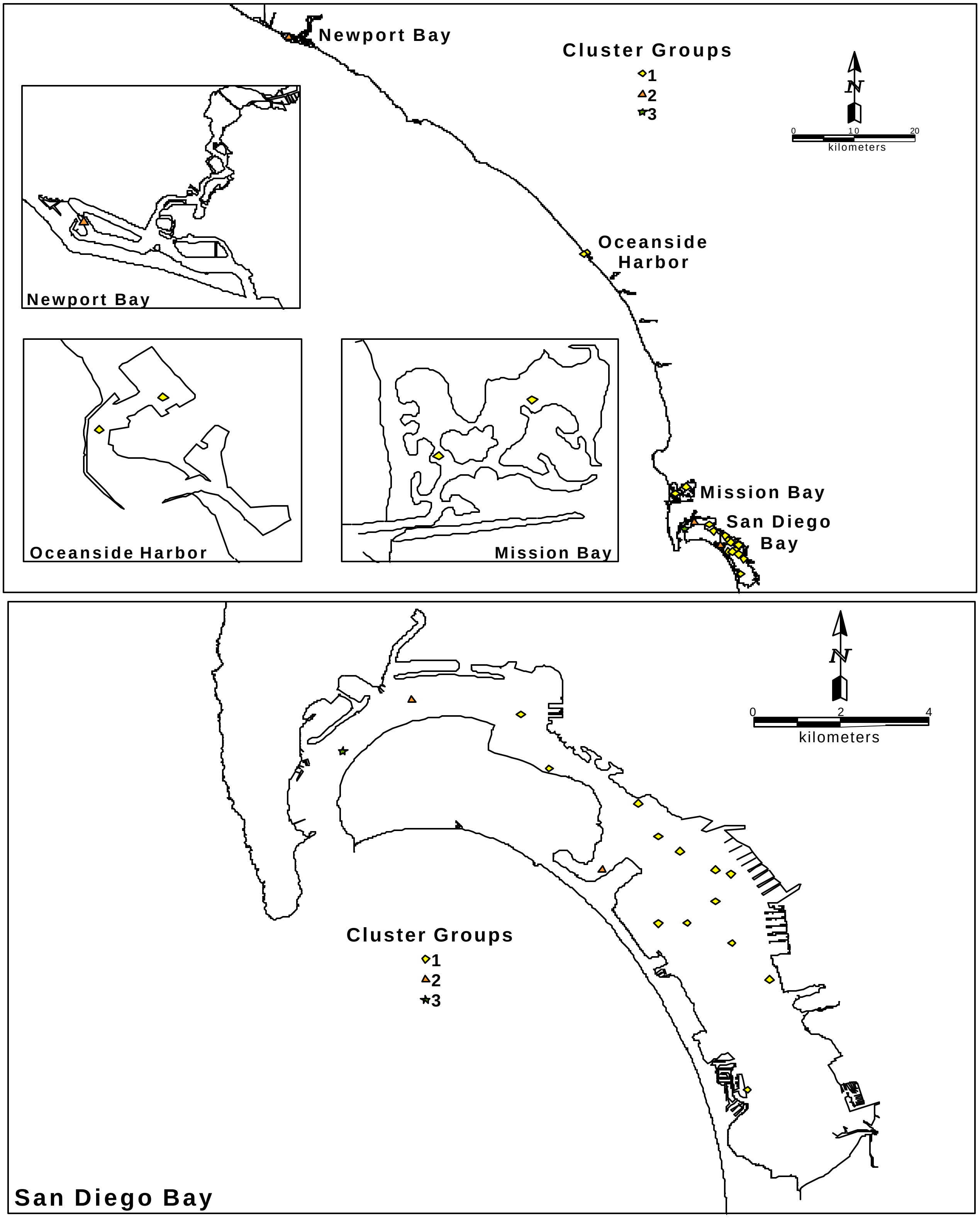



**Figure 4.8 (continued)**

**Table 4.8**

Distribution of the abundant and frequently occurring megabenthic invertebrate species among the main station cluster groups for all bays and harbors sampled as part of Bight'98. '—'= not present. The three most abundant species per group are shown in bold type.

| | SG1 | SG2 | SG3 |
|---|---|---|---|
| Number of hauls | 17 | 23 | 15 |
| Mean No. of species per haul | 6 | 8 | 5 |
| (Range) | (1-13) | (2-15) | (2-14) |
| Mean No. of individuals per haul | 69 | 95 | 19 |
| (Range) | (3-387) | (6-567) | (2-78) |
| Mean depth per haul (m) | 7 | 9 | 16 |
| (Range) | (2-11) | (3-25) | (7-27) |
| **Species** | **Mean Abundance** | | |
| *Crepidula onyx* | 4.4 | 0.1 | — |
| Porifera sp SD4 | 0.5 | — | — |
| *Ostrea sp* | 4.6 | 0.2 | — |
| ***Musculista senhousia*** | **29.0** | 0.7 | — |
| *Argopecten ventricosus* | 0.8 | 0.2 | — |
| ***Microcosmus squamiger*** | **11.2** | 2.7 | — |
| ***Bulla gouldiana*** | **4.8** | **12.0** | — |
| *Penaeus californiensis* | 0.1 | 5.5 | 0.9 |
| *Navanax inermis* | — | 1.0 | 0.3 |
| *Styela sp* | 0.4 | 1.8 | — |
| *Mytilus galloprovincialis* | — | 7.8 | — |
| ***Pyromaia tuberculata*** | 0.3 | **21.4** | **4.8** |
| ***Crangon nigromaculata*** | — | **12.4** | **2.0** |
| ***Philine auriformis*** | — | 7.4 | **6.0** |
| *Astropecten armatus* | — | 0.0 | 0.5 |

*Philine auriformis*, the decapods *P. tuberculata, Crangon nigromaculata* and *P. californiensis,* and the seastar *Astropecten armatus*.

## SUMMARY & DISCUSSION

This survey provided a snapshot of the demersal fish and megabenthic invertebrate assemblages that were present in soft bottom areas of San Diego Bay during the summer of 1998. Populations of these organisms appeared healthy during this time, as indicated by the lack of physical abnormalities on both fishes and invertebrates. The absence of fin erosion in the fish community suggests that conditions have generally improved since 1984-1988 when there was a relatively high prevalence of fin erosion in black croaker and barred sea bass (see McCain et al. 1992). Overall, relatively few species of fish and invertebrates were encountered in the various trawls conducted during 1998. The round stingray, spotted sand bass, and barred sand bass were the dominant species of fish captured in terms of abundance and frequency of occurrence, although California halibut and diamond turbot were also common in the Bay. Many of the spotted sand bass and round stringrays, and almost all of the barred sand bass and California halibut appeared to be juveniles. The presence of significant numbers of immature fishes in San Diego Bay is expected since many species are known to use the Bay as nursery grounds (Cross and Allen 1993, Allen et al. 2002).

The dominant trawl-caught invertebrate in San Diego Bay was *Musculista senhousia*, a non-indigenous bivalve that was also prevalent in benthic grab samples (see Chapter 3). Other frequently occurring invertebrates included another non-indigenous species, the ascidian *Microcosmus squamiger*, and two species of previously undescribed sponges, Porifera sp SD4 and Porifera sp SD5. The contribution of marine sponges to the megabenthic invertebrate community was significant in terms of biomass. For example, Porifera sp SD4 and Porifera sp SD5 contributed as much as 97% of the biomass at a station.

The fish and invertebrate assemblages that occurred in the central part of San Diego Bay differed from those found near the entrance of the Bay, as well as from assemblages occurring in most other embayments sampled during Bight'98. Species that characterized the central and southern parts of San Diego Bay in 1998 were typical of embayments in general. These included the round stingray and spotted sand bass, as well as the bivalve *Musculista senhousia*, the ascidean *Microcosmus squamiger*, the oyster *Ostrea* sp., and the slipper shell *Crepidula onyx*. Fish and invertebrates that were found towards the mouth of San Diego Bay and in other Southern California Bight bays and harbors (e.g., Los Angeles/Long Beach Harbor) are typically more representative of open coastal areas. In terms of fish these included specklefin midshipman, California tonguefish and California lizardfish. Common invertebrates in these areas included the yellowleg shrimp *Penaeus californiensis*, the blackspotted bay shrimp *Crangon nigromaculata*, the northern kelp crab *Pugettia producta*, the California spiny lobster *Panulirus interruptus*, and the isopod *Synidotea harfodi*.

Overall, the species of fish and invertebrates encountered in San Diego Bay during 1998 were similar to those reported previously (e.g., USDoN, SWDIV and SDUPD 2000, Allen et al. 2002). For example, Allen et al. (2002) also found that the round stingray, spotted sand bass, barred sand bass and California halibut were dominant in the Bay in terms of frequency, abundance, and biomass. In addition, Allen et al. (2002) determined that the species composition was different in the north of the Bay than in the central and south regions. They attributed the higher number of species near the entrance of the bay to better water circulation and cited temperature, salinity, and distance from the mouth of the bay as environmental factors that impacted the distribution of fish. However, these authors also reported 78 species of fish from the surveys they performed between 1994 and 1999, which contrasts sharply with the 16 species reported herein for 1998. This discrepancy is mostly due to the fewer habitat types trawled in the present study and also to the fact that Allen et al. (2002) used multiple types of sampling gear (e.g., trawls, seines, gill nets). Consequently, the data reported for fish populations in this survey represent a relatively limited portion of San Diego Bay (i.e., trawlable areas deeper than 3 m).

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# Bioaccumulation of Contaminants in Fish Tissues

Harbor Island Yacht Basin, looking west from Convair Lagoon

# *Chapter 5*
# Bioaccumulation of Contaminants in Fish Tissues

## INTRODUCTION

The bioaccumulation of contaminants in fishes from San Diego Bay is of great public concern since the Bay is a popular fishing location for many people, despite the prevalence of various types of pollutants (see USDoN, SWDIV and SDUPD 2000). Contaminant levels in the tissues of Bay fishes, however, have not been studied since the early 1990's (e.g., SDCDH 1990, McCain et al. 1992). To address these concerns, bottom dwelling (i.e., demersal) fishes were collected throughout San Diego Bay to assess more recent levels of contamination.

Contaminants can accumulate in the tissues of fish through various exposure pathways (Tetra Tech 1985). Exposure routes for demersal fishes include adsorption or absorption of dissolved chemical constituents from ambient waters, and the ingestion of pollutant-containing suspended particulate matter or sediment particles. Fish may also accumulate pollutants by directly consuming contaminated plant and animal food sources. Once incorporated into the tissues of a fish, a contaminant can be transferred to and bioconcentrated in upper trophic level predators, including other fish, birds, marine mammals, and humans.

This chapter presents an assessment of contaminant levels in the tissues of fish collected from San Diego Bay in the summer of 1998. These data will provide baseline information against which to measure future trends of contamination in Bay fishes. Contaminant levels in whole fish samples of California halibut from San Diego Bay were compared to a) predator protection thresholds established by Environment Canada (1997, 1998), and to b) halibut sampled in other southern California bays and harbors during the Bight'98 regional survey. In addition, samples of muscle tissue from various species of sport fish were analyzed to address human health concerns, since this is the tissue most often consumed by people.

## MATERIALS & METHODS

### Sample Collection and Processing

Five species of fish were collected at 24 stations in San Diego Bay during the summer of 1998 and analyzed for the accumulation of contaminants in their tissues (Figure 5.1, Table 5.1). Whole fish samples of California halibut (*Paralichthys californicus*) were collected at seven stations and analyzed for the presence of pesticides and polychlorinated biphenyl congeners (PCBs). Contaminant levels in these fish were compared to those for other bays and harbors in Southern California and to predator protection limits for mammals and birds. Muscle tissue samples were collected from sport fish at the remaining 17 stations in San Diego Bay and and analyzed for the presence of metals, pesticides and PCBs. The results of these analyses were compared to human health limits. The fish sampled for muscle tissues included California halibut, calico bass (*Paralabrax clathratus*), spotted sand bass (*Paralabrax maculatofasciatus*), barred sand bass (*Paralabrax nebulifer*), and yellowfin croaker (*Umbrina roncador*). Muscles tissues were analyzed for these five species because it is the tissue most often consumed by people, and for which the most consumption limits are available.

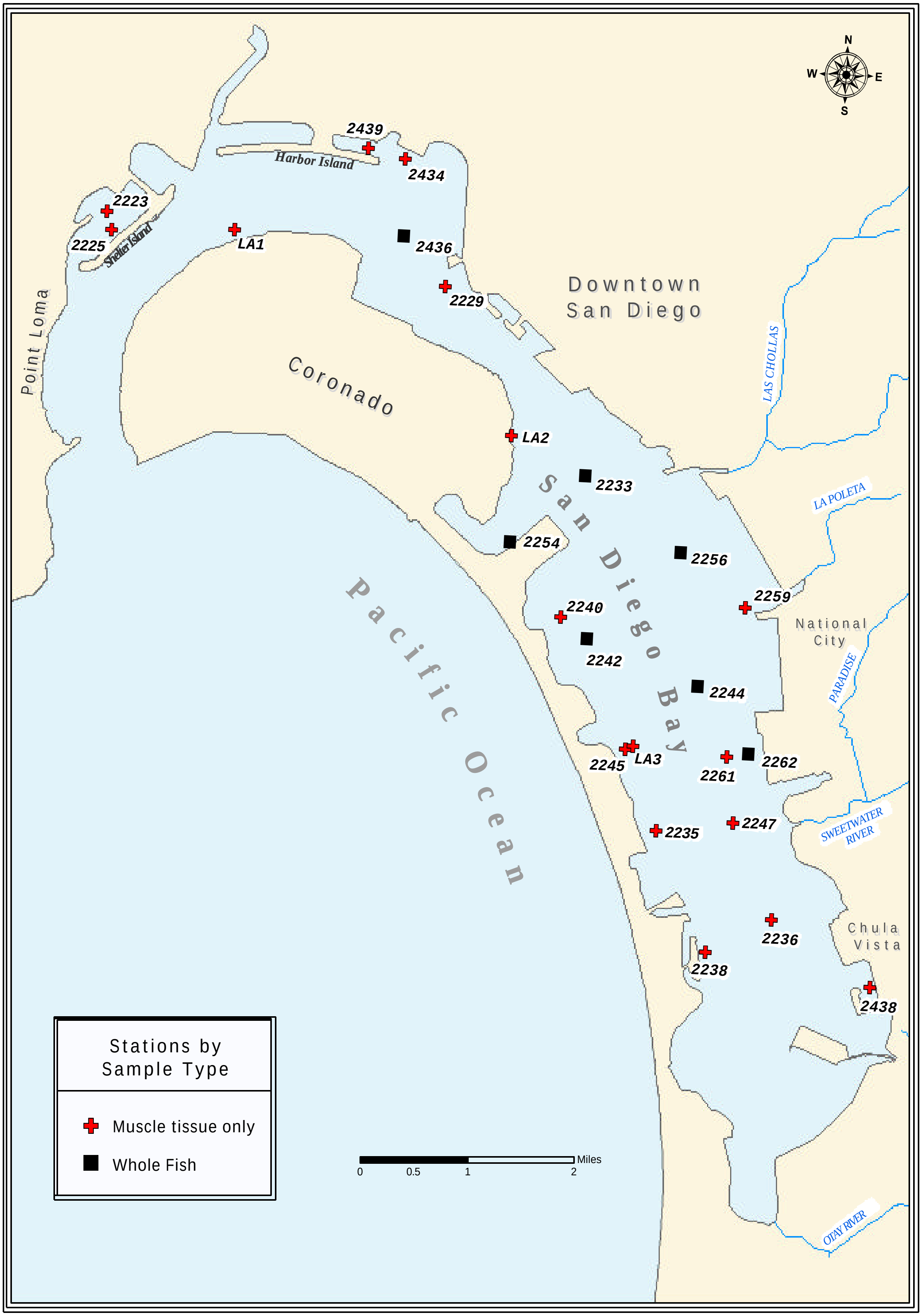


**Figure 5.1**
San Diego Bay fish tissue stations sampled during 1998.

**Table 5.1**

Summary of species of fish sampled by tissue type at each San Diego Bay station during 1998. OT= otter trawl, RF= rig fishing.

| Station | Collection Method | Tissue | Species |
|---|---|---|---|
| 2233 | OT | Whole Fish | California halibut |
| 2242 | OT | Whole Fish | California halibut |
| 2244 | OT | Whole Fish | California halibut |
| 2254 | OT | Whole Fish | California halibut |
| 2256 | OT | Whole Fish | California halibut |
| 2262 | OT | Whole Fish | California halibut |
| 2436 | OT | Whole Fish | California halibut |
| 2223 | RF | Muscle | Spotted sand bass |
| 2225 | RF | Muscle | Spotted sand bass |
| 2229 | RF | Muscle | Barred sand bass |
| 2235 | RF | Muscle | Spotted sand bass |
| 2236 | RF | Muscle | Spotted sand bass |
| 2238 | RF | Muscle | Spotted sand bass |
| 2240 | RF | Muscle | Spotted sand bass |
| 2245 | RF | Muscle | Yellowfin croaker |
| 2247 | RF | Muscle | Spotted sand bass |
| 2259 | RF | Muscle | Barred sand bass |
| 2261 | RF | Muscle | Spotted sand bass |
| 2434 | RF | Muscle | Calico bass |
| 2438 | RF | Muscle | Spotted sand bass |
| 2439 | RF | Muscle | Spotted sand bass |
| LA1* | misc. | Muscle | California halibut |
| LA2* | misc. | Muscle | Spotted sand bass |
| LA3* | misc. | Muscle | Spotted sand bass |

* additional fish from Dr. Larry Allen, collected by various methods

California halibut for the whole fish samples were collected from otter trawls conducted as part of Bight'98 (see Chapter 4). Only fish in the 5-20 cm size-class range (standard length) were retained for analysis. After collection, all fish were wrapped in aluminum foil, placed into ziplock bags, and then transported to the lab and stored frozen until processed. Prior to processing, the fish were sorted into composite samples of six fish each. The fish were then partially defrosted, rinsed in deionized water to remove visible particles, and shaken dry. The standard length (cm) and weight (g) of each fish used in the composite samples were recorded (Appendix E.1). Additionally, individual fish weights were summed to give a total weight for each composite sample. The whole fish composites were homogenized in chilled blenders, which consisted of 1-liter glass containers with silicone rubber gaskets and aluminum foil-lined lids. A volume of deionized water equal to the composite weight was combined with the fish tissue to facilitate blending. The entire sample was then blended for less than two minutes to obtain a smooth homogenate. The homogenate was then placed in glass jars, sealed, labeled, and stored at -20$^{o}$C prior to chemical analysis for pesticides (e.g., DDT, chlordane) and PCB congeners (see Appendix E.2). All samples were delivered to the City of San Diego Wastewater Chemistry Laboratory within six months. All contaminant concentrations resulting from these analyses were doubled in order to account for the water added to each sample.

Muscle tissues were analyzed for sport fish considered representative of a typical sport fisher's catch using rod and reel type gear at most stations. However, Dr. Larry Allen used several methods to collect fish at the three sites designated LA1-LA3. Only fish > 11 cm in standard length were kept and processed. All fish were wrapped in aluminum foil, placed into ziplock bags, and then transported to the lab and stored frozen until processed. In the lab, various sport fish were sorted into composite samples containing a minimum of three fish each. The fish were then partially defrosted and cleaned with a paper towel to remove loose scales and excess mucus. The standard length (cm) and weight (g) of the fish used in each composite sample were recorded (Appendix E.1). Muscle tissues were subsequently dissected from all the fish included in each composite. These dissections were carried out on Teflon pads that were cleaned between samples. The muscle samples were then placed in glass jars, sealed, labeled, and stored at -20$^{o}$C. All samples were delivered to the City of San Diego Wastewater Chemistry Laboratory within seven days of dissection for the subsequent analysis of priority pollutants, including metals, pesticides, and PCBs (Appendix E.3). A detailed description of all analytical **protocols may be obtained from the City's Wastewater Chemistry Laboratory**

### Data Analysis

Prior to any analysis, all values less than method detection limits (MDLs) were eliminated from the dataset. The MDLs for the contaminants analyzed in this study are listed in Appendices E.2 and E.3. Total DDT (tDDT) was calculated as the sum of DDT and its DDD and DDE derivatives. Total PCB (tPCB) was calculated as the sum of all PCB congeners. Metal and pesticide concentrations in the muscle tissues of fish were compared to national and international seafood action limits for humans (see Mearns et al. 1991).

Whole fish samples from San Diego Bay, Los Angeles/Long Beach Harbor, Marina Del Rey, Newport Harbor, and Ventura Harbor were compared to predator protection thresholds as determined by Environment Canada (1997, 1998). These thresholds are risk-based guidelines for marine mammals and birds, set at 14.0 ppb for tDDT and 0.79 ng (TEQ)/kg for tPCB, where TEQ is the toxic equivalent quotient. PCB TEQs were calculated separately for each sample as the sum of concentrations of the individual PCB congeners multiplied by their relative dioxin-like toxicity. The toxicity factors used in this study were those recommended by the World Health Organization for PCB congeners 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189, and differ for mammals and birds based on physiological differences (see Van den Berg et al. 1998).

## RESULTS

### Contaminants in Muscle Tissues of Fishes from San Diego Bay

#### *Metals*

Trace metal contamination varied in the tissues of fishes captured in San Diego Bay. Detections rates exceeded 80% for mercury, zinc, iron and selenium, but were much lower (< 30%) for aluminum, arsenic, chromium and copper (Table 5.2). In general, most metals that were detected were present at relatively low concentrations. Only chromium and arsenic occurred at levels that reached or exceeded USFDA and international action limits. These standards represent thresholds that indicate undesirable concentrations in fish tissues and are used to prevent the sale of contaminated seafood (Mearns et al. 1991). Arsenic, for example, exceeded the median international standard in one sample of barred sand bass collected at station

## Table 5.2

Concentrations of metals (ppm) and pesticides (ppb) detected in fish muscle samples, listed by station and species. Values exceeding US FDA action levels, Median International Standards or Cal/EPA screening levels, are shown in bold. BSB = barred sand bass; CB = calico bass; CH = California halibut; SSB = spotted sand bass; YC = yellowfin croaker.

| | | Metals (ppm) | | | | | | | | Pesticides (ppb) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | Species | Al | As | Cr | Cu | Fe | Hg | Se | Zn | tDDT | tChlor | Dieldrin |
| 2229 | BSB | — | **4.8** | — | — | 6.0 | 0.028 | 0.20 | 2.02 | 5.68 | — | — |
| 2259 | BSB | — | — | — | — | 3.1 | 0.061 | 0.21 | 3.43 | 10.70 | — | — |
| 2434 | CB | — | — | — | — | 7.0 | 0.055 | 0.24 | 3.22 | 15.00 | — | — |
| LA1 | CH | — | — | 0.18 | 0.79 | 5.5 | 0.010 | — | 3.86 | 3.27 | — | — |
| 2223 | SSB | — | — | — | — | 5.8 | 0.066 | 0.24 | 4.21 | 10.50 | — | 0.46 |
| 2225 | SSB | — | — | — | — | 7.5 | 0.082 | 0.20 | 4.86 | 7.80 | — | 1.17 |
| 2235 | SSB | 4.0 | — | — | 0.40 | 7.8 | 0.077 | 0.23 | 3.83 | 6.27 | — | — |
| 2236 | SSB | — | — | — | — | 7.0 | 0.078 | 0.20 | 2.69 | 5.03 | — | — |
| 2238 | SSB | — | — | — | — | 12.1 | 0.068 | 0.23 | 3.51 | 4.53 | — | — |
| 2240 | SSB | — | — | — | — | 7.8 | 0.041 | 0.20 | 3.73 | 4.65 | — | — |
| 2247 | SSB | — | — | — | — | 7.1 | 0.093 | 0.14 | 3.02 | — | — | — |
| 2261 | SSB | — | — | — | 1.05 | 9.2 | 0.047 | 0.13 | 4.27 | 7.57 | — | — |
| 2438 | SSB | — | — | **1.00** | — | 9.7 | 0.039 | 0.24 | 4.39 | 6.12 | — | — |
| 2439 | SSB | — | — | — | — | 13.1 | 0.157 | 0.18 | 3.93 | 10.10 | — | — |
| LA2 | SSB | — | — | — | 1.52 | 7.3 | 0.074 | 0.22 | 4.60 | 4.06 | — | — |
| LA3 | SSB | — | — | 0.50 | 2.57 | 10.8 | 0.032 | — | 5.13 | — | — | — |
| 2245 | YC | — | — | — | — | 6.7 | 0.192 | — | 4.58 | 7.52 | 0.87 | |
| | All Species % Detect | 6 | 6 | 18 | 29 | 100 | 100 | 82 | 100 | 88 | 6 | 12 |
| US FDA Action Level * | | | | | | | 1.0 | | | 5000 | 300 | 300 |
| Median International Standard** | | | 1.4 | 1.0 | 20.0 | | 0.5 | 0.3 | 70.0 | 5000 | 100 | 400 |
| Cal/EPA screening level | | | | | | | | | | 100 | | |

*From Table 3-4 in Kyle 1998. Standards are action limits for commercial fin fish.
**From Table 2.3 in Mearns et al. 1991. All international standards are for shellfish, but are often applied to fish. All limits apply to the sale of seafood for human consumption.

2229 along the Silver Strand (Figure 5.1). The single elevated chromium value was recorded for a muscle sample from spotted sand bass collected at station 2438 inside the Chula Vista Marina.

### *Pesticides*

DDT was found in the muscle tissues of all species of fish collected in the Bay at an overall detection rate of 88% (Table 5.2). Concentrations ranged from 3.27 ppb in a California halibut sample to 15 ppb in a calico bass sample. The four highest DDT values occurred in fishes collected at stations 2434 and 2439 located near Convair Lagoon, at station 2259 near the NASSCO shipyards, and at station 2223 in the Shelter Island Yacht Basin (see Figure 5.1). Two other pesticides, chlordane and dieldrin, were also detected in muscle tissues, although less frequently than DDT. Dieldrin, for example, was found in two spotted sand bass samples collected

## Table 5.3

Concentrations (ppb) of PCBs detected in muscle tissue samples of fish collected in San Diego Bay during 1998. Data are presented for total PCBs (tPCB) and individual congeners. BSB = barred sand bass; CB = calico bass; CH = California halibut; SSB = spotted sand bass; YC = yellowfin croaker.

| | | | PCB Congeners (ppb) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | Species | tPCB | 49 | 52 | 66 | 99 | 101 | 105 | 110 | 118 | 138 | 149 | 153 | 170 | 180 | 187 |
| 2229 | BSB | 43.6 | —- | —- | —- | —- | 7.9 | —- | —- | 8.1 | 9.6 | —- | 18.0 | —- | —- | —- |
| 2259 | BSB | 95.5 | —- | —- | —- | 8.0 | 11.0 | —- | —- | 11.0 | 15.0 | 8.3 | 27.0 | —- | 7.3 | 7.9 |
| 2434 | CB | 172.2 | 9.0 | 11.0 | 9.7 | 13.0 | 21.0 | —- | 11.0 | 18.0 | 18.0 | 12.0 | 32.0 | —- | 7.9 | 9.6 |
| LA1 | CH | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- |
| 2223 | SSB | 106.9 | —- | —- | —- | 13.0 | 10.0 | —- | —- | 16.5 | 18.5 | —- | 32.5 | —- | 8.3 | 8.2 |
| 2225 | SSB | 105.0 | —- | —- | —- | 11.0 | 12.0 | —- | —- | 17.0 | 17.0 | —- | 32.0 | —- | 7.4 | 8.6 |
| 2235 | SSB | 55.3 | —- | —- | —- | 7.9 | 7.6 | —- | —- | 7.8 | 11.0 | —- | 21.0 | —- | —- | —- |
| 2236 | SSB | 11.0 | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | 11.0 | —- | —- | —- |
| 2238 | SSB | 21.8 | —- | —- | —- | —- | —- | —- | —- | —- | 6.8 | —- | 15.0 | —- | —- | —- |
| 2240 | SSB | 46.4 | —- | —- | —- | —- | —- | —- | —- | 8.1 | 11.0 | —- | 21.0 | —- | —- | 6.3 |
| 2247 | SSB | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- |
| 2261 | SSB | 55.3 | —- | —- | —- | —- | 8.3 | —- | —- | 8.8 | 10.0 | —- | 22.0 | —- | —- | 6.2 |
| 2438 | SSB | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- |
| 2439 | SSB | 133.4 | 3.3 | 3.8 | 6.0 | 8.5 | 14.4 | 5.0 | 4.1 | 20.5 | 17.7 | 4.8 | 30.5 | 2.9 | 6.5 | 5.5 |
| LA2 | SSB | 109.6 | —- | —- | —- | 12.0 | 9.7 | —- | —- | 15.0 | 20.0 | —- | 36.0 | —- | 7.7 | 9.2 |
| LA3 | SSB | 7.6 | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | 7.6 | —- | —- | —- |
| 2245 | YC | 12.0 | —- | —- | —- | —- | —- | —- | —- | —- | —- | —- | 12.0 | —- | —- | —- |
| | All Species % Detect | 82 | 12 | 12 | 12 | 41 | 53 | 6 | 12 | 59 | 65 | 18 | 82 | 6 | 35 | 47 |

at stations 2223 and 2225 in the Shelter Island Yacht Basin. Additionally, although chlordane is considered a contaminant of concern in San Diego Bay (see USDoN, SWDIV and SDUPD 2000), this pesticide was found in only one sample of yellowfin croaker collected at station 2245 near the Silver Strand. All pesticide concentrations were less than international, federal and state consumption limits.

***PCBs***

PCBs were found in the muscle tissues of almost all species of fish collected in the Bay (Table 5.3). The overall detection rate was 82%, and tPCB values ranged from 7.6 to 172.2 ppb. For most samples, tPCB was largely composed of the congeners 153, 138, 118, and 101. Samples with the highest concentrations tended to have the greatest number of congeners present. The highest tPCB concentrations occurred in calico bass and spotted sand bass samples collected at stations 2434 and 2439 near Convair Lagoon, an area known for high PCB sediment contamination (see Fairey et al. 1996).

Most tPCB concentrations reported herein were much higher than typically reported in the muscle tissues of flatfish, rockfish and sand bass sampled in offshore waters off of Point Loma and southern San Diego (City of San Diego 1996, 1997, 1998, 1999, 2000a, 2000b, 2000c, 2001a, 2001b, 2002a, 2002b). However, human health thresholds for PCB concentrations in muscle tissues have been established only for PCBs quantified as commercial mixtures (i.e., Aroclors), and therefore could not be applied directly to the congener data reported here.

## Contaminants in Whole Fish from San Diego Bay

***Pesticides***

DDT occurred in all California halibut whole fish samples collected in this study at concentrations ranging from 18 to 70 ppb (Table 5.4). The highest DDT concentration was found in fish collected at station 2233 located just south of the Coronado Bridge in the middle of the Bay. The lowest concentrations occurred in fish collected at stations 2254 and 2262 located along the edges of the Bay (see Figure 5.1). All values exceeded the predator risk threshold of 14 ppb for DDT (see Environment Canada 1997). No chlordane was detected in any of the whole fish samples analyzed during this study.

***PCBs***

PCBs were also detected in all of the California halibut samples collected in San Diego Bay (Table 5.4). Total PCB concentrations ranged from 63 to 323 ppb, with over 70% of the samples exceeding 200 ppb. The highest PCB value was found in fish collected at station 2242 located mid-channel across from the Naval Station San Diego (see Figure 5.1). The lowest PCB concentration was detected in fish collected at station 2262, which coincided with one of the lowest levels of DDT found in the halibut samples.

Total PCB was composed primarily of congeners 153, 138 and 101, all of which occurred in 100% of the whole fish samples (Table 5.4). PCB 118, the only detected congener with recognized dioxin-like toxicity (see Van den Berg et al. 1998), was among several other congeners detected in 86% of the fish. Each of the six halibut samples with PCB 118 present had PCB TEQs that were greater than the Environment Canada predator protection threshold value for mammals. Because PCB 118 is considered 10 times less toxic to birds than to mammals (Van den Berg et al. 1998), none of these samples exceeded the threshold for birds.

## Table 5.4

Concentrations (ppb) of total DDT and PCBs detected in whole fish samples of California halibut from San Diego Bay.

| | | | PCB Congeners | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **tDDT** | **tPCB** | **99** | **101** | **110** | **118** | **138** | **149** | **151** | **153** | **180** | **187** |
| **2233** | 70 | 310 | 27 | 39 | 20 | 28 | 45 | 32 | 7 | 76 | 13 | 24 |
| **2242** | 40 | 323 | 26 | 36 | 18 | 30 | 52 | 30 | — | 84 | 19 | 28 |
| **2244** | 32 | 240 | 20 | 32 | 18 | 22 | 34 | 24 | — | 60 | 12 | 19 |
| **2254** | 18 | 248 | 23 | 24 | 14 | 28 | 39 | 21 | — | 65 | 14 | 21 |
| **2256** | 42 | 254 | 22 | 32 | 16 | 24 | 36 | 26 | — | 66 | 12 | 20 |
| **2262** | 19 | 63 | — | 14 | — | — | 17 | — | — | 32 | — | — |
| **2436** | 36 | 161 | 17 | 24 | — | 18 | 26 | 18 | — | 44 | — | 14 |
| **Freq (%)** | 100 | 100 | 86 | 100 | 71 | 86 | 100 | 86 | 14 | 100 | 71 | 86 |
| **Min** | 18 | 63 | 17 | 14 | 14 | 18 | 17 | 18 | 7 | 32 | 12 | 14 |
| **Max** | 70 | 323 | 27 | 39 | 20 | 30 | 52 | 32 | 7 | 84 | 19 | 28 |
| **Mean** | 37 | 226 | 22 | 29 | 17 | 25 | 36 | 25 | 7 | 61 | 14 | 21 |

### Comparison of San Diego Bay to Other Embayments

***Pesticides***

DDT was detected in 100% of the whole fish samples of California halibut collected from the different embayments sampled during Bight'98 (Table 5.5). The average tDDT concentration in halibut from San Diego Bay was about twice that of fish from Marina Del Rey, but substantially less than in fish collected in the Los Angeles/Long Beach, Newport, and Ventura harbors. The only sample that had a tDDT concentration less then the predator protection threshold for bird and mammal consumers occurred in Marina Del Rey. Although chlordane was found in halibut from Los Angeles/Long Beach Harbor, Marina Del Rey and Newport Harbor, this compound was not detected in any whole fish sample from San Diego Bay.

***PCBs***

PCBs were detected in 100% of the whole halibut samples from San Diego Bay, Marina Del Rey and Newport Harbor, in 40% of the samples from Los Angeles/Long Beach Harbor (Table 5.5). No PCBs were detected in the samples from Ventura Harbor . Fish from San Diego Bay averaged much higher concentrations of PCBs in their tissues than those from the other bays, which was probably due to historically acute PCB sediment contamination (USDoN, SWDIV and SDUPD 2000). None of the whole fish samples collected in any SCB embayment had PCB concentrations that exceeded the predator risk threshold for marine birds. In contrast, several values did exceed the threshold for marine mammals, including each of the samples from Newport and Ventura Harbors, 86% of the samples from San Diego Bay, and 20% of the samples from Los Angeles/Long Beach Harbor.

## SUMMARY & DISCUSSION

Fishes collected in San Diego Bay during 1998 contained many of the ‘contaminants of concern’ reported previously for sediments in the Bay (e.g., chromium, copper, lead, mercury, zinc, tributyltin, chlordane, PCBs) (USDoN, SWDIV and SDUPD 2000). PCBs and the metals mercury and zinc were detected in almost all

## Table 5.5

Concentrations (ppb) of pesticides and PCBs detected in whole fish samples from San Diego Bay compared to other bays and harbors sampled during Bight'98. Sample size in parenthases.

| | | SDBay (7) | Newport Harbor (1) | LA/LB Harbor (5) | Marina Del Rey (4) | Ventura Harbor (1) |
|---|---|---|---|---|---|---|
| Total DDT | %Detect | 100 | 100 | 100 | 100 | 100 |
| | range | 18-70 | na | 26-187 | 7-35 | na |
| | mean | 37 | 235 | 71 | 18 | 113 |
| Total PCB | %Detect | 100 | 100 | 40 | 100 | 0 |
| | range | 63-323 | na | 16-103 | 7-50 | —- |
| | mean | 228 | 35 | 60 | 23 | —- |
| Total Chlordane | %Detect | 0 | 100 | 20 | 25 | 0 |
| | range | —- | na | na | na | —- |
| | mean | —- | 5 | 5 | 2 | —- |
| Total DDT Threshold* | | | | | | |
| | %exceed | 100 | 100 | 100 | 50 | 100 |
| PCB Thresholds** | | | | | | |
| Mammals | %exceed | 86 | 100 | 20 | 0 | 0 |
| Birds | %exceed | 0 | 0 | 0 | 0 | 0 |

* = 14 ppb, predator protection threshold from Environment Canada 1997.
** = 0.00079 TEQ ppb predator protection threshold for mammals and birds, where TEQ calculated as summed concentration x toxicity of each congener, determined separately for mammals and birds based on different physiology (Environment Canada 1998, see also Bight'98 reports).

muscle tissue samples. In contrast, the other contaminants of concern were found much less frequently or not at all. Additional contaminants found in the muscles of Bay fishes included aluminum, arsenic, iron, selenium and the pesticide DDT. DDT and PCBs were also detected in all of the whole fish samples of California halibut collected in the Bay. Tissue contamination levels could not be associated with the sediments at specific collection sites since none of the species of fish analyzed demonstrate strong site fidelity, and because the overall sample area is relatively small.

Contaminant levels in muscle tissues and whole fish samples were assessed relative to two different types of thresholds in this study. In order to address human health concerns, concentrations of contaminants in the muscles of San Diego Bay fishes were compared to both national and international limits. Almost all of these values were below consumption limits. Arsenic and chromium were the only exceptions, with each exceeding the median international standard in a single sample. In contrast, concentrations of PCBs and DDT in whole fish samples were compared to the more recent mammal and bird predator protection thresholds (see Environment Canada 1997). All of these samples had PCB and DDT levels that exceeded the limits for mammals, while only concentrations of DDT exceeded the limit for birds.

Levels of PCB and DDT contamination in whole fish samples were compared among the various embayments sampled during Bight'98. Detection rates and concentrations of PCBs were much higher in halibut samples from San Diego Bay than in the other bays and harbors. In contrast, DDT concentrations and detection rates were similar in fish from all of the southern California embayments.

It was not possible to determine temporal trends in contamination levels for San Diego Bay fishes. This was due to differences between this study and previous surveys in terms of analytical techniques, and the types of tissues and species analyzed. However, some comparisons were possible between this study in 1998 and a survey performed by the San Diego County Department of Health Services in 1988-1989 using muscle tissues from similar species of fish (SDCDH 1990). For example, arsenic levels were slightly higher, chromium levels were similar, and concentrations of DDT (i.e., p,p,-DDE in SDCDH 1990), mercury and selenium were lower in this survey than in 1989-1989. Comparisons were also possible between fishes collected in San Diego Bay and those collected in offshore coastal waters off San Diego. While levels of metals and pesticides were similar, PCB concentrations were substantially higher in the muscle tissues of fishes from San Diego Bay than typically reported for coastal flatfish, rockfish, and sand bass sampled off Point Loma and southern San Diego (e.g., City of San Diego 1996, 1997, 1998, 1999, 2000a, 2000b, 2000c, 2001a, 2001b, 2002a, 2002b).

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# Appendices

# Appendix A

# Summary of Stations

## Appendix A.1

Summary of station locations and type of sampling conducted at each station in San Diego Bay during 1998.

| Station | Latitude | Longitude | Sed Chem | Benthics | Trawl | Fish Tissue[b] | Comments[c] |
|---|---|---|---|---|---|---|---|
| 2221 | 32° 43.671’ | 117° 12.307’ | x | x | | | |
| 2222 | 32° 43.127’ | 117° 13.551’ | x | x | | | |
| 2223 | 32° 42.925’ | 117° 13.831’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2224 | 32° 42.785’ | 117° 14.046’ | x | x | | | |
| 2225 | 32° 42.804’ | 117° 13.812’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2226 | 32° 42.667’ | 117° 13.899’ | x | x | | | |
| 2227 | 32° 43.424’ | 117° 12.482’ | x | x | | | |
| 2228 | 32° 43.444’ | 117° 10.690’ | x | x | | | |
| 2229 | 32° 42.537’ | 117° 10.562’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2230 | 33° 42.152’ | 117° 10.719’ | x | x | x | ns | Station sampled by SPAWAR. Insufficient fish for TB |
| 2231 | 32° 41.679’ | 117° 09.393’ | x | x | x | ns | Insufficient fish for TB |
| 2232 | 32° 41.541’ | 117° 09.839’ | ns | ns | ns | ns | Station sampled by SPAWAR. Station abandoned; <3 m. |
| 2233 | 32° 41.149’ | 117° 09.110’ | x | x | x | x | |
| 2234 | 32° 40.874’ | 117° 09.336’ | ns | ns | | | Station abandoned; <3 m |
| 2235 | 32° 38.448’ | 117° 08.216’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2236 | 32° 37.814’ | 117° 07.069’ | ns | ns | ns | RF | Station abandoned (except TB); <3 m |
| 2237 | 32° 37.595’ | 117° 07.379’ | ns | ns | | | Station abandoned; <3 m |
| 2238 | 32° 37.525’ | 117° 07.719’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2239 | 32° 40.944’ | 117° 08.406’ | x | x | x | ns | |
| 2240 | 32° 40.052’ | 117° 09.245’ | x | x | ns | RF | Station abandoned for trawls; too shallow |
| 2241 | 32° 40.216’ | 117° 08.189’ | x | x | x | ns | Insufficient fish for TB |
| 2242 | 32° 39.898’ | 117° 08.985’ | x | x | x | x | |
| 2243 | 32° 39.870’ | 117° 08.559’ | x | x | x | ns | Insufficient fish for TB |
| 2244 | 32° 39.583’ | 117° 07.909’ | x | x | x | x | |
| 2245 | 32° 39.050’ | 117° 08.562’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2246 | 32° 38.713’ | 117° 07.150’ | ns | ns | ns | ns | Station abandoned; <3 m |
| 2247 | 32° 38.540’ | 117° 07.484’ | x | x | ns | RF | Station abandoned for trawls; too shallow |
| 2248 | 32° 38.013’ | 117° 07.796’ | ns | ns | ns | ns | Station abandoned; <3 m |
| 2249 | 32° 37.280’ | 117° 07.687’ | x | x | x | ns | Insufficient fish for TB |

a) station not in Bight’98 field manual, added as extra trawl only stations due to lack of sampling success
b) RF = sampled for fish muscle by rig fishing because not trawlable
c) unless otherwise indicated, samples were collected by the City

## Appendix A.1 (continued)

| Station | Latitude | Longitude | Sed Chem | Benthics | Trawl | TB[b] | Comments[c] |
|---|---|---|---|---|---|---|---|
| 2250 | 32º 37.132’ | 117º 07.014’ | ns | ns | ns | ns | Station abandoned; <3 m |
| 2251 | 32º 42.138’ | 117º 09.724’ | x | x | | | |
| 2252 | 32º 41.512’ | 117º 09.171’ | x | x | | | |
| 2253 | 32º 41.288’ | 117º 08.286’ | x | x | | | Station sampled by SPAWAR. |
| 2254 | 32º 40.635’ | 117º 09.794’ | x | x | x | x | Station sampled by SPAWAR. |
| 2255 | 32º 40.678’ | 117º 07.764’ | x | x | | | |
| 2256 | 32º 40.611’ | 117º 08.152’ | x | x | x | x | |
| 2257 | 32º 40.610’ | 117º 08.045’ | x | x | | | |
| 2258 | 32º 40.555’ | 117º 07.928’ | x | x | x | ns | Insufficient fish for TB |
| 2259 | 32º 40.209’ | 117º 07.486’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2260 | 32º 40.031’ | 117º 07.799’ | x | x | | | |
| 2261 | 32º 39.049’ | 117º 07.590’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2262 | 32º 39.090’ | 117º 07.376’ | x | x | x | x | |
| 2263 | 32º 42.963’ | 117º 10.559’ | x | x | | | |
| 2264 | 32º 41.123’ | 117º 07.969’ | x | x | | | Station sampled by SPAWAR. |
| 2265 | 32º 41.033’ | 117º 08.418’ | x | x | | | |
| 2433 | 32º 43.341’ | 117º 12.553’ | x | x | | | |
| 2434 | 32º 43.494’ | 117º 11.018’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2435 | 32º 42.692’ | 117º 13.375’ | x | x | x | ns | Insufficient fish for TB |
| 2436 | 32º 42.902’ | 117º 10.987’ | x | x | x | x | |
| 2437 | 32º 40.879’ | 117º 10.298’ | ns | ns | | | Station abandoned; obstructions. |
| 2438 | 32º 37.338’ | 117º 06.102’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2439 | 32º 43.566’ | 117º 11.371’ | x | x | ns | RF | Station abandoned for trawls; obstruction |
| 2440 | 32º 43.109’ | 117º 10.489’ | x | x | | | |
| 2441 | 32º 41.469’ | 117º 14.281’ | x | x | | | Station sampled by SPAWAR. |
| 2442 | 32º 41.352’ | 117º 14.225’ | x | x | | | Station sampled by SPAWAR. |
| 2571[a] | na | na | | | x | ns | Insufficient fish for TB |
| 2573[a] | na | na | | | x | ns | Insufficient fish for TB |

a) station not in Bight’98 field manual, added as extra trawl only stations due to lack of sampling success
b) RF = sampled for fish muscle by rig fishing because not trawlable
c) unless otherwise indicated, samples were collected by the City

# Appendix B

# Supporting Data

# 1998 San Diego Bay Stations

# Sediment Quality

# Appendix B.1

Sediment chemistry constituents analyzed for San Diego Bay during 1998. Method detection limits (MDL) are listed in parentheses.

**Organic Indicators (%)**

| | |
|---|---|
| Total Nitrogen (NA) | Total Organic Carbon (NA) |

**Metals (ppm)**

| | | | |
|---|---|---|---|
| Aluminum (5) | Cadmium (0.5) | Manganese (0.48) | Thallium (10) |
| Antimony (5) | Chromium (3) | Mercury (0.03) | Tin (12) |
| Arsenic (0.08) | Copper (2) | Nickel (3) | Zinc (4) |
| Barium (0.042) | Iron (3) | Selenium (0.11) | |
| Beryllium (0.2) | Lead (5) | Silver (3) | |

**Polycylic Aromatic Hydrocarbons (ppb)**

| | | | |
|---|---|---|---|
| 1-methylnaphthalene (39) | Acenaphthene (42) | Benzo(e)pyrene (18) | Fluorene (46) |
| 1-methylphenanthrene (29) | Acenaphthylene (25) | Benzo(G,H,I)perylene (25) | Indeno(1,2,3-CD) |
| 2,3,5-trimethylnaphthalene (39) | Anthracene (35) | Benzo(K)fluoranthene (20) | pyrene (22) |
| 2,6-dimethylnaphthalene (43) | Benzo(A)anthracene (23) | Biphenyl (42) | Naphthalene (36) |
| 2-methylnaphthalene (39) | Dibenzo(A,H)anthracene (23) | Chrysene (21) | Perylene (18) |
| 3,4-benzo(B)fluoranthene (27) | Benzo(A)pyrene (18) | Fluoranthene (39) | Phenanthrene (37) |

**Polychlorinated Biphenyl Compounds (PCB Congeners) (ppb)**

| | | | |
|---|---|---|---|
| PCB 18 (1000) | PCB 81 (4700) | PCB 126 (1100) | PCB 169 (1700) |
| PCB 28 (960) | PCB 87 (1800) | PCB 128 (8900) | PCB 170 (1600) |
| PCB 37 (1700) | PCB 99 (4100) | PCB 138 (1900) | PCB 177 (2300) |
| PCB 44 (980) | PCB 101(1200) | PCB 149 (1700) | PCB 180 (2700) |
| PCB 49 (1300) | PCB 105 (930) | PCB 151 (1100) | PCB 183 (1400) |
| PCB 52 (1600) | PCB 110 (990) | PCB 153/168 (1200, 1400) | PCB 187 (1300) |
| PCB 66 (1000) | PCB 114 (1000) | PCB 156 (1800) | PCB 189 (1600) |
| PCB 70 (1000) | PCB 118 (1100) | PCB 157 (5600) | PCB 194 (1800) |
| PCB 74 (7900) | PCB 119 (1200) | PCB 158 (1100) | PCB 201 (2300) |
| PCB 77 (3700) | PCB 123 (9600) | PCB 167 (5000) | PCB 206 (5800) |

**Chlorinated Pesticides (ppt)**

| | | | |
|---|---|---|---|
| Aldrin (1400) | BHC, Beta isomer (140) | Endosulfan Sulfate (430) | o,p-DDT (390) |
| Alpha (cis) Chlordane (550) | BHC, Delta isomer (1300) | Endrin aldehyde (ND) | p,p-DDD (910) |
| Alpha Chlordene (160) | BHC, Gamma isomer (240) | Heptachlor epoxide (240) | p,p-DDE (440) |
| Gamma (trans) Chlordane (640) | | Cis Nonachlor (270) | Methoxychlor |
| (3800) | p,p-DDT (940) | | |
| Alpha Endosulfan (340) | Dieldrin (420) | Mirex (1800) | Oxychlordane |
| (1900) | | | |
| Beta Endosulfan (1400) | Endrin (470) | o,p-DDD (260) | Trans Nonachlor |
| (190) | | | |
| BHC, Alpha isomer (320) | Heptachlor (410) | o,p-DDE (390) | Toxaphene (ND) |

**Biocides (ppt)**

Tributyltin (ND)

## Appendix B.2

Summary of organic loading indicators and particle size parameters for San Diego Bay during 1998. Data include depth; total nitrogen (TN); total organic carbon (TOC); fine sediment particles (Fines); median, mean, and standard deviation (SD) of phi size. "Sediment composition" reflects field observations.

| Station | Depth m | TN % | TOC % | Fines % | Phi Size Median | Phi Size Mean | Phi Size SD | Sediment Composition |
|---|---|---|---|---|---|---|---|---|
| 2221 | 3.8 | 0.080 | 0.859 | 69.0 | 4.7 | 5.1 | 1.7 | olive green silt |
| 2222 | 4.8 | 0.112 | 0.985 | 72.0 | 5.4 | 5.6 | 1.9 | olive green silt |
| 2223 | 3.6 | 0.129 | 1.113 | 77.0 | 5.6 | 5.6 | 1.8 | olive green silt |
| 2224 | 4.5 | 0.078 | 0.645 | 40.0 | 3.4 | 4.0 | 2.0 | olive green silt |
| 2225 | 3.6 | 0.095 | 1.029 | 55.0 | 4.0 | 4.4 | 2.2 | gray silt with shell hash |
| 2226 | 4.8 | 0.210 | 1.727 | 91.0 | 6.0 | 6.1 | 1.6 | gray and brown silt, sulfides |
| 2227 | 8.8 | 0.101 | 0.932 | 50.0 | 4.1 | 4.6 | 2.0 | olive green silt with shell hash |
| 2228 | 5.2 | 0.084 | 0.730 | 45.0 | 3.9 | 4.3 | 1.5 | olive green silt |
| 2229 | 11.5 | 0.102 | 0.925 | 41.0 | 3.1 | 4.0 | 2.4 | olive green silt with shell hash |
| 2230 | 3.5 | 0.031 | 0.201 | 10.0 | 2.6 | 2.5 | 1.2 | olive green fine sand |
| 2231 | 13.1 | 0.076 | 0.639 | 29.0 | 2.8 | 3.6 | 2.7 | olive green silt/ fine sand with shell hash |
| 2233 | 8.8 | 0.056 | 0.450 | 34.0 | 3.2 | 4.0 | 1.9 | olive green silt/clay with shell hash |
| 2235 | 3.6 | 0.074 | 0.640 | 45.0 | 3.5 | 4.3 | 2.3 | gray silt |
| 2238 | 3.3 | 0.113 | 0.958 | 57.0 | 4.5 | 5.0 | 2.2 | gray silt |
| 2239 | 11.2 | 0.069 | 0.715 | 34.0 | 3.1 | 4.0 | 2.2 | olive green silt/clay with shell hash |
| 2240 | 3.3 | 0.058 | 0.547 | 42.0 | 3.1 | 4.0 | 2.3 | olive green silt with shell hash |
| 2241 | 3.9 | 0.067 | 0.517 | 18.0 | 2.9 | 3.4 | 1.8 | olive green silt/fine sand |
| 2242 | 3.7 | 0.077 | 0.742 | 31.0 | 3.0 | 4.0 | 2.1 | olive green silt |
| 2243 | 3.9 | 0.076 | 0.487 | 35.0 | 3.1 | 4.0 | 2.2 | olive green silt |
| 2244 | 3.3 | 0.039 | 0.297 | 20.0 | 3.0 | 3.4 | 1.4 | olive green silt |
| 2245 | 3.9 | 0.098 | 0.784 | 58.0 | 4.4 | 4.7 | 2.4 | olive green silt/clay |
| 2247 | 3.3 | 0.067 | 0.582 | 44.0 | 3.5 | 4.4 | 2.3 | olive green silt |
| 2249 | 3.0 | 0.147 | 1.349 | 72.0 | 5.4 | 5.6 | 2.1 | gray silt |
| 2251 | 8.5 | 0.138 | 1.994 | 72.0 | 5.4 | 5.5 | 2.1 | olive green silt |
| 2252 | 10.9 | 0.032 | 0.593 | 16.0 | 2.3 | 2.9 | 2.2 | red/brown/black mixed sed & shell hash |
| 2253 | 7.4 | 0.142 | 1.567 | 66.0 | 5.0 | 5.2 | 2.1 | olive green silt/clay |
| 2254 | 4.5 | 0.065 | 0.662 | 33.0 | unavailable | | | olive green fine sand/silt/clay |
| 2255 | 10.6 | 0.085 | 1.176 | 59.0 | 4.7 | 4.9 | 2.3 | olive green silt with shell hash |
| 2256 | 8.2 | 0.150 | 1.261 | 67.0 | 5.0 | 5.3 | 2.1 | olive green silt/clay |
| 2257 | 8.5 | 0.137 | 1.632 | 77.0 | 5.8 | 5.8 | 2.0 | olive green silt/clay |
| 2258 | 11.2 | 0.127 | 1.443 | 71.0 | 5.6 | 5.5 | 2.2 | olive green silt/clay with shell hash |
| 2259 | 10.9 | 0.113 | 1.242 | 66.0 | 5.1 | 5.1 | 2.4 | olive green silt/clay |
| 2260 | 3.6 | 0.061 | 0.513 | 27.0 | 3.0 | 3.8 | 1.9 | olive green silt |
| 2262 | 10.3 | 0.152 | 1.644 | 74.0 | 5.7 | 5.7 | 2.1 | olive green silt |
| 2263 | 13.1 | 0.127 | 1.248 | 73.0 | 5.5 | 5.5 | 2.0 | olive green silt |
| 2264 | 10.1 | 0.170 | 2.007 | 73.0 | 5.5 | 5.6 | 2.0 | olive green silt/clay |
| 2265 | 11.2 | 0.061 | 0.354 | 13.0 | 2.3 | 2.5 | 1.6 | olive green silt with shell hash |
| 2433 | 9.1 | 0.121 | 1.168 | 71.0 | 5.2 | 5.4 | 1.9 | olive green and gray silt |
| 2434 | 3.3 | 0.083 | 0.714 | 45.0 | 5.4 | 5.5 | 2.0 | olive green silt with shell hash |
| 2435 | 12.1 | 0.073 | 0.548 | 49.0 | 4.0 | 4.3 | 2.0 | olive green silt |
| 2436 | 11.0 | 0.140 | 1.361 | 53.0 | 4.3 | 4.5 | 2.4 | olive green silt with shell hash |
| 2438 | 3.4 | 0.102 | 0.921 | 64.0 | 4.9 | 5.1 | 2.3 | gray silt/clay |
| 2439 | 3.0 | 0.100 | 1.026 | 53.0 | 3.8 | 4.3 | 1.6 | olive green silt |
| 2440 | 10.0 | 0.054 | 0.496 | 38.0 | 3.2 | 3.9 | 2.1 | olive green silt |
| 2441 | 15.6 | 0.191 | 1.974 | 79.0 | 5.5 | 5.6 | 1.7 | olive green and black silt/clay |
| 2442 | 13.3 | 0.239 | 1.987 | 79.0 | 5.5 | 5.6 | 1.8 | olive green and black silt/clay, sulfides |
| **Mean** | 7.2 | 0.10 | 0.99 | 51.9 | 4.2 | 4.6 | 2.0 | |

## Appendix B.3

Concentrations (ppm) and detection rates (% Detect) of metals at each San Diego Bay station sampled during 1998. Values below method detection limits are indicated with "nd." Missing data is indicated with "N/A."

| Station | Al | Sb | As | Ba | Be | Cd | Cr | Cu | Fe | Pb | Mn | Hg | Ni | Se | Ag | Ti | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2221 | 39700 | 7.9 | 8.1 | 127.0 | 0.64 | 0.07 | 57.2 | 130.0 | 38200 | 39.2 | 254.0 | 0.472 | 18.6 | 0.14 | 0.51 | nd | nd | 197.0 |
| 2222 | 36100 | 13.1 | 7.9 | 91.9 | 0.70 | 0.19 | 44.8 | 171.0 | 37900 | 36.8 | 220.0 | 1.690 | 16.8 | 0.22 | 0.39 | nd | nd | 180.0 |
| 2223 | 28400 | 7.3 | 8.3 | 76.3 | 0.47 | 0.06 | 39.2 | 128.0 | 29200 | 36.7 | 184.0 | 1.030 | 13.8 | 0.11 | 0.35 | nd | nd | 153.0 |
| 2224 | 14600 | 8.6 | 4.1 | 43.8 | 0.25 | 0.08 | 18.2 | 58.3 | 16300 | 12.9 | 128.0 | 0.402 | 7.9 | nd | 0.30 | nd | nd | 82.6 |
| 2225 | 18300 | 10.4 | 4.2 | 47.0 | 0.33 | 0.05 | 24.7 | 127.0 | 19400 | 22.1 | 136.0 | 0.692 | 9.1 | nd | 0.30 | nd | nd | 130.0 |
| 2226 | 38200 | 10.8 | 7.0 | 106.0 | 0.72 | 0.13 | 51.7 | 220.0 | 36400 | 47.1 | 241.0 | 1.030 | 18.3 | 0.31 | 0.61 | nd | nd | 216.0 |
| 2227 | 23500 | 5.0 | 5.7 | 73.7 | 0.36 | 0.20 | 27.4 | 53.9 | 23800 | 17.9 | 186.0 | 0.234 | 11.1 | 0.18 | 0.46 | nd | nd | 112.0 |
| 2228 | 23100 | nd | 5.6 | 76.7 | 0.30 | 0.23 | 42.8 | 68.8 | 23100 | 36.7 | 185.0 | 0.455 | 11.5 | 0.13 | 0.79 | nd | nd | 131.0 |
| 2229 | 20700 | nd | 5.4 | 52.4 | 0.37 | 0.09 | 31.6 | 58.9 | 20000 | 24.5 | 162.0 | 0.316 | 9.3 | 0.17 | 0.41 | nd | nd | 99.3 |
| 2230 | 5720 | nd | 2.3 | 13.8 | nd | N/A | 11.3 | 16.1 | 6380 | 10.8 | 53.0 | 0.379 | nd | 0.12 | N/A | 18.0 | nd | 38.3 |
| 2231 | 16100 | nd | 4.7 | 39.6 | 0.31 | 0.04 | 26.7 | 58.1 | 16500 | 21.6 | 130.0 | 0.224 | 8.0 | 0.13 | 0.30 | nd | nd | 92.5 |
| 2233 | 16200 | nd | 4.3 | 39.0 | 0.32 | 0.01 | 28.5 | 52.0 | 15900 | 26.8 | 121.0 | 0.316 | 7.9 | nd | nd | nd | nd | 106.0 |
| 2235 | 27800 | nd | 6.4 | 63.9 | 0.50 | 0.10 | 37.5 | 58.2 | 25400 | 21.3 | 174.0 | 0.239 | 10.7 | 0.31 | 0.48 | 11.0 | nd | 136.0 |
| 2238 | 28200 | nd | 5.9 | 60.4 | 0.51 | 0.17 | 33.1 | 55.1 | 25700 | 18.1 | 175.0 | 0.169 | 12.2 | 0.30 | 0.43 | nd | nd | 143.0 |
| 2239 | 21900 | nd | 4.8 | 55.9 | 0.44 | 0.08 | 35.5 | 75.1 | 21400 | 34.0 | 157.0 | 0.422 | 10.1 | 0.13 | 0.51 | nd | nd | 121.0 |
| 2240 | 17900 | nd | 4.3 | 40.3 | 0.29 | 0.08 | 29.5 | 47.4 | 18200 | 22.5 | 115.0 | 0.263 | 8.1 | 0.19 | 0.51 | 15.0 | nd | 103.0 |
| 2241 | 22000 | 7.0 | 6.0 | 45.0 | 0.32 | 0.09 | 34.2 | 73.5 | 20300 | 32.1 | 198.0 | 0.268 | 9.2 | 0.21 | 0.54 | nd | nd | 126.0 |
| 2242 | 16600 | nd | 4.3 | 35.9 | 0.29 | 0.10 | 25.4 | 42.0 | 15100 | 17.8 | 114.0 | 0.300 | 6.8 | 0.15 | 0.49 | nd | nd | 89.8 |
| 2243 | 11200 | nd | 3.7 | 25.0 | 0.24 | 0.10 | 20.8 | 38.8 | 11600 | 19.9 | 80.2 | 0.239 | 5.1 | 0.15 | 0.50 | nd | nd | 81.2 |
| 2244 | 14100 | 10.0 | 4.2 | 33.4 | 0.25 | 0.10 | 21.2 | 41.8 | 13600 | 15.4 | 112.0 | 0.177 | 5.7 | nd | 0.39 | nd | nd | 82.4 |
| 2245 | 29500 | 13.5 | 7.0 | 64.6 | 0.45 | 0.13 | 40.8 | 69.0 | 26900 | 24.6 | 168.0 | 0.331 | 11.8 | 0.21 | 0.71 | 6.5 | nd | 146.0 |
| 2247 | 23700 | nd | 6.2 | 47.7 | 0.43 | 0.11 | 28.3 | 53.4 | 20400 | 17.4 | 170.0 | 0.157 | 8.5 | 0.34 | 0.41 | 10.0 | nd | 103.0 |
| 2249 | 41900 | 24.3 | 8.0 | 82.5 | 0.53 | 0.21 | 47.1 | 84.3 | 34600 | 29.1 | 230.0 | 0.220 | 16.8 | 0.42 | 0.52 | nd | nd | 197.0 |
| 2251 | 33700 | nd | 10.4 | 103.0 | 0.69 | 0.22 | 62.4 | 196.0 | 35000 | 82.5 | 218.0 | 0.569 | 17.4 | 0.30 | 1.03 | nd | nd | 259.0 |
| 2252 | 8720 | nd | 4.3 | 22.0 | nd | 0.04 | 14.8 | 31.1 | 11600 | 13.8 | 108.0 | 0.113 | 4.2 | nd | 0.20 | nd | nd | 64.2 |
| 2253 | 35400 | nd | 10.6 | 121.0 | 0.63 | N/A | 53.8 | 252.0 | 32900 | 68.7 | 235.0 | 0.786 | 16.2 | 0.46 | N/A | 11.0 | nd | 314.0 |
| 2254 | 11700 | 9.3 | 6.2 | 25.9 | 0.20 | N/A | 23.3 | 74.9 | 13100 | 24.9 | 81.7 | 0.359 | 5.6 | 0.22 | N/A | 12.0 | nd | 113.0 |
| 2255 | 26400 | 8.9 | 5.6 | 79.3 | 0.49 | 0.17 | 51.2 | 146.0 | 25100 | 52.8 | 149.0 | 0.696 | 13.4 | 0.15 | 1.04 | nd | nd | 206.0 |
| 2256 | 29000 | nd | 7.5 | 82.2 | 0.54 | 0.20 | 54.3 | 128.0 | 30300 | 54.1 | 193.0 | 0.632 | 14.3 | 0.20 | 1.29 | nd | nd | 197.0 |
| 2257 | 44300 | nd | 9.1 | 105.0 | 0.77 | 0.18 | 66.7 | 157.0 | 38200 | 64.1 | 238.0 | 0.511 | 18.7 | 0.28 | 1.25 | nd | nd | 233.0 |
| 2258 | 39100 | nd | 7.8 | 94.3 | 4.93 | 0.16 | 60.0 | 143.0 | 35200 | 53.0 | 244.0 | 0.664 | 16.4 | 0.27 | 0.95 | nd | nd | 211.0 |
| 2259 | 35900 | nd | 5.6 | 99.9 | 0.64 | 0.14 | 50.4 | 145.0 | 33000 | 44.4 | 219.0 | 0.403 | 15.0 | 0.13 | 0.75 | 10.0 | nd | 180.0 |
| 2260 | 14200 | 5.8 | 4.1 | 33.1 | 0.25 | 0.09 | 23.9 | 50.8 | 14400 | 20.4 | 112.0 | 0.216 | 7.1 | nd | 0.45 | nd | nd | 87.5 |
| 2262 | 45800 | nd | 10.3 | 102.0 | 0.80 | 0.16 | 59.8 | 200.0 | 40600 | 45.6 | 334.0 | 0.321 | 19.0 | 0.25 | 0.69 | 17.0 | nd | 232.0 |
| 2263 | 28500 | nd | 7.3 | 83.0 | 0.56 | 0.21 | 57.4 | 118.0 | 29200 | 41.6 | 189.0 | 0.688 | 16.4 | 0.23 | 0.91 | nd | nd | 180.0 |
| 2264 | 42900 | nd | 15.6 | 123.0 | 0.79 | N/A | 69.2 | 247.0 | 39100 | 193.0 | 237.0 | 0.621 | 21.2 | 0.47 | N/A | 15.0 | nd | 420.0 |
| 2265 | 6240 | nd | 2.5 | 20.0 | 1.52 | 0.07 | nd | 18.0 | 8190 | 12.0 | 62.3 | 0.065 | nd | nd | 0.19 | nd | nd | 43.2 |
| 2433 | 30800 | 13.5 | 8.3 | 91.1 | 0.54 | 0.25 | 34.5 | 71.6 | 30900 | 21.0 | 236.0 | 0.263 | 14.9 | 0.22 | 0.50 | nd | nd | 126.0 |
| 2434 | 23400 | 8.8 | 6.2 | 75.5 | 0.38 | 0.17 | 49.8 | 68.9 | 23100 | 31.6 | 215.0 | nd | 11.6 | 0.16 | 0.64 | nd | nd | 132.0 |
| 2435 | 21000 | nd | 5.1 | 75.1 | 0.20 | 0.14 | 20.6 | 28.4 | 21400 | 7.1 | 170.0 | 0.123 | 9.9 | nd | 0.19 | nd | nd | 64.4 |
| 2436 | 35000 | 11.2 | 10.6 | 103.0 | 0.65 | 0.21 | 53.1 | 94.7 | 34300 | 37.2 | 296.0 | 0.458 | 17.0 | 0.27 | 0.62 | 12.5 | nd | 157.0 |
| 2438 | 36400 | nd | 7.0 | 85.4 | 0.67 | 0.18 | 42.5 | 101.0 | 32200 | 20.2 | 216.0 | 0.099 | 14.0 | 0.34 | 0.64 | 10.0 | nd | 163.0 |
| 2439 | 29800 | nd | 5.6 | 89.8 | 0.56 | 0.16 | 74.1 | 133.0 | 28300 | 45.2 | 202.0 | 0.468 | 14.3 | 0.18 | 0.56 | nd | nd | 203.0 |
| 2440 | 14700 | 14.5 | 4.8 | 46.2 | 0.30 | 0.04 | 24.3 | 41.8 | 15800 | 20.6 | 127.0 | 0.235 | 7.2 | 0.14 | nd | nd | nd | 81.1 |
| 2441 | 35100 | 20.4 | 12.4 | 101.0 | 0.66 | N/A | 43.9 | 71.8 | 33100 | 21.9 | 247.0 | 0.191 | 16.6 | 0.64 | N/A | nd | nd | 123.0 |
| 2442 | 32000 | nd | 8.6 | 94.8 | 0.58 | N/A | 41.9 | 77.7 | 30800 | 21.1 | 233.0 | 0.176 | 16.0 | 0.61 | N/A | 13.0 | nd | 139.0 |
| **Mean** | 25989 | 4.6 | 6.6 | 69.5 | 0.57 | 0.13 | 38.9 | 95.1 | 25045 | 34.4 | 179.5 | 0.406 | 11.8 | 0.21 | 0.55 | 3.5 | 0 | 147.7 |
| **N** | 46 | 46 | 46 | 46 | 46 | 40 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 40 | 46 | 46 | 46 |
| **% Detect** | 100 | 41 | 100 | 100 | 96 | 100 | 98 | 100 | 100 | 100 | 100 | 98 | 96 | 83 | 95 | 28 | 0 | 100 |

## Appendix B.4

Concentrations (ppb) of detected polycyclic aromatic hydrocarbons (PAH) in San Diego Bay during 1998. Values below method detection limits are designated as "nd."

| Station | Total PAH | 2,6-dimethyl-naphthalene | 3,4-benzo(B)-fluoranthene | Acenaph-thylene | Anthracene | Benzo(A)-anthracene | Benzo(A)-pyrene |
|---|---|---|---|---|---|---|---|
| 2221 | 99 | nd | 14.9 | nd | nd | 9.3 | 14.6 |
| 2222 | 249 | nd | 60.0 | nd | nd | 16.7 | 35.7 |
| 2223 | 139 | nd | 32.8 | nd | nd | 11.8 | 22.2 |
| 2224 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2225 | 193 | nd | 27.5 | nd | nd | 17.6 | 28.7 |
| 2226 | 735 | nd | 148.0 | nd | nd | 68.3 | 107.0 |
| 2227 | 524 | nd | 87.4 | nd | nd | 53.3 | 66.9 |
| 2228 | 716 | nd | 131.0 | nd | nd | 63.5 | 100.0 |
| 2229 | 1285 | nd | 88.2 | 39.5 | 60.8 | 99.5 | 106.0 |
| 2230 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2231 | 493 | nd | 66.7 | nd | nd | 33.9 | 65.9 |
| 2233 | 17 | nd | nd | nd | nd | nd | 0.0 |
| 2235 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2238 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2239 | 605 | nd | 95.5 | nd | nd | 47.6 | 82.0 |
| 2240 | 137 | nd | 41.0 | nd | nd | 12.2 | 28.8 |
| 2241 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2242 | 197 | nd | 37.4 | nd | nd | nd | 33.0 |
| 2243 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2244 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2245 | 70 | nd | 29.9 | nd | nd | nd | 20.8 |
| 2247 | 38 | nd | 28.0 | nd | nd | nd | 18.9 |
| 2249 | 209 | nd | nd | nd | nd | 25.8 | 24.4 |
| 2251 | 4710 | nd | 760.0 | 98.3 | 164.0 | 366.0 | 567.0 |
| 2252 | 16 | nd | nd | nd | nd | nd | 0.0 |
| 2253 | 1571 | nd | 306.0 | 24.3 | 32.9 | 125.0 | 223.0 |
| 2254 | 10768 | nd | 2010.0 | 241.0 | 368.0 | 1000.0 | 1150.0 |
| 2255 | 1944 | nd | 384.0 | 23.9 | 38.5 | 193.0 | 272.0 |
| 2256 | 247 | nd | 42.7 | nd | nd | 19.9 | 34.8 |
| 2257 | 326 | nd | 56.0 | nd | nd | 27.4 | 46.9 |
| 2258 | 312 | nd | 49.0 | nd | nd | 20.2 | 51.3 |
| 2259 | 2347 | nd | 480.0 | 69.7 | 104.0 | 165.0 | 372.0 |
| 2260 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2262 | 457 | nd | 83.8 | nd | nd | 43.4 | 64.0 |
| 2263 | 2615 | nd | 424.0 | 52.1 | 207.0 | 178.0 | 334.0 |
| 2264 | 3003 | 25.1 | 515.0 | 59.5 | 102.0 | 240.0 | 371.0 |
| 2265 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2433 | 426 | nd | 73.7 | nd | nd | 51.1 | 53.1 |
| 2434 | 972 | nd | 189.0 | nd | nd | 78.5 | 128.0 |
| 2435 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2436 | 398 | nd | 56.9 | nd | nd | 37.0 | 51.9 |
| 2438 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2439 | 542 | nd | 100.0 | nd | nd | 40.7 | 66.4 |
| 2440 | nd | nd | nd | nd | nd | nd | 0.0 |
| 2441 | 1367 | 24.6 | 152.0 | 12.8 | 75.7 | 129.0 | 110.0 |
| 2442 | 5925 | 28.9 | 510.0 | 58.8 | 512.0 | 575.0 | 398.0 |
| **Mean** | 949 | 1.7 | 153.9 | 14.8 | 36.2 | 81.5 | 109.7 |

## Appendix B.4 (continued)

| Station | Benzo(E)-pyrene | Benzo(G,H,I)-perylene | Benzo(K)-fluoranthene | Chrysene | Dibenzo(A,H)-anthracene | Fluoranthene | Fluorene |
|---|---|---|---|---|---|---|---|
| 2221 | 12.3 | 12.7 | 14.4 | 9.5 | nd | nd | nd |
| 2222 | 30.3 | 25.2 | 36.8 | 20.2 | nd | 23.3 | nd |
| 2223 | 20.2 | 13.5 | 21.6 | 16.6 | nd | nd | nd |
| 2224 | nd | nd | nd | nd | nd | nd | nd |
| 2225 | 18.4 | nd | 34.5 | 46.0 | nd | nd | nd |
| 2226 | 91.7 | 50.1 | 103.0 | 93.0 | nd | 59.3 | nd |
| 2227 | 55.4 | 36.3 | 56.3 | 71.1 | nd | 62.3 | nd |
| 2228 | 84.4 | 63.6 | 77.4 | 79.4 | nd | 72.3 | nd |
| 2229 | 80.4 | 54.7 | 104.0 | 121.0 | nd | 142.0 | nd |
| 2230 | nd | nd | nd | nd | nd | nd | nd |
| 2231 | 60.1 | 49.0 | 66.9 | 50.9 | nd | 41.9 | nd |
| 2233 | nd | nd | nd | nd | nd | nd | nd |
| 2235 | nd | nd | nd | nd | nd | nd | nd |
| 2238 | nd | nd | nd | nd | nd | nd | nd |
| 2239 | 74.6 | 49.7 | 80.5 | 70.1 | nd | 55.9 | nd |
| 2240 | 27.5 | 26.1 | 10.4 | nd | nd | nd | nd |
| 2241 | nd | nd | nd | nd | nd | nd | nd |
| 2242 | 29.0 | 29.9 | 30.6 | 21.3 | nd | nd | nd |
| 2243 | nd | nd | nd | nd | nd | nd | nd |
| 2244 | nd | nd | nd | nd | nd | nd | nd |
| 2245 | 21.6 | nd | nd | nd | nd | nd | nd |
| 2247 | 18.8 | nd | nd | nd | nd | nd | nd |
| 2249 | 21.8 | nd | 22.6 | 25.4 | nd | 43.9 | nd |
| 2251 | 499.0 | 282.0 | 329.0 | 536.0 | 97.6 | 503.0 | nd |
| 2252 | nd | nd | nd | nd | nd | nd | nd |
| 2253 | 200.0 | 87.0 | 188.0 | 134.0 | 43.3 | 143.0 | nd |
| 2254 | 1180.0 | 289.0 | 1160.0 | 1330.0 | 193.0 | 1500.0 | 54.0 |
| 2255 | 205.0 | 91.0 | 195.0 | 227.0 | 48.9 | 220.0 | nd |
| 2256 | 32.1 | 22.7 | 30.9 | 26.0 | nd | 20.2 | nd |
| 2257 | 43.9 | 27.2 | 46.7 | 38.1 | nd | 25.7 | nd |
| 2258 | 47.8 | 21.3 | 40.0 | 37.6 | nd | 19.7 | nd |
| 2259 | 304.0 | 123.0 | 277.0 | 279.0 | 65.6 | 94.6 | nd |
| 2260 | nd | nd | nd | nd | nd | nd | nd |
| 2262 | 60.9 | 35.4 | 65.1 | 58.2 | nd | 39.3 | nd |
| 2263 | 263.0 | 122.0 | 305.0 | 357.0 | 59.4 | 146.0 | 27.6 |
| 2264 | 306.0 | 54.0 | 350.0 | 436.0 | 37.3 | 251.0 | nd |
| 2265 | nd | nd | nd | nd | nd | nd | nd |
| 2433 | 48.0 | 30.4 | 49.4 | 63.7 | nd | 46.3 | nd |
| 2434 | 122.0 | 73.7 | 124.0 | 100.0 | 28.6 | 98.6 | nd |
| 2435 | nd | nd | nd | nd | nd | nd | nd |
| 2436 | 42.1 | 33.7 | 51.2 | 48.9 | nd | 48.4 | nd |
| 2438 | nd | nd | nd | nd | nd | nd | nd |
| 2439 | 72.0 | 42.9 | 73.6 | 73.4 | nd | 48.3 | nd |
| 2440 | nd | nd | nd | nd | nd | nd | nd |
| 2441 | 86.7 | 29.0 | 107.0 | 192.0 | nd | 220.0 | nd |
| 2442 | 284.0 | 73.2 | 388.0 | 808.0 | 49.1 | 1340.0 | nd |
| Mean | 96.6 | 40.2 | 96.5 | 116.7 | 13.5 | 114.5 | 1.8 |

## Appendix B.4 (continued)

| Station | Indeno(1,2,3-CD)-pyrene | Perylene | Phenanthrene | Pyrene |
|---|---|---|---|---|
| 2221 | 9.7 | nd | nd | 16.8 |
| 2222 | 23.8 | 11.0 | nd | 25.5 |
| 2223 | 13.5 | nd | nd | 19.7 |
| 2224 | nd | nd | nd | nd |
| 2225 | 11.2 | nd | nd | 36.8 |
| 2226 | 50.5 | 29.1 | nd | 83.1 |
| 2227 | 33.1 | 18.9 | nd | 70.1 |
| 2228 | 54.8 | 27.6 | nd | 92.9 |
| 2229 | 48.3 | 27.9 | 211.0 | 190.0 |
| 2230 | nd | nd | nd | nd |
| 2231 | 39.6 | 19.6 | nd | 65.5 |
| 2233 | nd | nd | nd | 16.6 |
| 2235 | nd | nd | nd | nd |
| 2238 | nd | nd | nd | nd |
| 2239 | 45.4 | 28.9 | nd | 70.2 |
| 2240 | nd | nd | nd | 32.2 |
| 2241 | nd | nd | nd | nd |
| 2242 | 23.9 | nd | nd | 29.0 |
| 2243 | nd | nd | nd | nd |
| 2244 | nd | nd | nd | nd |
| 2245 | nd | nd | nd | 27.2 |
| 2247 | nd | nd | nd | nd |
| 2249 | nd | nd | nd | 45.0 |
| 2251 | 254.0 | 131.0 | 218.0 | 665.0 |
| 2252 | nd | nd | nd | 16.0 |
| 2253 | 94.2 | 58.3 | 41.6 | 176.0 |
| 2254 | 361.0 | 291.0 | 311.0 | 1340.0 |
| 2255 | 99.0 | 68.5 | 41.2 | 221.0 |
| 2256 | 19.7 | 11.4 | nd | 29.0 |
| 2257 | 25.0 | 11.5 | nd | 33.3 |
| 2258 | 20.8 | 12.6 | nd | 41.1 |
| 2259 | 138.0 | 111.0 | 49.2 | 195.0 |
| 2260 | nd | nd | nd | nd |
| 2262 | 35.9 | nd | nd | 54.5 |
| 2263 | 124.0 | 96.5 | 75.0 | 268.0 |
| 2264 | 76.5 | 95.0 | 60.0 | 540.0 |
| 2265 | nd | nd | nd | nd |
| 2433 | 27.3 | nd | nd | 56.4 |
| 2434 | 72.8 | 35.0 | nd | 111.0 |
| 2435 | nd | nd | nd | nd |
| 2436 | 29.9 | nd | nd | 54.6 |
| 2438 | nd | nd | nd | nd |
| 2439 | 39.3 | 19.2 | nd | 66.0 |
| 2440 | nd | nd | nd | nd |
| 2441 | 34.1 | 37.4 | 86.1 | 223.0 |
| 2442 | 89.0 | 114.0 | 207.0 | 1000.0 |
| Mean | 41.2 | 27.3 | 28.3 | 128.5 |

## Appendix B.5

Concentrations (ppt: parts per trillion) of polychlorinated biphenyl compounds (PCBs) in San Diego Bay during 1998. Values below method detection limits are designated as "nd."

| Station | Total PCB | PCB101 | PCB105 | PCB110 | PCB118 | PCB138 | PCB149 | PCB151 | PCB153 |
|---|---|---|---|---|---|---|---|---|---|
| 2221 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2222 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2223 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2224 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2225 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2226 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2227 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2228 | 16200 | nd | nd | 1900 | 5100 | nd | nd | nd | 3300 |
| 2229 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2230 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2231 | 1500 | nd | nd | nd | nd | nd | nd | nd | 1500 |
| 2233 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2235 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2238 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2239 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2240 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2241 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2242 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2243 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2244 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2245 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2247 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2249 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2251 | 17700 | nd | nd | 1700 | 6500 | nd | nd | nd | 4700 |
| 2252 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2253 | 123800 | 23000 | 6100 | 6400 | 18000 | 15000 | nd | 5100 | 9900 |
| 2254 | 2900 | nd | nd | nd | 1200 | nd | nd | nd | 1700 |
| 2255 | 16500 | 5500 | nd | 1400 | 2900 | nd | 2600 | nd | 4100 |
| 2256 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2257 | 1700 | nd | nd | nd | nd | nd | nd | nd | 1700 |
| 2258 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2259 | 9900 | nd | nd | 1300 | 4900 | nd | nd | nd | 3700 |
| 2260 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2262 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2263 | 10300 | nd | nd | 1800 | 5000 | nd | nd | nd | 3500 |
| 2264 | 24200 | 10000 | nd | 2800 | 3600 | nd | 3100 | nd | 4700 |
| 2265 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2433 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2434 | 7100 | nd | nd | 1100 | 3500 | nd | nd | nd | 2500 |
| 2435 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2436 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2438 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2439 | 49800 | 7600 | 3300 | 3300 | 10000 | 8400 | nd | nd | 5900 |
| 2440 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2441 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 2442 | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| **Mean** | 6122 | 1002 | 204 | 472 | 1320 | 509 | 124 | 111 | 1026 |

## Appendix B.5 (continued)

| Station | PCB187 | PCB44 | PCB52 | PCB66 | PCB70 | PCB87 | PCB99 |
|---|---|---|---|---|---|---|---|
| 2221 | nd | nd | nd | nd | nd | nd | nd |
| 2222 | nd | nd | nd | nd | nd | nd | nd |
| 2223 | nd | nd | nd | nd | nd | nd | nd |
| 2224 | nd | nd | nd | nd | nd | nd | nd |
| 2225 | nd | nd | nd | nd | nd | nd | nd |
| 2226 | nd | nd | nd | nd | nd | nd | nd |
| 2227 | nd | nd | nd | nd | nd | nd | nd |
| 2228 | nd | nd | nd | nd | 5900 | nd | nd |
| 2229 | nd | nd | nd | nd | nd | nd | nd |
| 2230 | nd | nd | nd | nd | nd | nd | nd |
| 2231 | nd | nd | nd | nd | nd | nd | nd |
| 2233 | nd | nd | nd | nd | nd | nd | nd |
| 2235 | nd | nd | nd | nd | nd | nd | nd |
| 2238 | nd | nd | nd | nd | nd | nd | nd |
| 2239 | nd | nd | nd | nd | nd | nd | nd |
| 2240 | nd | nd | nd | nd | nd | nd | nd |
| 2241 | nd | nd | nd | nd | nd | nd | nd |
| 2242 | nd | nd | nd | nd | nd | nd | nd |
| 2243 | nd | nd | nd | nd | nd | nd | nd |
| 2244 | nd | nd | nd | nd | nd | nd | nd |
| 2245 | nd | nd | nd | nd | nd | nd | nd |
| 2247 | nd | nd | nd | nd | nd | nd | nd |
| 2249 | nd | nd | nd | nd | nd | nd | nd |
| 2251 | nd | nd | nd | nd | 4800 | nd | nd |
| 2252 | nd | nd | nd | nd | nd | nd | nd |
| 2253 | 2800 | 3500 | 8200 | nd | 12000 | 7100 | 6700 |
| 2254 | nd | nd | nd | nd | nd | nd | nd |
| 2255 | nd | nd | nd | nd | nd | nd | nd |
| 2256 | nd | nd | nd | nd | nd | nd | nd |
| 2257 | nd | nd | nd | nd | nd | nd | nd |
| 2258 | nd | nd | nd | nd | nd | nd | nd |
| 2259 | nd | nd | nd | nd | nd | nd | nd |
| 2260 | nd | nd | nd | nd | nd | nd | nd |
| 2262 | nd | nd | nd | nd | nd | nd | nd |
| 2263 | nd | nd | nd | nd | nd | nd | nd |
| 2264 | nd | nd | nd | nd | nd | nd | nd |
| 2265 | nd | nd | nd | nd | nd | nd | nd |
| 2433 | nd | nd | nd | nd | nd | nd | nd |
| 2434 | nd | nd | nd | nd | nd | nd | nd |
| 2435 | nd | nd | nd | nd | nd | nd | nd |
| 2436 | nd | nd | nd | nd | nd | nd | nd |
| 2438 | nd | nd | nd | nd | nd | nd | nd |
| 2439 | nd | nd | nd | 2300 | 9000 | nd | nd |
| 2440 | nd | nd | nd | nd | nd | nd | nd |
| 2441 | nd | nd | nd | nd | nd | nd | nd |
| 2442 | nd | nd | nd | nd | nd | nd | nd |
| **Mean** | 61 | 76 | 178 | 50 | 689 | 154 | 146 |

## Appendix B.6

Concentrations (ppt: parts per trillion) of total DDT and the detected DDT derivatives for San Diego Bay during 1998.

| Station | Total DDT | p,p-DDD | p,p-DDE | p,p-DDT |
|---|---|---|---|---|
| 2221 | nd | nd | nd | nd |
| 2222 | nd | nd | nd | nd |
| 2223 | nd | nd | nd | nd |
| 2224 | nd | nd | nd | nd |
| 2225 | nd | nd | nd | nd |
| 2226 | 780 | nd | 780 | nd |
| 2227 | nd | nd | nd | nd |
| 2228 | nd | nd | nd | nd |
| 2229 | nd | nd | nd | nd |
| 2230 | nd | nd | nd | nd |
| 2231 | nd | nd | nd | nd |
| 2233 | nd | nd | nd | nd |
| 2235 | nd | nd | nd | nd |
| 2238 | nd | nd | nd | nd |
| 2239 | nd | nd | nd | nd |
| 2240 | nd | nd | nd | nd |
| 2241 | nd | nd | nd | nd |
| 2242 | 2100 | nd | nd | 2100 |
| 2243 | nd | nd | nd | nd |
| 2244 | nd | nd | nd | nd |
| 2245 | nd | nd | nd | nd |
| 2247 | 1000 | nd | 1000 | nd |
| 2249 | 910 | nd | 910 | nd |
| 2251 | nd | nd | nd | nd |
| 2252 | nd | nd | nd | nd |
| 2253 | 3200 | nd | 3200 | nd |
| 2254 | nd | nd | nd | nd |
| 2255 | 2060 | 660 | 1400 | nd |
| 2256 | nd | nd | nd | nd |
| 2257 | nd | nd | nd | nd |
| 2258 | nd | nd | nd | nd |
| 2259 | nd | nd | nd | nd |
| 2260 | nd | nd | nd | nd |
| 2262 | nd | nd | nd | nd |
| 2263 | nd | nd | nd | nd |
| 2264 | 7300 | nd | 2900 | 4400 |
| 2265 | nd | nd | nd | nd |
| 2433 | nd | nd | nd | nd |
| 2434 | nd | nd | nd | nd |
| 2435 | nd | nd | nd | nd |
| 2436 | nd | nd | nd | nd |
| 2438 | nd | nd | nd | nd |
| 2439 | nd | nd | nd | nd |
| 2440 | nd | nd | nd | nd |
| 2441 | nd | nd | nd | nd |
| 2442 | nd | nd | nd | nd |
| **Mean** | 377 | 14 | 222 | 141 |

# Appendix B.7

Summary of various sediment quality parameters for the nine bays and harbors sampled during the Bight'98 regional survey. LA/LB Harbor = Los Angeles/Long Beach Harbor.

| | Ventura Harbor | Channel Is. Harbor | Marina Del Rey | LA/LB Harbor | Anaheim Bay | Newport Harbor | Dana Pnt Harbor | Mission Bay | San Diego Bay |
|---|---|---|---|---|---|---|---|---|---|
| **N** | 1 | 3 | 7 | 36 | 3 | 11 | 3 | 3 | 46 |
| ***Metals (ppm)*** | | | | | | | | | |
| **Aluminum** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Mean** | 17300 | 26533 | 19990 | 25878 | 16437 | 37973 | 17100 | 19097 | 25989 |
| **95%CI** | — | 5066 | 6532 | 2428 | 6690 | 8979 | 10931 | 18157 | 3074 |
| **Antimony** | | | | | | | | | |
| **%Detect** | 100 | 33 | 100 | 42 | 100 | 100 | 100 | 33 | 41 |
| **Mean** | 0.2 | — | 0.2 | 1.4 | 0.2 | 0.6 | 0.2 | — | 11.1 |
| **95%CI** | — | — | 0.1 | 1.2 | 0.1 | 0.1 | 0.2 | — | 2.2 |
| **Arsenic** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Mean** | 9.7 | 10.5 | 7.7 | 11.6 | 6.0 | 8.6 | 6.0 | 4.2 | 6.6 |
| **95%CI** | — | 2.3 | 2.0 | 1.7 | 2.8 | 1.7 | 3.4 | 3.3 | 0.8 |
| **Barium** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Mean** | 97.0 | 132.4 | 94.1 | 203.4 | 95.3 | 131.3 | 122.6 | 60.3 | 69.5 |
| **95%CI** | — | 25.2 | 26.0 | 34.6 | 61.0 | 25.3 | 13.7 | 51.1 | 8.8 |
| **Beryllium** | | | | | | | | | |
| **%Detect** | 100 | 67 | 100 | 94 | 100 | 100 | 100 | 67 | 96 |
| **Mean** | 0.690 | 1.061 | 0.509 | 0.869 | 0.541 | 0.639 | 0.384 | 0.410 | 0.599 |
| **95%CI** | — | 0.469 | 0.140 | 0.120 | 0.231 | 0.219 | 0.156 | 0.196 | 0.209 |
| **Cadmium** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 92 | 100 | 100 | 100 | 100 | 95 |
| **Mean** | 0.650 | 0.891 | 0.545 | 0.654 | 0.626 | 1.130 | 0.197 | 0.068 | 0.129 |
| **95%CI** | — | 0.098 | 0.273 | 0.155 | 0.548 | 0.292 | 0.001 | 0.053 | 0.019 |
| **Iron** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Mean** | 36500 | 34767 | 29030 | 35633 | 25500 | 34582 | 17967 | 18687 | 25045 |
| **95%CI** | — | 4250 | 8520 | 2906 | 11001 | 6620 | 7889 | 15914 | 2665 |
| **Lead** | | | | | | | | | |
| **%Detect** | 100 | 67 | 100 | 92 | 100 | 100 | 100 | 33 | 100 |
| **Mean** | 24.9 | 26.2 | 88.2 | 42.5 | 47.8 | 28.2 | 13.2 | — | 34.4 |
| **95%CI** | — | 26.9 | 23.4 | 8.4 | 40.6 | 15.3 | 9.8 | — | 8.4 |
| **Nickel** | | | | | | | | | |
| **%Detect** | 100 | 100 | 86 | 100 | 100 | 100 | 100 | 67 | 96 |
| **Mean** | 44.0 | 33.7 | 30.7 | 30.1 | 18.8 | 22.1 | 10.5 | 11.6 | 12.4 |
| **95%CI** | — | 4.6 | 4.9 | 4.2 | 11.3 | 3.4 | 3.0 | 9.8 | 1.3 |
| **Selenium** | | | | | | | | | |
| **%Detect** | 100 | 67 | 86 | 47 | 100 | 100 | 100 | 100 | 83 |
| **Mean** | 2.00 | 1.18 | 1.50 | 1.43 | 1.47 | 0.95 | 0.70 | 0.37 | 0.25 |
| **95%CI** | — | 0.34 | 0.44 | 0.41 | 1.05 | 0.29 | 0.11 | 0.26 | 0.04 |
| **Silver** | | | | | | | | | |
| **%Detect** | 100 | 67 | 100 | 89 | 67 | 73 | 33 | 100 | 90 |
| **Mean** | 0.130 | 0.548 | 1.131 | 1.271 | 0.445 | 0.131 | — | 0.185 | 0.574 |
| **95%CI** | — | 0.885 | 0.443 | 0.518 | 0.186 | 0.064 | — | 0.249 | 0.086 |

## **Appendix B.7** continued

| | Ventura Harbor | Channel Is. Harbor | Marina Del Rey | LA/LB Harbor | Anaheim Bay | Newport Harbor | Dana Pnt Harbor | Mission Bay | San Diego Bay |
|---|---|---|---|---|---|---|---|---|---|
| **N** | 1 | 3 | 7 | 36 | 3 | 11 | 3 | 3 | 46 |
| ***Pesticides (ppt)*** | | | | | | | | | |
| **Total Chlordane** | | | | | | | | | |
| **%Detect** | 100 | 100 | 86 | 33 | 100 | 100 | 100 | 0 | 0 |
| **Mean** | 4.6 | 7.8 | 8.1 | 5.7 | 3.9 | 4.8 | 0.8 | — | — |
| **95%CI** | — | 7.5 | 4.9 | 4.1 | 2.7 | 1.6 | 0.7 | — | — |
| **Total DDT** | | | | | | | | | |
| **%Detect** | 100 | 100 | 100 | 97 | 100 | 100 | 100 | 0 | 15 |
| **Mean** | 236.9 | 198.9 | 35.2 | 64.8 | 60.3 | 69.6 | 7.8 | — | 2.5 |
| **95%CI** | — | 203.7 | 10.7 | 21.7 | 36.6 | 16.2 | 5.6 | — | 1.7 |

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# Appendix C

# Supporting Data

# 1998 San Diego Bay Stations

# Macrobenthic Communities

# Appendix C.1

Summary of major benthic community parameters at station station sampled in San Diego Bay during 1998. Data for each station are per 0.1m$^2$ grab for: SR= Species Richness (number of species); Abun=Abundance (number of individuals); H'=Diversity; J'=Evenness; Dom=Swartz Dominance (number of species composing 75% of a community by abundance).

| | Stations | SR | Abun | H' | J' | Dom |
|---|---|---|---|---|---|---|
| *Cluster Group A* | 2439 | 35 | 536 | 2.4 | 0.7 | 6 |
| | 2233 | 44 | 395 | 2.7 | 0.7 | 9 |
| | 2255 | 31 | 391 | 2.1 | 0.6 | 5 |
| | Mean | 36.7 | 440.7 | 2.4 | 0.7 | 6.7 |
| *Cluster Group B* | 2264 | 30 | 237 | 2.7 | 0.8 | 8 |
| | 2259 | 25 | 102 | 2.6 | 0.8 | 8 |
| | Mean | 27.5 | 169.5 | 2.7 | 0.8 | 8.0 |
| *Cluster Group C* | 2249 | 40 | 600 | 2.3 | 0.6 | 4 |
| | 2238 | 42 | 760 | 2.5 | 0.7 | 6 |
| | 2247 | 37 | 900 | 2.1 | 0.6 | 5 |
| | 2438 | 38 | 384 | 2.6 | 0.7 | 6 |
| | 2235 | 30 | 551 | 2.1 | 0.6 | 4 |
| | 2242 | 30 | 1117 | 1.8 | 0.5 | 3 |
| | 2243 | 50 | 966 | 2.7 | 0.7 | 8 |
| | 2245 | 28 | 487 | 2.2 | 0.7 | 5 |
| | 2262 | 30 | 542 | 2.1 | 0.6 | 4 |
| | Mean | 36.1 | 700.8 | 2.3 | 0.6 | 5.0 |
| *Cluster Group D* | 2240 | 42 | 1201 | 2.2 | 0.6 | 4 |
| | 2244 | 52 | 1376 | 2.7 | 0.7 | 8 |
| | 2434 | 54 | 576 | 3.3 | 0.8 | 15 |
| | 2230 | 76 | 1372 | 2.7 | 0.6 | 9 |
| | 2260 | 54 | 2263 | 1.8 | 0.5 | 3 |
| | 2241 | 50 | 1526 | 2.3 | 0.6 | 5 |
| | 2254 | 36 | 684 | 2.2 | 0.6 | 6 |
| | 2253 | 36 | 465 | 2.3 | 0.6 | 5 |
| | 2256 | 31 | 237 | 2.7 | 0.8 | 8 |
| | 2251 | 38 | 1194 | 1.9 | 0.5 | 3 |
| | 2257 | 38 | 503 | 2.3 | 0.6 | 6 |
| | 2440 | 65 | 651 | 3.2 | 0.8 | 13 |
| | 2239 | 28 | 1030 | 1.7 | 0.5 | 3 |
| | 2258 | 42 | 826 | 2.3 | 0.6 | 5 |
| | 2265 | 50 | 1543 | 2.4 | 0.6 | 7 |
| | Mean | 46.1 | 1029.8 | 2.4 | 0.6 | 6.7 |
| *Cluster Group E* | 2223 | 40 | 816 | 2.7 | 0.7 | 8 |
| | 2225 | 79 | 3149 | 2.3 | 0.5 | 5 |
| | 2221 | 40 | 824 | 2.6 | 0.7 | 8 |
| | 2224 | 44 | 383 | 2.9 | 0.8 | 10 |
| | 2222 | 40 | 693 | 1.8 | 0.5 | 3 |
| | 2226 | 64 | 1012 | 2.6 | 0.6 | 8 |
| | Mean | 51.2 | 1146.2 | 2.5 | 0.6 | 7.0 |
| *Cluster Group F* | 2252 | 38 | 327 | 2.8 | 0.8 | 9 |
| | 2436 | 54 | 599 | 3.1 | 0.8 | 11 |
| | 2229 | 71 | 705 | 3.1 | 0.7 | 14 |
| | 2231 | 78 | 1502 | 2.8 | 0.6 | 8 |
| | Mean | 60.3 | 783.3 | 2.9 | 0.7 | 10.5 |
| *Cluster Group G* | 2228 | 44 | 251 | 3.1 | 0.8 | 12 |
| | 2227 | 55 | 933 | 2.9 | 0.7 | 10 |
| | 2433 | 64 | 709 | 3.1 | 0.7 | 11 |
| | 2435 | 65 | 466 | 3.4 | 0.8 | 16 |
| | 2263 | 49 | 343 | 3.2 | 0.8 | 14 |
| | 2442 | 58 | 388 | 2.9 | 0.7 | 9 |
| | 2441 | 96 | 1672 | 3.2 | 0.7 | 12 |
| | Mean | 61.6 | 680.3 | 3.1 | 0.8 | 12.0 |

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# Appendix D

# Supporting Data

# 1998 San Diego Bay Stations

# Demersal Fishes and Megabenthic Invertebrates

## Appendix D.1

Marine debris collected each trawl station sampled in San Diego Bay during 1998.

| Date | Station | Type | Number | Weight |
|---|---|---|---|---|
| 13-Aug-98 | 2230 | Marine Veg. | L | T |
| 13-Aug-98 | 2231 | Marine Veg | H | M |
| 14-Aug-98 | 2233 | Benthic debris | M | L |
| | 2239 | none recorded | | |
| | 2241 | none recorded | | |
| 13-Aug-98 | 2242 | Marine Veg. | P | T |
| 24-Aug-98 | 2243 | Marine Veg. | L | L |
| 18-Aug-98 | 2244 | Marine Veg. | M | L |
| | | Benthic Debris | M | M |
| 18-Aug-98 | 2249 | Marine Veg. | L | T |
| | | Benthic Debris | L | L |
| 13-Aug-98 | 2254 | Marine Veg. | M | M |
| 17-Aug-98 | 2256 | Benthic Debris | M | M |
| 17-Aug-98 | 2258** | Rock | L | M |
| | | Marine Veg. | P | T |
| | | Benthic Debris | M (oyster/shell hash) | M |
| 18-Aug-98 | 2262 | Marine Veg. | L | L |
| | | Benthic Debris | L | L |
| 14-Aug-98 | 2436 | Marine Veg. | L | L |
| 24-Aug-98 | 2571 | Marine Veg. | P | T |
| 24-Aug-98 | 2573 | Marine Veg. | L | L |

** metal, cans, plastic present.

| Number Codes: | | | Weight Codes: |
|---|---|---|---|
| Present | P=1 | Trace | T=0.0-0.1 Kg |
| Low | L=2-10 | Low | L=0.2-1.0 Kg |
| Moderate | M=11-100 | Moderate | M=1.1-10 Kg |
| High | H=>100 | High | H=>10 Kg |

## Appendix D.2

Summary of demersal fish species captured in San Diego Bay during 1998. Data are number of fish collected (N) and minimum, maximum, and mean length.

| Taxon/Species[1] | Common Name | N | LENGTH Min | Max | Mean |
|---|---|---|---|---|---|
| RAJIFORMES | | | | | |
| Rhinobatidae | | | | | |
| *Rhinobatos productus* | shovelnose guitarfish | 1 | 27 | 27 | 27 |
| Dasyatidae | | | | | |
| *Dasyatis dipterura* | diamond stingray | 2 | 43 | 79 | 61 |
| Gymnuridae | | | | | |
| *Gymnura marmorata* | California butterfly ray | 1 | 36 | 36 | 36 |
| Urolophidae | | | | | |
| *Urolophus halleri* | round stingray | 86 | 15 | 36 | 25 |
| CLUPEIFORMES | | | | | |
| Engraulidae | | | | | |
| *Anchoa delicatissima* | slough anchovy | 15 | 6 | 7 | 7 |
| AULOPIFORMES | | | | | |
| Synodontidae | | | | | |
| *Synodus lucioceps* | California lizardfish | 4 | 12 | 16 | 14 |
| BATRACHOIDIFORMES | | | | | |
| Batrachoididae | | | | | |
| *Porichthys myriaster* | specklefin midshipman | 9 | 18 | 30 | 24 |
| GASTEROSTEIFORMES | | | | | |
| Hippocampinae | | | | | |
| *Hippocampus ingens* | Pacific seahorse | 2 | 17 | 23 | 20 |
| PERCIFORMES | | | | | |
| Serranidae | | | | | |
| *Paralabrax maculatofasciatus* | spotted sand bass | 63 | 11 | 29 | 21 |
| *Paralabrax nebulifer* | barred sand bass | 51 | 12 | 21 | 14 |
| Sciaenidae | | | | | |
| *Cheilotrema saturnum* | black croaker | 13 | 16 | 25 | 21 |
| *Genyonemus lineatus* | white croaker | 6 | 15 | 20 | 17 |
| PLEURONECTIFORMES | | | | | |
| Paralichthyidae | | | | | |
| *Paralichthys californicus* | California halibut | 47 | 4 | 45 | 14 |
| Pleuronectidae | | | | | |
| *Hypsopsetta guttulata* | diamond turbot | 13 | 13 | 23 | 19 |
| *Pleuronichthys ritteri* | spotted turbot | 18 | 7 | 16 | 12 |
| Cynoglossidae | | | | | |
| *Symphurus atricauda* | California tonguefish | 18 | 8 | 12 | 10 |

[1]Taxonomic arrangement from Nelson 1994.

## Appendix D.3

Demersal fish abundance and biomass by station

| **ABUNDANCE** | 2230 | 2231 | 2233 | 2239 | 2241 | 2242 | 2243 | 2244 | 2249 | 2254 | 2256 | 2258 | 2262 | 2436 | 2571 | 2573 | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barred sand bass | 3 | 4 | 3 | 6 | 4 | 4 | 2 | | 2 | 2 | 9 | 5 | 1 | 5 | | 1 | 51 |
| Black croaker | | 5 | 2 | 2 | | | | | | | 1 | | | 2 | 1 | | 13 |
| California butterfly ray | | | | | | | | | | | 1 | | | | | | 1 |
| California halibut | | | 3 | 3 | 4 | 3 | 3 | 2 | | 2 | 3 | 3 | 13 | 5 | 3 | | 47 |
| California lizardfish | | | | | | | | | | | | | | 1 | 1 | 2 | 4 |
| California tonguefish | | | | | | | | | | | | | | 7 | 10 | 1 | 18 |
| Diamond stingray | | | | 1 | | | | | | | 1 | | | | | | 2 |
| Diamond turbot | | 1 | | 1 | 1 | 1 | | | 2 | | | | 1 | 3 | 3 | | 13 |
| Pacific seahorse | | | 1 | | | 1 | | | | | | | | | | | 2 |
| Round stingray | | 1 | 7 | 4 | 31 | 12 | 12 | 7 | | 5 | 5 | | | 1 | 1 | | 86 |
| Shovelnose guitarfish | | | | | | | 1 | | | | | | | | | | 1 |
| Slough anchovy | | | | | | | | | | | | | | 13 | 2 | | 15 |
| Specklefin midshipman | | | | | | | | | | | 1 | | | | 8 | | 9 |
| Spotted sand bass | 1 | 5 | 7 | 5 | 7 | 2 | 13 | 4 | 1 | 6 | 3 | 5 | 2 | | 2 | | 63 |
| Spotted turbot | 3 | 4 | 1 | | | 1 | 1 | | | | | | | 6 | | 2 | 18 |
| White croaker | | | | | | | | | | | | 2 | | | | 4 | 6 |
| Overall: | 7 | 20 | 24 | 22 | 47 | 24 | 32 | 13 | 5 | 15 | 24 | 15 | 17 | 43 | 31 | 10 | 349 |

| **BIOMASS** | 2230 | 2231 | 2233 | 2239 | 2241 | 2242 | 2243 | 2244 | 2249 | 2254 | 2256 | 2258 | 2262 | 2436 | 2571 | 2573 | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barred sand bass | 0.2 | 0.3 | 0.1 | 0.3 | 0.4 | 0.4 | 1.0 | | 0.1 | 0.1 | 0.9 | 0.4 | 0.1 | 0.7 | | 0.1 | 5.1 |
| Black croaker | | 1.1 | 0.7 | 0.6 | | | | | | | 0.3 | | | 0.5 | 0.3 | | 3.5 |
| California butterfly ray | | | | | | | | | | | 1.8 | | | | | | 1.8 |
| California halibut | | | 0.2 | 0.4 | 0.3 | 0.1 | 0.1 | 0.1 | | 0.1 | 0.3 | 0.2 | 0.4 | 0.7 | 2.8 | | 5.7 |
| California lizardfish | | | | | | | | | | | | | | 0.1 | 0.1 | 0.1 | 0.3 |
| California tonguefish | | | | | | | | | | | | | | 0.1 | 0.1 | 0.1 | 0.3 |
| Diamond stingray | | | | 9.0 | | | | | | | 3.0 | | | | | | 12.0 |
| Diamond turbot | | 0.3 | | 0.4 | 0.1 | 0.1 | | | 0.1 | | | | 0.1 | 0.8 | 0.5 | | 2.4 |
| Pacific seahorse | | | 0.1 | | | 0.1 | | | | | | | | | | | 0.2 |
| Round stingray | | 0.3 | 1.4 | 1.0 | 10.5 | 2.0 | 2.0 | 1.5 | | 0.8 | 1.2 | | | 0.1 | 0.3 | | 21.1 |
| Shovelnose guitarfish | | | | | | | 0.1 | | | | | | | | | | 0.1 |
| Slough anchovy | | | | | | | | | | | | | | 0.1 | 0.1 | | 0.2 |
| Specklefin midshipman | | | | | | | | | | | 0.1 | | | | 2.0 | | 2.1 |
| Spotted sand bass | 0.2 | 1.6 | 2.9 | 1.9 | 1.5 | 0.6 | 2.0 | 0.9 | 0.1 | 0.5 | 1.5 | 2.4 | 0.3 | | 1.0 | | 17.4 |
| Spotted turbot | 0.2 | 0.3 | 0.1 | | | 0.1 | 0.1 | | | | | | | 0.2 | | 0.1 | 1.1 |
| White croaker | | | | | | | | | | | | 0.1 | | | | 0.6 | 0.7 |
| Overall: | 0.6 | 3.9 | 5.5 | 13.6 | 12.8 | 3.4 | 5.3 | 2.5 | 0.3 | 1.5 | 9.1 | 3.1 | 0.9 | 3.3 | 7.2 | 1.0 | 74.0 |

# Appendix D.4

Taxonomic listing of invertebrates and total abundance for each species collected in San Diego Bay during 1998.

| Taxon[1] | Species | N | Taxon[1] | Species | N |
|---|---|---|---|---|---|
| PORIFERA | | 5 | ARTHROPODA | | |
| | *Leucilla nuttingi* | 1 | Crustacea | | |
| | Porifera sp SD 1 | 1 | Malacostraca | | |
| | Porifera sp SD 2 | 2 | Isopoda | | |
| | Porifera sp SD 4 | 8 | | *Synidotea harfordi* | 1 |
| | Porifera sp SD 5 | 5 | Decapoda | | |
| | Porifera sp SD 6 | 1 | | *Crangon nigromaculata* | 1 |
| | Porifera sp SD 7 | 1 | | *Lophopanopeus frontalis* | 5 |
| | Porifera sp SD 8 | 1 | | *Lophopanopeus bellus* | 1 |
| | Porifera sp SD 10 | 1 | | *Loxorhynchus sp* | 1 |
| CNIDARIA | | | | *Panulirus interruptus* | 1 |
| Anthozoa | | | | *Penaeus californiensis* | 10 |
| | *Acanthoptilum sp* | 1 | | *Pugettia producta* | 1 |
| | Actinaria sp SD 1 | 15 | | *Pyromaia tuberculata* | 5 |
| MOLLUSCA | | | | *Synalpheus lockingtoni* | 3 |
| Gastropoda | | | ECHINODERMATA | | |
| | *Bulla gouldiana* | 68 | Asteroidea | | |
| | *Crepidula onyx* | 77 | | *Asterina miniata* | 1 |
| | *Crucibulum spinosum* | 62 | CHORDATA | | |
| | *Diaulula sandiegensis* | 3 | Ascidiacea | | 4 |
| | *Doriopsilla albopunctata* | 1 | | *Ciona sp* | 3 |
| | *Haminoea vesicula* | 1 | | *Microcosmus squamiger* | 190 |
| | *Nassarius tiarula* | 69 | | *Styela montereyensis* | 3 |
| | *Navanax inermis* | 1 | | *Styela plicata* | 19 |
| | *Pteropurpura festiva* | 10 | | | |
| Bivalvia | | | | | |
| | *Argopecten ventricosus* | 7 | | | |
| | *Leptopecten latiauratus* | 1 | | | |
| | *Limaria hemphilli* | 2 | | | |
| | *Musculista senhousia* | 498 | | | |
| | *Ostrea sp* | 79 | | | |
| Cephalopoda | | | | | |
| | *Loligo opalescens* | 2 | | | |

[1]Taxonomic arrangement from SCAMIT listing 2001.

# Appendix D.5

Megabenthic invertebrate abundance by station.

| | 2233 | 2239 | 2262 | 2436 | 2258 | 2231 | 2573 | 2571 | 2249 | 2241 | 2244 | 2254 | 2243 | 2242 | 2230 | 2256 | survey: |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Acanthoptilum* sp | | | | 1 | | | | | | | | | | | | | 1 |
| Actiniaria sp SD 1 | | | | | | | | | | | | | 15 | | | | 15 |
| *Argopecten ventricosus* | 1 | 1 | 1 | | | | | | | 1 | | | | | 1 | 2 | 7 |
| ASCIDIACEA | | | | | | | | | | 1 | 1 | 1 | 1 | | | | 4 |
| *Asterina miniata* | | | | 1 | | | | | | | | | | | | | 1 |
| *Bulla gouldiana* | | | | | | | | | 1 | 57 | | | 1 | 9 | | | 68 |
| *Ciona* sp | 2 | | | | | 1 | | | | | | | | | | | 3 |
| *Crangon nigromaculata* | | | | | | | 1 | | | | | | | | | | 1 |
| *Crepidula onyx* | 4 | | | | 68 | 1 | | | | | | 3 | | | | 1 | 77 |
| *Crucibulum spinosum* | | | | 2 | 60 | | | | | | | | | | | | 62 |
| *Diaulula sandiegensis* | 1 | | | | | 2 | | | | | | | | | | | 3 |
| *Doriopsilla albopunctata* | | | | | | 1 | | | | | | | | | | | 1 |
| *Haminoea vesicula* | | | | | | | | | | | | 1 | | | | | 1 |
| *Leptopecten latiauratus* | | | | 1 | | | | | | | | | | | | | 1 |
| *Leucilla nuttingi* | | | | | | | | | | | | 1 | | | | | 1 |
| *Limaria hemphilli* | | | | | | 2 | | | | | | | | | | | 2 |
| *Loligo opalescens* | | | | | | | | | | | | 2 | | | | | 2 |
| *Lophopanopeus bellus* | | | | | | | | | | | | 1 | | | | | 1 |
| *Lophopanopeus frontalis* | | 3 | | 2 | | | | | | | | | | | | | 5 |
| *Loxorhynchus* sp | 1 | | | | | | | | | | | | | | | | 1 |
| *Microcosmus squamiger* | 3 | | 1 | | 160 | 1 | | | 1 | | | | | | | 24 | 190 |
| *Musculista senhousia* | 1 | 52 | 30 | | 36 | | | | | 107 | | 9 | 8 | 10 | 9 | 236 | 498 |
| *Nassarius tiarula* | | | 36 | 31 | 1 | | | | | | | | | | 1 | | 69 |
| *Navanax inermis* | | | | | | | | | | | | 1 | | | | | 1 |
| *Ostrea* sp | 1 | | | | 52 | | | | | | | 1 | | | | 25 | 79 |
| *Panulirus interruptus* | | | | | | | | 1 | | | | | | | | | 1 |
| *Penaeus californiensis* | | | | | | | | 9 | | | | | | | | 1 | 10 |
| Porifera sp SD 1* | | | | | | | | | | | 1 | | | | | | 1 |
| Porifera sp SD 2* | | | | | | | | | | | | | 1 | 1 | | | 2 |
| Porifera sp SD 4* | 1 | 1 | | 1 | 1 | 2 | | | | 1 | | | 1 | | | | 8 |
| Porifera sp SD 5* | | 1 | 1 | 1 | | 1 | | | | | | | | | | 1 | 5 |
| Porifera sp SD 6* | | | | | 1 | | | | | | | | | | | | 1 |
| Porifera sp SD 7* | | | 1 | | | | | | | | | | | | | | 1 |
| Porifera sp SD 8* | | | | | | 1 | | | | | | | | | | | 1 |
| Porifera sp SD 10* | | | | | | | | | 1 | | | | | | | | 1 |
| Porifera* | | | | | | | | | | | 1 | 4 | | | | | 5 |
| *Pteropurpura festiva* | 1 | | | 2 | | 5 | | | | | 2 | | | | | | 10 |
| *Pugettia producta* | | | | | | | 1 | | | | | | | | | | 1 |
| *Pyromaia tuberculata* | 1 | | | 4 | | | | | | | | | | | | | 5 |
| *Styela montereyensis* | | | | | | 1 | | | | | | | | | | 2 | 3 |
| *Styela plicata* | 2 | | | | 8 | | | | 4 | | | | 5 | | | | 19 |
| *Synalpheus lockingtoni* | 1 | | | | | | | | | | | | | | | 2 | 3 |
| *Synidotea harfordi* | | | | | | | 1 | | | | | | | | | | 1 |
| by survey: | 20 | 58 | 70 | 46 | 387 | 18 | 3 | 10 | 7 | 167 | 5 | 24 | 32 | 20 | 11 | 294 | 1172 |

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# Appendix E

# Supporting Data

# 1998 San Diego Bay Stations

# Bioaccumulation of Contaminants in Fish Tissues

## Appendix E.1

Lengths and weights of individual fish collected for fish tissue analysis from San Diego Bay during 1998.

| | | | SL (cm) | | | Weight (g) | | |
|---|---|---|---|---|---|---|---|---|
| STATION | Species | n | min | max | avg | min | max | avg |
| **Muscle samples** | | | | | | | | |
| 2223 | Spotted sand bass | 3 | 23 | 26 | 25 | 291 | 378 | 335 |
| 2225 | Spotted sand bass | 3 | 21 | 25 | 23 | 194 | 395 | 282 |
| 2229 | Barred sand bass | 3 | 14 | 15 | 14 | 74 | 84 | 77 |
| 2235 | Spotted sand bass | 3 | 19 | 23 | 21 | 161 | 272 | 218 |
| 2236 | Spotted sand bass | 3 | 17 | 28 | 23 | 117 | 455 | 288 |
| 2238 | Spotted sand bass | 3 | 21 | 24 | 22 | 206 | 303 | 245 |
| 2240 | Spotted sand bass | 3 | 17 | 30 | 23 | 126 | 615 | 339 |
| 2245 | Yellowfin croaker | 3 | 20 | 25 | 23 | 148 | 279 | 218 |
| 2247 | Spotted sand bass | 3 | 19 | 25 | 22 | 161 | 361 | 246 |
| 2259 | Barred sand bass | 3 | 14 | 22 | 19 | 76 | 215 | 166 |
| 2261 | Spotted sand bass | 3 | 15 | 27 | 19 | 69 | 408 | 182 |
| 2434 | Calico bass | 3 | 18 | 19 | 18 | 123 | 171 | 150 |
| 2438 | Spotted sand bass | 3 | 16 | 17 | 17 | 88 | 109 | 100 |
| 2439 | Spotted sand bass | 3 | 18 | 25 | 21 | 159 | 391 | 252 |
| LA1 | California halibut | 3 | 21 | 24 | 22 | 150 | 225 | 185 |
| LA2 | Spotted sand bass | 3 | 18 | 23 | 21 | 172 | 310 | 257 |
| LA3 | Spotted sand bass | 3 | 11 | 19 | 14 | 35 | 138 | 75 |
| **Whole fish** | | | | | | | | |
| 2233 | California halibut | 6 | 10 | 21 | 14 | 13 | 143 | 51 |
| 2242 | California halibut | 6 | 10 | 20 | 12 | 13 | 117 | 36 |
| 2244 | California halibut | 6 | 9 | 11 | 10 | 13 | 21 | 17 |
| 2254 | California halibut | 6 | 10 | 14 | 12 | 16 | 50 | 32 |
| 2256 | California halibut | 6 | 10 | 18 | 13 | 14 | 87 | 37 |
| 2262 | California halibut | 6 | 10 | 13 | 12 | 13 | 33 | 23 |
| 2436 | California halibut | 4 | 15 | 20 | 18 | 48 | 130 | 97 |

## Appendix E.2

Analyzed constituents with MDLs for whole fish samples collected from San Diego Bay during 1998; na = not available.

| | | | | | |
|---|---|---|---|---|---|
| **Chlorinated Pesticides (ppb)** | | | | | |
| Alpha (cis) Chlordane | 2.3 | o,p-DDD | 4.7 | p,p-DDD | 4.4 |
| Gamma (trans) Chlordane | na | o,p-DDE | 2.1 | p,p-DDE | 4.2 |
| | | o,p-DDT | 2.5 | p,p-DDT | 11.3 |
| **PCB Congeners (ppb)** | | | | | |
| PCB 18 | 5.0 | PCB 101 | 7.1 | PCB 157 | 6.1 |
| PCB 28 | 8.8 | PCB 105 | 6.5 | PCB 158 | 6.0 |
| PCB 37 | 7.2 | PCB 110 | 6.6 | PCB 167 | 6.1 |
| PCB 44 | 9.6 | PCB 114 | 6.1 | PCB 169 | 6.1 |
| PCB 49 | 8.9 | PCB 118 | 6.5 | PCB 170 | 5.9 |
| PCB 52 | 6.8 | PCB 119 | 6.8 | PCB 177 | 6.0 |
| PCB 65 | 8.4 | PCB 123 | 6.7 | PCB 180 | 5.6 |
| PCB 66 | 6.2 | PCB 126 | 6.6 | PCB 183 | 5.7 |
| PCB 70 | 6.4 | PCB 128 | 6.3 | PCB 187 | 5.8 |
| PCB 74 | 6.7 | PCB 138 | 6.6 | PCB 189 | 5.6 |
| PCB 77 | 7.1 | PCB 149 | 6.5 | PCB 194 | 5.2 |
| PCB 81 | 6.5 | PCB 151 | 6.3 | PCB 201 | 5.5 |
| PCB 87 | 6.5 | PCB 153/168 | na | PCB 206 | 4.9 |
| PCB 99 | 6.7 | PCB 156 | 6.1 | | |

# Appendix E.3

Analyzed constituents with MDLs for fish muscle tissue samples collected from San Diego Bay during 1998; na = not available.

**Metals (ppm)**

| | | | | | |
|---|---|---|---|---|---|
| Aluminum | 2.60 | Copper | 0.76 | Silver | 0.62 |
| Antimony | 3.70 | Iron | 1.30 | Thallium | 5.70 |
| Arsenic | 1.40 | Lead | 2.50 | Tin | 4.60 |
| Beryllium | 0.04 | Manganese | 0.23 | Zinc | 0.58 |
| Cadmium | 0.34 | Mercury | 0.01 | Nickel | 0.79 |
| Chromium | 0.33 | Selenium | 0.13 | | |

**Chlorinated Pesticides (ppb)**

| | | | | | |
|---|---|---|---|---|---|
| Aldrin | 0.84 | Endrin | 0.80 | o,p-DDD | 0.86 |
| Alpha (cis) Chlordane | 0.79 | Endrin aldehyde | 0.72 | o,p-DDE | 1.02 |
| Alpha Chlordene | 0.88 | Gamma (trans) Chlordane | 0.96 | o,p-DDT | 1.19 |
| Alpha Endosulfan | 1.56 | Heptachlor | 2.31 | p,p-DDD | 2.37 |
| Beta Endosulfan | 2.42 | Heptachlor epoxide | 0.90 | p,p-DDE | 1.23 |
| BHC, Alpha isomer | 3.15 | Hexachlorobenzene | 1.91 | p,p-DDT | 1.65 |
| BHC, Beta isomer | 4.54 | Methoxychlor | 4.66 | | |
| BHC, Delta isomer | 1.74 | Mirex | 0.96 | | |
| BHC, Gamma isomer | 0.86 | Oxychlordane | 1.19 | | |
| Cis Nonachlor | 0.92 | Toxaphene | na | | |
| Dieldrin | 0.86 | Trans Nonachlor | 2.81 | | |
| Endosulfan Sulfate | 1.98 | | | | |

**PCB Congeners (ppb)**

| | | | | | |
|---|---|---|---|---|---|
| PCB 18 | 6.6 | PCB 101 | 6.7 | PCB 157 | 5.6 |
| PCB 28 | 7.4 | PCB 105 | 5.8 | PCB 158 | 5.9 |
| PCB 37 | 6.3 | PCB 110 | 6.3 | PCB 167 | 6.2 |
| PCB 44 | 6.1 | PCB 114 | 5.9 | PCB 169 | 5.7 |
| PCB 49 | 6.4 | PCB 118 | 6.3 | PCB 170 | 5.4 |
| PCB 52 | 6.2 | PCB 119 | 6.8 | PCB 177 | 5.8 |
| PCB 65 | 6.4 | PCB 123 | 6.5 | PCB 180 | 5.7 |
| PCB 66 | 6.3 | PCB 126 | 5.7 | PCB 183 | 6.0 |
| PCB 70 | 6.8 | PCB 128 | 5.6 | PCB 187 | 6.0 |
| PCB 74 | 7.1 | PCB 138 | 6.1 | PCB 189 | 5.6 |
| PCB 77 | 6.0 | PCB 149 | 6.3 | PCB 194 | 5.2 |
| PCB 81 | 6.3 | PCB 151 | 6.5 | PCB 200 | 5.9 |
| PCB 87 | 6.0 | PCB 153/168 | 6.3 | PCB 201 | na |
| PCB 99 | 6.7 | PCB 156 | 5.7 | PCB 206 | 5.5 |