San Diego Bay
9-51

THE CITY OF SAN DIEGO

December 11, 2003

Mr. Peter Michael
Marine Waters - Staff Environmental Scientist
Regional Water Quality Control Board
San Diego Region
9174 Sky Park Court, Suite 100
San Diego, CA 92123

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Dear Sir:

Enclosed is the ***DRAFT*** 1998 San Diego Bay Report prepared in accordance with the memorandum of understanding between the RWQCB and the City of San Diego. This report contains data summaries and statistical analyses of the data collected from San Diego Bay as part of the Southern California Bight 1998 Regional Monitoring Project (Bight'98). Six sections are included for your review: Executive Summary, Introduction, Sediment Quality, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, and Bioaccumulation of Contaminants in Fish Tissues.

Please review and comment on the enclosed draft. In order to facilitate release of this report by January, 2004, we would appreciate receipt of your written comments by December 24, 2003 in person or via U.S. mail. Should you have any questions about the analyses or interpretations of data, the direction and content of this report, or if you need additional time to complete your review, please feel free to contact me at (619) 758-2334, or Ami Groce, the project lead for this report, at (619) 758-2324.

Sincerely,

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DP:dp
Enclosure: ***DRAFT*** 1998 San Diego Bay Report

cc: Alan Langworthy, Deputy Director, EMTS
Timothy D. Stebbins, Senior Marine Biologist

2003 DEC 11 P 1:54
REGIONAL WATER QUALITY CONTROL BOARD

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1998 San Diego Bay Report

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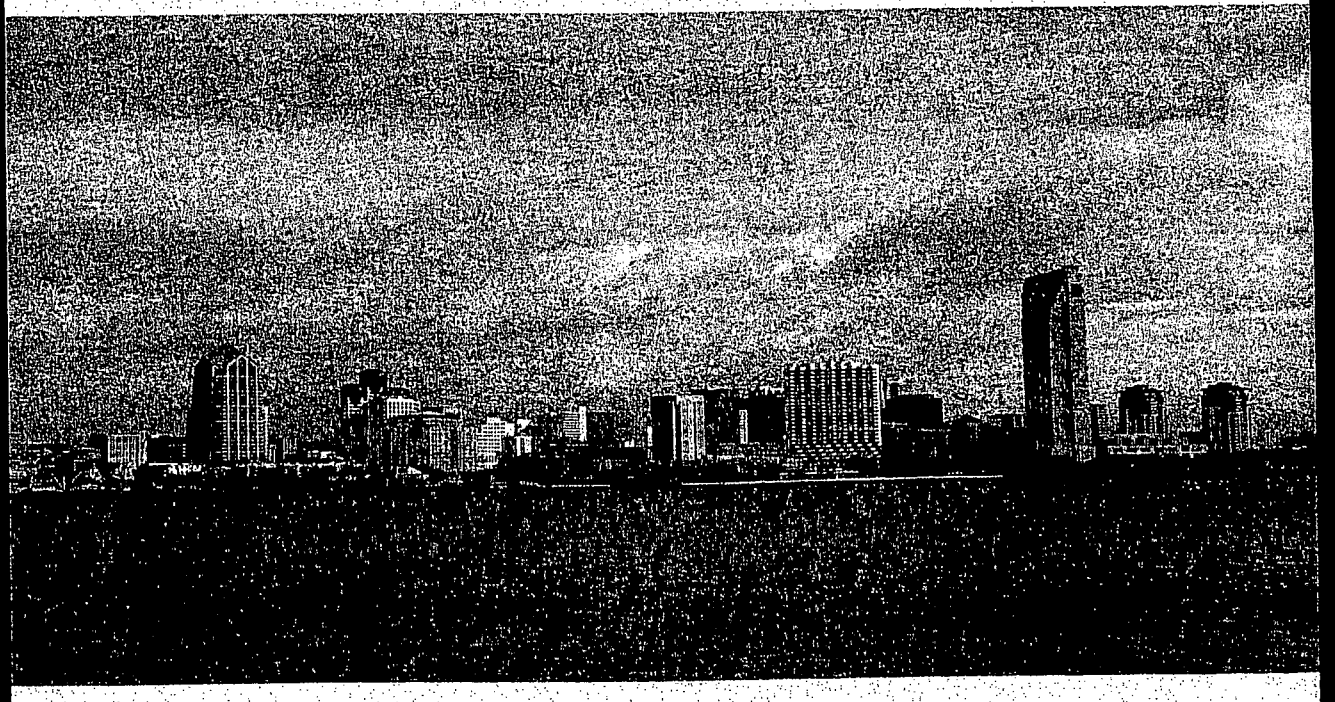

City of San Diego
Ocean Monitoring Program
Metropolitan Wastewater Department
Environmental Monitoring and Technical Services Division

1998 San Diego Bay Report

Prepared By:

City of San Diego
Ocean Monitoring Program
Metropolitan Wastewater Department
Environmental Monitoring and Technical Services Division

December 2003

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Cover: Downtown San Diego from the Bay, photo by Daniel Ituarte.

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Executive Summary

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 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 benthic 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. Overall, San Diego Bay had lower contaminant loads compared to the other nine bays and harbors sampled during Bight'98, although certain contaminants occurred in relatively high concentrations in Bay sediments. San Diego Bay ranked among the top three of these embayments 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 or sub-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. A total of 349 fish were collected from these trawls, representing 16 species. Each haul was small in terms of the total abundance and diversity of fish. Dominant species that occurred frequently in relatively large 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.

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 to San Diego 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 a 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 results of the 1998 survey of San Diego Bay provides valuable data against which future changes in fish and invertebrate communities may be measured. However, an appreciation for the implications of non-indigenous species such as the bivalve *Musculista senhousia* will be vital to 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

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. San Diego Bay also harbors several important natural resources, including salt marches, tidal flats, bird nesting and foraging sites, and essential fish habitats such as eelgrass beds. These natural resources are primarily 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). 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 to gain a better understanding of the environmental conditions of the Bay (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 organizations 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 state of San Diego Bay, identify long term trends within the Bay (e.g., trends in sediment contaminant levels), and to address public concern 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, tri-butyl-tin, 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., macroalage, 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 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 parameters and stations sampled 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 herein is unique in that it includes the first random survey of fish and invertebrate populations in the Bay, as well as 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 due to the incorporation of data for these areas that were collected at the same time using the same sample design (i.e., Bight'98 data).

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Sediment Quality

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 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 load as well as the percentages of silt and clay provides useful information on sediment conditions, which in turn, 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 goals 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, this chapter presents a comparison of sediment conditions in San Diego Bay to those of other bays and harbors sampled during Bight'98.

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).

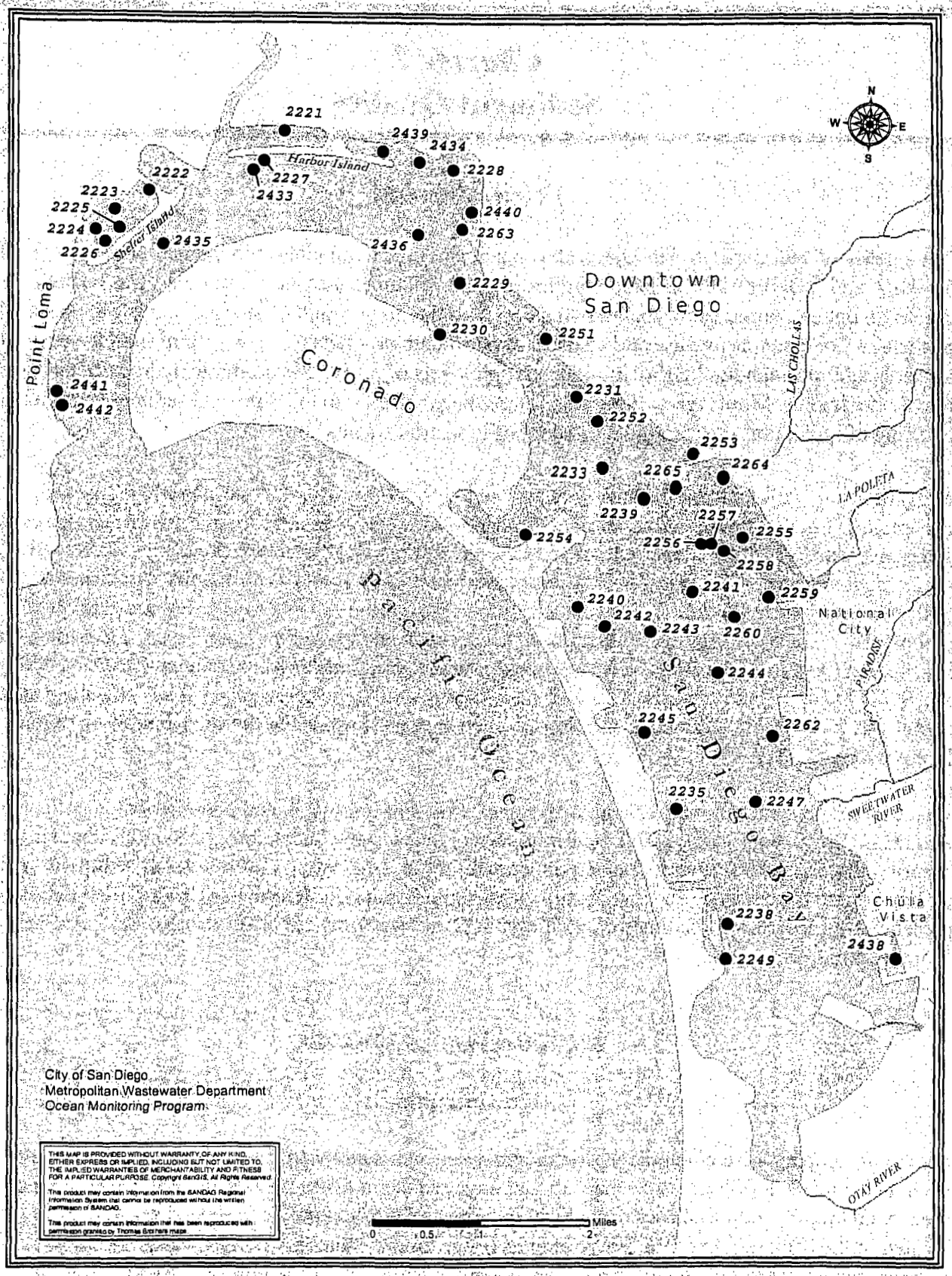

Figure 2.1

Benthic sediment stations sampled in San Diego Bay during 1998.

Laboratory Analyses

Analyses of sediment grain 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 Probably Effects Level (PEL) of MacDonald (1994).

Comparison of San Diego Bay to Other Embayments

Sediment samples were collected from 114 stations distributed among nine 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 was 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 each sediment chemistry parameter

that was detected. In order to address the inherent differences in analytical techniques and instrumentation among the 11 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 10th 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 most 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, where the coarsest sediments were found.

Indicators of Organic Loading

The 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). Both 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 ($r = 0.85$, $p<0.05$), 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 10th 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 within 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 fine sediments were dominant. 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 ($r = 0.7$, $p<0.01$). 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

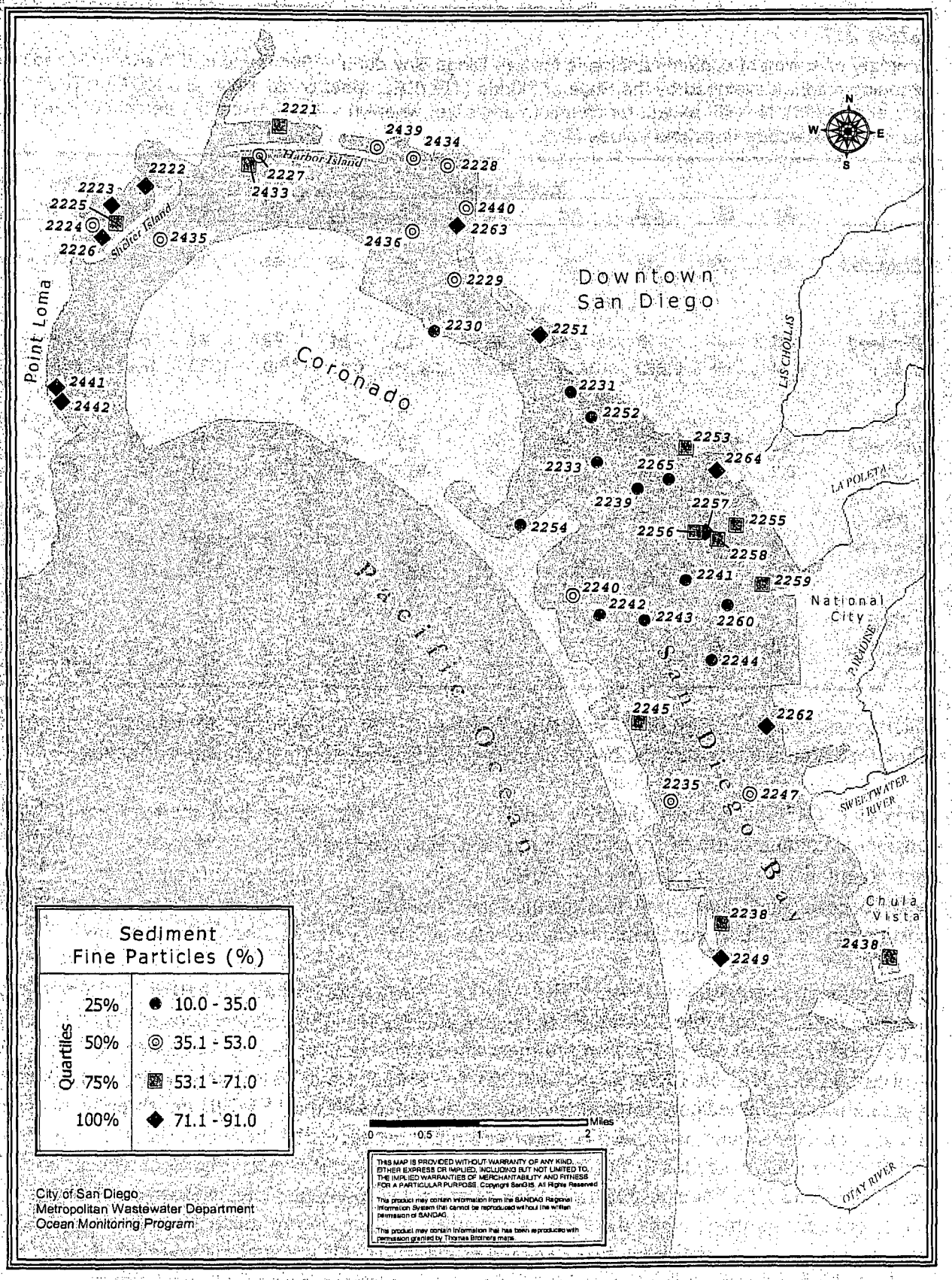

Figure 2.2

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

which to assess metal enrichment (Schiff and Weisberg 1998). In this survey, 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.

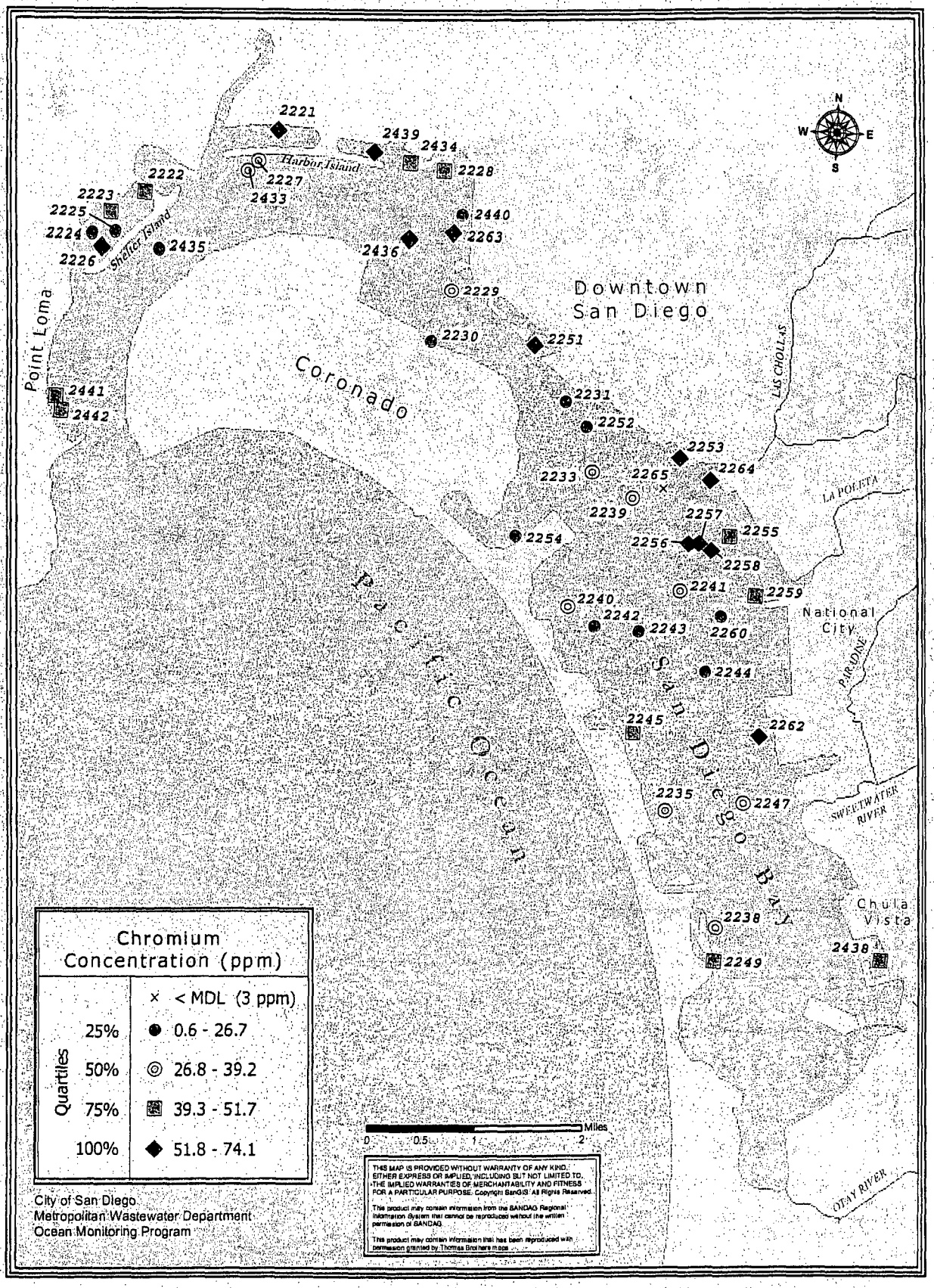

Figure 2.3

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

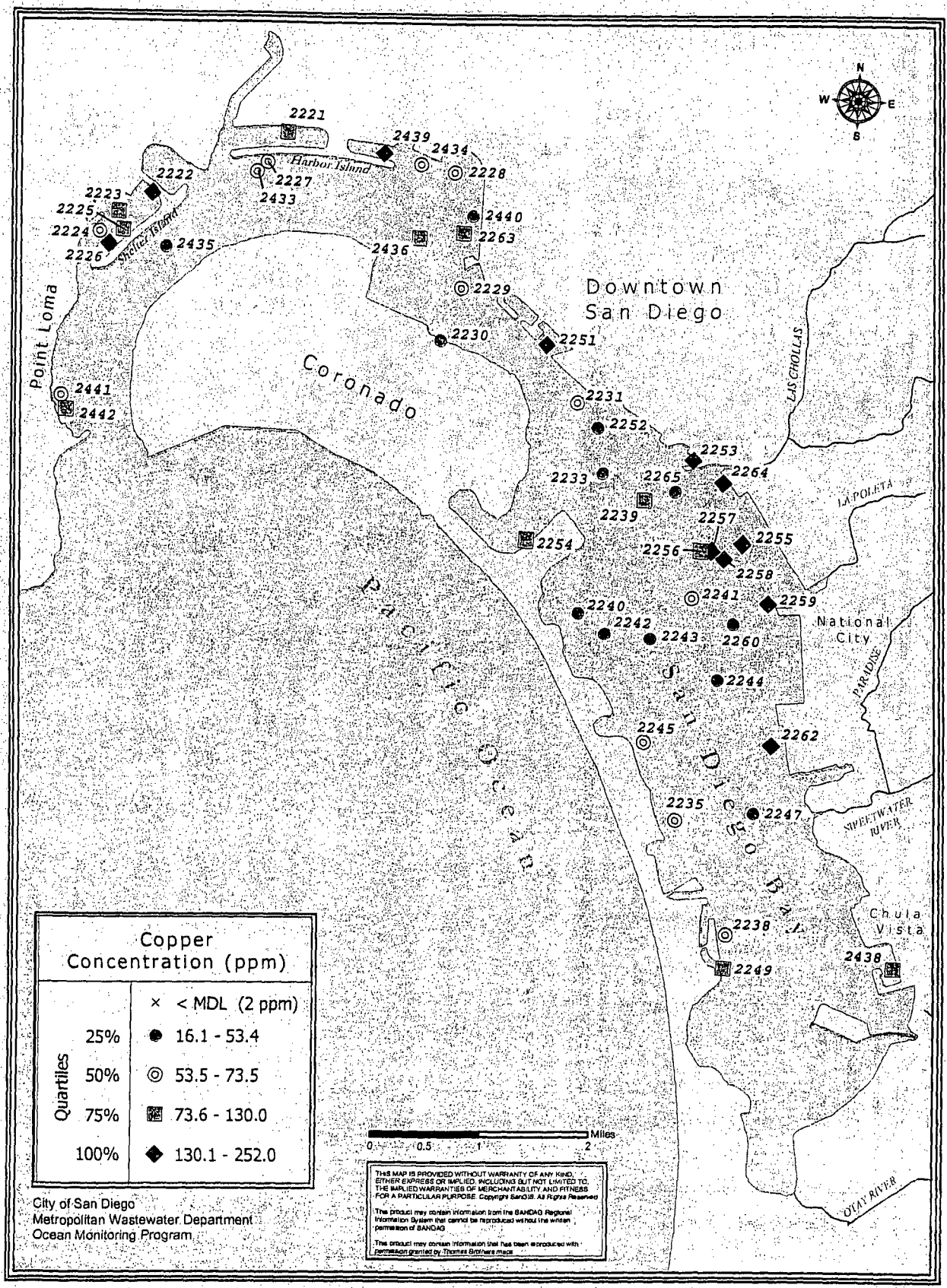

Figure 2.4

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

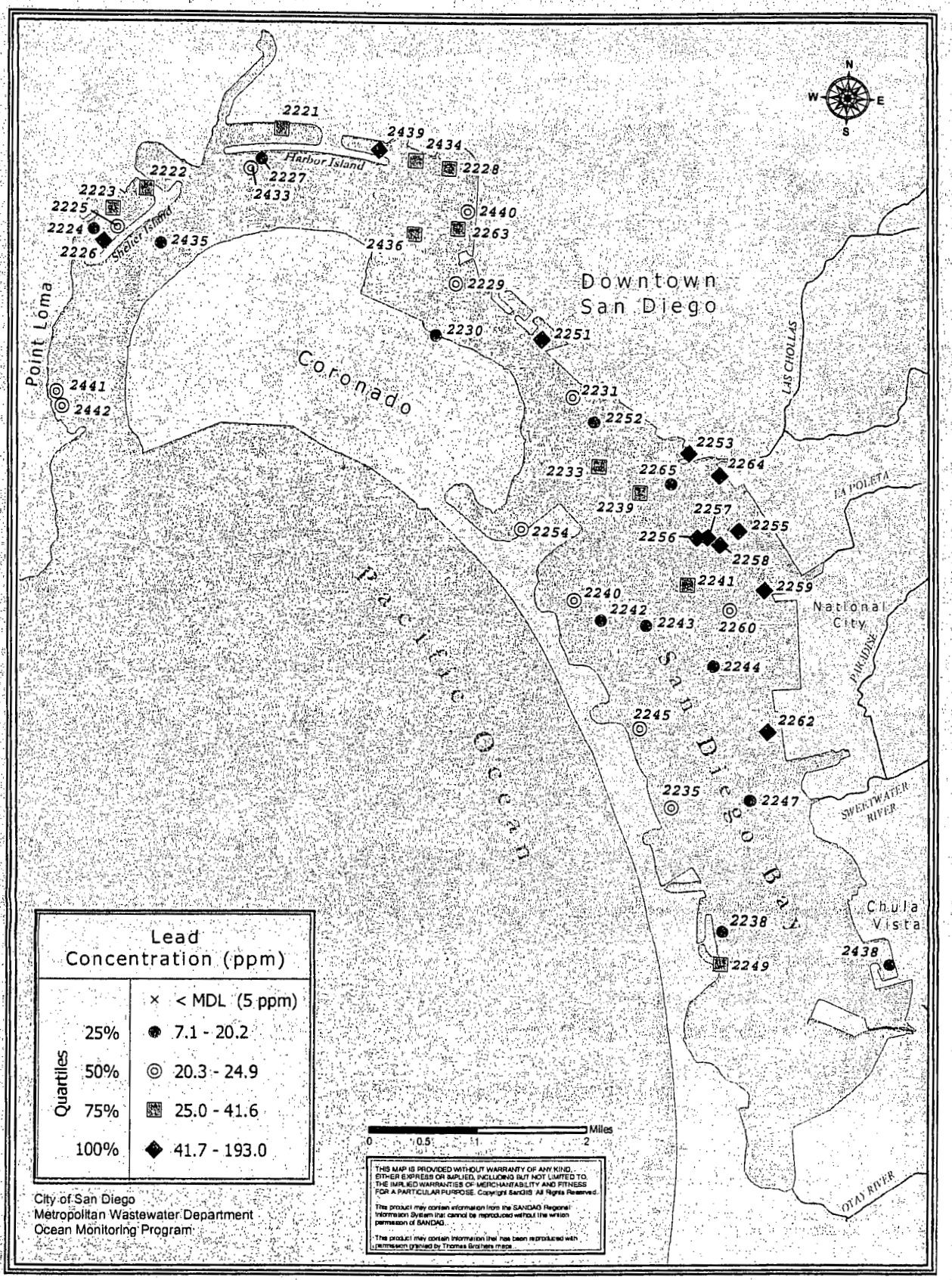

Figure 2.5
Quartile distributions of lead concentrations (ppm) for San Diego Bay during 1998.

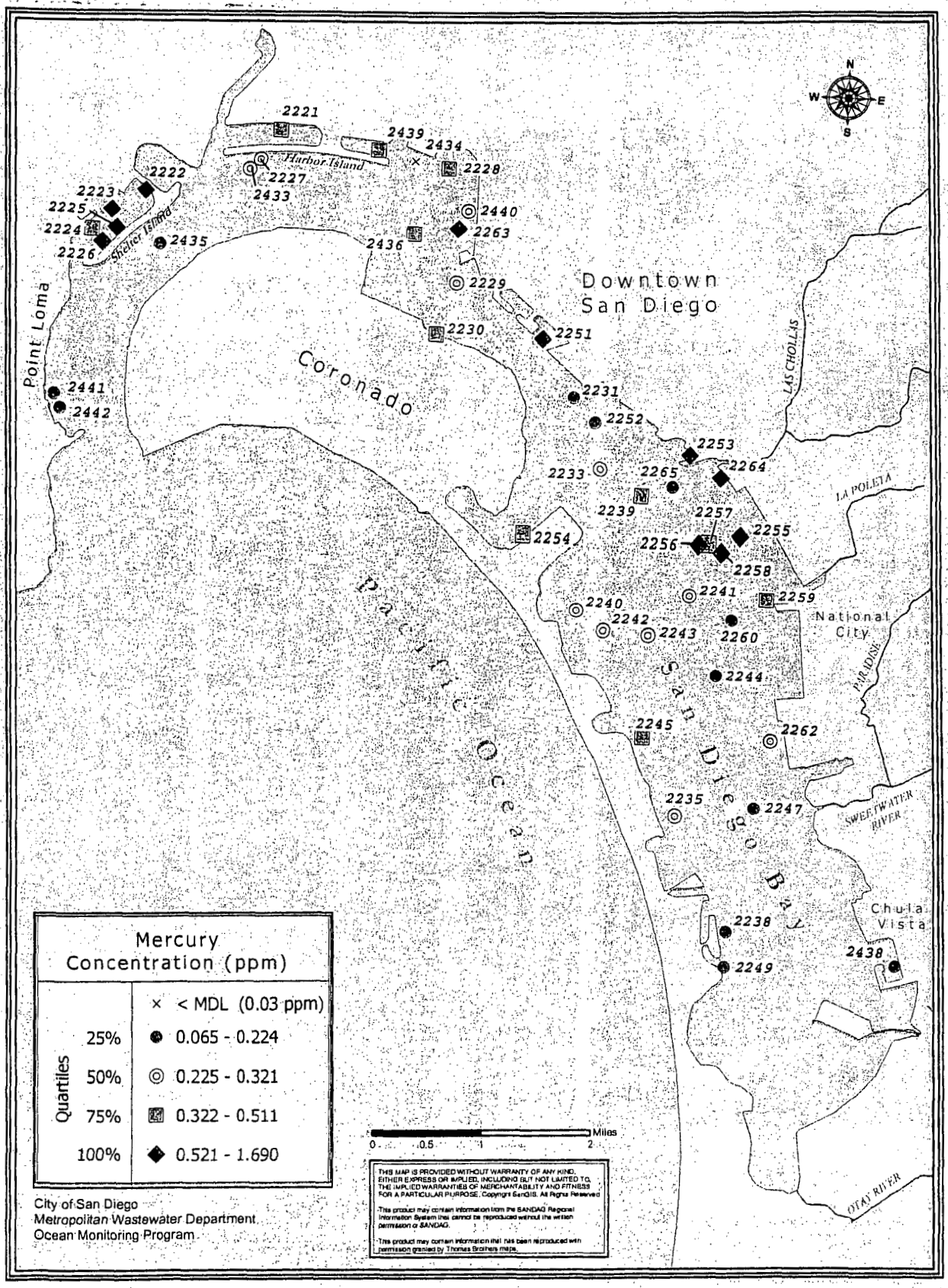

Figure 2.6
Quartile distributions of mercury concentrations (ppm) for San Diego Bay during 1998.

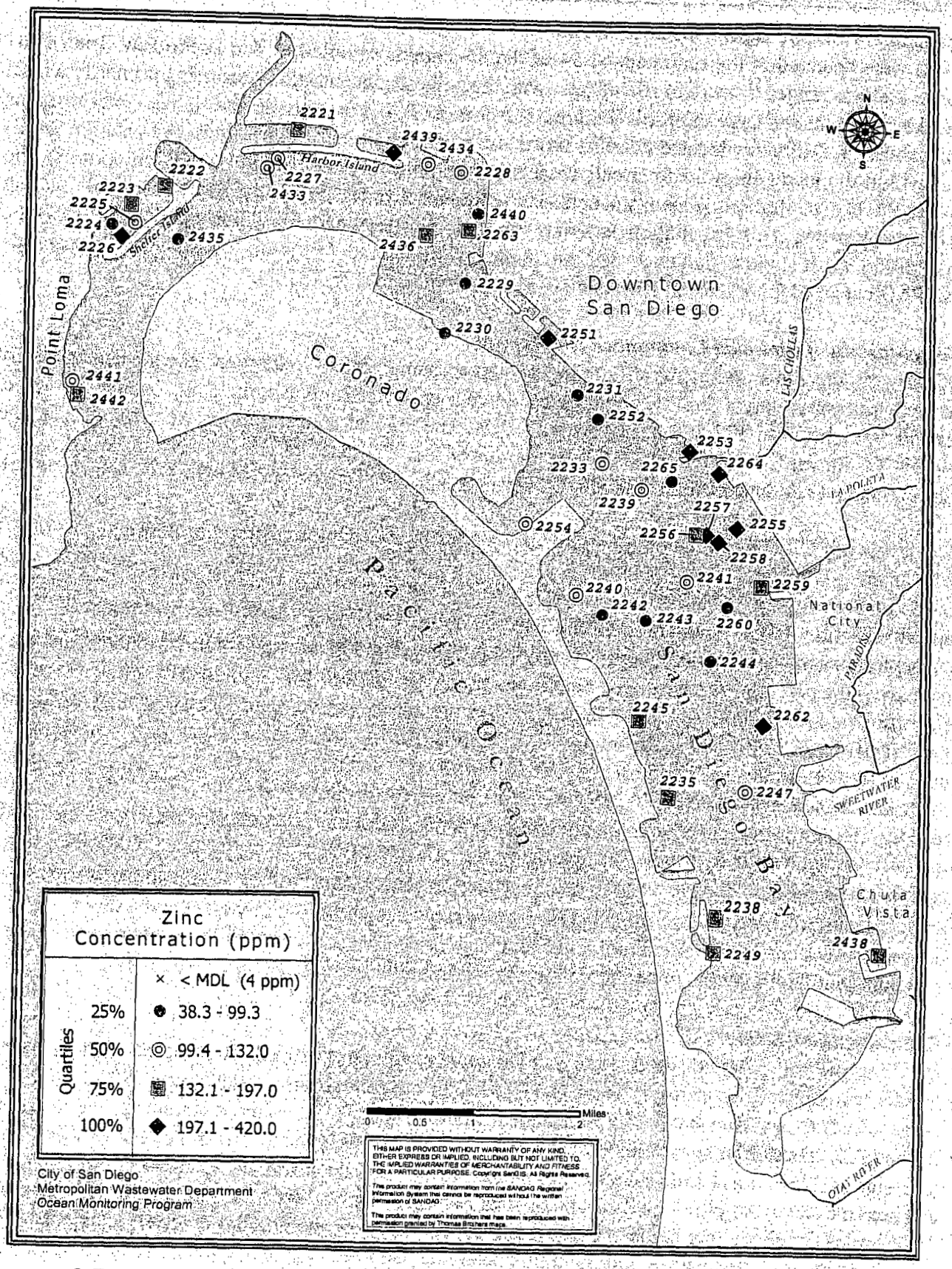

Figure 2.7
Quartile distributions of zinc concentrations (ppm) for San Diego Bay during 1998.

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 (t-DDT) 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 t-DDT 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 screening criteria: TEL (○) < ERL (△) < PEL (•) < ERM (▲). * = Areas previously identified as having elevated contaminant loads or toxicity levels by the State Water Resources Control Board (CRWQCB-SDR 1997). 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	○	▲		○	•	○	△	○		△			small boat marina (HIWB)
2222	○	▲			•	○	▲	○		△			small boat marina (SIYB)*
2223	△	▲			•	○	▲			△			small boat marina (SIYB)*
2224		▲			△		△						small boat marina (SIYB)*
2225		▲			•	△	○						small boat marina (SIYB)*
2226		▲			•	△	▲	○		△			small boat marina (SIYB)*
2227		▲			△		△						anchorage off Harbor Island
2228					△	○	△		○	○			anchorage near Embarcadero tuna fleet*
2235					△		△			○			north of Crown Cove - sandy shore
2238					△		△			○			near Coronado Cays Yacht Club
2239					△	○	△						dredged channel
2241		▲			△	○	△			○			dredged channel
2242					△		△						△ near Naval Amphibious Base
2244		▲			△		△						dredged channel
2245		▲			△		△			○			near small boat marina (Navy Yacht club)
2249	○	▲			△		△	○		△			small boat marina (Coronado Cays)
2251	△			○	•	△	△	○	△	△	△		shipyard near 10th Ave. Marine Terminal*
2253	△			○	•	△	▲	○		•		△	NASSCO Shipyard*
2254		▲			△		△				△		small boat marina (Naval vessels)
2255		▲			•	△	△		△	△	○	△	Naval Station SD*
2256	○			○	•	△	△		△	△			dredged channel, near Naval Station SD
2257	△			○	•	△	△	○	△	△			dredged channel, near Naval Station SD
2258	○			○	•	△	△	○	○	△			dredged channel, near Naval Station SD
2259					•	○	△		○	△	○		Naval Station SD / 7th St. Channel*
2260		▲			△		△						dredged channel
2262	△			○	•	○	△	○		△			near 24th St. Marine Terminal*
2263	○			○	•	○	△	○	○	△	○		downtown (Broadway & Navy Piers)*
2264	△			○	•	•	△	△		▲	○	○	Naval Station SD, near Las Chollas Crk*
2433	△	▲			△		△			○			anchorage off Harbor Island
2434		▲			△	○				○			near Coast Guard facility
2436	△	▲		○	△	○	△	○		△			dredged channel
2439				○	•	○	△			△			small boat marina (HIEB)
2440		▲			△		△						downtown (B St. Pier)*
2441	△	▲			△		△	○					Ballast Point Naval Submarine Base*
2442	△				△		△	○		○	△		Ballast Point Naval Submarine Base*

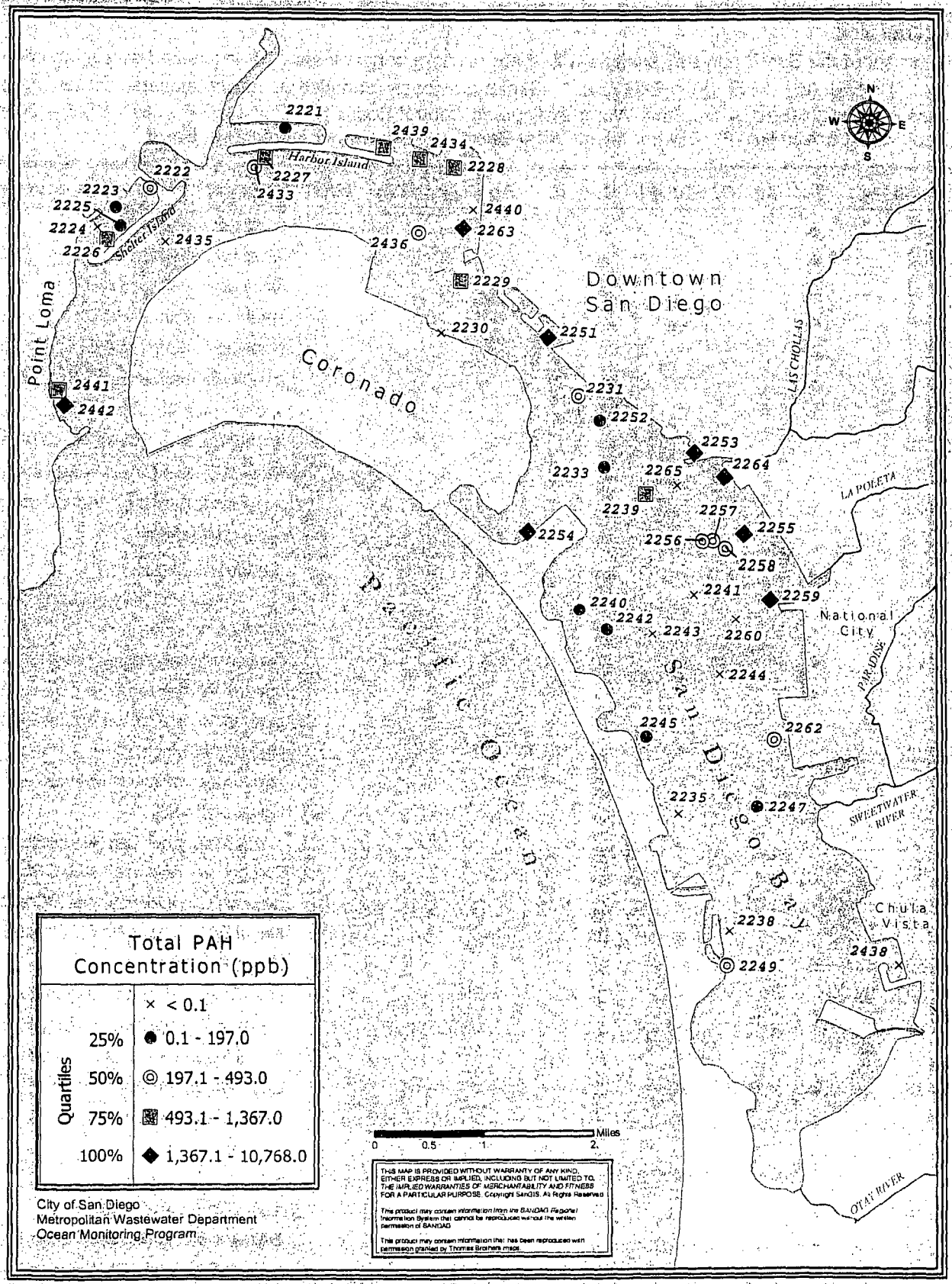

Figure 2.8

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

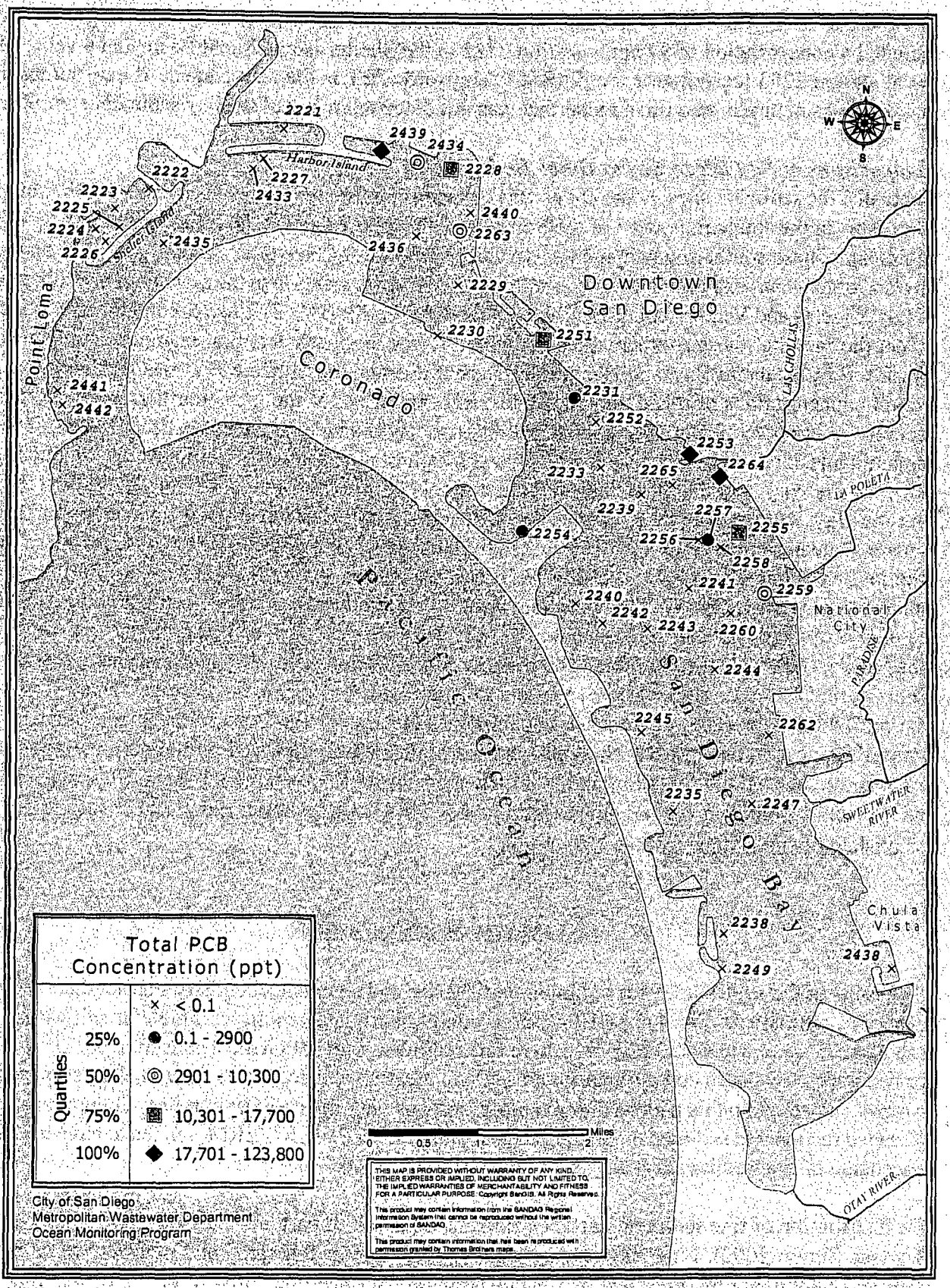

Figure 2.9
Quartile distributions of detected tPCB concentrations (ppt) for San Diego Bay during 1998.

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 above 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 that allow suspended particles to settle (Knox 2001; USDoN, SWDIV and SDUPD 2000; USGS 1994; Valkirs et al. 1991). In contrast, coarse sediments were most prevalent in the central portion of the bay where the

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

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).

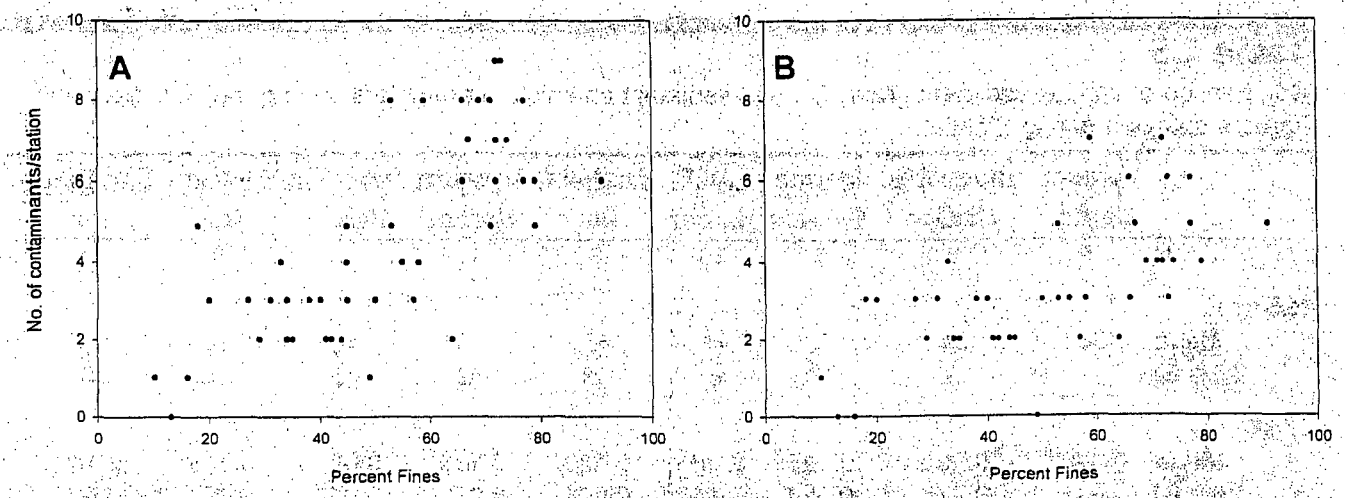

Figure 2.10
The number of instances per station that (**A**) TEL and (**B**) ERL sediment screening criteria were exceeded plotted against the percentage of fine sediments per station.

Metal contamination in San Diego Bay continues to be widespread. Every station had measurable quantities of at least 15 metals, 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. Seventy four percent of the stations had measurable quantities of PAHs, but 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 has 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 during the 1998 Bight survey even though Fairey et al. (1996) found PCBs to be widespread. The low detection rates presented herein may reflect, in part, the differences in instrumentations and the use of 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., 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, in 1998 DDT was detected at only seven stations, 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 U.S. 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 the legislation was to limit the use of TBT to Navy ships and larger commercial vessels. Finally, mean concentrations of t-DDT 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, MESO 1998, CRWQCB-SDR 1997, 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

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

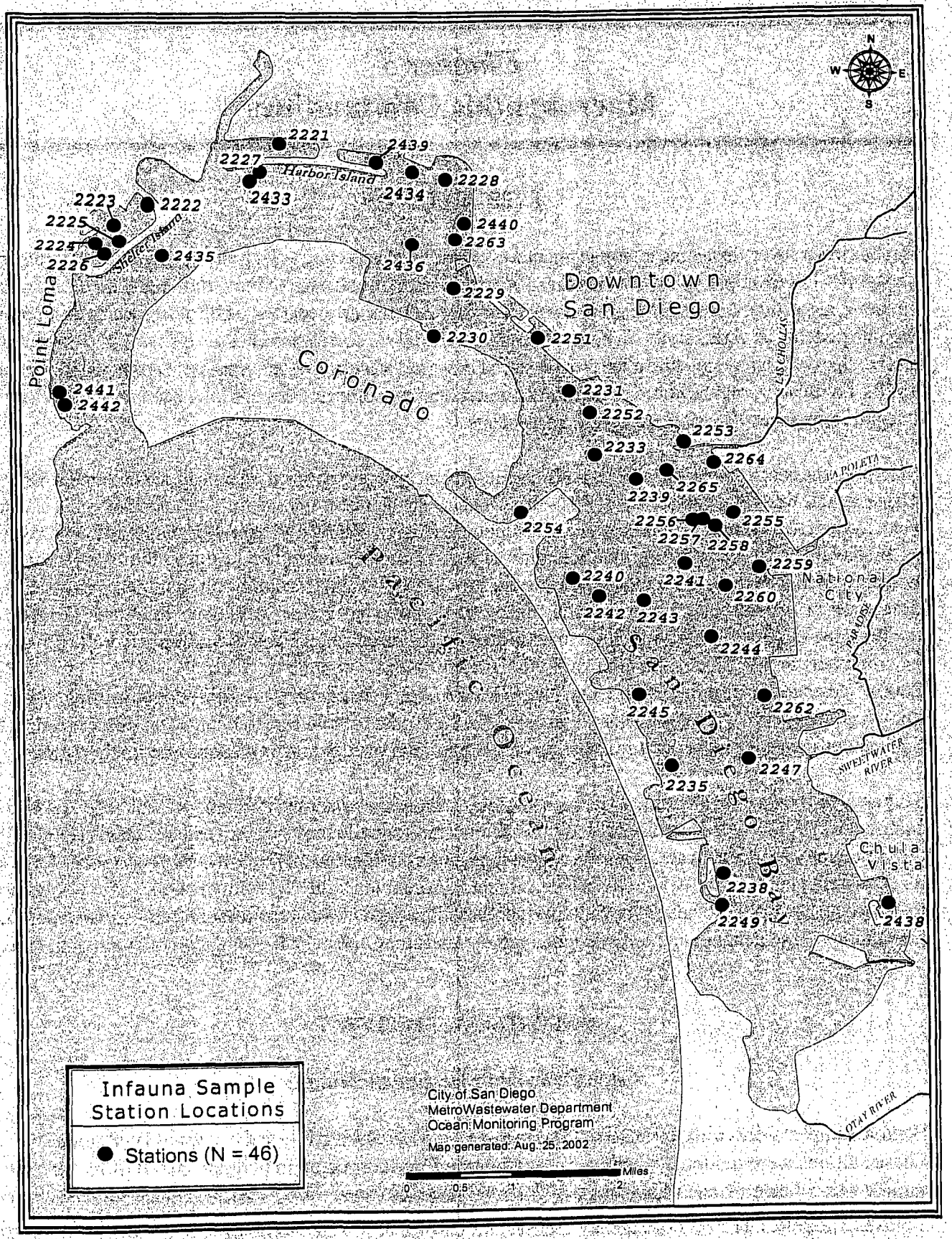

Figure 3.1
Station locations in San Diego Bay for benthic survey conducted during 1998.

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 that was 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 (74-2145)	164 (11-1187)	103 (2-839)	17 (1-91)	830 (102-3149)
SR	23 (14-48)	9 (3-26)	9 (2-21)	6 (1-14)	47 (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 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 20 to 5,210 per 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 11,000 per m^2. This ecologically important mussel was also found at more than 95% of the stations. Two other nonindigenous species were also widespread and abundant; 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 near the mouth of

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. Nonindigenous species are shown in blue.

Species (Taxa)	Higher Taxa	MS	MO	PO
Ten Most Abundant				
1. *Mediomastus* sp	Polychaeta: Capitellidae	108.2	108.2	100%
2. *Musculista senhousia*	Mollusca: Bivalvia	85.5	89.3	96%
3. *Euchone limnicola*	Polychaeta: Sabellidae	84.7	99.9	85%
4. *Pseudopolydora paucibranchiata*	Polychaeta: Spionidae	72.0	89.5	80%
5. Lumbrineridae †	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%
3. *Euchone limnicola*	Polychaeta: Sabellidae	84.7	99.9	85%
4. *Pseudopolydora paucibranchiata*	Polychaeta: Spionidae	72.0	89.5	80%
5. *Musculista senhousia*	Mollusca: Bivalvia	85.5	89.3	96%
6. Lumbrineridae †	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*	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*	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%

† = unidentified juveniles and/or damaged specimens

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.

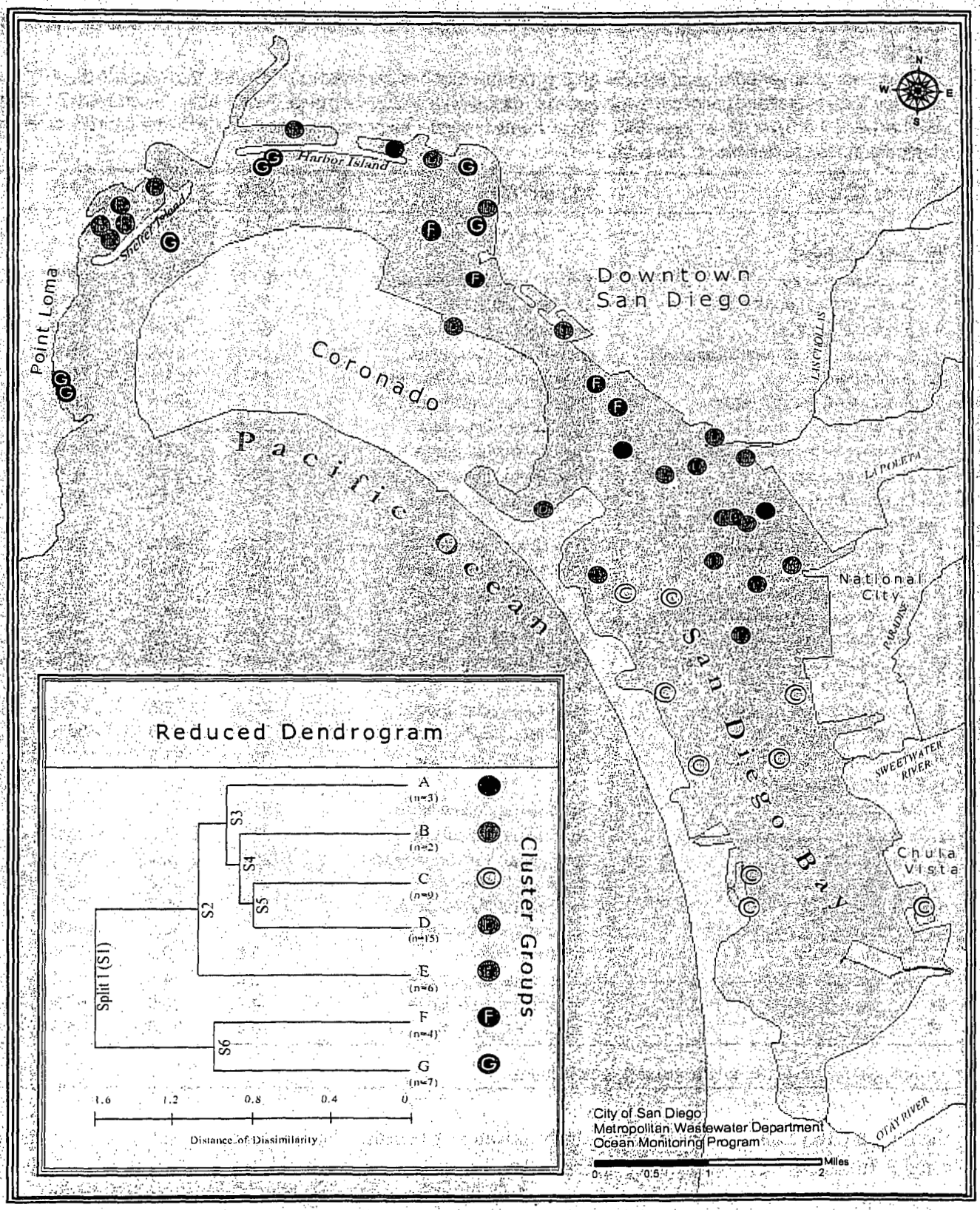

Figure 3.2

Reduced dendrogram represents the results of ordination and classification analyses 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 100cm tidal amplitude. Average tidal amplitude was 85 cm with a maximum spring tide of 270 cm (Sutton and Helly 2002). Graphics provided by John Helly of the San Diego Supercomputer Center.

Table 3.3

Summary of environmental parameters and contaminants of concern for San Diego Bay 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 shown in red.

Cluster Group	Depth	Fines	Cu	Hg	Zn	Pb	tDDT	tPAH	tPCB
A	7.5 (3.0-10.6)	50 (38-60)	110 (52-146)	0.49 (0.32-0.70)	172 (106-206)	42 (27-53)	2060 (nd-2060)	834 (17-1934)	33150 (nd-49800)
B	10.5 (10.1-10.9)	71 (69-73)	196 (145-247)	0.51 (0.40-0.62)	300 (180-420)	119 (44-193)	7300 (nd-7300)	2675 (2347-3003)	17050 (9900-24200)
C	4.3 (3.0-10.3)	54 (33-75)	78 (39-200)	0.23 (0.10-0.33)	143 (81-232)	24 (17-46)	1337 (nd-2100)	194 (nd-457)	nd
D	6.8 (3.3-11.2)	43 (12-78)	92 (18-252)	0.40 (nd-0.79)	143 (38-314)	36 (11-83)	3200 (nd-3200)	2183 (nd-10768)	30640 (nd-123800)
E	4.2 (3.6-4.8)	68 (41-91)	139 (58-220)	0.89 (0.40-1.69)	160 (83-216)	32 (13-47)	780 (nd-780)	283 (nd-735)	nd
F	11.6 (10.9-13.1)	37 (17-56)	61 (31-95)	0.28 (0.11-0.46)	103 (64-157)	24 (14-37)	nd	548 (nd-1285)	1500 (nd-1500)
G	11.0 (5.2-13.3)	64 (46-80)	70 (28-118)	0.30 (0.12-0.69)	125 (64-180)	24 (7-42)	nd	1929 (nd-5925)	13250 (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 & 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./ 0.1m²). The three most abundant taxa per cluster group are shown in bold type; nonindigenous species are shown in blue.

Species (Taxon)	Higher Taxa Code *	Cluster Groups A	B	C	D	E	F	G
Lumbrineris sp †	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	A	4.3	.	4.4	91.5	**300.8**	4.3	9.1
Oligochaeta †	A	14.3	1.0	4.3	1.4	7.0	0.3	3.9
Musculista senhousia	M	37.3	10.5	**114.1**	**155.7**	61.2	6.3	6.1
***Mediomastus* sp** †	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 †	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	M	1.0	12.0	8.1	20.5	16.2	29.5	**79.1**
Diplocirrus sp SD1	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 † = unidentified juveniles and/or damaged specimens

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. Nonindigenous species are shown in blue. 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							
Species (Taxa)	SD (n=46)	MB (n=3)	DP (n=3)	N (n=11)	A (n=3)	LALB (n=36)	MDR (n=7)	CI (n=4)
Mediomastus sp	1	p	p	6	1	p	3	7
Musculista senhousia	2	10		4	p	p	p	
Euchone limnicola	3	p	5	1	5	p	2	5
Pseudopolydora paucibranchiata	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							
Species (Taxa)	SD (n=46)	MB (n=3)	DP (n=3)	N (n=11)	A (n=3)	LALB (n=36)	MDR (n=7)	CI (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	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	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%

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, and 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 assemblage characterized by high numbers of the nonindigenous bivalve *Musculista senhousia*. This assemblage 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 diversity, with each averaging fewer than 80 individuals and less than 12 taxa per grab.

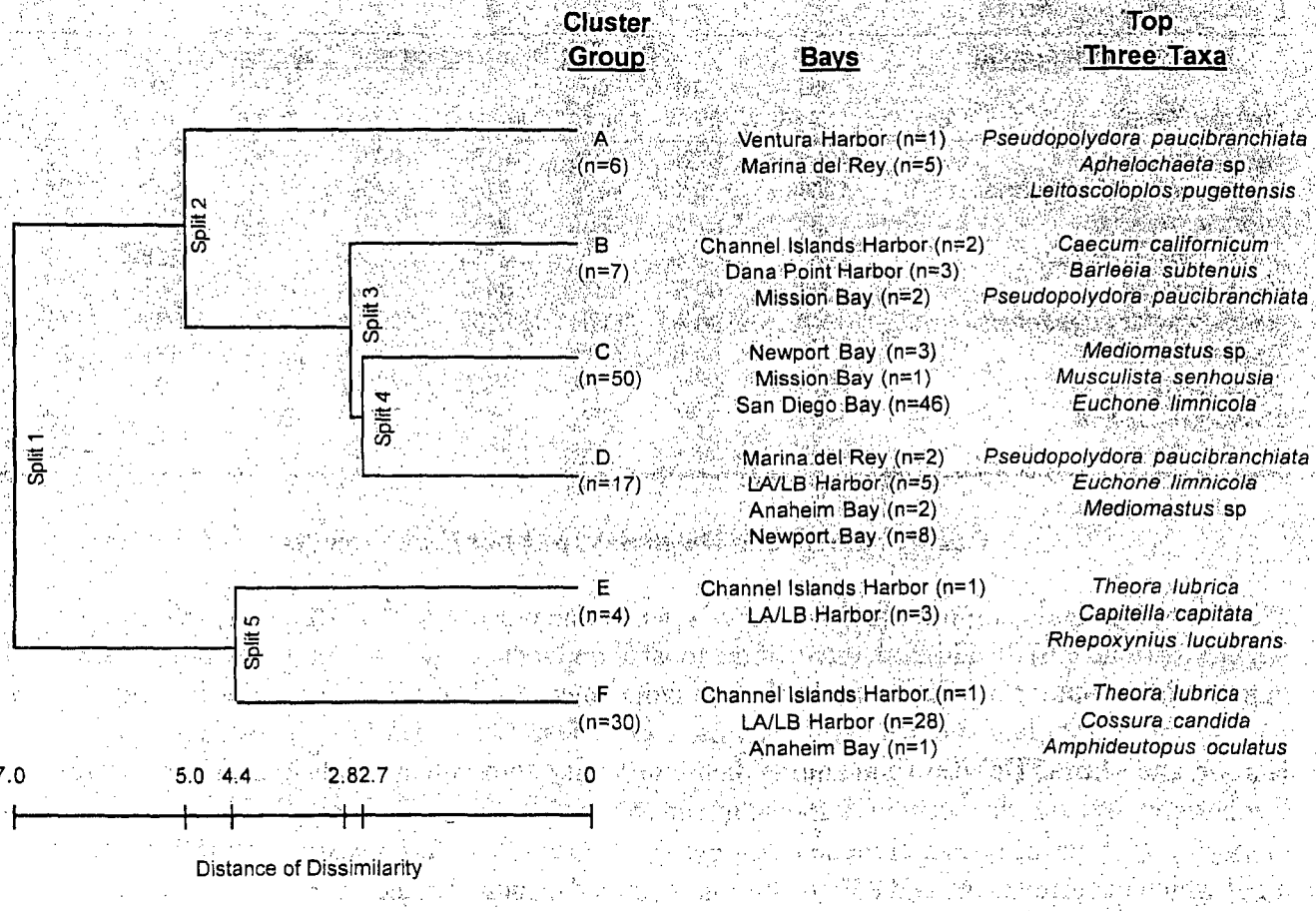

Figure 3.4

Cluster results of macrofaunal abundance data for Bight98 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 0.1 m^2 for each assemblage (n=# of stations). Nonindigenous species are shown in blue.

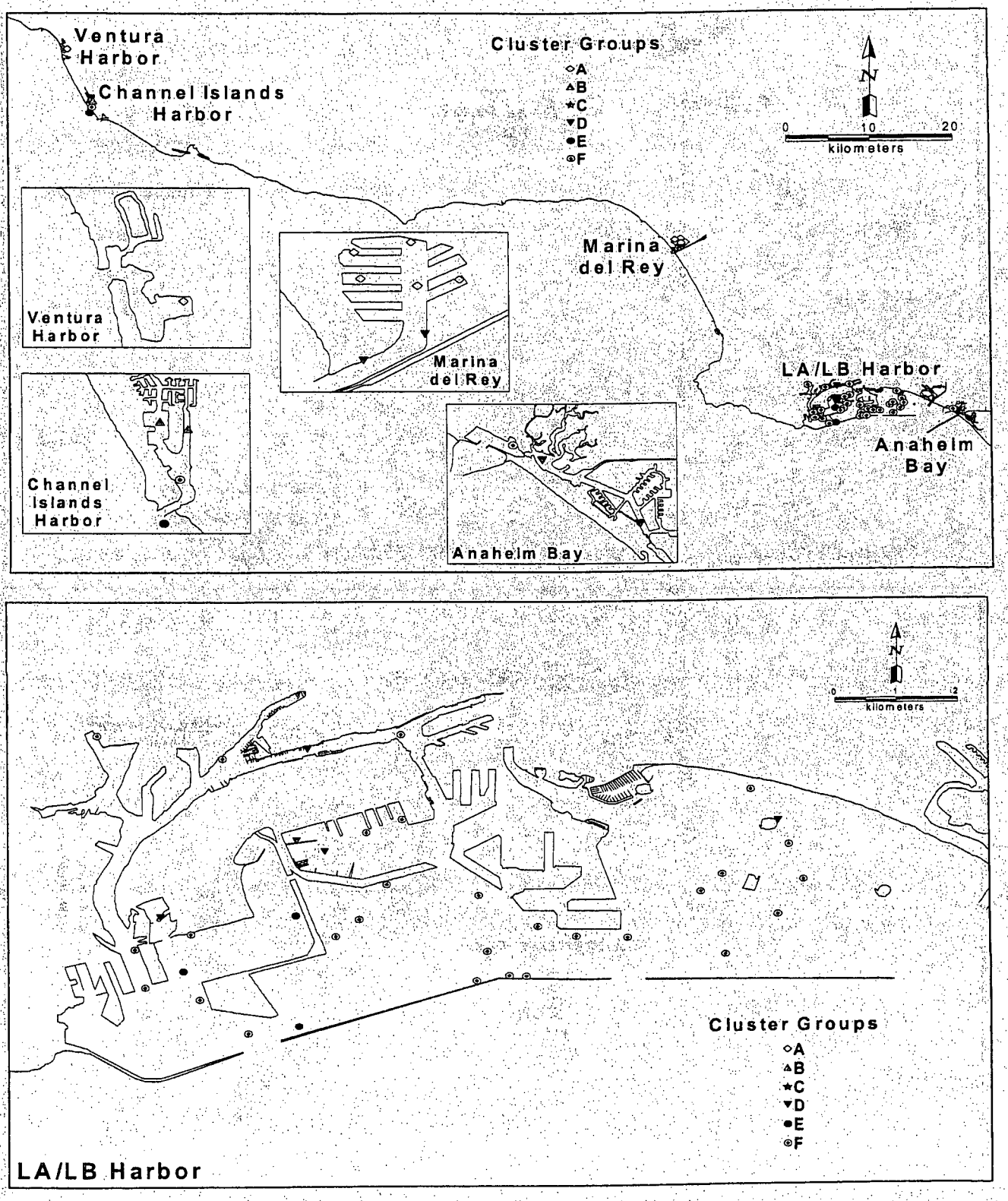

Figure 3.5

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

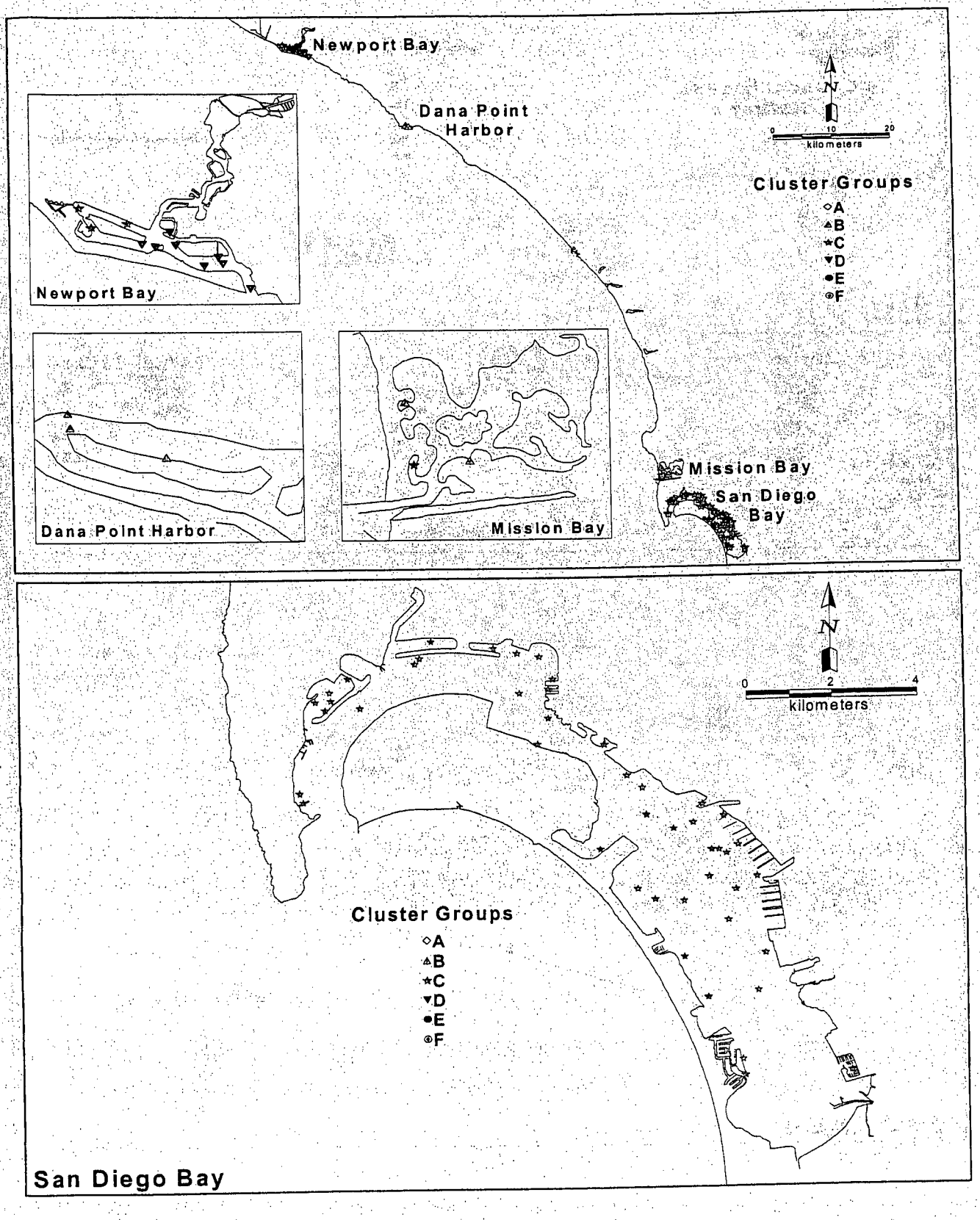

Figure 3.5 (continued)

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 Bight'98 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, USDN et al. 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

Chapter 4
Demersal Fishes and Megabenthic Invertebrates

INTRODUCTION

Bays and estuaries serve as home to large populations of megabenthic invertebrates (i.e., large epibenthic, trawl-caught invertebrate organisms) and as important nursery and refuge areas for many fish species (Cross and Allen 1993). Very few of these habitats remain in southern California however, because many have been degraded or altered through development. 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 fish species. The fishes of San Diego Bay have been studied extensively to provide a better understanding of this important habitat (see review in USDoN, SWDIV and SDUPD 2000). Of the 86 species reported from the Bay, some of the most common demersal fishes in San Diego Bay include California halibut, spotted and barred sand bass and round sting rays. In contrast to the fish assemblages, invertebrate assemblages have been studied much less extensively. The majority of the megebenthic invertebrate epifauna include various species of sponge, gastropods, bivalves and decapods (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 demersal fish and megabenthic 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 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. Sponges were recorded 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

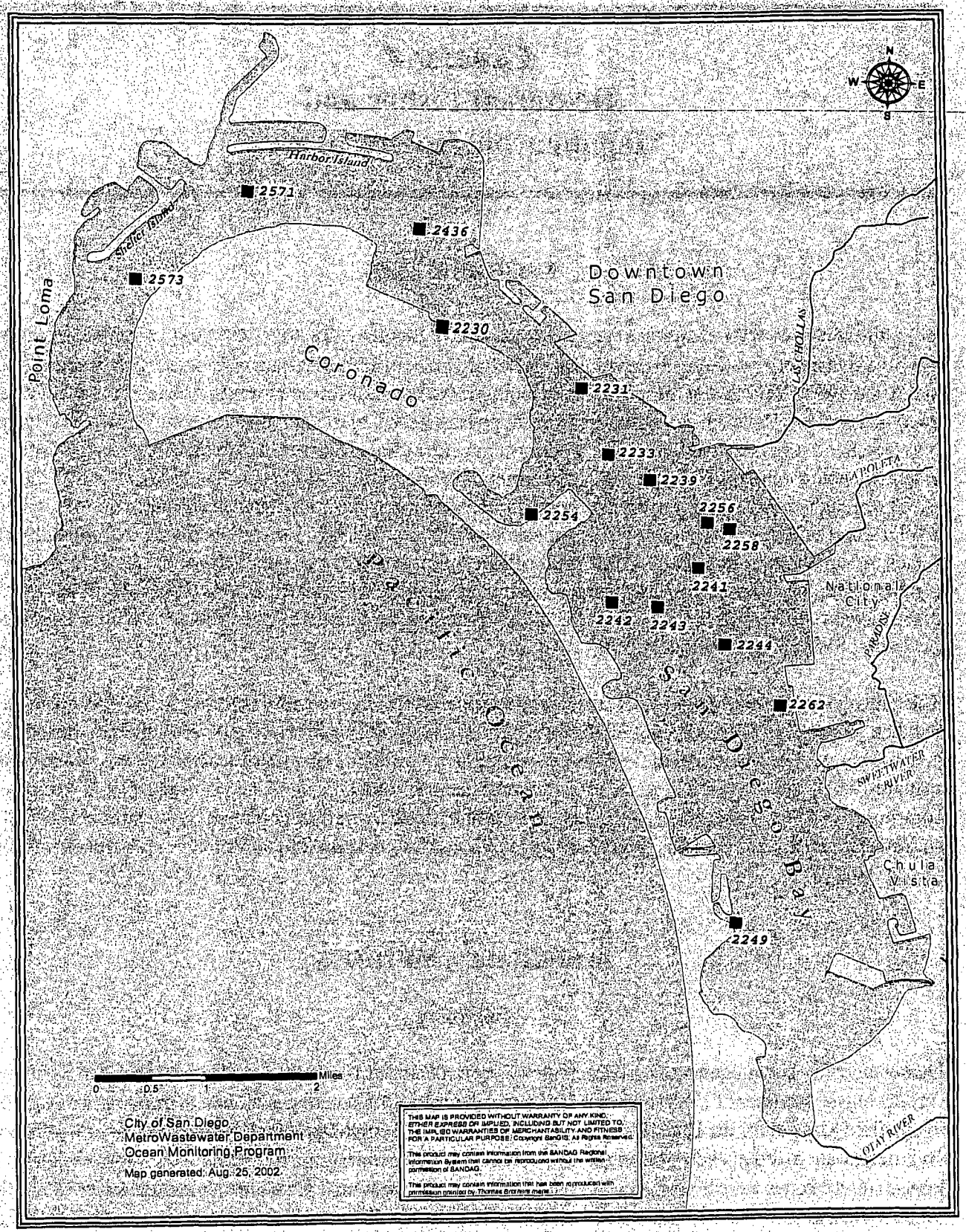

Figure 4.1
Otter trawl station locations sampled in San Diego Bay during 1998.

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 invertebrate biomass was measured as a composite weight of all species combined. The type and amount of 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 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 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

The trawls 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, Appendix D.2 and Appendix 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 mean 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 and only one instance of parasitic infestation on a barred sand bass collected from Glorietta Bay (station 2254).

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 as mean values per station.

STATION	RICH	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**

The four most widely occurring species included 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 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 (≤3 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 to 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 all the 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 off 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 their life history. Almost all of the barred sand bass and California halibut had lengths which correspond to juveniles, indicating that they use the bay primarily as a nursery (Figure 4.3). 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 (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 juvenile and adult life stages. Round stingrays ranged from 15 to 36 cm, 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. They 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 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.

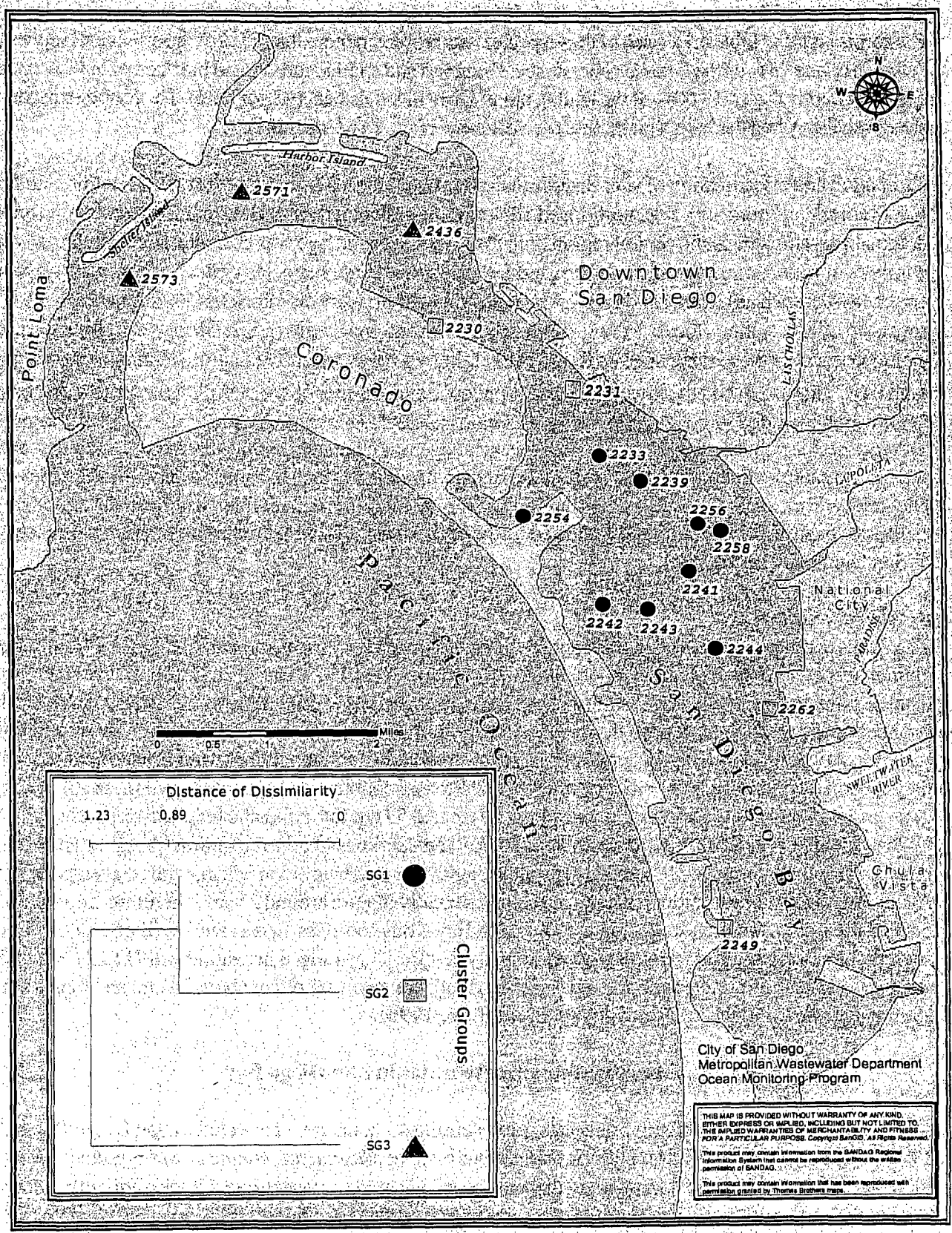

Figure 4.2
Classification analyses of demersal fish collected in San Diego Bay during 1998.

Table 4.3

Distribution of the abundant and frequently occurring fish species among the main station cluster groups for San Diego Bay. '—'= not present.

	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

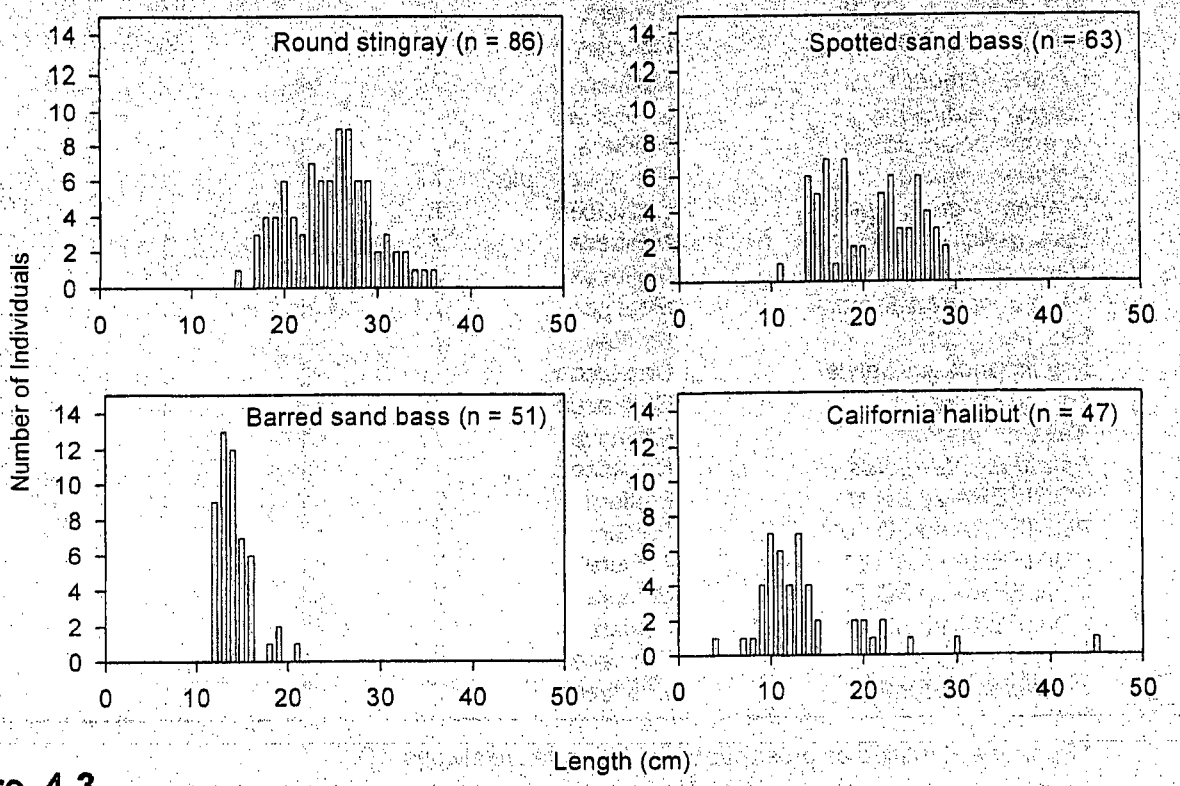

Figure 4.3

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 as mean values per station. P-BM = average sponge biomass per station (subset of total).

STATION	RICH	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**

The contribution of marine sponges to the total catch was significant, but abundance estimates were not possible because they 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 biomass (e.g., 97% at station 2258) was indicative of their dominance, as well as their contribution as a substrate.

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, near the middle of the Bay. Abundance per trawl averaged from 3 near the mouth of the Bay (station 2573) to 387 individuals near the middle of the Bay (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).

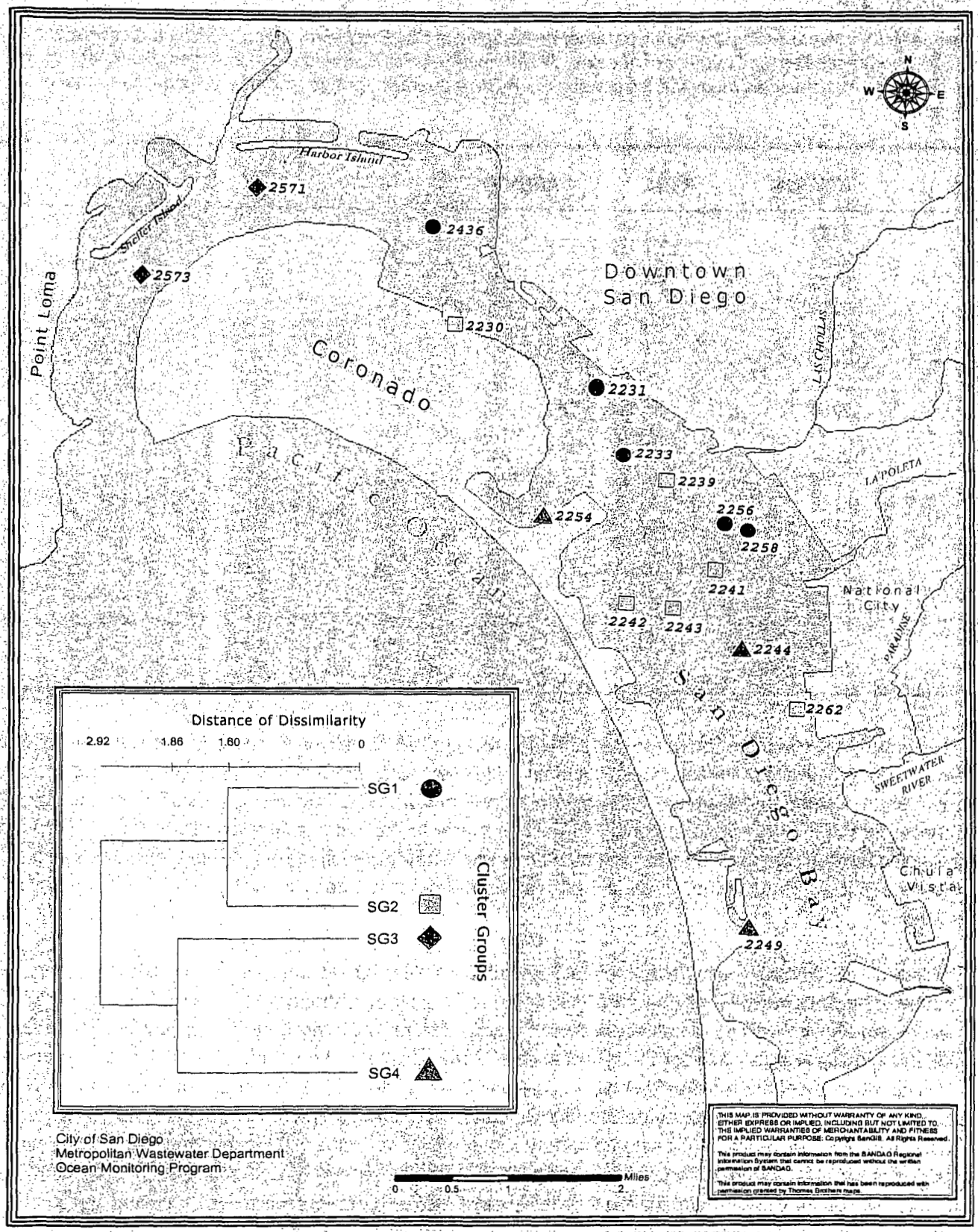

Figure 4.4
Classification analyses of megabenthic invertebrates collected in San Diego Bay during 1998.

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.

	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 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 San Diego Bay. SG1 consisted of five relatively deep stations located along the east half of the Bay. This section of the 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*, *Panulirus interruptus*, and the isopod *Synidotea harfodi*. In

contrast, sites comprising SG4 contained 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 at each site: one California halibut was collected at Newport Harbor, and three anchovies at 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 (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 remaining 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., from 4 to 1051 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 tongue fish were also prominent members of this assemblage. These fishes were also collected in large numbers close to the mouth of San Diego Bay (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.

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, comprised SG5 (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 habitat (e.g., spotfin croaker, shiner and black perch, and white seaperch). This assemblage of fish may reflect the presence of various structures in the vicinity of the trawl locations.

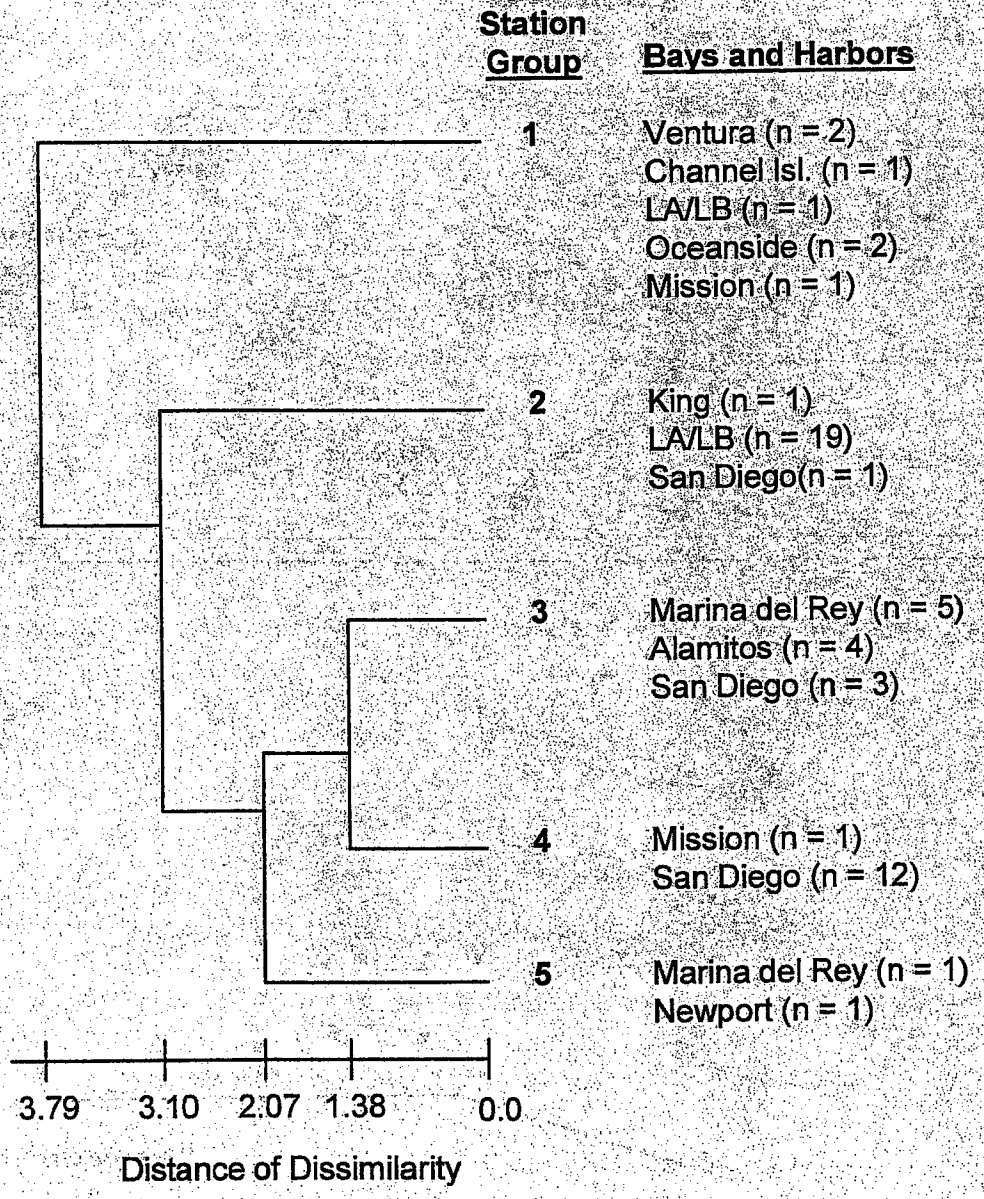

Figure 4.5
Classification analyses of demersal fishes collected from all bays and harbors sampled as part of Bight'98.

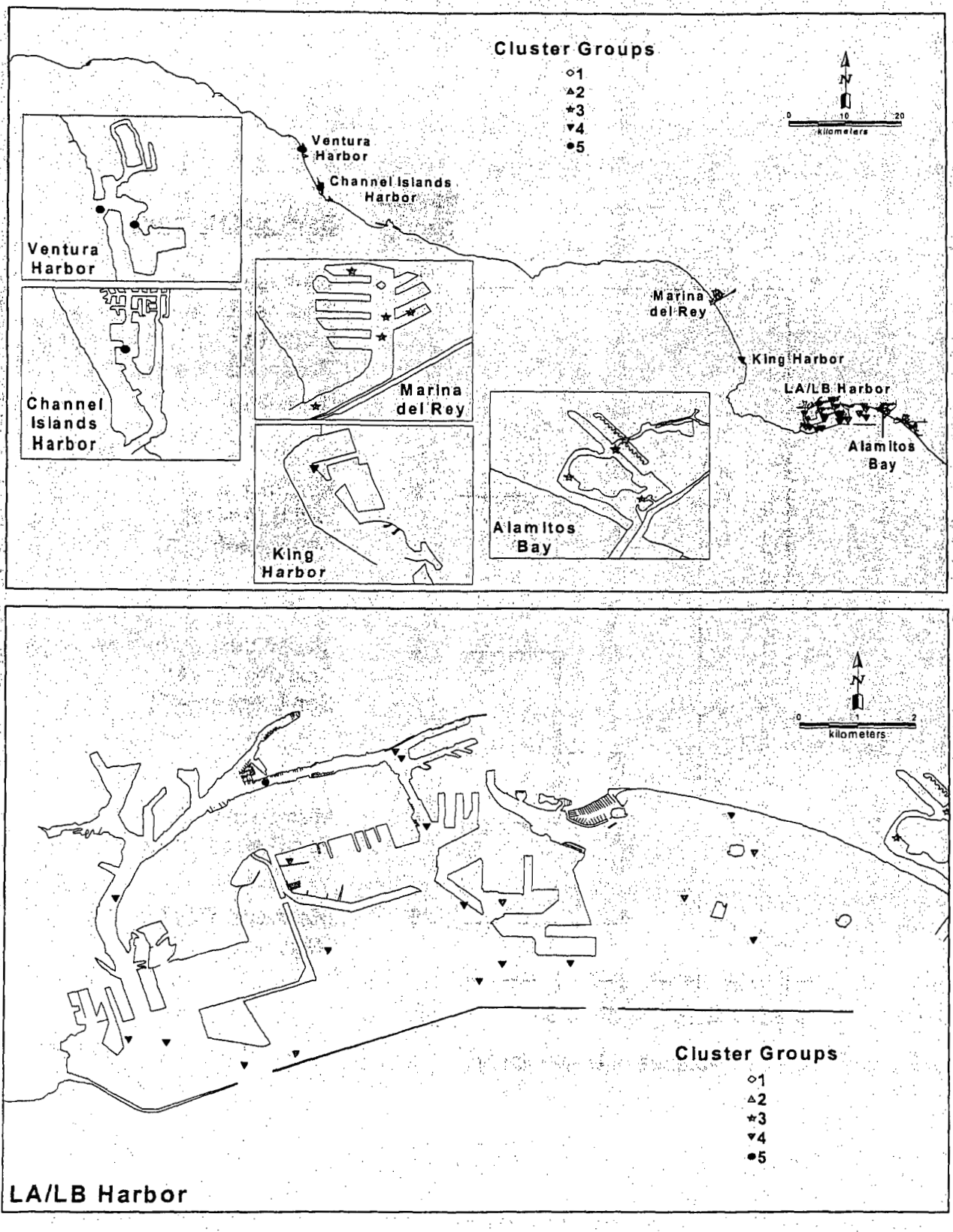

Figure 4.6

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

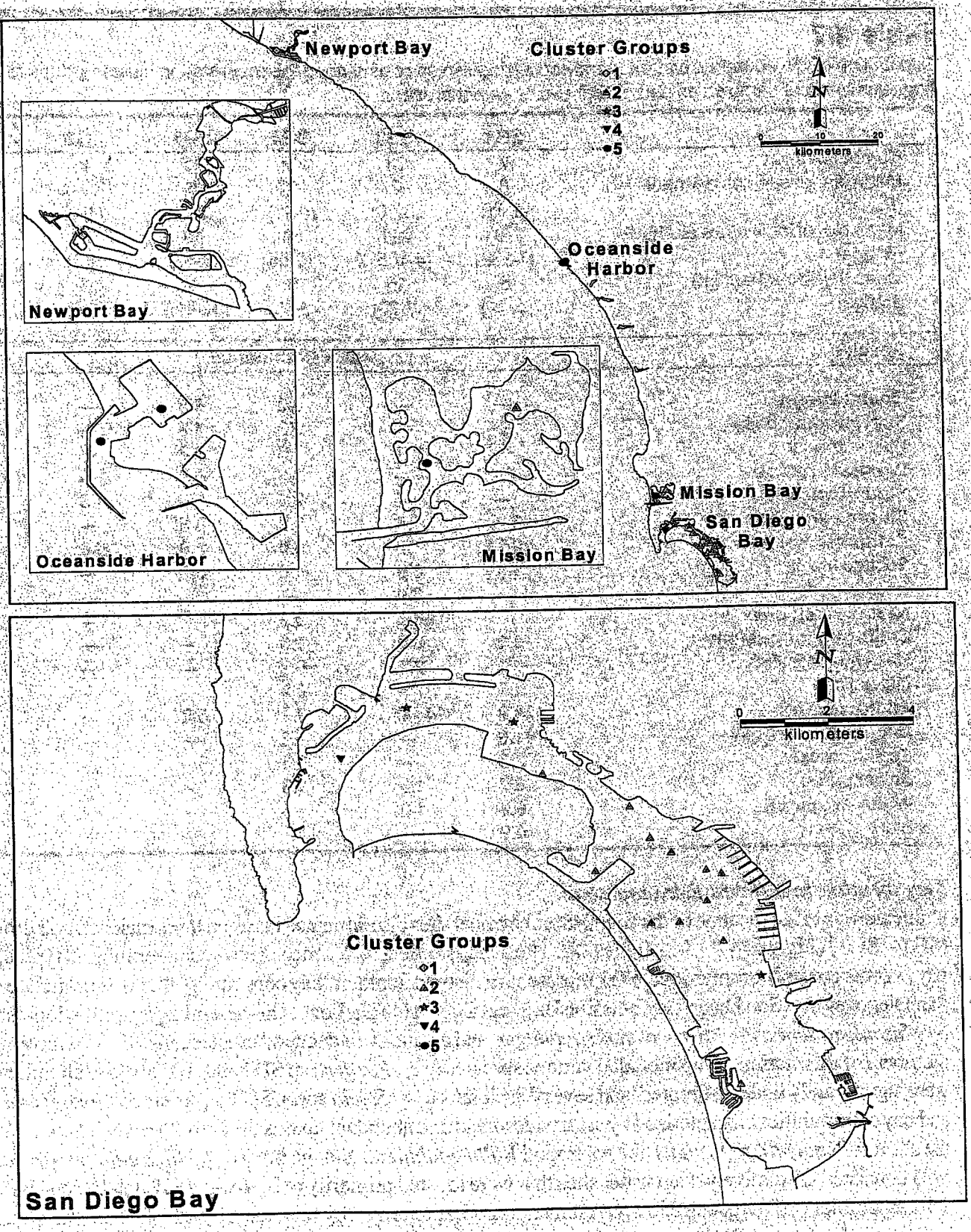

Figure 4.6 (continued)

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.

	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	—	—	—	—

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

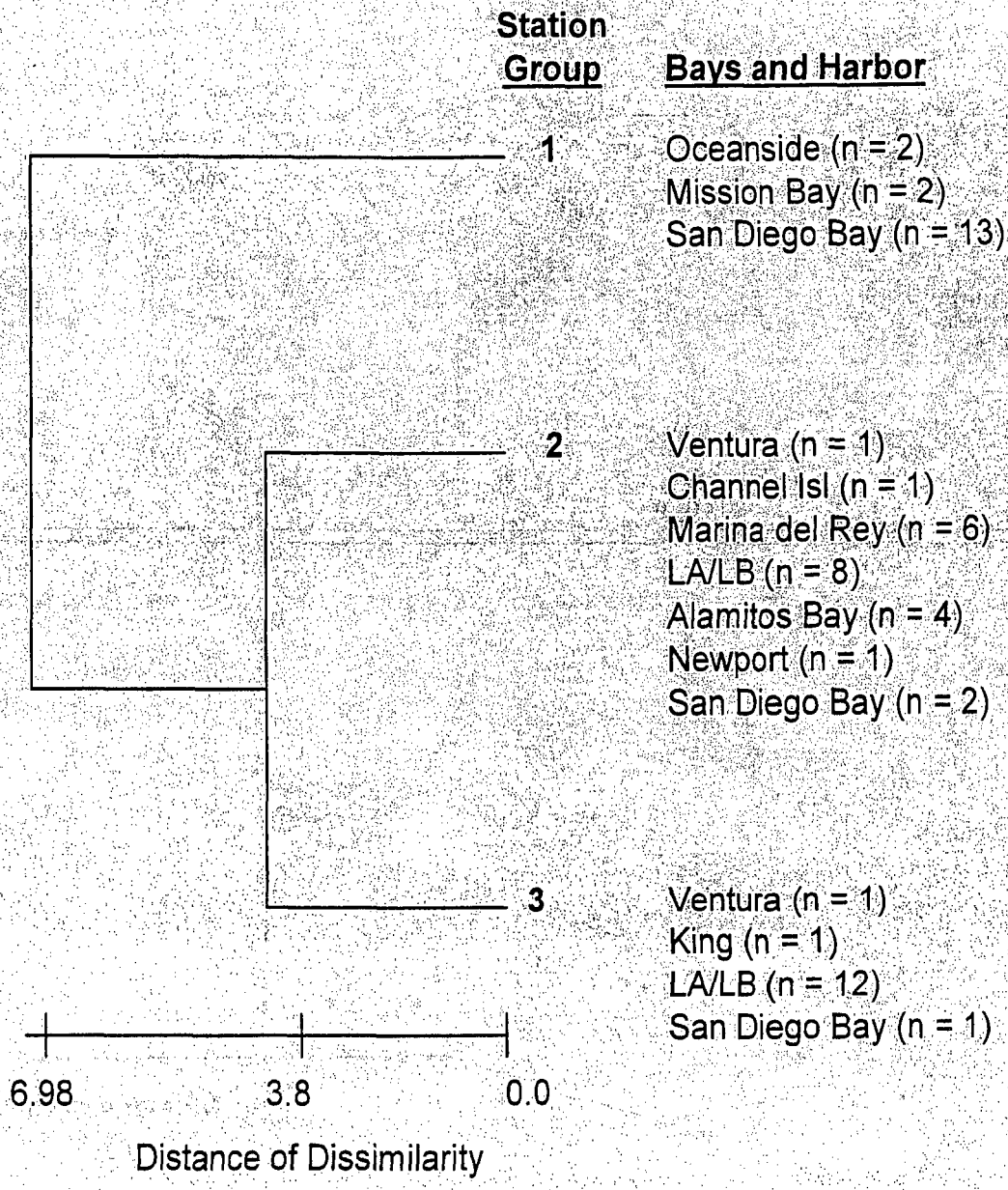

Figure 4.7
Classification analyses of megabenthic invertebrates collected from all bays and harbors sampled as part of Bight'98.

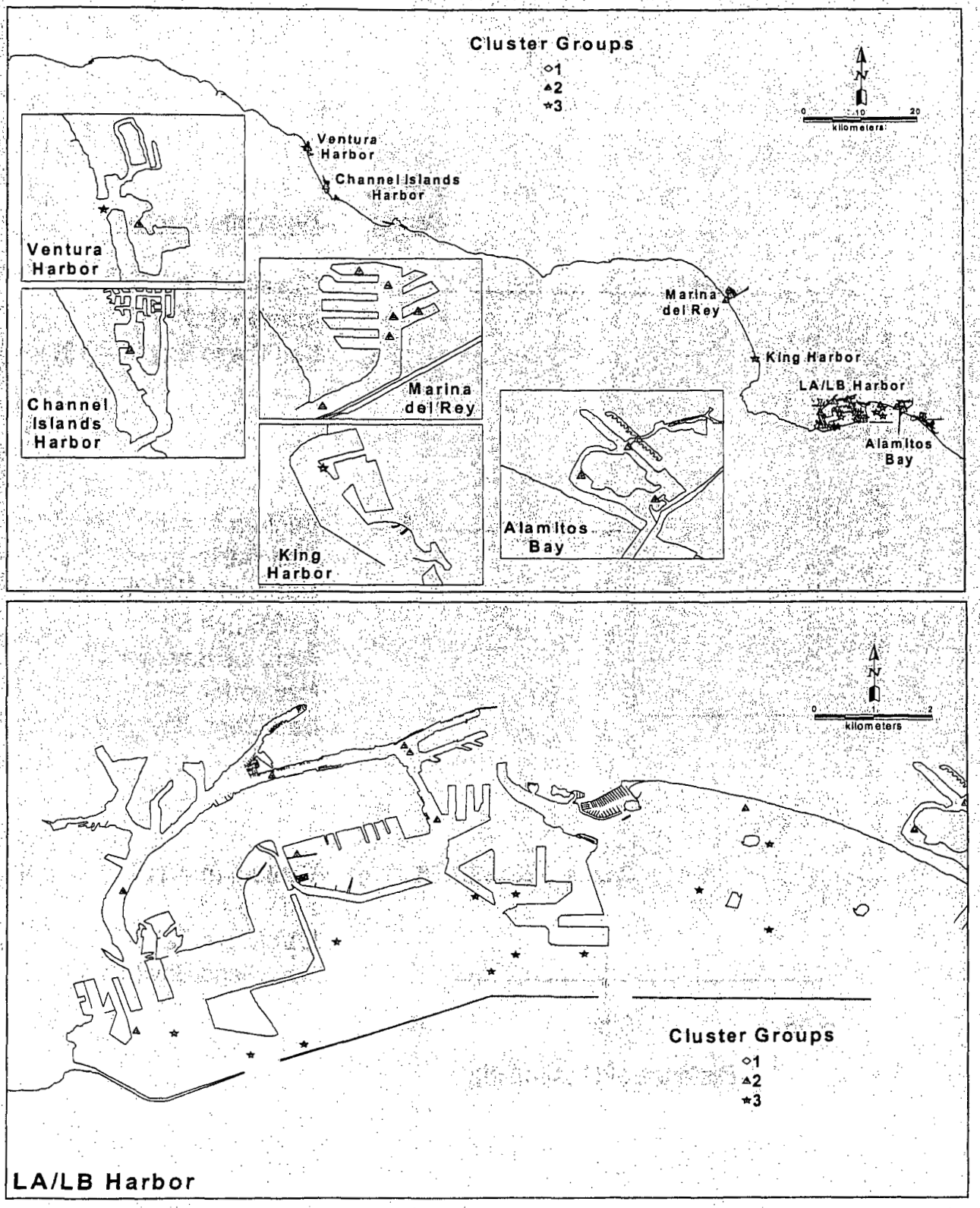

Figure 4.8

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

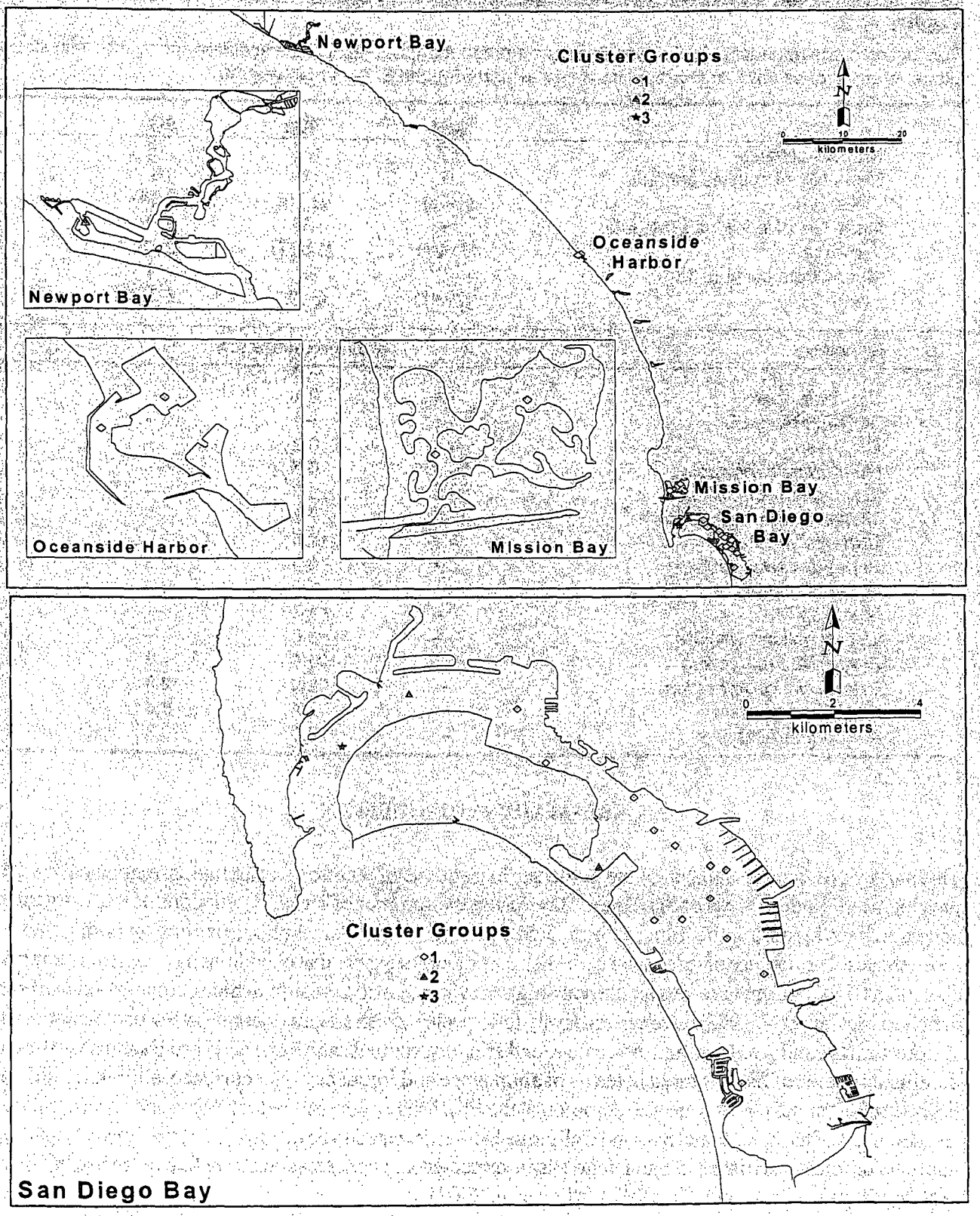

Figure 4.8 (continued)

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 Bight98. '—'= not present.

	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

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., LA/ 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., Allen et al. 2002, USDoN, SWDIV and SDUPD 2000). 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, Allen et al. (2002) 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

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 are 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

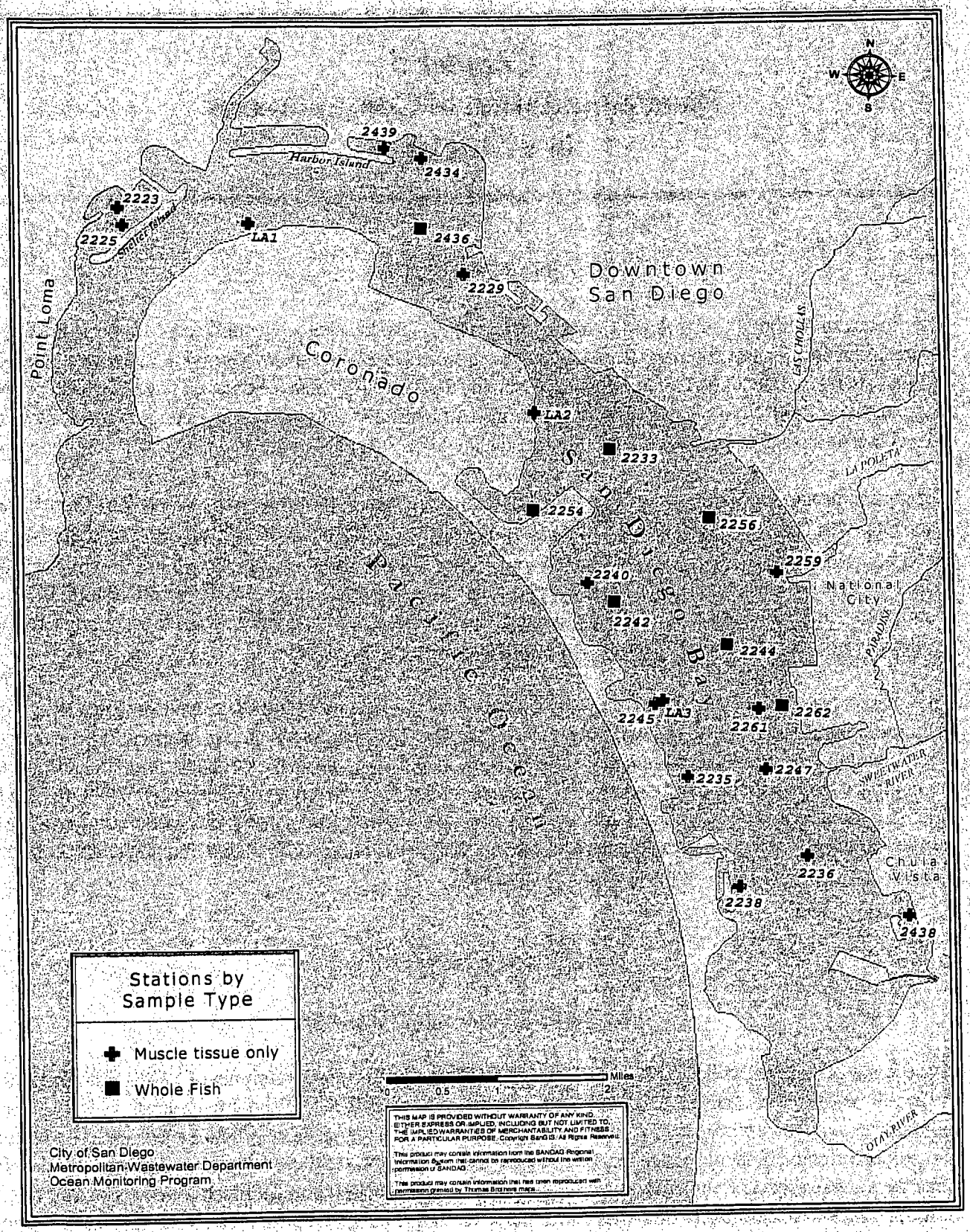

Figure 5.1
San Diego Bay fish tissue stations sampled during 1998.

Table 5.1

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

Project	Station	Collection Method	Tissue	Species
Bight98	2233	OT	Whole Fish	California halibut
Bight98	2242	OT	Whole Fish	California halibut
Bight98	2244	OT	Whole Fish	California halibut
Bight98	2254	OT	Whole Fish	California halibut
Bight98	2256	OT	Whole Fish	California halibut
Bight98	2262	OT	Whole Fish	California halibut
Bight98	2436	OT	Whole Fish	California halibut
Bay98	2223	RF	Muscle	Spotted sand bass
Bay98	2225	RF	Muscle	Spotted sand bass
Bay98	2229	RF	Muscle	Barred sand bass
Bay98	2235	RF	Muscle	Spotted sand bass
Bay98	2236	RF	Muscle	Spotted sand bass
Bay98	2238	RF	Muscle	Spotted sand bass
Bay98	2240	RF	Muscle	Spotted sand bass
Bay98	2245	RF	Muscle	Yellowfin croaker
Bay98	2247	RF	Muscle	Spotted sand bass
Bay98	2259	RF	Muscle	Barred sand bass
Bay98	2261	RF	Muscle	Spotted sand bass
Bay98	2434	RF	Muscle	Calico bass
Bay98	2438	RF	Muscle	Spotted sand bass
Bay98	2439	RF	Muscle	Spotted sand bass
Bay98*	LA1	misc.	Muscle	California halibut
Bay98*	LA2	misc.	Muscle	Spotted sand bass
Bay98*	LA3	misc.	Muscle	Spotted sand bass

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

croaker (*Umbrina roncador*). Muscles 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.

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 2 minutes to obtain a smooth homogenate. The homogenate was then placed in glass jars, sealed, labeled, and stored at -20°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°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 (LA/LB) 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

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.

international standard in one sample of barred sand bass collected at station 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,

(OEHHA)
20 ng/g

Table 5.3

Concentrations (ppb) of PCBs detected in muscle samples from 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

although less frequently than DDT. Dieldrin, for example, was found in two spotted sand bass samples collected 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, listed by station.

			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, and were absent from Ventura Harbor (Table 5.5). 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*						
	%over	100	100	100	50	100
PCB Thresholds**						
Mammals	%over	86	100	20	0	0
Birds	%over	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 demonstrates 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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Appendix A

Summary of Stations

Appendix A.1

Summary of parameters collected at each station sampled in San Diego Bay during 1998. Latitudes and longituteds are listed as degrees and minutes.

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	32 37.132	117 07.014	ns	ns	ns	ns	Station abandoned; <3 m
2251	32 42.138	117 09.724	x	x			
2252	32 41.512	117 09.171	x	x			
2253	32 41.288	117 08.286	x	x			Station sampled by SPAWAR.
2254	32 40.635	117 09.794	x	x	x	x	Station sampled by SPAWAR.
2255	32 40.678	117 07.764	x	x			
2256	32 40.611	117 08.152	x	x	x	x	
2257	32 40.610	117 08.045	x	x			
2258	32 40.555	117 07.928	x	x	x	ns	Insufficient fish for TB
2259	32 40.209	117 07.486	x	x	ns	RF	Station abandoned for trawls; obstruction
2260	32 40.031	117 07.799	x	x			
2261	32 39.049	117 07.590	x	x	ns	RF	Station abandoned for trawls; obstruction
2262	32 39.090	117 07.376	x	x	x	x	
2263	32 42.963	117 10.559	x	x			
2264	32 41.123	117 07.969	x	x			Station sampled by SPAWAR.
2265	32 41.033	117 08.418	x	x			
2433	32 43.341	117 12.553	x	x			
2434	32 43.494	117 11.018	x	x	ns	RF	Station abandoned for trawls; obstruction
2435	32 42.692	117 13.375	x	x	x	ns	Insufficient fish for TB
2436	32 42.902	117 10.987	x	x	x	x	
2437	32 40.879	117 10.298	ns	ns			Station abandoned; obstructions.
2438	32 37.338	117 06.102	x	x	ns	RF	Station abandoned for trawls; obstruction
2439	32 43.566	117 11.371	x	x	ns	RF	Station abandoned for trawls; obstruction
2440	32 43.109	117 10.489	x	x			
2441	32 41.469	117 14.281	x	x			Station sampled by SPAWAR.
2442	32 41.352	117 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 the Bight'98 regional survey. 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)	

Polyclic 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)

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 the Bight'98 regional survey. 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.

	Depth	TN	TOC	Fines	Phi Size			
Station	m	%	%	%	Median	Mean	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 the Bight'98 regional survey. 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 the Bight'98 regional survey. 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 (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.5

Concentrations (ppt: parts per trillion) of polychlorinated biphenyl compounds (PCBs) in San Diego Bay during the Bight'98 regional survey. 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

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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.6

Concentrations (ppt: parts per trillion) of total DDT and the detected DDT derivatives for San Diego Bay during the Bight'98 regional survey.

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 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 0.1m² 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
PORIFERA		5
	Leucilla nuttingi	1
	PORIFERA sp SD 1	1
	PORIFERA sp SD 2	2
	PORIFERA sp SD 4	8
	PORIFERA sp SD 5	5
	PORIFERA sp SD 6	1
	PORIFERA sp SD 7	1
	PORIFERA sp SD 8	1
	PORIFERA sp SD 10	1
CNIDARIA		
Anthozoa		
	Acanthoptilum sp	1
	ACTINIARIA sp SD 1	15
MOLLUSCA		
Gastropoda		
	Bulla gouldiana	68
	Crepidula onyx	77
	Crucibulum spinosum	62
	Diaulula sandiegensis	3
	Doriopsilla albopunctata	1
	Haminoea vesicula	1
	Nassarius tiarula	69
	Navanax inermis	1
	Pteropurpura festiva	10
Bivalvia		
	Argopecten ventricosus	7
	Leptopecten latiauratus	1
	Limaria hemphilli	2
	Musculista senhousia	498
	Ostrea sp	79
Cephalopoda		
	Loligo opalescens	2
ARTHROPODA		
Crustacea		
Malacostraca		
Isopoda		
	Synidotea harfordi	1
Decapoda		
	Crangon nigromaculata	1
	Lophopanopeus frontalis	5
	Lophopanopeus bellus	1
	Loxorhynchus sp	1
	Panulirus interruptus	1
	Penaeus californiensis	10
	Pugettia producta	1
	Pyromaia tuberculata	5
	Synalpheus lockingtoni	3
ECHINODERMATA		
Asteroidea		
	Asterina miniata	1
CHORDATA		
Ascidiacea		4
	Ciona sp	3
	Microcosmus squamiger	190
	Styela montereyensis	3
	Styela plicata	19

[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.

STATION	Species	n	SL (cm) min	SL (cm) max	SL (cm) avg	Weight (g) min	Weight (g) max	Weight (g) 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