CHEMISTRY, TOXICITY AND BENTHIC COMMUNITY CONDITIONS IN SEDIMENTS OF THE SAN DIEGO BAY REGION

FINAL REPORT

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Marine Pollution Studies Laboratory

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EXECUTIVE SUMMARY

The following report describes and evaluates chemical and biological data collected from San Diego Bay and its historical tributaries between October, 1992 and May, 1994. The study was conducted as part of the ongoing Bay Protection and Toxic Cleanup Program, a legislatively mandated program designed to assess the degree of chemical pollution and associated biological effects in California's bays and harbors. The workplan for this study resulted from a cooperative agreement between the State Water Resources Control Board and the National Oceanic and Atmospheric Administration (NOAA). Monitoring and reporting aspects of the study were conducted by the Environmental Services Division, of the California Department of Fish and Game, and its subcontractors.

The study objectives were:

1. Determine presence or absence of adverse biological effects in representative areas of the San Diego Bay Region;

2. Determine relative degree or severity of adverse effects, and distinguish more severely impacted sediments from less severely impacted sediments;

3. Determine relative spatial extent of toxicant-associated effects in the San Diego Bay Region;

4. Determine relationships between toxicants and measures of effects in the San Diego Bay Region.

The research involved chemical analysis of sediments, benthic community analysis and toxicity testing of sediments and sediment pore water. Chemical analyses and bioassays were performed using aliquots of homogenized sediment samples collected synoptically at each station. Analysis of the benthic community structure was made on a subset of the total number of stations sampled.

Three hundred and fifty stations were sampled between October, 1992 and May, 1994. Areas sampled included San Diego Bay, Mission Bay, the San Diego River Estuary and the Tijuana River Estuary and are collectively termed "the San Diego Bay Region" in the following document. Two types of sampling designs were utilized: direct point sampling and stratified random sampling.

Chemical pollution was demonstrated by using comparisons to established sediment quality guidelines. Two sets of guidelines were used: the Effects Range-Low (ERL)/Effects Range-Median (ERM) guidelines developed by NOAA (Long and Morgan, 1990; Long *et al.*, 1995) and the Threshold Effects Level (TEL)/Probable Effects Level (PEL) guidelines used in Florida (McDonald, 1993; McDonald, 1994). Copper, mercury, zinc, total chlordane, total PCBs and the PAHs were most often found to exceed critical ERM or PEL values

and were considered the major chemicals or chemical groups of concern in the San Diego Bay Region. ERM and PEL summary quotients were used to develop chemical indices for addressing the pollution of sediments with multiple chemicals. An ERM summary quotient >0.85 or a PEL summary quotient >1.29 was indicative of stations where multiple chemicals were significantly elevated. Stations with any chemical concentration >4 times its respective ERM or >5.9 times its respective PEL were considered to exhibit elevated chemistry. Summary quotients and magnitude of sediment quality guideline exceedances were used as additional information to help prioritize stations of concern for Regional Water Quality Control Board staff.

Identification of degraded and undegraded habitat (as determined by macrobenthic community structure) was conducted using a cumulative, weight-of-evidence approach. Analyses were performed to identify relationships between community structure within and between each station or site (*e.g.,* diversity/evenness indices, analyses of habitat and species composition, construction of dissimilarity matrices for pattern testing, assessment of indicator species, and development of a benthic index, cluster analyses, and ordination analyses).

Analyses of the 75 stations sampled for benthic community structure identified 23 undegraded stations, 43 degraded and 9 transitional stations. All sampled stations with an ERM summary quotient >0.85 were found to have degraded communities. All sampled stations with P450 Reporter Gene System responses above 60 μg/g BaPEq. were similarly found to have degraded benthic communities.

The statistical significance of toxicity test results was determined using two approaches: the reference envelope approach and laboratory control comparison approach used by the United States Environmental Protection Agency- Environmental Monitoring and Assessment Program and NOAA- National Status and Trends programs. The reference envelope approach indicated that toxicity for the *Rhepoxynius* (amphipod) sediment test was significant when survival was less than 48% in samples tested. No reference envelope was calculated for the urchin fertilization or development tests due to high variability in pore water data from reference stations.

The laboratory control comparison approach was used to compare test sediment samples against laboratory controls for determination of statistically significant differences in test organism response. Criteria for toxicity in this approach were 1) survival less than 80% of the control value and 2) significant difference between test samples and controls, as determined using a t-test. Using this approach, there was no absolute value below which all samples could be considered toxic, although survival below a range of 72-80% was generally considered toxic.

Using the EMAP definition of toxicity, 56% of the total area sampled was toxic to *Rhepoxynius*. For the *Strongylocentrotus* larval development test, percent of total area toxic was 29%, 54%, and 72% respectively for 25%, 50%, and undiluted pore water concentrations. Samples representing 14%, 27%, or 36% of the study area were toxic to both *Strongylocentrotus* in pore water (25%, 50%, or undiluted, respectively) and *Rhepoxynius* in solid phase sediment.

Linear regression analyses failed to reveal strong correlations between amphipod survival and chemical concentration. It is suspected instead of a linear response to chemical pollutants, most organisms are tolerant of pollutants until a threshold is exceeded. Comparisons to established sediment quality guideline thresholds demonstrate an increased incidence of toxicity for San Diego Bay Region samples with chemical concentrations exceeding the ERM or PEL values. It is further suspected toxicity in urban bays is caused by exposure to complex mixtures of chemicals. Comparisons to ERM summary quotients (multiple chemical indicators) demonstrate that the highest incidence of toxicity (>78%) is found in samples with elevated ERM summary quotients (>0.85).

Statistical analyses of the P450 Reporter Gene System responses versus the PAHs in sediment extracts demonstrated that this biological response indicator was significantly correlated ($r^2 = 0.86$) with sediment PAH (total and high molecular weight) concentration.

Stations requiring further investigation were prioritized based on existing evidence. Each station receiving a high, moderate or low priority ranking meets one or more of the criteria under evaluation for determining hot spot status in the Bay Protection and Toxic Cleanup Program. Those meeting all criteria were given the highest priority for further action. A ranking scheme was developed to evaluate stations of lower priority.

Seven stations (representing four sites) were given a high priority ranking, 43 stations were given a moderate priority ranking, and 57 stations were given a low priority ranking. The seven stations receiving the high priority ranking were in the Seventh Street channel area, two naval shipyard areas near the Coronado Bridge, and the Downtown Anchorage area west of the airport. The majority of stations given moderate rankings were associated with commercial areas and naval shipyard areas in the vicinity of the Coronado Bridge. Low priority stations were interspersed throughout the San Diego Bay Region.

A review of historical data supports the conclusions of the current research. Recommendations are made for complementary investigations which could provide additional evidence for further characterizing stations of concern.

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AA	Atomic Absorption
ASTM	American Society for Testing Materials
AVS	Acid Volatile Sulfide
BPTCP	Bay Protection and Toxic Cleanup Program
CDF	Cumulative Distribution Frequencies
CDFG	California Department of Fish and Game
CH	Chlorinated Hydrocarbon
COC	Chain of Custody
COR	Chain of Records
EDTA	Ethylenediaminetetraacetic Acid
EMAP	Environmental Monitoring and Assessment Program
ERL	Effects Range Low
ERM	Effects Range Median
ERMQ	Effects Range Median Summary Quotient
EqP	Equilibrium Partitioning Coefficient
FAAS	Flame Atomic Absorption Spectroscopy
GC/ECD	Gas Chromatograph Electron Capture Detection
GFAAS	Graphite Furance Atomic Absorption Spectroscopy
HCl	Hydrochloric Acid
HDPE	High-density Polyethylene
HMW PAH	High Molecular Weight Polynuclear Aromatic Hydrocarbons
HNO_3	Nitric Acid
HPLC/SEC	High Performance Liquid Chromatography Size Exclusion
H_2S	Hydrogen Sulfide
IDORG	Identification and Organizational Number
KCL	Potassium Chloride
LC_{50}	Lethal Concentration (to 50 percent of test organisms)
LMW PAH	Low Molecular Weight Polynuclear Aromatic Hydrocarbons
MDL	Method Detection Limit
MDS	Multi-Dimensional Scaling
MLML	Moss Landing Marine Laboratories
MPSL	Marine Pollution Studies Laboratory
NH_3	Ammonia
NOAA	National Oceanic and Atmospheric Administration
NOEC	No Observed Effect Concentration
NS&T	National Status and Trends Program
P450	Cytochrome P450 Enzyme System
PAH	Polynuclear Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
PEL	Probable Effects Level
PELQ	Probable Effects Level Summary Quotient
PPE	Porous Polyethylene
PVC	Polyvinyl Chloride
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
REF	Reference
RGS	P450 Reporter Gene System
RWQCB	Regional Water Quality Control Board
SCCWRP	Southern Calif. Coastal Waters Research Project

SPARC	Scientific Planning and Review Committee
SQC	Sediment Quality Criteria
SWRCB	State Water Resources Control Board
T	Temperature
TBT	Tributyltin
TFE	Tefzel Teflon®
TEL	Threshold Effects Level
TIE	Toxicity Identification Evaluation
TOC	Total Organic Carbon
TOF	Trace Organics Facility
UCSC	University of California Santa Cruz
USEPA	U.S. Environmental Protection Agency
WCS	Whole Core Squeezing

Units

liter = 1 l
milliliter = 1 ml
microliter = 1 μl
gram = 1 g
milligram = 1 mg
microgram = 1 μg
nanogram = 1 ng
kilogram = 1 kg
1 part per thousand (ppt) = 1 mg/g
1 part per million (ppm) = 1 mg/kg, 1 μg/g
1 part per billion (ppb) = 1 μg/kg, 1 ng/g

INTRODUCTION

Purpose

In 1992, the State Water Resources Control Board (SWRCB) and the National Oceanic and Atmospheric Administration (NOAA) entered into a three-year cooperative agreement to assess potential adverse biological effects from sediments in coastal bays and harbors of Southern California (SWRCB and NOAA, 1991, 1992, 1993). The study area for the three-year cooperative agreement extended south of the Palos Verdes Peninsula to the USA/Mexico border. The majority of work focused on selected coastal bays, harbors and lagoons where depth ranged from approximately 60 meters to the upper limit of the tidal range. In the first phase of the study, data were collected, analyzed, and reported from the Los Angeles/Long Beach areas (SWRCB and NOAA, 1994).

This report presents results from data collected in the San Diego Bay area during the second and third years of the cooperative agreement. The study was performed in San Diego Bay, Mission Bay, San Diego River Estuary, and Tijuana River Estuary in southern California (Figure 1).

The purposes of the present study were:

1. Determine presence or absence of statistically significant toxicity effects in representative areas of the San Diego Bay Region;

2. Determine relative degree or severity of observed effects, and distinguish more severely impacted sediments from less severely impacted sediments;

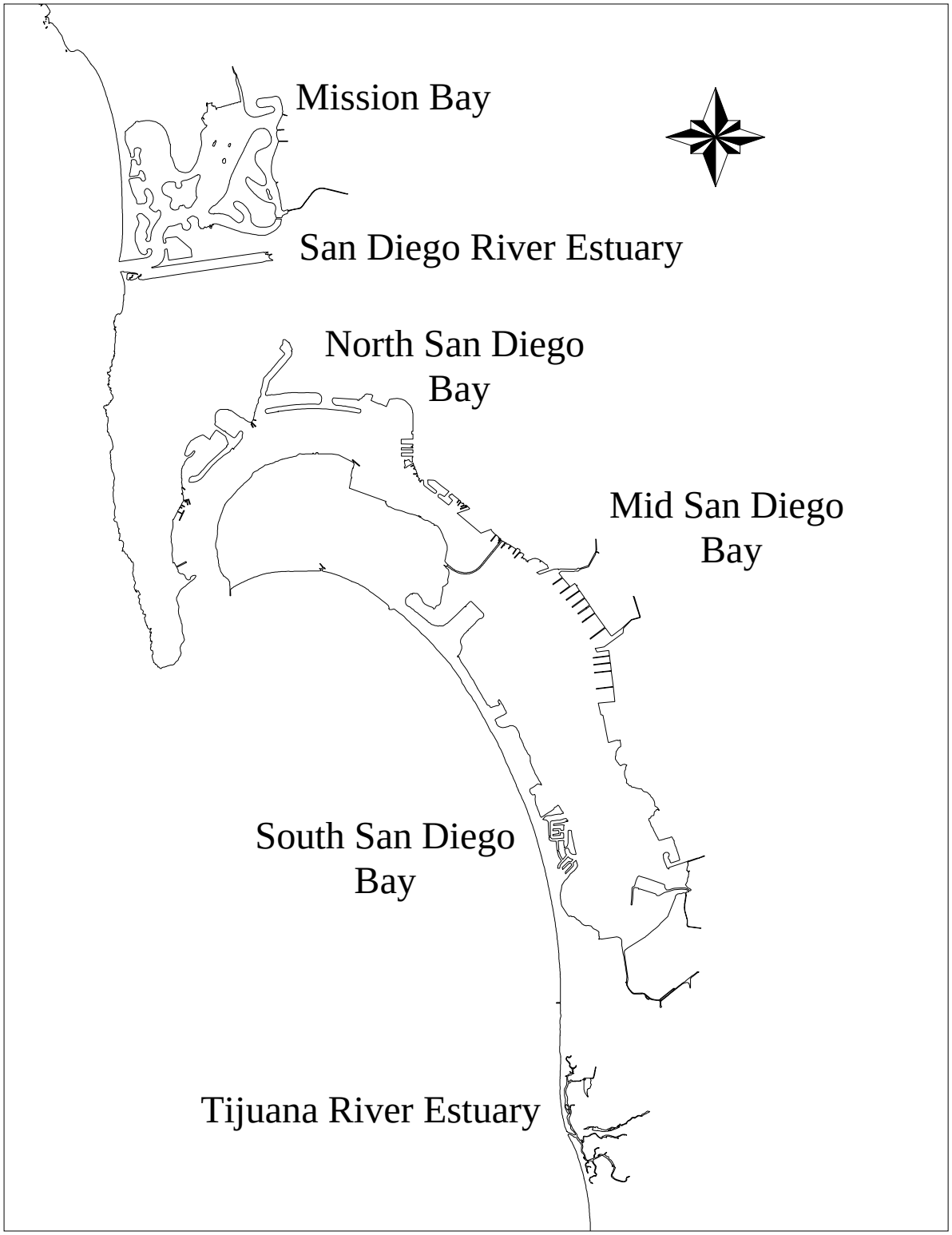
3. Determine relative areal extent of significant toxicity in the San Diego Bay Region;

4. Determine relationships between pollutants and measures of effects in these bays.

Programmatic Background and Needs

Due to the long history of human activity in San Diego Bay and its surrounding waters, there is a need to assess any environmentally detrimental effects which have been associated with those activities. The cooperative agreement between NOAA and SWRCB was designed to investigate these environmental effects by evaluating the biological and chemical state of San Diego Bay sediments. The methods used to assess environmental impacts include sediment and interstitial water bioassays, sediment chemistry analysis, and benthic community analysis. The study areas included San Diego Bay, Mission Bay, Tijuana River Estuary, and the San Diego River. Although these water bodies are separated physically, and are quite different in character, for simplicity they will often be referred to collectively as the "San Diego Bay Region" in this report (Figure 1). The SWRCB and NOAA have common programmatic needs for this research, however, some differences exist. NOAA is mandated by Congress to conduct a

Figure 1
San Diego Bay Region Study Area



program of research and monitoring on marine pollution. Much of this research is conducted through the National Status and Trends (NS&T) Program and the Coastal Ocean Program. The NS&T Program performs intensive regional studies on the magnitude and extent of toxicant-associated bioeffects in selected coastal embayments and estuaries. Areas chosen for these regional studies were those in which pollutant concentrations indicate the greatest potential for biological effect. These biological studies augment regular chemical monitoring activities of the NS&T Program, and provide a means for estimating the extent of toxicity associated with measured concentrations of sediment pollutants.

The California Water Code, Division 7, Chapter 5.6, Section 13390 mandates the State Water Resources Control Board and the Regional Water Quality Control Boards to provide the maximum protection of existing and future beneficial uses of bays and estuarine waters and to plan for remedial actions at those identified toxic hot spots where the beneficial uses are being threatened by toxic pollutants.

A cooperative agreement between NOAA and SWRCB has been implemented through the Bay Protection and Toxic Cleanup Program (BPTCP). Sediment characterization approaches currently used by the BPTCP range from chemical or toxicity monitoring only, to monitoring designs which attempt to generally correlate the presence of pollutants with toxicity or benthic community degradation. Studies were designed, managed, and coordinated by the SWRCB's Bays and Estuaries Unit as a cooperative effort with NOAA's Bioeffects Assessment Branch, and the California Department of Fish and Game's (CDFG) Marine Pollution Studies Laboratory. Funding was provided by the SWRCB and NOAA's Coastal Ocean Program.

Research for the San Diego Bay Region involved toxicity testing and chemical analysis of sediments and sediment pore water. Toxicity tests and chemical analysis were performed using aliquots of homogenized sediment samples collected synoptically from each station, resulting in paired data. Analyses of benthic community structure and P450 enzyme induction were also made on a subset of the total number of stations sampled.

Field and laboratory work was accomplished under interagency agreement with, and under the direction of, the CDFG. Sample collections were performed by staff of the San Jose State University Foundation at the Moss Landing Marine Laboratories, Moss Landing, CA (MLML). Trace metals analyses were performed by CDFG personnel at the trace metal facility at Moss Landing Marine Laboratories. Synthetic organic pesticides, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) were analyzed at the UCSC trace organics analytical facility at Long Marine Laboratory in Santa Cruz, California. MLML staff also performed total organic carbon (TOC) and grain size analyses, as well as benthic community analyses. Toxicity testing was conducted by the University of California at Santa Cruz (UCSC) staff at the CDFG toxicity testing laboratory at Granite Canyon,

California. P450 Reporter Gene System analyses were conducted by Columbia Analytical Services in Carlsbad, CA.

Study Area

San Diego Bay

San Diego Bay is the southern-most embayment on the west coast of the United States. It is located within the Southern California Bight and is the largest embayment along the 1450 kilometer stretch of coastline between San Francisco and Central Baja California. Located 16 kilometers northwest of the Mexico border, it is considered one of the finest natural harbors in the world. This reputation is due mainly to its deep entrance and protection from weather it provides ships. San Diego Bay lies entirely in the county of San Diego, extending from the entrance at Point Loma southward to the mouth of the Otay River.

San Diego Bay is a natural, nearly-enclosed, crescent-shaped estuary that encompasses approximately 52 square kilometers. It is approximately 24 kilometers (km) in length and varies from 0.4 km to 5.8 km in width. Depths in the Bay vary from 18 meters near the mouth to less than 1 meter in the southern part of the bay, with the average depth for the entire bay being slightly more than 12 meters. The Bay is much deeper and narrower than it was historically, due mainly to dredging of channels and filling of nearshore areas.

San Diego Bay opens to the Pacific Ocean and is classified as an estuarine system due to its fresh water dilution. The diversion of the San Diego River to Mission Bay by the U.S. Army Corps of Engineers in 1857 was the first major reduction of freshwater input into the bay (Smith, 1977). Sweetwater River and the Otay River were also main sources of freshwater for San Diego Bay, although these sources have been greatly reduced over the years as a result of dam construction, extensive ground water use, and limited rainfall in recent years. Freshwater input is now limited to periodic surface drainage from the metropolitan area and intermittent flow from several rivers and creeks during periods of rainfall. Because of the dry Mediterranean-like climate that characterizes San Diego Bay, average annual rainfall in the Bay is usually between 10 and 13 inches, the majority of which falls between November and February.

Tides in San Diego Bay demonstrate marked variation between the heights of two high tides and two low tides that occur daily, classifying them as diurnal. The range between mean higher high water (MHHW) and mean lower low water (MLLW) is 1.6 meters and the extreme range of tides within the Bay is approximately 2.9 meters (Browning and Speth, 1973). Tidal currents are strongest in the northern part of the Bay where surface velocities reach 2.9 knots on ebb tide and 2.2 knots on flood tide (U.S. Army Corps of Engineers, 1973). Tidal currents are reduced considerably in the shallower central and south bay areas. Average tidal flushing for San Diego Bay is about 30% of the

entire Bay water volume exchanged per tidal cycle (12.5 hours). This volume of water is referred to as the tidal prism and in San Diego Bay represents approximately 74,000,000 cubic meters. Tidal flushing rates differ drastically between the Bay entrance and South Bay. Complete tidal flushing for the South Bay requires seven to fourteen days, whereas, the entrance of the Bay may only require one to two days. It has been estimated over the last century, tidal flushing in San Diego Bay has been reduced by 30% due to channel dredging and landfill projects (Browning and Speth, 1973).

San Diego Bay is a sedimentary environment with the bay floor and bay margins characterized by sand, silt and clay deposits (Peeling, 1974). Sand deposits are found near the Bay's mouth and along western margins, while finer silt and clay deposits are located on the eastern margins and at the southern end of the Bay.

An early navigation chart issued by the U.S. Coastal Survey in 1859 shows an undredged Bay fifteen miles long with a channel varying in depth from 22.2 meters decreasing to 3.6 meters. This natural channel stretched for 13 kilometers from the tip of Point Loma to the South Bay. Salt marshes existed at the mouths of seven creeks and river tributaries.

The early residents of the San Diego Bay area were Native Americans, who hunted and fished in the Bay; Spanish, Mexican, and American ranchers, who traded hides and tallow; and the early Yankee whalers who established camps in North Bay. These groups appeared to have little impact on the water quality in the Bay. By 1830 there were 16 American whaling vessels operating out of San Diego Bay. The whaling industry reached its peak in 1871-72 when 55,000 gallons of oil and 200 tons of whalebone were shipped from Point Loma. Americans participating in the New Town land boom of the 1880's settled in the central San Diego Bay area, site of the present downtown San Diego. This settlement soon represented a considerable increase in the population of the area as well as a dramatic threat to water quality in the Bay.

The Cuyamaca Dam and a flume were completed in 1888, diverting freshwater from eastern mountains into what is now Chollas Reservoir. Forty miles of sewers coupled with a sewage reservoir and outfall located in San Diego Bay off Market street were also completed in 1888. This sewage system marked the beginning of the decline in water quality for the Bay. Conditions within the Bay continued to decline because of the increase in population (30,000 in 1901) and acceptance of the Bay as a major harbor for the U.S. Navy and civilian commerce.

During the next four decades communications and aviation stations were added and docking facilities expanded. Naval facilities expanded greatly during World War II as business and industry boomed. In 1940, the population had increased to 200,000 causing a failure of the overloaded sewage collection and treatment facilities. In 1943, raw or minimally treated sewage was being

discharged into the Bay from 15 outfalls. After World War II and the Korean War, San Diego Bay was subject to the dumping of more than 50 million gallons of sewage and industrial waste per day (San Diego Interagency Water Quality Panel, 1989).

In 1950, the population of the San Diego metropolitan area had increased to over 400,000. In an attempt to curtail the flow of raw sewage into the Bay, San Diego and several neighboring communities combined their sewage outfalls into one system. Unfortunately, this new system was constantly operating on overload and discharging directly into the Bay. Simultaneously, the Bay received untreated industrial discharge from five fish canneries, a large rendering operation, a kelp processing plant, four aircraft manufacturing plants, several shipyards, and the Pacific coast's largest naval base, naval air station, and submarine base (San Diego Interagency Water Quality Panel, 1989). The California Regional Water Quality Control Board was established in 1950 (following the passage of the Dickey Act in 1949). Through extensive water sampling it was concluded that the entire Bay had become contaminated, due to heavy loading of domestic and industrial wastes. Dissolved oxygen concentrations in the Bay had declined to about half normal levels and turbidity in the water resulted in a visibility of less than 1 meter. Bait and game fish had virtually disappeared from the Bay. Coliform bacteria were routinely isolated from the Bay at significant levels. In 1955, the State Board of Public Health and the San Diego Department of Public Health declared much of the Bay contaminated, and posted quarantine and warning signs along 10 miles of shoreline. By 1963, sludge deposits from the treatment plant outfall were two meters deep, extended 200 meters seaward, and along 9000 meters of the shoreline.

A report in the early 1950's from the Regional Board and the San Diego Sewerage Survey report indicated sewage discharge into the Bay was becoming a major problem which had to be corrected. In 1960, San Diego voters approved a bond ($42.5 million) which allowed construction to begin on the Metropolitan Sewerage System. In August of 1963, a massive collection, treatment, and ocean disposal system began operation and by February, 1964, domestic sewage disposal had been eliminated from San Diego Bay. Following the completion of the new sewage treatment plant, dissolved oxygen concentrations rose to an average of more than 5 parts per million, visibility increased to 2 meters, and coliform bacteria counts dropped within the federal safety standards. Plankton blooms were scarce and sludge deposits of more than 30 cm were seldom reported. The sewage system currently processes 170 million gallons of waste per day (City of San Diego, 1995)

Routine sampling, beginning in the 1970's, revealed new information regarding the presence of industrial wastes in the Bay. Regulatory standards were developed for the protection of humans and wildlife based on new sampling systems and more refined analytical techniques. The conventional engineering and bacteriological data gathered earlier did not adequately address

the issue of toxic waste in the Bay. During the late 1980's, the press regarded San Diego Bay as being heavily contaminated, particularly for PCBs. Although conditions in the Bay are similar to other urban influenced embayments in the United States, San Diego Bay has serious problems with chemical pollution. A number of toxic hotspots in the Bay have been identified on lists of water quality impairment such as Clean Water Act Section 303(d), Section 319, Section 304(l) and Section 131.11.

Mission Bay

Mission Bay is located 9 kilometers north of Point Loma and encompasses an area of 1860 hectares. It has two main tributaries, Tecolote creek and Rose creek (Dexter, 1983). Originally named False Bay because its entrance was near San Diego Bay and occasionally fooled ship captains, it is now considered a recreational small-craft harbor (United States Coast Pilot, 1994). Prior to the development of Mission Bay park in 1946, Mission Bay was a natural estuary of over 2020 hectares of salt marshes, tidal channels, and a shallow central bay. Between 1946 and 1962 major dredging within the Bay and modifications to the San Diego River flood control channel gave way to its present-day configuration. Today it is a highly modified lagoon which receives freshwater input only during infrequent, heavy rains. The major additions of freshwater into Mission Bay occur at Rose Inlet, in the northeastern portion of the Bay, and Tecolote Creek, in the southeast. Because of this limited amount of freshwater, the salinities throughout the Bay do not change markedly. Mean tidal range is 1.2 meters and the mean diurnal range is 1.7 meters at the Bay entrance (Levin, 1983).

As a result of circulation patterns within Mission Bay, a variety of sediments are found. In the mouth of the Bay and near the main channel, water movement is sufficient to maintain a sandy bottom. In other parts of the Bay, such as Sail Bay and sites located further east, sediments are muddy with a high silt and clay content (Dexter, 1983).

Tecolote and Rose creeks carry urban pollutants such as oil, grease, fertilizers, and high sediment loads into the back bay. Furthermore, sewer lines back up occasionally into the back bay. The lack of water circulation in the back bay allows these pollutants to accumulate and has resulted in quarantines for several months at a time (Marcus, 1989).

Tijuana River Estuary

The Tijuana River Estuary is located 16 kilometers southeast of Point Loma. Although the estuary is situated entirely within the boundaries of San Diego County, three-fourths of its watershed is in Mexico. It is a wetland dominated estuary with no major embayment, however, a series of channels allows for a relatively narrow ocean connection (Herron, 1972). In the classification scheme developed by Prichard (1967), Tijuana Estuary is considered an intermittent coastal plain estuary due to the large

freshwater input during the winter wet season. During most years, the river mouth has been open and tidal flushing has prevailed. The intertidal area supports salt marsh vegetation (*Salicornia virginica*, *Spartina foliosa*), whereas mudflats and sandflats occupy only a small fraction of the estuary (Zedler *et al.*, 1992).

The Tijuana River Estuary has been altered substantially by natural and human disturbances. In the early 1900's, sewage disposal practices led to dredging of the east-west channel in order to connect an adjacent waste collecting lagoon with the estuary. Dikes were then created to subdivide the lagoon into three wastewater receiving ponds, however, these dikes were later removed to increase tidal flow. Gravel extraction for street and dike construction created isolated ponds within the estuary. Long-term dumping and filling altered most of the peripheral topography, while extensive damage to the southern half of the estuary from military, agricultural, and horse-raising activities is evident (Marcus, 1989).

Wastewater flow from Tijuana has been a serious threat to water quality in the estuary. In 1988, approximately 30 million gallons of sewage per day were produced while only 17 million gallons were collected. The remaining 13 million gallons emptied directly into the Tijuana River and estuary (Seamans, 1988). Breaks in the Tijuana sewer line, which carried collected sewage to an ocean outfall, were also common.

Recent U.S. projects have reduced the threat of sewage pollution. An interceptor on the Tijuana River, completed in early October 1991, diverts approximately 15 million gallons of sewage a day to the San Diego wastewater facility (Zedler, 1992). A sewage treatment plant is planned for the U.S. side of the border, and a new ocean outfall is under evaluation.

Sampling Design

Two basic sampling designs were used to meet both SWRCB's and NOAA's goals. A directed point sampling design was required to address SWRCB's need to identify specific toxic hot spots. A stratified random sampling design was required to address NOAA's need to evaluate spatial extent of pollution. This has resulted in a data set of 350 samples collected between October, 1992 and May, 1994. Of the 350 total samples, 229 were collected from directed point sampled stations and 121 were collected from randomly sampled stations.

When directed point sampling design was required, a two step process was used. Areas of interest were identified, by regional and state water board staff, for sampling during an initial "screening phase". Station locations (latitude & longitude) were predetermined by agreement with the SWRCB, NOAA, Regional Water Quality Control Boards, and DFG personnel. Changing of the site location during sediment collection was allowed only under the following conditions:

1. Lack of access to predetermined site,
2. Inadequate or unusable sediment (i.e. rocks or gravel)
3. Unsafe conditions
4. Agreement of appropriate staff

This phase of work was intended to give a broad assessment of toxicity throughout the San Diego Bay area using multiple test species and toxicity endpoints. Fifty-six stations were sampled during the period between October, 1992 and January, 1993. Chemical analysis was performed on selected samples in which toxicity results prompted further analysis. Stations which met certain criteria during the screening phase, or during the random sampling phase, were then selected for a second round of sampling, termed the "confirmation phase". During this phase sampling was replicated and chemical analysis of samples was more extensive. In addition, benthic community analysis was performed on all confirmation stations sampled during the summer of 1993. Evidence from this two step process is used to establish a higher level of certainty for stations which may later be identified as "toxic hot spots".

Stratified random sampling began in March, 1993 and continued through August, 1993, with a total of 121 stations sampled. The San Diego Bay Region was stratified into areas of similar physical characteristics or uses, such as transit channels, anchorages, marinas, commercial shipping or military uses, and designated as 95 blocks of known size (Figures 2a & 2b). Station coordinates were chosen randomly within the boundaries of each sampling block by USEPA Environmental Monitoring and Assessment Program (USEPA-EMAP) personnel using a computer program developed for that purpose. Eight alternate locations were chosen for each block, a maximum of two of which were actually sampled (Weisberg *et al.*, 1993). This stratified random design "forces"

Figure 2a
Sampling Blocks for Random Stations
San Diego Bay

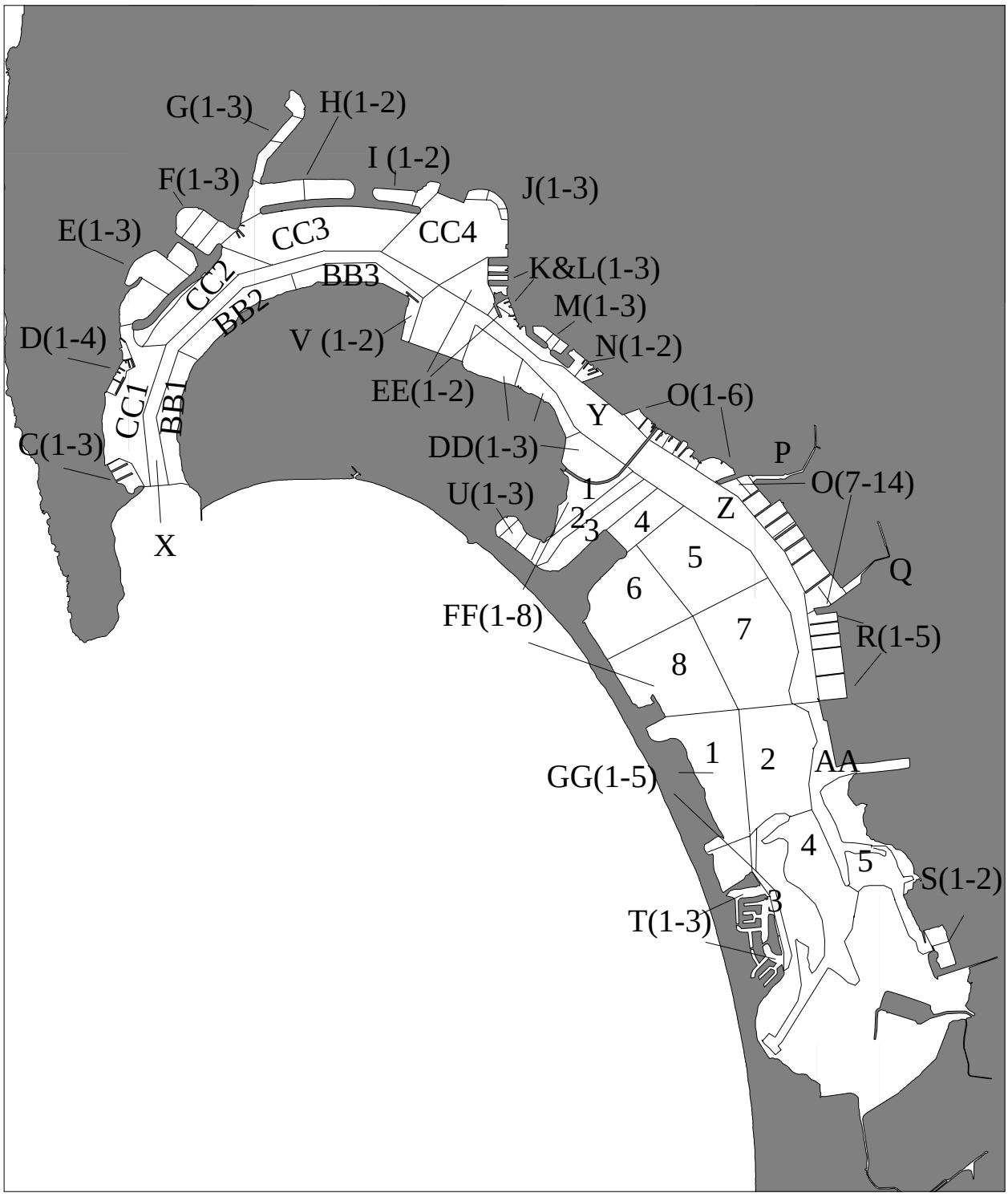
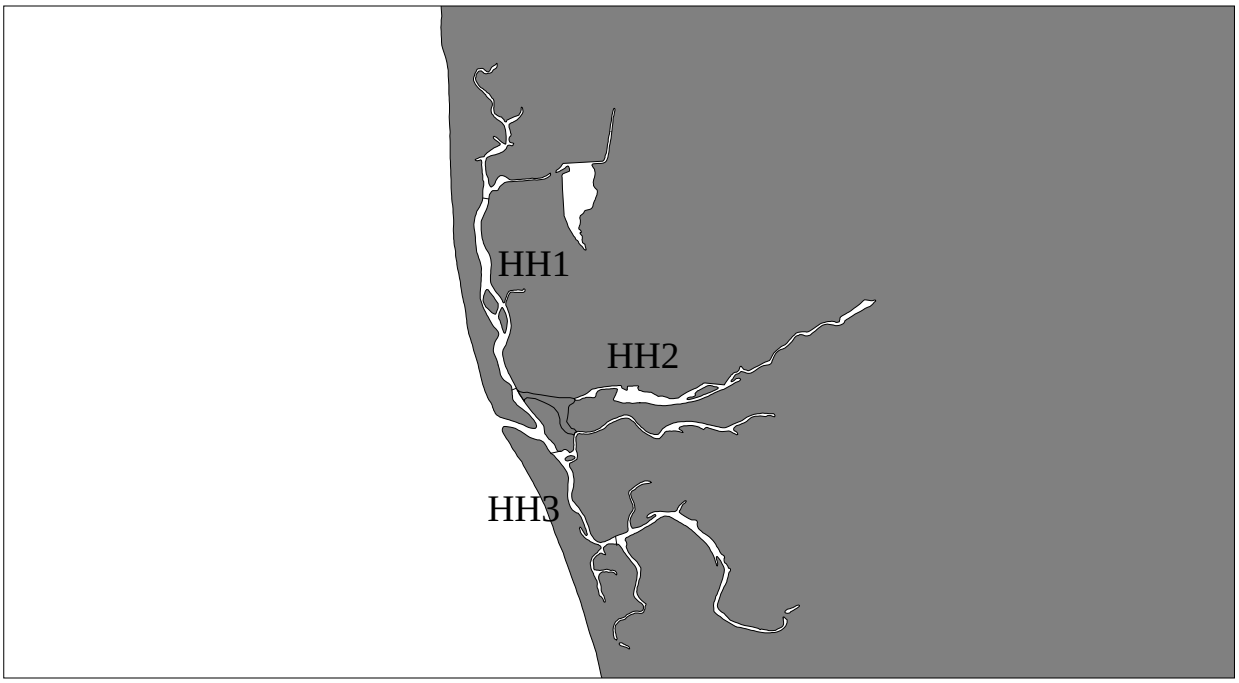


Figure 2b
Sampling Blocks for Random Stations
Mission Bay and San Diego River Estuary

Tijuana River Estuary



random samples to cover all areas of the Bay, whereas a pure random design most likely would miss some areas and oversample others. In the field, sampling was attempted at each designated location (x1-x8), beginning with x1, until a sample was retrieved which met sample acceptability criteria. For example, in block FF2, Station number 93124 was sampled at the random location x1 while in block FF3, Station #93172 was sampled at random location x4 because the grain size was too coarse at locations x1, x2 and x3. Of the 121 stations sampled, ≈15% could not be sampled at the random x1 location, due to the location being inaccessible by boat because of obstructions, vessel moorings, piers or shallow depths. Similarly, ≈3% were not sampled because the grain size was too coarse at the x1 location. Samples were collected successfully at alternate locations (x2, x3, x4, ...) for all stations where x1 was not sampled. This sampling design allows data from random stations to be used for calculation of areal extent of toxicity in the San Diego Bay Region. Chemical analyses were only performed on a limited number of random station samples.

From the combined sampling designs, a total of 350 samples were collected from 183 station locations in the San Diego Bay Region (Figure 3(a-d)). Station locations which were sampled more than once were always resampled at the original location using navigational equipment and lineups. Bioassay tests, grain size and total organic carbon analyses were performed on all 350 samples. Trace metal analysis was performed on 217 samples. Trace synthetic organic analysis was performed on 229 samples. Benthic community analysis was performed on 75 samples.

Sample Collection and Processing

Summary of Methods

Specific techniques used for collecting and processing samples are described in this section. Because collection of sediments influences the results of all subsequent laboratory and data analyses, it was important that samples be collected in a consistent and conventionally acceptable manner. Field and laboratory technicians were trained to conduct a wide variety of activities using standardized protocols to ensure comparability in sample collection among crews and across geographic areas. Sampling protocols in the field followed the accepted procedures of EMAP, NS&T, and ASTM and included methods to avoid cross-contamination; methods to avoid contamination by the sampling activities, crew, and vessel; collection of representative samples of the target surficial sediments; careful temperature control, homogenization and subsampling; and chain of custody procedures.

Cleaning Procedures

All sampling equipment (*i.e.*, containers, container liners, scoops, water collection bottles) was made from non-contaminating materials and was precleaned and packaged protectively prior to entering the field. Sample collection gear and samples were handled only by personnel wearing non-contaminating

Figure 3a
Sampling Locations
North San Diego Bay

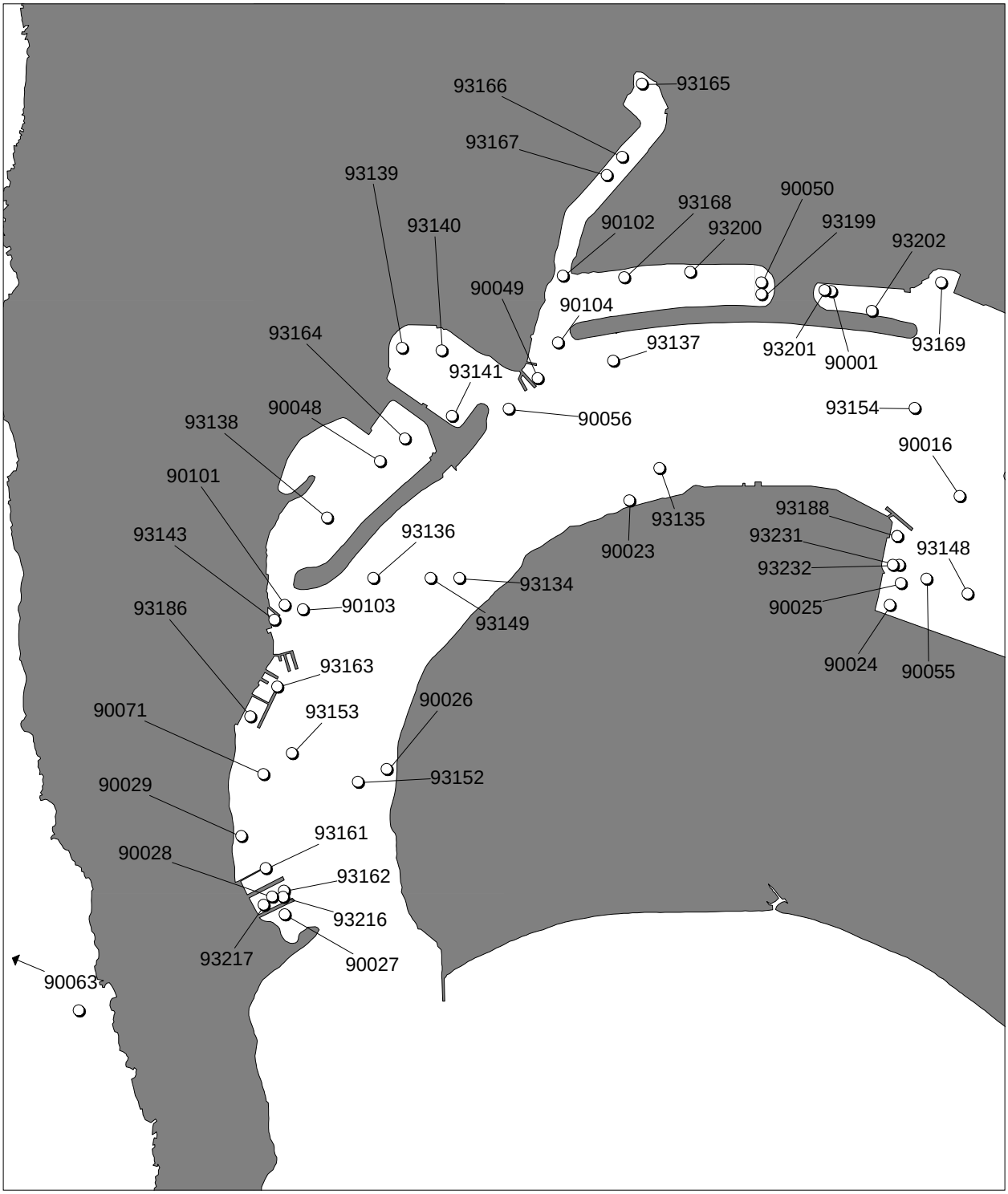


Figure 3b
Sampling Locations
Mid San Diego Bay

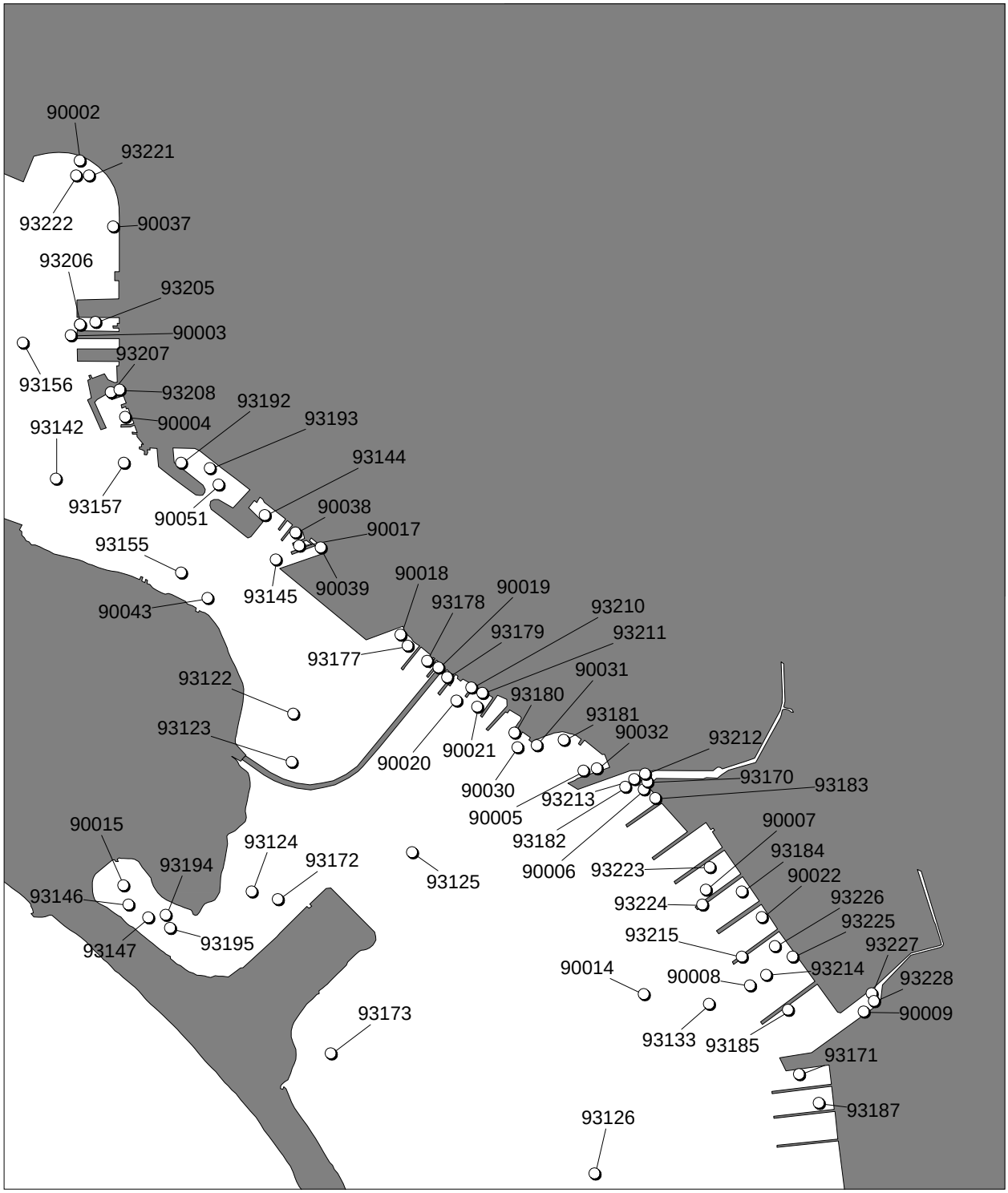


Figure 3c
Sampling Locations
South San Diego Bay

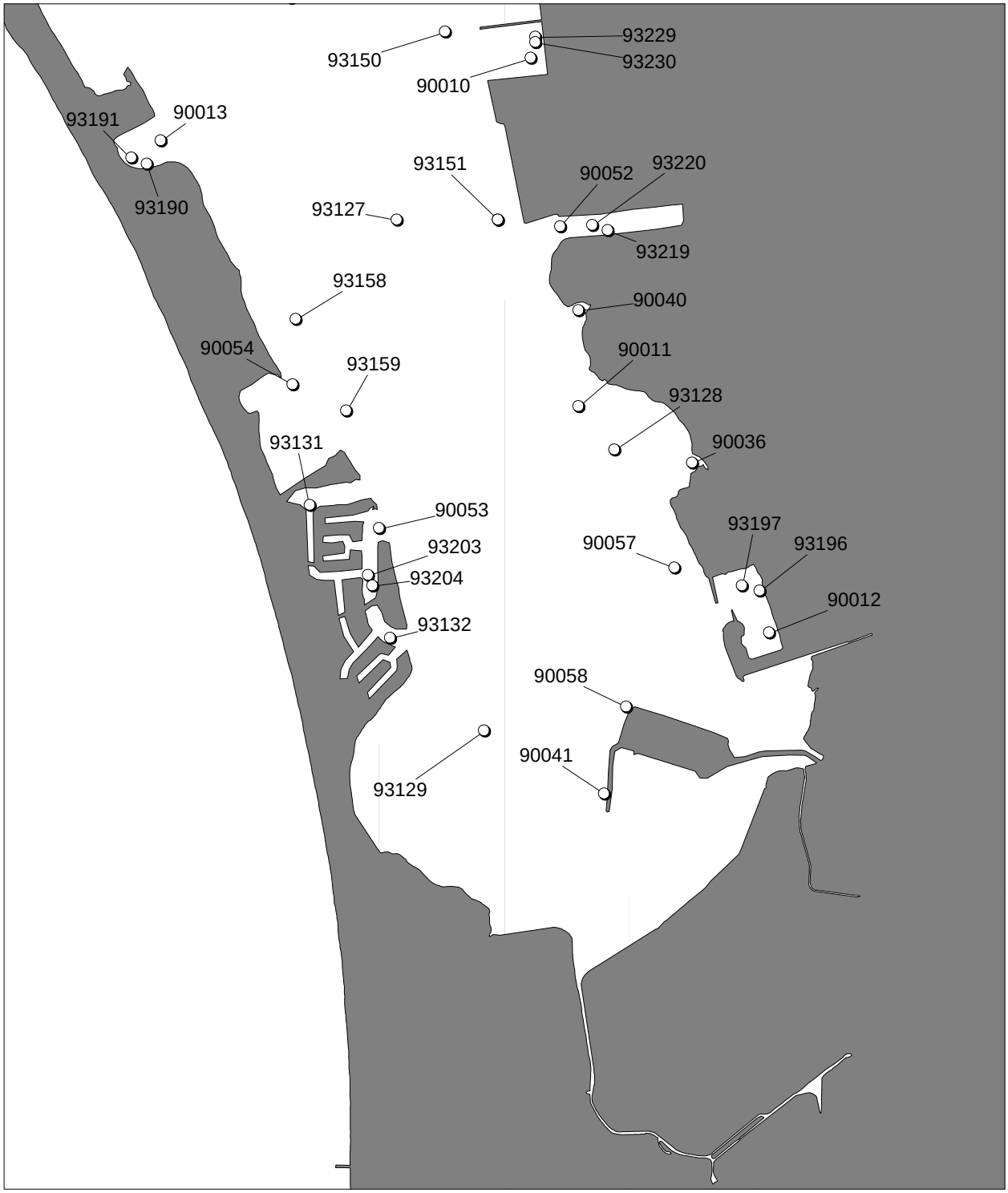


Figure 3d
Sampling Locations
Mission Bay and San Diego River Estuary

Tijuana River Estuary

polyethylene gloves. All sample collection equipment (excluding the sediment grab) was cleaned by using the following sequential process:

> Two-day soak and wash in Micro® detergent, three tap-water rinses, three deionized water rinses, a three-day soak in 10% HCl, three ASTM Type II Milli-Q® water rinses, air dry, three petroleum ether rinses, and air dry.

All cleaning after the Micro® detergent step was performed in a positive pressure "clean" room to prevent airborne contaminants from contacting sample collection equipment. Air supplied to the clean room was filtered.

The sediment grab was cleaned prior to entering the field, and between sampling stations, by utilizing the following sequential steps: a vigorous Micro® detergent wash and scrub, a sea-water rinse, a 10% HCl rinse, and a methanol rinse. The sediment grab was scrubbed with seawater between successive deployments at the same station to remove adhering sediments from contact surfaces possibly originating below the sampled layer.

Sample storage containers were cleaned in accordance with the type of analysis to be performed upon its contents. All containers were cleaned in a positive pressure "clean" room with filtered air to prevent airborne contaminants from contacting sample storage containers.

Plastic containers (HDPE or TFE) for trace metal analysis media (sediment, archive sediment, pore water, and subsurface water) were cleaned by: a two-day Micro® detergent soak, three tap-water rinses, three deionized water rinses, a three-day soak in 10% HCl or HNO_3, three Type II Milli-Q® water rinses, and air dry.

Glass containers for total organic carbon, grain size or synthetic organic analysis media (sediment, archive sediment, pore water, and subsurface water) and additional teflon sheeting cap-liners were cleaned by: a two-day Micro® detergent soak, three tap-water rinses, three deionized water rinses, a three-day soak in 10% HCl or HNO_3, three Type II Milli-Q® water rinses, air dry, three petroleum ether rinses, and air dry.

Sediment Sample Collection

All sampling locations (latitude & longitude), whether altered in the field or predetermined, were verified using a Magellan NAV 5000 Global Positioning System, and recorded in the field logbook. The primary method of sediment collection was by use of a $0.1m^2$ Young-modified Van Veen grab aboard a sampling vessel. Modifications include a non-contaminating Kynar coating which covered the grab's sample box and jaws. After the filled grab sampler was secured on the boat gunnel, the sediment sample was inspected carefully. The following acceptability criteria were met prior to taking sediment samples. If a sample did not meet all the criteria, it was rejected and another sample was collected.

1. Grab sampler was not over-filled (*i.e.*, the sediment surface was not pressed against the top of the grab).
2. Overlying water was present, indicating minimal leakage.
3. Overlying water was not excessively turbid, indicating minimal sample disturbance.
4. Sediment surface was relatively flat, indicating minimal sample disturbance.
5. Sediment sample was not washed out due to an obstruction in the sampler jaws.
6. Desired penetration depth was achieved (*i.e.*, 10 cm).
7. Sample was muddy (>30% fines), not sandy or gravelly.
8. Sample did not include excessive shell, organic or man-made debris.

It was critical that sample contamination be avoided during sample collection. All sampling equipment (*i.e.*, siphon hoses, scoops, containers) was made of non-contaminating material and was cleaned appropriately before use. Samples were not touched with un-gloved fingers. In addition, potential airborne contamination (*e.g.*, from engine exhaust, cigarette smoke) was avoided. Before sub-samples from the grab sampler were taken, the overlying water was removed by slightly opening the sampler, being careful to minimize disturbance or loss of fine-grained surficial sediment. Once overlying water was removed, the top 2 cm of surficial sediment was sub-sampled from the grab. Subsamples were taken using a precleaned flat bottom scoop. This device allowed a relatively large sub-sample to be taken from a consistent depth. When subsampling surficial sediments, unrepresentative material (e.g., large stones or vegetative material) was removed from the sample in the field. Small rocks and other small foreign material remained in the sample. Determination of overall sample quality was determined by the chief scientist in the field. Such removals were noted on the field data sheet. For the sediment sample, the top 2 cm was removed from the grab and placed in a pre-labeled polycarbonate container. Between grabs or cores, the sediment sample in the container was covered with a teflon sheet, and the container covered with a lid and kept cool. When a sufficient amount of sediment was collected, the sample was covered with a teflon sheet assuring no air bubbles. A second, larger teflon sheet was placed over the top of the container to ensure an air tight seal, and nitrogen was vented into the container to purge it of oxygen. If water depth did not permit boat entrance to a site (*e.g.*, <1 meter), divers sampled that site using sediment cores (diver cores). Cores consisted of a 10 cm diameter polycarbonate tube, 30 cm in length, including plastic end caps to aid in transport. Divers entered a study site from one end and sampled in one direction, so as to not disturb the sediment with feet or fins. Cores were taken to a depth of at least 15 cm. Sediment was extruded out of the top end of the core to the prescribed depth of 2-cm, removed with a polycarbonate spatula and deposited into a cleaned polycarbonate tub. Additional samples were taken with the same seawater rinsed core tube until the required total sample volume was attained. Diver core samples were treated the

same as grab samples, with teflon sheets covering the sample and nitrogen purging. All sample acceptability criteria were met as with the grab sampler.

Replicate benthic samples (n=5) were obtained at predetermined sites from separate deployments of the sampler. Three of the replicates were positioned according to the BPTCP sampling protocol (*e.g.*, located by previously assigned lat/long coordinates), while the other two replicates were chosen within the location range of the previous three samples. The coring device was 10 cm in diameter and 14 cm in height, enclosing a 0.0075 m^2 area. Corers were placed into sediment with minimum disruption of the surface sediments, capturing essentially all surface-active fauna as well as species living deeper in the sediment. Corers were pushed about 12 cm into the sediment and retrieved by digging along one side, removing the corer and placing the intact sediment core into a pvc screening device. Sediment cores were sieved through a 0.5 mm screen and residues (*e.g.*, organisms and remaining sediments) were rinsed into pre-labeled storage bags and preserved with a 10% formalin solution. After 3 to 4 days, samples were rinsed and transferred into 70% isopropyl alcohol and stored for future taxonomy and enumeration.

Transport of Samples

Six-liter sample containers were packed (three to an ice chest) with enough ice to keep them cool for 48 hours. Each container was sealed in precleaned, large plastic bags closed with a cable tie to prevent contact with other samples or ice or water. Ice chests were driven back to the laboratory by the sampling crew or flown by air freight within 24 hours of collection.

Homogenization and Aliquoting of Samples

Samples remained in ice chests (on ice, in double-wrapped plastic bags) until the containers were brought back to the laboratory for homogenization. All sample identification information (station numbers, etc.) was recorded on Chain of Custody (COC) and Chain of Record (COR) forms prior to homogenizing and aliquoting. A single container was placed on plastic sheeting while also remaining in original plastic bags. The sample was stirred with a polycarbonate stirring rod until mud appeared homogeneous.

All prelabeled jars were filled using a clean teflon or polycarbonate scoop and stored in freezer/refrigerator (according to media/analysis) until analysis. The sediment sample was aliquoted into appropriate containers for trace metal analysis, organic analysis, pore water extraction, and bioassay testing. Samples were placed in boxes sorted by analysis type and leg number. Sample containers for sediment bioassays were placed in a refrigerator (4^{o}C) while sample containers for sediment chemistry (metals, organics, TOC and grain size) were stored in a freezer (-20^{o}C).

Procedures for the Extraction of Pore Water

The BPTCP primarily used whole core squeezing to extract pore water. The whole core squeezing method, developed by Bender *et*

al. (1987), utilizes low pressure mechanical force to squeeze pore water from interstitial spaces. The following squeezing technique was a modification of the original Bender design with some adaptations based on the work of Fairey (1992), Carr *et al.* (1989), and Long and Buchman (1989). The squeezer's major features consist of an aluminum support framework, 10 cm i.d. acrylic core tubes with sampling ports and a pressure regulated pneumatic ram with air supply valves. Acrylic subcore tubes were filled with approximately 1 liter of homogenized sediment and pressure was applied to the top piston by adjusting the air supply to the pneumatic ram. At no time during squeezing did air pressure exceed 200 psi. A porous prefilter (PPE or TFE) was inserted in the top piston and used to screen large (> 70 microns) sediment particles. Further filtration was accomplished with disposable TFE filters of 5 microns and 0.45 microns in-line with sample effluent. Sample effluent of the required volume was collected in TFE containers under refrigeration. Pore water was subsampled in the volumes and specific containers required for archiving, chemical or toxicological analysis. To avoid contamination, all sample containers, filters and squeezer surfaces in contact with the sample were plastics (acrylic, PVC, and TFE) and cleaned with previously discussed clean techniques.

Chain of Records & Custody
Chain-of-records documents were maintained for each station. Each form was a record of all sub-samples taken from each sample. IDORG (a unique identification number for only that sample), station numbers and station names, leg number (sample collection trip batch number), and date collected were included on each sheet. A Chain-of-Custody form accompanied every sample so that each person releasing or receiving a subsample signed and dated the form.

Authorization/Instructions to Process Samples
Standardized forms entitled "Authorization/Instructions to Process Samples" accompanied the receipt of any samples by any participating laboratory. These forms were completed by DFG personnel, or its authorized designee, and were signed and accepted by both the DFG authorized staff and the staff accepting samples on behalf of the particular laboratory. The forms contain all pertinent information necessary for the laboratory to process the samples, such as the exact type and number of tests to run, number of laboratory replicates, dilutions, exact eligible cost, deliverable products (including hard and soft copy specifications and formats), filenames for soft copy files, expected date of submission of deliverable products to DFG, and other information specific to the lab/analyses being performed.

Trace Metals Analysis of Sediments

Summary of Methods
Trace Metals analyses were conducted at the California Department of Fish and Game's (CDFG) Trace Metals Facility at Moss Landing, CA. Table 1 indicates the trace metals analyzed and lists method detection limits for sediments. These methods were modifications

of those described by Evans and Hanson (1993) as well as those developed by the CDFG (California Department of Fish and Game, 1990). Samples were selected for chemical analyses by SWRCB staff based on results from toxicity tests.

Analytes and Detection Limits

Table 1 - Trace Metal Detection Limits in Sediments (μg/g, dry weight).

Aluminum	1	Antimony	0.1
Arsenic	0.1	Cadmium	0.01
Chromium	0.1	Copper	0.1
Iron	0.1	Lead	0.1
Manganese	0.05	Mercury	0.03
Nickel	0.1	Selenium	0.2
Silver	0.01	Tin	0.02
Tributyltin	0.013	Zinc	0.05

Sediment Digestion Procedures

One gram aliquot of sediment was placed in a pre-weighed Teflon vessel, and one ml concentrated 4:1 nitric:perchloric acid mixture was added. The vessel was capped and heated in a vented oven at 130^0 C for four hours. Three ml Hydrofluoric acid were added to vessel, recapped and returned to oven overnight. Twenty ml of 2.5% boric acid were added to vessel and placed in oven for an additional 8 hours. Weights of vessel and solution were recorded, and solution transfered to 30 ml polyethylene bottles.

Atomic Absorption Methods

Samples were analyzed by furnace AA on a Perkin-Elmer Zeeman 3030 Atomic Absorption Spectrophotometer, with an AS60 auto sampler, or a flame AA Perkin Elmer Model 2280. Samples, blanks, matrix modifiers, and standards were prepared using clean techniques inside a clean laboratory. ASTM Type II water and ultra clean chemicals were used for all standard preparations. All elements were analyzed with platforms for stabilization of temperatures. Matrix modifiers were used when components of the matrix interferes with adsorption. The matrix modifier was used for Sn, Sb and Pb. Continuing calibration check standards (CLC) were analyzed with each furnace sheet, and calibration curves were run with three concentrations after every 10 samples. Blanks and standard reference materials, MESS1, PACS, BCSS1 or 1646 were analyzed with each set of samples for sediments.

Trace Organic Analysis of Sediments (PCBs, Pesticides, and PAHs)

Summary of Methods

Analytical sets of 12 samples were scheduled such that extraction and analysis will occur within a 40 day window. The methods employed by the UCSC-TOF were modifications of those described by Sloan *et al*. (1993). Tables 2 and 3 indicate the pesticides, PCBs, and PAHs currently analyzed and list method detection limits for sediments on a dry weight basis.

Analytes and Detection Limits

Table 2. Organochlorine Pesticides Analyzed and Their Detection Limits in Sediment, ng/g dry weight.

Aldrin	0.5
cis-Chlordane	0.5
trans-Chlordane	0.5
alpha-Chlordene	0.5
gamma-Chlordene	0.5
Chlorpyrifos	1.0
Dacthal	0.2
o,p'-DDD	1.0
p,p'-DDD	0.4
o,p'-DDE	1.0
p,p'-DDE	1.0
p,p'-DDMS	3.0
p,p'-DDMU	2.0
o,p'-DDT	1.0
p,p'-DDT	1.0
p,p'-Dichlorobenzophenone	3.0
Dieldrin	0.5
Endosulfan I	0.5
Endosulfan II	1.0
Endosulfan sulfate	2.0
Endrin	2.0
Ethion	2.0
alpha-HCH	0.2
beta-HCH	1.0
gamma-HCH	0.2
delta-HCH	0.5
Heptachlor	0.5
Heptachlor Epoxide	0.5
Hexachlorobenzene	0.2
Methoxychlor	1.5
Mirex	0.5
cis-Nonachlor	0.5
trans-Nonachlor	0.5
Oxadiazon	2.0
Oxychlordane	0.5
Toxaphene	10

Table 3. PCB Congeners and PAHs Analyzed and Their Detection Limits in Sediment, ng/g dry weight.

NIST Congeners:

PCB Congener 8	PCB Congener 128
PCB Congener 18	PCB Congener 138
PCB Congener 28	PCB Congener 153
PCB Congener 44	PCB Congener 170
PCB Congener 52	PCB Congener 180
PCB Congener 66	PCB Congener 187
PCB Congener 87	PCB Congener 195
PCB Congener 101	PCB Congener 206

Table 3 (cont.). PCB Congeners and PAHs Analyzed and Their Detection Limits in Sediment, ng/g dry weight.

PCB Congener 105	PCB Congener 209
PCB Congener 118	

Additional Congeners:

PCB Congener 5	PCB Congener 137
PCB Congener 15	PCB Congener 149
PCB Congener 27	PCB Congener 151
PCB Congener 29	PCB Congener 156
PCB Congener 31	PCB Congener 157
PCB Congener 49	PCB Congener 158
PCB Congener 70	PCB Congener 174
PCB Congener 74	PCB Congener 177
PCB Congener 95	PCB Congener 183
PCB Congener 97	PCB Congener 189
PCB Congener 99	PCB Congener 194
PCB Congener 110	PCB Congener 201
PCB Congener 132	PCB Congener 203

All individual PCB Congener detection limits were 1 ng/g dry weight.

Aroclors:

Aroclor 5460	50

Polycyclic Aromatic Hydrocarbons

Naphthalene	5
2-Methylnaphthalene	5
1-Methylnaphthalene	5
Biphenyl	5
2,6-Dimethylnaphthalene	5
Acenaphthylene	5
Acenaphthene	5
2,3,5-Trimethylnaphthalene	5
Fluorene	5
Phenanthrene	5
Anthracene	5
1-Methylphenanthrene	5
Fluoranthrene	5
Pyrene	5
Benz[a]anthracene	5
Chrysene	5
Benzo[b]fluoranthrene	5
Benzo[k]fluoranthrene	5
Benzo[e]pyrene	5
Benzo[a]pyrene	5
Perylene	5
Indo[1,2,3-cd]pyrene	5
Dibenz[a,h]anthracene	5
Benzo[ghi]perylene	5

Extraction and Analysis
Samples were removed from the freezer and allowed to thaw. A 10 gram sample of sediment was removed for chemical analysis and an independent 10 gram aliquot was removed for dry weight determinations. The dry weight sample was placed into a pre-weighed aluminum pan and dried at 110◦C for 24 hours. The dried sample was reweighed to determine the sample's percent moisture. The analytical sample was extracted 3 times with methylene chloride in a 250-mL amber Boston round bottle on a modified rock tumbler. Prior to rolling, sodium sulfate, copper, and extraction surrogates were added to the bottle. Sodium sulfate dehydrates the sample allowing for efficient sediment extraction. Copper, which was activated with hydrochloric acid, complexes free sulfur in the sediment.

After combining the three extraction aliquots, the extract was divided into two portions, one for chlorinated hydrocarbon (CH) analysis and the other for polycyclic aromatic hydrocarbon (PAH) analysis.

The CH portion was eluted through a silica/alumina column, separating the analytes into two fractions. Fraction 1 (F1) was eluted with 1% methylene chloride in pentane and contains > 90% of p,p'-DDE and < 10% of p,p'-DDT. Fraction 2 (F2) analytes were eluted with 100% methylene chloride. The two fractions were exchanged into hexane and concentrated to 500 µL using a combination of rotary evaporation, controlled boiling on tube heaters, and dry nitrogen blow downs.

F1 and F2 fractions were analyzed on Hewlett-Packard 5890 Series gas chromatographs utilizing capillary columns and electron capture detection (GC/ECD). A single 2 µl splitless injection was directed onto two 60m x 0.25mm i.d. columns of different polarity (DB-17 & DB-5; J&W Scientific) using a glass Y-splitter to provide a two dimensional confirmation of each analyte. Analytes were quantified using internal standard methodologies. The extract's PAH portion was eluted through a silica/alumina column with methylene chloride. It then underwent additional cleanup using size-exclusion high performance liquid chromatography (HPLC/SEC). The collected PAH fraction was exchanged into hexane and concentrated to 250 µL in the same manner as the CH fractions.

Total Organic Carbon Analysis of Sediments

Summary of Methods
Samples were received in the frozen state and allowed to thaw at room temperature. Source samples were gently stirred and sub-samples were removed with a stainless steel spatula and placed in labeled 20 ml polyethylene scintillation vials. Approximately 5 grams equivalent dry weight of the wet sample was sub-sampled.

Sub-samples were treated with two, 5 ml additions of 0.5 N, reagent grade HCl to remove inorganic carbon (CO^{-3}), agitated, and centrifuged to a clear supernate. Some samples were retreated with HCl to remove residual inorganic carbon. The evolution of gas during HCl treatment indicates the direct presence of inorganic carbon (CO^{-3}). After HCl treatment and decanting, samples were washed with approximately 15 ml of deionized-distilled water, agitated, centrifuged to a clear supernate, and decanted. Two sample washings were required to remove weight determination and analysis interferences.

Prepared samples were placed in a 60◦ C convection oven and allowed to come to complete dryness (approx. 48 hrs.). Visual inspection of the dried sample before homogenization was used to ensure complete removal of carbonate containing materials, (shell fragments). Two 61 mm (1/4") stainless steel solid balls were added to the dried sample, capped and agitated in a commercially available ball mill for three minutes to homogenize the dried sample.

A modification of the high temperature combustion method, utilizing a Weatstone bridge current differential was used in a commercially available instrument, (Control Equipment Co., 440 Elemental Analyzer) to determine carbon and nitrogen concentrations. The manufactures suggested procedures were followed. The methods are comparable to the validation study of USEPA method MARPCPN I. Two to three aliquotes of 5-10 mg of dried prepared sub-sample were used to determine carbon and nitrogen weight percent values. Calibration of the instrument was with known standards using Acetanilide or L-Cystine. Detection limits are 0.2 ug/mg, carbon and 0.01 ug/mg nitrogen dry weight.

The above methods and protocols are modifications of several published papers, reference procedures and analytical experimentation experience (Franson, 1981; Froelich, 1980; Hedges and Stern, 1983; MARPCPN I, 1992).

Quality Control/Quality Assurance

Quality control was tested by the analysis of National Research Council of Canada Marine Sediment Reference Material, BCSS-1 at the beginning and end of each sample analysis set (20-30 individual machine analyses). All analyzed values were within suggested criteria of $\pm$ 0.09% carbon (2.19% Average). Nitrogen was not reported on the standard data report, but was accepted at $\pm$ 0.008% nitrogen (0.195% Average) from the EPA study. Quality assurance was monitored by re-calibration of the instrument every twenty samples and by the analysis of a standard as a unknown and comparing known theoretical percentages with resultant analyzed percentages. Acceptable limits of standard unknowns were less than $\pm$ 2%. Duplicate or triplicate sample analysis variance (standard deviation/mean) greater than 7% is not accepted. Samples were re-homogenized and re-analyzed until the variance between individual runs fell below the acceptable limit of 7.0%.

Grain Size Analysis of Sediments

Summary of Methods
The procedure used combined wet and dry sieve techniques to determine particle size of sediment samples. Methods follow those of Folk (1974).

Sample Splitting and Preparation
Samples were thawed and thoroughly homogenized by stirring with a spatula. Spatulas were rinsed of all adhering sediment between samples. Size of the subsample for analysis was determined by the sand/silt ratio of the sample. During splitting, the sand/silt ratio was estimated and an appropriate sample weight was calculated. Subsamples were placed in clean, pre-weighed beakers. Debris was removed and any adhering sediment was washed into the beaker.

Wet Sieve Analysis (separation of coarse and fine fraction)
Beakers were placed in a drying oven and sediments were dried at less than 55◦C until completely dry (approximately three days). Beakers were removed from drying oven and allowed to equilibrate to room temperature for a least a half-hour. Each beaker and its contents were weighed to the nearest .01 g. This weight minus the empty beaker weight was the total sample weight. Sediments in beakers were disaggregated using 100 ml of a dispersant solution in water (such as 50g Calgon/L water) and the sample was stirred until completely mixed and all lumps disappear. The amount and concentration of dispersant used was recorded on the data sheet for each sample. Sample beakers were placed in an ultrasonic cleaner for 15 minutes for disaggregation. Sediment dispersant slurry was poured into a 63 μm (ASTM #230, 4 phi) stainless steel or brass sieve in a large glass funnel suspended over a 1L hydrometer cylinder by a ring stand. All fine sediments were washed through the sieve with water. Fine sediments were captured in a 1L hydrometer cylinder. Coarse sediments remaining in sieve were collected and returned to the original sample beaker for quantification.

Dry Sieve Analysis (coarse fraction)
The coarse fraction was placed into a preweighed beaker, dried at 55-65◦C, allowed to acclimate, and then weighed to 0.01 g. This weight, minus the empty beaker weight, was the coarse fraction weight. The coarse fraction was poured into the top sieve of a stack of ASTM sieves having the following sizes: No. 10 (2.0 mm), 18 (1.0 mm), 45 (0.354 mm), 60 (0.25 mm), 80 (0.177 mm), 120 (0.125 mm), and 170 (0.088 mm). The stack was placed on a mechanical shaker and shaken at medium intensity for 15 minutes. After shaking, each sieve was inverted onto a large piece of paper and tapped 5 times to free stuck particles. The sieve fractions were added cumulatively to a weighing dish, and the cumulative weight after each addition determined to 0.01g. The sample was returned to its original beaker, and saved until sample computations were completed and checked for errors.

Analytical Procedures
Fractional weights and percentages for various particle size fractions were calculated. If only wet sieve analysis was used, weight of fine fraction was computed by subtracting coarse fraction from total sample weight, and percent fine composition was calculated using fine fraction and total sample weights. If dry sieve was employed as well, fractional weights and percentages for the sieve were calculated using custom software on a Macintosh computer. Calibration factors were stored in the computer.

Benthic Community Analysis

Summary of Methods
Each catalogued sample was processed individually in the laboratory to obtain an accurate assessment of species diversity and abundance. All macroinvertebrates were sorted from residues under a dissecting microscope, identified to lowest possible taxon, and counted. Laboratory processing of benthic cores consists of both rough and fine sorting. Initial sorting separates animals into large taxonomic groups such as polychaetes, crustaceans, mollusks and other (*e.g.*, phoronids). Bound laboratory logbooks were maintained and used to record number of samples processed by each technician, as well as results of any sample resorts, if necessary. Sorters were required to sign and date a Milestone Progress Checksheet for each replicate sample processed. Specimens of similar taxonomic groups were placed in vials and labelled internally and externally with project, date collected, site/station information, and IDORG. Samples were selected for benthic community analysis by SWRCB staff based on results from toxicity tests.

In-house senior taxonomists and outside specialists processed and verified the accuracy of species identification and enumeration. An archived voucher specimen collection was established at this time.

Toxicity Testing

Summary of Methods
All toxicity tests were conducted at the California Department of Fish and Game's Marine Pollution Studies Laboratory (MPSL) at Granite Canyon. Toxicity tests were conducted by personnel from the Institute of Marine Sciences, University of California, Santa Cruz.

Pore Water Samples
Once at MPSL, frozen pore water samples were stored in the dark, at -12^{0}C, until required for testing. Experiments performed by the U.S. National Biological Survey have shown no effects of freezing porewater upon the results of toxicity tests (Carr *et al*., 1995). Samples were thawed on the day of a test, and pH,

temperature, salinity, and dissolved oxygen were measured in all samples to verify water quality criteria were within the limits defined for test protocol. Pore water samples with salinities outside specified ranges for each protocol were adjusted to within the acceptable range. Salinities were increased by the addition of hypersaline brine, 60 to 80 parts per thousand (ppt), drawn from partially frozen seawater. Dilution water consisted of Granite Canyon seawater (32 to 34 ppt). Water quality parameters were measured at the beginning and end of each test. Dissolved oxygen concentrations and pH were measured using an Orion EA940 expandable ion analyzer. Salinity was measured with a refractometer. Temperature of each sample was measured with a mercury thermometer.

Measurement of Ammonia and Hydrogen Sulfide

Total ammonia concentrations were measured using an Orion Model 95-12 Ammonia Electrode. The concentration of unionized ammonia was derived from the concentration of total ammonia using the following equation (from Whitfield 1974, 1978):

$$[NH_3] = [\text{total ammonia}] \times ((1 + \text{antilog}(pK_a^\circ - pH))^{-1}),$$

where pK_a° is the stoichiometric acidic hydrolysis constant for the test temperature and salinity. Values for pK_a°were experimentally derived by Khoo *et al*. (1977). The method detection limit for total ammonia was 0.1 mg/L.

Total sulfide concentrations were measured using an Orion Model 94-16 Silver/Sulfide Electrode, except that samples tested after February, 1994, were measured on a spectrophotometer using a colorimetric method (Phillips et al. in press). The concentration of hydrogen sulfide was derived from the concentration of total sulfide by using the following equation (ASCE 1989):

$$[H_2S] = [S^{2-}] \times (1 - ((1 + \text{antilog}(pK_a^\circ - pH))^{-1})),$$

where temperature and salinity dependent pK_a° values were taken from Savenko (1977). The method detection limit for total sulfide was 0.1 mg/L for the electrode method, and 0.01 mg/L for the colorimetric method. Values and corresponding detection limits for unionized ammonia and hydrogen sulfide were an order of magnitude lower than those for total ammonia and total sulfide, respectively.

Subsurface Water Samples

The subsurface water toxicity tests are water column toxicity tests (abalone development, mussel development, etc..) performed on water collected with the modified Van Veen grab. A water sample bottle on the frame of the grab and a stopper is pulled as the jaws of the grab close for a sediment sample. The water sample is consequently collected approximately 0.5 meters above the bottom. Subsurface water samples were held in the dark at 4^0C until testing. Toxicity tests were initiated within 14 days of

the sample collection date. Water quality parameters, including ammonia and sulfide concentrations, were measured in one replicate test container from each sample in the overlying water as described above. Measurements were taken at the beginning and end of all tests.

Sediment Samples
Bedded sediment samples were held at 4^0C until required for testing. All *Rhepoxynius abronius* and *Neanthes arenaceodentata* solid phase sediment tests were initiated within 14 days of the sample collection date. All sediment samples were processed according to procedures described in ASTM (1992). Water quality parameters, including ammonia and sulfide concentrations, were measured in one replicate test container from each sample in the overlying water as described above. Measurements were taken at the beginning and end of all *Rhepoxynius* and *Neanthes* tests, and during overlying water renewals in the *Neanthes* tests.

Sea Urchin Larval Development Test
The sea urchin (*Strongylocentrotus purpuratus*) larval development test was conducted on all pore water samples. Details of the test protocol were given in Dinnel (1992). A brief description of the method follows.

Sea urchins were collected from the Monterey County coast near Granite Canyon, and held at MPSL at ambient seawater temperature and salinity (approx. 32±2 ppt) until testing. Adult sea urchins were held in complete darkness to preserve gonadal condition. On the day of a test, urchins were induced to spawn in air by injection with 0.5M KCl. Eggs and sperm collected from the urchins were mixed in seawater at a 500 to 1 sperm to egg ratio, and embryos were distributed to test containers within 1 hour of fertilization. Test containers were polyethylene-capped, sea-water leached, 20ml glass scintillation vials containing 5 mls of pore water. Each test container was inoculated with approximately 150 embryos (30/ml). All pore water samples were tested at three concentrations: 100, 50 and 25% pore water, each having three replicates. Pore water samples were diluted when necessary with one micron-filtered Granite Canyon seawater. Laboratory controls were included with each set of samples tested. Controls include a dilution water control consisting of Granite Canyon seawater, a brine control with all samples that require brine adjustment, and in some tests a frozen seawater control consisting of Granite Canyon seawater that has been frozen along with the pore water samples. Tests were conducted at ambient seawater salinity (usually 33±2 ppt). A positive control reference test was conducted concurrently with each pore water test using a dilution series of copper chloride as a reference toxicant.

After an exposure of 72 or 96 hours (no difference in results was detectable between these periods), larvae were fixed in 5% buffered formalin. Approximately 100 larvae in each container were examined under an inverted light microscope at 100x to determine the proportion of normally developed larvae as

described by Dinnel (1992). Visual clues used to identify embryos as normal included development of skeletal rods (spicules) that extend beyond half the length of the larvae and normal development of a three part gut. Slow growing embryos were considered abnormal.

Percent normal development was calculated as:

$$\frac{\text{(Number of normally developed larvae) X 100}}{\text{(Total number of observed larvae + number of abnormal larvae)}}$$

Sea Urchin Fertilization Test
The sea urchin (*Strongylocentrotus purpuratus*) fertilization test was conducted on pore water samples. Details of the test protocol were described in Dinnel *et al*. (1987).

Sea urchins were from the same stock described for the sea urchin larval development test. On the day of a test, urchins were induced to spawn in air by injection with 0.5M KCl. Sperm were exposed in test containers for sixty minutes before approximately 1000 eggs were added. After twenty minutes of fertilization, the test was fixed in a 5% buffered formalin solution. A constant sperm to egg ratio of 500 to 1 was used in all tests. This ratio maintained fertilization in the 70-90% range required by the test protocol. Fertilization was determined by the presence or absence of a fertilization membrane (raised chorion completely surrounding the egg). Test containers were polyethylene-capped, sea-water leached, 20ml glass scintillation vials containing 5 mls of pore water. All pore water samples were tested at three concentrations: 100, 50 and 25% pore water, each having three replicates. Pore water samples were diluted with one micron-filtered Granite Canyon seawater. Laboratory controls were included with each set of samples tested. Controls included a dilution water control consisting of Granite Canyon seawater, a brine control with all samples that require brine adjustment, and in some tests a frozen seawater control consisting of Granite Canyon seawater that has been frozen along with the pore water samples. Tests were conducted at ambient seawater salinity (usually 33±2 ppt). A positive control reference test was conducted concurrently with each pore water test using a dilution series of copper chloride as a reference toxicant. All eggs in each container were examined under an inverted light microscope at 100x, and counted as either fertilized or unfertilized.

Percent fertilization was calculated as:

$$\frac{\text{(Number of fertilized eggs) x 100}}{\text{(Number of fertilized eggs + number of unfertilized eggs)}}$$

Sea Urchin Cytogenetics Test
Analysis of cytogenetic abnormalities using sea urchin embryos followed methods described in Hose (1985). Sea urchin embryos were exposed to pore water for 48 hours then preserved in 5% buffered formalin. Embryos were placed on a clean glass

microscope slide and excess formalin removed with tissue paper. Embryos were then treated with a few drops of aceto-orcein stain (19 parts aceto-orcein:one part propionic acid) for approximately 1 to 3 minutes, and a cover slip was then applied to the darkly stained embryos. Excess stain was removed by blotting, and embryos were compressed into a monolayer by application of direct pressure. Embryo monolayer preparations were observed under oil immersion using either an Olympus BH2 or Tiyoda light microscope at 100x magnification. Cytogenetic abnormalities were observed in mitotic cells in anaphase and telophase. Possible aberrations observed followed those described in Hose (1985), including: stray or lagging chromosomes, accentric or attached chromosome fragments, and translocated or side-arm bridges . Because a majority of the embryos exposed to the 100 and 50% pore water concentrations displayed gross developmental abnormalities, mitotic aberrations were generally assessed using embryos exposed to 25% pore water.

Red Abalone Larval Development Test

The red abalone (*Haliotis rufescens*) larval development test was conducted on all subsurface water samples. Details of the test protocol were described in Anderson *et al*. (1990). The following was a brief description of the method. Adult male and female abalone were induced to spawn separately using a dilute solution of hydrogen peroxide in sea water. Fertilized eggs were distributed to the test containers within 1 hour of fertilization. Test containers were polyethylene-capped, seawater leached scintillation vials containing 10 mls of sample water. Each of five replicate test containers were inoculated with 100 embryos (10/ml).

Positive control reference tests using zinc sulfate as a reference toxicant were conducted concurrently with each batch of samples. A negative sea water control consisting of one micron-filtered Granite Canyon seawater was tested along with sub-surface water samples and zinc concentrations. After 48 hours of exposure, developing larvae were fixed in 5% buffered formalin. Approximately 100 larvae in each container were examined under an inverted light microscope at 100x to determine the proportion of veliger larvae with normal shells as described in Anderson et al. (1990).

Percent normal development was calculated as:

$$\frac{\text{(Number of normally developed larvae) x 100}}{\text{Total number of observed larvae}}$$

Amphipod Tests

Solid-phase sediment sample toxicity was assessed using the 10-day amphipod survival toxicity test protocol for *Rhepoxynius abronius* (ASTM 1993).

All test organisms were obtained from Northwest Aquatic Sciences in Yaquina Bay, Oregon. Amphipods were separated into groups of approximately 100 each, placed in polyethylene boxes containing

Yaquina Bay collection site sediment, and then shipped on ice via overnight courier. Upon arrival at Granite Canyon, the amphipods were acclimated slowly (<2 ppt per day) to 28 ppt sea water (T =15^{0}C). Once acclimated to 28 ppt, the animals were held for an additional 48 hours prior to inoculation into the test containers.

Test containers were one liter glass beakers or jars containing two cm of sediment and filled to the 700 ml line with seawater adjusted to 28 ppt using spring water or distilled well water. Test sediments were not sieved for indigenous organisms prior to testing although at the conclusion of the test, the presence of predators was noted and recorded on the data sheet. Test sediment and overlying water were allowed to equilibrate for 24 hours, after which 20 amphipods were placed in each beaker along with 28 ppt seawater to fill test containers to the one liter line. Test chambers were aerated gently and illuminated continuously at ambient laboratory light levels.

Five laboratory replicates of each sample were tested for ten days. A negative sediment control consisting of five lab replicates of Yaquina Bay home sediment was included with each sediment test. After ten days, the sediments were sieved through a 0.5 mm Nytex screen to recover the test animals, and the number of survivors was recorded for each replicate.

Positive control reference tests were conducted concurrently with each sediment test using cadmium chloride as a reference toxicant. For these tests, amphipod survival was recorded in three replicates of four cadmium concentrations after a 96 hour water-only exposure. A negative seawater control consisting of one micron-filtered Granite Canyon sea water, diluted to 28 ppt was compared to all cadmium concentrations.

Amphipod survival for each replicate was calculated as:

$$\frac{\text{(Number of surviving amphipods) X 100}}{\text{(Initial number of amphipods)}}$$

Polychaete Tests

A subset of sediment samples was tested using *Neanthes arenaceodentata*. The protocol follows procedures described by Johns *et al.* (1990). Newly emergent juvenile *Neanthes* (2 to 3 weeks old) were obtained from Dr. Donald Reish in Long Beach, California. Worms were shipped in seawater in plastic bags at ambient temperature via overnight mail. Upon arrival at MPSL, worms were allowed to acclimate gradually to 28 ppt with <2 ppt daily incremental salinity adjustments. Once acclimated, the worms were maintained for at least 48 hours, and no longer than 10 days, before the start of a test.

The test setup was similar to the amphipod test. Test containers were one liter glass beakers or jars, each containing 2 cm of sediment and filled to the 700 ml line with 28 ppt seawater. Seawater was adjusted to the appropriate salinity using spring

water or distilled well water. After test sediment and overlying water were allowed to equilibrate for 24 hours, 5 worms were placed in each of 5 replicate beakers per sample, and 28 ppt seawater was added up to the one liter line. Test chambers were aerated and illuminated continuously during the 20-day test period. Worms were fed TetraMin® every 2 days, and water was renewed every 3 days. At the end of 20 days, samples were sieved through 0.5mm Nitex® screens, and the number of surviving worms recorded. Surviving worms were placed in pre-weighed foil in a drying oven until they reached a constant weight. Worms were weighed to the nearest 0.1mg.

Worm survival for each replicate was calculated as:

$$\frac{\text{(Number of surviving worms)} \times 100}{\text{Initial number of worms}}$$

Mean weight/worm for each replicate was calculated as:

$$\frac{\text{(Total weight) - (foil weight)}}{\text{Number of surviving worms}}$$

Positive control reference tests were conducted using cadmium chloride as a reference toxicant. Worm survival for 10 worms was recorded in three replicates of four cadmium concentrations in seawater after 96 hours of exposure. A negative seawater control consisting of one micron-filtered Granite Canyon seawater was compared to all cadmium concentrations. A negative sediment control consisting of Yaquina Bay amphipod home sediment was also included in each test.

Mussel Development Test

The bay mussel (*Mytilus edulis*) larval development test was conducted on pore water and sub-surface water samples for which salinity was in the range of 0-26 parts per thousand (ppt). Details of the test protocol are given in ASTM (1992). A brief description of the method follows.

Mussels were shipped via overnight courier and held at MPSL at ambient temperature (11-13°C) and salinity (32-34 ppt) until testing. On the day of a test, adult mussels were transferred to 25°C water to induce spawning through heat stress. Sperm and eggs were mixed in 25 ppt water to give a final sperm-to-egg ratio of 15 to 1. After approximately 20 minutes, fertilized eggs were rinsed on a 25 μm screen to remove excess sperm. Embryos were distributed to the test containers after approximately 90% of the embryos exhibited first cell cleavage (approximately 1 hour).

Test containers were polyethylene-capped, sea water-leached, 20 ml glass scintillation vials containing 10 mls of test solution. Each test container was inoculated with approximately 250 embryos (25/ml). Pore water samples were tested at 25 ± 2 ppt. Low salinity samples were adjusted to 25 ppt using frozen seawater brine. Controls consisted of one micron-filtered Granite Canyon sea water adjusted to 25 ppt, and a separate brine control consisting of sea water brine adjusted to 25 ppt with distilled water. A positive control reference test was conducted concurrently with each test using a dilution series of cadmium chloride as a reference toxicant.
After a 48-hour exposure period, larvae were fixed in 5% buffered formalin. All larvae in each container were examined under an inverted light microscope at 100x to determine the proportion of normally developed larvae as described in ASTM (1992). The percentage normally developed larvae was calculated as:

$$\frac{\text{Observed number of live normal larvae} \times 100}{\text{Mean number of live embryos inoculated at start of test}}$$

Statistical Analysis of Toxicity Test Data
A total of three hundred fifty solid-phase sediment samples were tested for toxicity to amphipods (*Rhepoxynius abronius)* as part of this study. A subset of 154 samples of solid-phase sediment samples were tested with the polychaete *Neanthes arenaceodentata*. Two hundred twenty-five pore water samples were tested using the purple sea urchin *(Strongylocentrotus purpuratus*) fertilization test; 196 samples were tested using the sea urchin larval development test; and 65 subsurface water (water column) samples were tested with the red abalone *(Haliotis rufescens)* larval development test. The bivalve mollusc *(Mytilus edulis)* larval development test was used to test eight sub-surface water and three pore water samples that had salinities below the threshold (26 ppt) selected for use of the sea urchin test.

There were three primary objectives for the toxicity testing portion of this study:
(1) Investigate the areal extent of toxicity in the San Diego Bay region by estimating the percent area considered toxic, based on toxicity test data for each individual protocol; (2) Identify those sites which were most toxic to assist in prioritization and designation of "toxic hot spots"; and (3) Evaluate the performance of each toxicity test protocol.

The first objective (investigating the spatial extent of toxicity) was primarily for use of the National Oceanic and Atmospheric Administration (NOAA)- National Status and Trends Program. The second objective (identifying and prioritizing individual sites as "toxic hot spots") was primarily for the California State Water Resources Control Board.

The different objectives required different sampling designs and different statistical approaches. The first objective, determination of the areal extent of toxicity, was accomplished through a process this report will refer to as the "EMAP approach": statistical procedures that compared samples from

randomly selected stations against the test controls. In this approach, classification of a particular test sample as "toxic" was determined by a two step statistical approach comparing test samples to laboratory controls, as described below.

To accomplish the second objective, distinguishing the most toxic stations in the region to assist in the designation and prioritization of "toxic hot spots", a relatively new statistical method was employed, termed the "reference envelope approach". This approach compared organism response (e.g. % survival) from an individual test sample with mean organism response from a group of reference sites presumed to represent optimal ambient conditions in the San Diego Bay region. Optimal ambient conditions are defined as indicative of conditions that can be found within the study area at sites that have relatively low pollutant concentrations and relatively undisturbed benthic communities. This method was intended to refine the definition of sample toxicity in order to identify a subset of toxic sites that were of greatest concern. This method is also described in detail below.

It should be noted that the EMAP approach and the reference envelope approach are distinctly different, yet complementary, statistical methods for determining toxicity. The intent of using two approaches is to identify non-toxic, significantly toxic and highly toxic locations based on multiple analyses of the data, for ranking toxicity results in a tiered approach.

EMAP Approach for Determining Spatial Extent of Toxicity

The "San Diego Bay Region" incorporates three non-connecting water bodies: San Diego Bay, Mission Bay and Tijuana Slough. Ideally these water bodies should be treated as discrete areas and analyzed separately to determine percent area toxic for each. However, the number of samples from Mission Bay and Tijuana Slough were 13 and 6, respectively, and these were considered too few to accurately represent toxicity in a frequency distribution.

Consequently, data from all three water bodies were combined in this report to determine the percentage of total area that was toxic.

In this analysis, sample toxicity was determined using procedures described by Schimmel *et al.* (1991); a method used in the EPA Environmental Monitoring Assessment Program (EMAP) and in similar NOAA studies nationwide (e.g., Long *et al.*, 1994). Using the EMAP approach, samples were defined as toxic if the following two criteria were met: (1) there was a significant difference in mean organism response (e.g. percent survival) between a sample and the control as determined using a t-test, and (2) mean organism response in the toxicity test was less than 80% of the laboratory control value. The t-test generates a t statistic by dividing the difference between control and test sample response by an expression of the variance between laboratory replicates. If the variation between control and test sample is sufficiently greater than the variation among laboratory replicates, the t-test

indicates a significant difference in response. A "separate variance" t-test was used to adjust the degrees of freedom to account for variance heterogeneity among samples (SYSTAT, 1992).

The second criterion, that sample response must be less than 80% of the control value to be considered toxic, is useful in eliminating those samples that were statistically different from controls only because of a very small variance among laboratory replicates. For example, a sample that had 90 ± 2 % *Rhepoxynius* survival would be significantly different from a control with survival of 96 ± 2 %, and would therefore be considered toxic based on a simple t-test even though the biological significance of this response would be negligible. By adding the second criterion, any sample with percent survival exceeding 80% of the controls would be considered non-toxic. The 80% level was established by examination of numerous amphipod toxicity data sets (Thursby and Schlekat, 1993). These researchers found that samples with survival less than 80% relative to controls were significantly different from controls about 90% of the time. Preliminary analyses of *Rhepoxynius* test data from the BPTCP indicate a similar level of statistical sensitivity. Based on this observation, the 80% criterion has been adopted previously (Schimmel *et al.*, 1991; USEPA/USACOE, 1991). Samples identified as toxic according to these criteria were used to estimate the percent of total area toxic within the San Diego Bay region.

Using Cumulative Distribution Frequencies to Characterize Spatial Extent

The stratified random sampling design, allowed 121 of the total 350 samples collected in this study, to be used to estimate the areal extent of toxicity. Samples collected using directed sampling (non-random sampling directed to areas of particular characteristics) were not included in this analysis since they may have been biased toward increased contamination. Directed non-random sampling was designed to address the State and Regional Water Quality Boards objective to identify and prioritize potential toxic hot spots. Samples were collected from randomly selected stations within 95 non-overlapping mapped blocks of known area in the San Diego Bay region (Figure 2). Total area sampled, calculated as the sum of all 95 block areas, was 40.9 km^2. The estimate of spatial toxicity was determined from cumulative distribution frequencies (CDFs) that relate toxicity response to percent of total sampled area. CDF calculations follow procedures used by both EMAP and NS&T.

CDFs were determined using calculated areas of each block normalized to the number of samples per block. Block areas were calculated using a planimeter on NOAA National Ocean Service navigation chart (means of three trials), calibrated to the scale of the charts. Because no more than two samples were collected per block, numbers of toxic samples per block ranged from 0 to 2, representing 0%, 50% or 100% of a given block area. By combining the blocks with their toxicity designations in a cumulative manner, the CDFs indicate the percentage of total area sampled that was toxic. Sample toxicity was determined from comparisons

with laboratory controls as described above in the EMAP approach; each sample with a mean significantly different from, and less than 80% of, the laboratory control mean was considered toxic. Calculations used to derive percent areas determined to be toxic are shown on worksheets in Appendix F. CDFs were generated from toxicity tests using *Rhepoxynius* survival (solid phase) and *Strongylocentrotus* larval development (pore water). There were insufficient data from randomly selected sites to generate CDFs for *Haliotis*, *Mytilus* and *Neanthes* tests.

The Reference Envelope Approach for Determining Toxicity

The second objective of this study was to assist in the identification of "toxic hotspots", where adverse biological impacts are observed in areas with localized concentrations of pollutants. Identification of problem sites was an essential step in prioritizing efforts to improve sediment and water quality through regulation and remediation programs. While it was possible large areas of San Diego Bay may be degraded to some extent, logistical constraints required efforts be focused on localized areas that were significantly more toxic than optimal ambient conditions that exist in the greater portion of the bay. In this study, a "reference envelope" statistical approach was employed (Smith,1995) to identify samples that exhibit significantly greater toxicity than expected in San Diego Bay as a whole.

The reference envelope approach uses data from "reference sites" to characterize the response expected from sites in the absence of localized pollution. Using data from the reference site population, a tolerance limit was calculated for comparison with data from test sites. Samples with toxicity values greater than the tolerance limit were considered toxic relative to the optimal ambient condition of the Bay.

This relative standard established using reference sites was conceptually different from what might be termed the absolute standard of test organism response in laboratory controls. Rather than comparing sample data to control data using t-tests, with laboratory replication used to characterize the variance component (as in the "EMAP approach" described above), the reference envelope approach compared sample data against a percentile of the reference population of data values, using variation among reference sites as the variance component. The reference envelope variance component, therefore, included variation among laboratory replicates, among field replicates, among sites, and among sampling events.

The reference stations were assumed to be a random sample from an underlying population of reference locations that serve as a standard for what we considered relatively non-impacted conditions. The toxicity measured at different reference locations will vary due to the different local conditions that can affect the toxicity results. In order to determine whether sediments from a test location were toxic, bioassay results for the test location were compared with bioassay results from the population of reference locations.

Assuming the bioassay results from the population of reference locations are normally distributed, an estimate of the probability that the test sediment is from the underlying reference station distribution can be made. For example, if the result for a test sediment was at the first percentile of the underlying reference location distribution (in the direction of toxicity), then there would be about a 1% chance that the test sediment was from the distribution of reference locations. The toxicity level at the first percentile of the reference distribution is not known because there were only limited samples from the underlying distribution and only an estimate could be made of where the first percentile lies. If an estimate of the first percentile value was made a large number of times, using different random samples from the reference distribution, a (non-central t) distribution of estimates, with the distribution mode at the actual first percentile would be obtained (Figure 4). In Figure 4, it can be seen from the distribution of estimates that about one half of the time the estimate from the sample was above the actual first percentile. Ideally, identification of an estimated toxicity value would cover the actual first percentile for a large percentage of the estimates (say 95% of the time). Such a value can be obtained from the left tail of the distribution of estimates where 5% of the estimates are less than the chosen value. The definition of p is the percentile of interest, and alpha is the acceptable error probability associated with an estimate of the pth percentile. Thus, in this example, p=1 and alpha = .05.

The toxicity level can be computed that will cover the pth percentile 1 minus alpha proportion of the time as the lower bound (L) of a tolerance interval (Vardeman 1992) as follows.

$$L = X_r - [\, g_{a,p,n} * S_r \,]$$

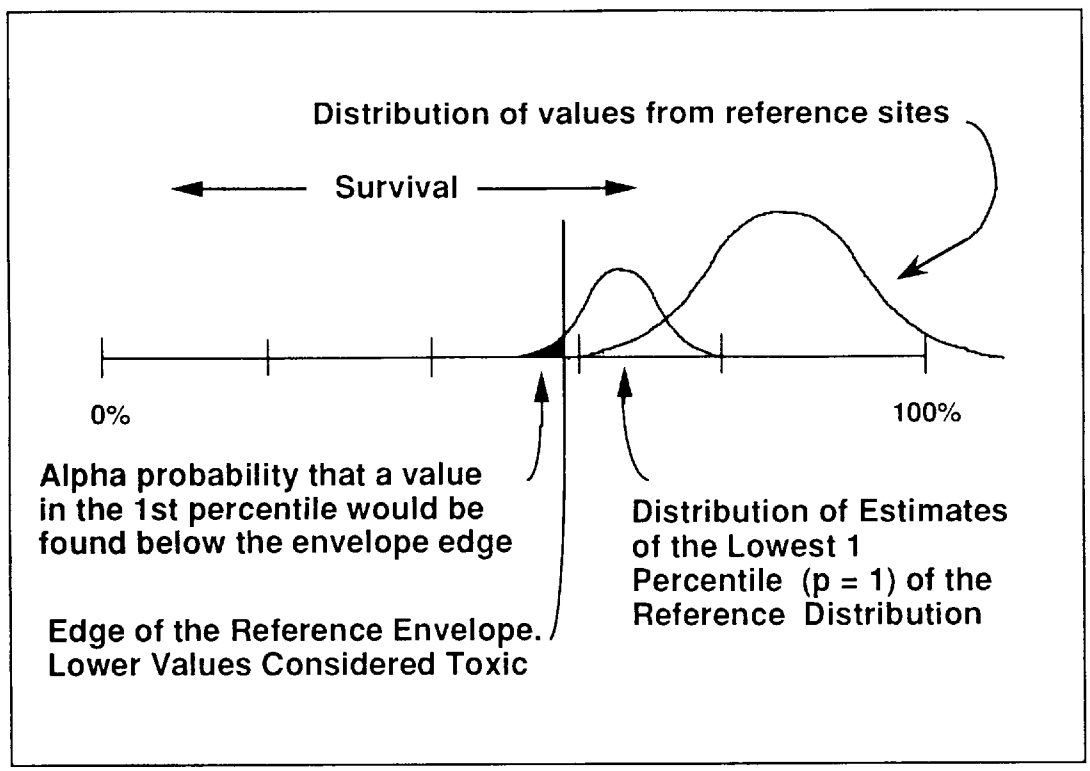
where X_r is the mean of the sample of reference stations, S_r is the standard deviation of the toxicity results among the reference stations, and n is the number of reference stations. The g values, for the given alpha, p, and n values, can be obtained from tables in Hahn and Meeker (1991) or Gilbert (1987). S contains the within- and between-location variability expected among reference locations. If the reference stations are sampled at different times, then S will also incorporate between-time variability. The "edge of the reference envelope" (L) represents a cutoff toxicity level used to distinguish toxic from non-toxic sediments. The value used for p will depend on the level of certainty needed for a particular regulatory situation. In this study a p value equal to 1% was chosen, to distinguish only the most toxic samples, that is, samples having a 95% certainty of being in the most toxic 1%.

Reference Station Selection for Reference Envelope

Reference stations were selected to represent optimal ambient conditions available in San Diego Bay, based on available chemistry and benthic community data. Toxicity data were not

used in the selection process. Stations were selected if both of the following criteria were met: 1) the benthic communities appeared relatively undisturbed (based on indices described in the benthic community analysis section), and 2) sediment chemical concentrations were below Effects Range Median (ERM) levels (Long *et al.*, 1995) and Probable Effects levels (PELs) (McDonald, 1994). Among all stations, both randomly and non-randomly

Figure 4. Schematic illustration of the method for determining the lower tolerance interval bound (edge of the reference envelope) to determine sample toxicity relative to a percentile of the reference site distribution.



selected, a total of 75 samples were analyzed for toxicity, chemistry and benthic ecology in this study. After screening these 75 samples, eleven stations in the San Diego Bay region were selected as reference stations (Table 4). It should be noted these stations were not selected prior to the initiation of the study, but were selected after all of the analyses for the study were completed.

P450 Reporter Gene System

Summary of Methods

A subset of thirty sediment samples was sent to Columbia Analytical Services (CAS) in Kelso, Washington for extraction with methylene chloride. Extracts of 20 g sediment samples were evaporated to 1 ml and placed in small vials for shipment to the Carlsbad, CA laboratory of CAS where 2 μl samples were applied in triplicate to genetically engineered human liver cancer cells (101L cells) developed by Dr. Robert Tukey of the University of California, at San Diego. A previous study partially funded by the State Board (Anderson *et al.*, 1995) had demonstrated that low levels of dioxin, coplanar PCBs and selected PAHs could be detected by the P450-RGS response to the extracts. When this small volume of solvent (with extracted contaminants) is applied to approximately one million cells in 2 ml of medium, induction of the CYP1A1 gene leads to production of the detoxification enzyme, P450, and the luminescent enzyme, luciferase. When the cells are lysed (after 16 hours) and the centrifugate tested with luciferin, the amount of light measured in a luminometer is a function of the concentration and potency of the contaminants on the sediments. When the contents of a single well (containing ≈ one million cells) are centrifuged and placed in the luminometer the resulting measure is in Relative Light Units (RLU). The RLUs of the solvent blank are set to unity and by dividing all RLU readings for the reference toxicant and samples by the RLUs of the blank, the data are converted to Fold Induction (or times background). To make the data more relevant to environmental samples, the data are converted to Equivalents of Benzo(a)pyrene (BaPEq), a ubiquitous PAH compound of environmental concern (U.S. EPA, 1995). To convert mean fold induction to BaPEq in μg/g dry weight, the fold induction values are divided by sixty, which (based on a dose response curve) is the response of the assay to 1μg/ml of Benzo(a)pyrene (BaP). The μg of BaP per volume of extract (e.g. 10 μl) is adjusted to an initial volume of 1 ml and this product divided by the dry grams of sample contained in the 1 ml extract. This method can be used to calculate Equivilants for PAHs, from benz(a)anthracene to benzo(g,h,i)perylene (Table 4), as well as dioxins/furans and coplanar PCBs. Both sediments and tissues (marine mussel) from San Diego Bay have been analyzed for the presence of P450 inducing compounds in previous studies (Anderson *et al.* 1996, in press a). The detailed methods and results of P450-RGS testing with standards and sediment extracts are described in Postlind *et al.* (1994), and Anderson *et al.* (1995). In 1996, three publications will be available describing the specific test methods (ASTM, Standard Methods,and CRC Press).

TABLE 4
REFERENCE STATIONS SELECTED FOR REFERENCE ENVELOPE ANALYSIS

Station #	Station Name	IDORG #	Leg	% Fines	TOC	ERMQ	PELQ	BENTHICS	Amphipod Surv.	Urchin Devo.(25%)
93112.0	MISSION BAY A8 (x1)-REP 1	856	21	30.12	0.81	0.065	0.116	UNDEGRADED	96 ± 5	20.2 ± 1
93112.0	MISSION BAY A8 (x1)-REP 2	857	21	37.28	0.94	0.082	0.134	UNDEGRADED	98 ± 3	89 ± 4
93112.0	MISSION BAY A8 (x1)-REP 3	858	21	43.56	0.91	0.089	0.145	UNDEGRADED	94 ± 5	53.6 ± 49
93202.0	EAST BASIN I1 (x5)	842	21	46.28	1.11	0.238	0.362	UNDEGRADED	83 ± 6	67.2 ± 17
90013.0	37 SWARTZ (MARINA)	815	20	88.21	1.37	0.217	0.347	UNDEGRADED	81 ± 8	73.8 ± 10
93190.0	MARINA II1 (x1)	816	20	93.97	1.22	0.219	0.356	UNDEGRADED	87 ± 12	59.4 ± 9
90053.0	35 SWARTZ (CORONADO CAYS)	843	21	91.85	1.47	0.180	0.292	UNDEGRADED	75 ± 11	29 ± 25
93108.0	MISSION BAY A4 (x1)-REP 2	860	21	64.60	1.87	0.104	0.166	UNDEGRADED	69 ± 14	78.5 ± 16
93195.0	GLORIETTA BAY U1 (x2)	823	20	48.24	0.95	0.239	0.369	UNDEGRADED	81 ± 9	0 ± 0
93194.0	GLORIETTA BAY U1 (x1)	822	20	55.80	1.14	0.232	0.371	UNDEGRADED	89 ± 7	46.3 ± 7
93231.0	CARRIER BASE V2 (x6)	1000	23	57.66	1.57	0.252	0.404	UNDEGRADED	74 ± 12	0 ± 0

None of the above samples exhibited any chemical exceedance of an ERM or PEL.
None of the above samples exhibited elevated ammonia or hydrogen sulfide during toxicity testing.
Amphipod Survival value is the mean and standard deviation from 5 laboratory replicates.
Urchin Development values are the mean and standard deviation of 5 replicates in 25% porewater.
ERM and PEL summary quotients are discussed in Appendix B and the report text.

Quality Assurance/Quality Control

Summary of Methods

Summaries of quality assurance and quality control procedures are described under separate cover in the Bay Protection and Toxic Cleanup Program Quality Assurance Project Plan (QAPP). This document describes procedures within the program which ensure data quality and integrity. Quality assurance procedures follow those of the NS&T Program to ensure comparability with other NOAA survey areas nationwide. In addition, individual laboratories prepare quality assurance evaluations of each discrete set of samples analyzed and authorized by task order. These documents were submitted to the California Department of Fish and Game for review, then forwarded to the State Water Resources Control Board for further review.

RESULTS

Tabulated data for all chemical, benthic, toxicological and P450-RGS analyses are presented in Appendices B, C, D and E. The summary data presented in the following results sections were used to demonstrate significant findings from the analysis of the full data set in Appendices B, C, and D.

Distribution of Chemical Pollutants

Chemical Specific Screening Values

There have been several recent studies associating pollutant concentrations with biological responses (Long and Morgan, 1990; MacDonald, 1992). These studies provide guidance for evaluating the degree to which sediment chemical pollutants levels are responsible for effects observed in a toxicity test. Reported values are based on individual chemical pollutants within sediments. Therefore, their application may be confounded when dealing with: biological effects which could be attributed to a synergistic effect of low levels of multiple chemicals, unrecognized chemicals, or physical parameters in the sediment which were not measured.

The National Status and Trends Program has used chemical and toxicological evidence from a number of modeling, field and laboratory studies to determine the ranges of chemical concentrations which are rarely, sometimes, or usually associated with toxicity (Long and Morgan, 1992). Evaluation of available data (Long *et al.*, 1995) has led to identification of three ranges in concentration for each chemical:

1) Minimal Effects Range: The range in concentration over which toxic effects are rarely observed:

2) Possible Effects Range: The range in concentrations over which toxic effects are occasionally observed;

3) Probable-Effects Range: The range in chemical concentrations over which toxic effects are frequently or always observed.

Two slightly different methods were used to determine these chemical ranges. One method developed by NOAA (Long and Morgan, 1990; Long *et al.*, 1995) used chemical data which were associated with a toxic biological effect. These data were used to determine the lower 10th percentile of ranked data where the chemical level was associated with an effect (Effects Range-Low, or ERL). Sediment samples in which all chemical concentrations were below the 25 ERL values were not expected to be toxic. The Effects Range-Median (ERM) reflects the 50th percentile of ranked data and represents the level above which effects are expected to occur. Effects are expected to occur occasionally when chemical concentrations fall between the ERL and ERM. The probability of toxicity was expected to increase with the number and degree of exceedances of the ERM values.

Another method identifies three ranges using chemical concentration data associated with both toxic biological effects and no observed effects (MacDonald, 1992; MacDonald, 1994; MacDonald *et al., In Press*). The ranges are identified as TEL (Threshold Effects Level) and the PEL (Probable Effects Level). TEL values were derived by taking the geometric mean of the 50th percentile of the "no effects" data and the 15th percentile of the "effects" data. The PEL values were derived by taking the geometric mean of the 85th percentile of the "no effects" data and the 50th percentile of the "effects" data. Although different percentiles were used for these two methods, they are in close agreement, usually within a factor of 2. Values reported for both methods are shown in Table 5. Neither of these methods is advocated over the use of the other in this report. Instead, both are used in the following analysis to create a weight of evidence which should help explain toxicity observed from some sediments.

A cautionary note should be included; the degree of confidence which MacDonald (1994) and Long *et al. (*1995) had in their respective guidelines varied considerably among the different chemicals. For example, they express low confidence in the values derived for nickel, mercury, DDTs, chlordane, dieldrin, and endrin. When more data becomes available regarding these chemicals and their potential effects, the guidelines may be revised, probably upward for some substances.

Primary Chemicals of Concern

Figure 5 presents a summary of the chemicals and chemical groups which exceeded ERM or PEL values at the 217 stations where complete chemical analysis was performed. Copper, mercury, zinc, total chlordane, total PCBs and the PAHs were most often found to exceed ERM or PEL values and are considered the six major chemicals or chemical groups of concern in the San Diego Bay

Table 5- Comparison of Sediment Screening Levels
Developed by NOAA and the State of Florida

SUBSTANCE	State of Florida (1) TEL	State of Florida (1) PEL	NOAA (2) ERL	NOAA (2) ERM
Organics (ug/kg- dry weight)				
Total PCBs	21.550	188.79	22.70	180.0
PAHs				
Acenaphthene	6.710	88.90	16.00	500.0
Acenaphthylene	5.870	127.89	44.00	640.0
Anthracene	46.850	245.00	85.30	1100.0
Fluorene	21.170	144.35	19.00	540.0
2-methylnaphthalene	20.210	201.28	70.00	670.0
Naphthalene	34.570	390.64	160.00	2100.0
Phenanthrene	86.680	543.53	240.00	1500.0
Total LMW-PAHs	311.700	1442.00	552.00	3160.0
Benz(a)anthracene	74.830	692.53	261.00	1600.0
Benzo(a)pyrene	88.810	763.22	430.00	1600.0
Chrysene	107.710	845.98	384.00	2800.0
Dibenz(a,h)anthracene	6.220	134.61	63.40	260.0
Fluoranthene	112.820	1493.54	600.00	5100.0
Pyrene	152.660	1397.60	665.00	2600.0
Total HMW-PAHs	655.340	6676.14	1700.00	9600.0
Total PAHs	1684.060	16770.54	4022.00	44792.0
Pesticides				
p,p'-DDE	2.070	374.17	2.20	27.0
p,p'-DDT	1.190	4.77		
Total DDT	3.890	51.70	1.58	46.1
Lindane	0.320	0.99		
Chlordane	2.260	4.79	0.50	6.0
Dieldrin	0.715	4.30	0.02	8.0
Endrin			0.02	45.0
Metals (mg/kg- dry weight)				
Arsenic	7.240	41.60	8.20	70.0
Antimony			2.00	2.5
Cadmium	0.676	4.21	1.20	9.6
Chromium	52.300	160.40	81.00	370.0
Copper	18.700	108.20	34.00	270.0
Lead	30.240	112.18	46.70	218.0
Mercury	0.130	0.70	0.15	0.7
Nickel	15.900	42.80	20.90	51.6
Silver	0.733	1.77	1.00	3.7
Zinc	124.000	271.00	150.00	410.0

(1) D.D. MacDonald, 1994

(2) Long et al., 1995

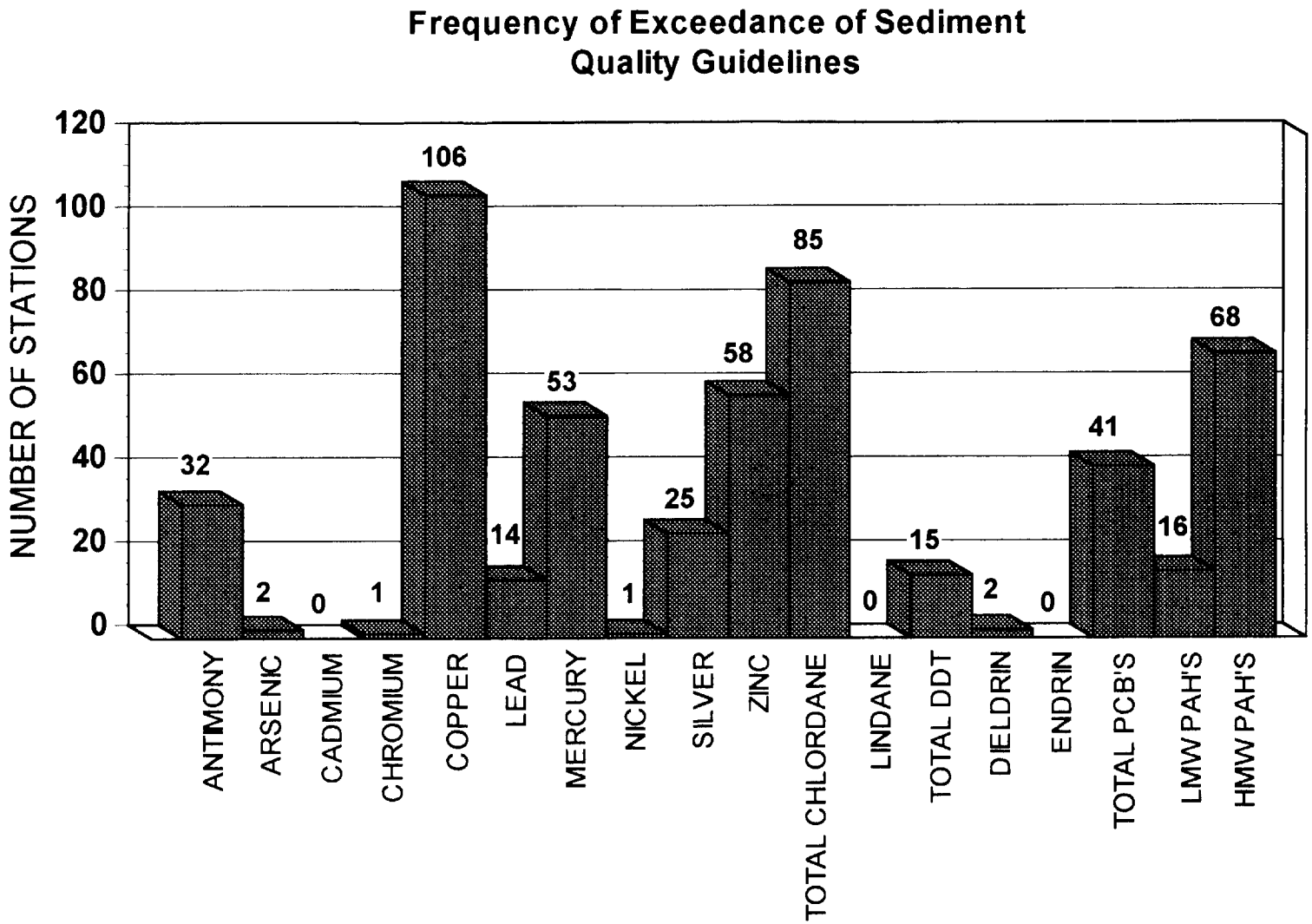


Figure 5. Number of stations which exceeded either the PEL or ERM values.

Region. MacDonald (1994) and Long *et al. (*1995) express relatively high confidence in the ERM and PEL values derived for copper, zinc, total PCBs and PAHs. Figures 6-12 map the geographical distribution of the six chemicals of concern throughout the San Diego Bay Region. Three ranges of chemical concentration are given for each chemical: (1) below the TEL, (2) between the TEL and PEL and (3) above the PEL to the maximum concentration determined.

Copper is a broad spectrum biocide which may be associated with acute and chronic toxicity, reduction in growth, and a wide variety of sublethal effects (Spear and Pierce, 1979). Elevated copper concentrations above the PEL (>108.2 mg/kg) or ERM (>270 mg/kg) were found throughout San Diego Bay (Figure 6(a-d)), with small boat harbors, commercial shipping berths and military berths most often impacted. Considering the historical use of copper based anti-fouling paint in the area, this distribution pattern is expected.

Zinc demonstrates a similar pattern of distribution, although actual exceedances of PEL levels (>271 mg/kg) or ERM levels (>410 mg/kg) only occur in the central portion of the bay, along the naval shipyard waterfront (Figure 7(a-d).

Mercury, particularly methylmercury, is highly toxic to aquatic biota. Although there is variability in sensitivity of different organisms to the substance, bioaccumulation of mercury in aquatic species has significant implications with respect to human health. PEL exceedances (> 0.696 mg/kg) and ERM exceedances (>0.71 mg/kg) of mercury were found in several small boat areas, near commercial shipping operations and predominately near naval shipyard areas (Figure 8(a-d)).

Polycyclic (polynuclear) aromatic hydrocarbons (PAHs) are base/neutral organic compounds with a fused ring structure of two or more benzene rings. They are components of crude and refined petroleum products and are also products of incomplete combustion of organic materials. Exposure to PAHs may result in a wide range of carcinogenic, teratogenic and mutagenic effects to terrestrial and aquatic organisms (Eisler, 1987). Due to their similar modes of toxic action, individual PAHs are often grouped into low and high molecular weight compounds, for concise reporting purposes. Individual PAHs used for the summations of low and high molecular weight PAHs in this report are given in Appendix B -Section VII. PAH pollution, as shown for high molecular weight PAHs in Figure 9(a-d), exceeds the PEL (>6676.14 μg/kg) or ERM (>9600 μg/kg) near commercial shipping operations and naval shipyard areas, as well as the submarine facility near the mouth of the harbor. The pattern for PEL (>1442 μg/kg) or ERM (>3160 μg/kg) exceedances of low molecular weight PAHs is similar to high molecular weight PAHs (Fig. 10(a-d)).

A significant concern is polychlorinated biphenyls (PCBs) levels found in sediments throughout San Diego Bay. PCBs are base/neutral compounds which are formed by direct chlorination of

Figure 6a
Copper Concentrations in Sediment
North San Diego Bay

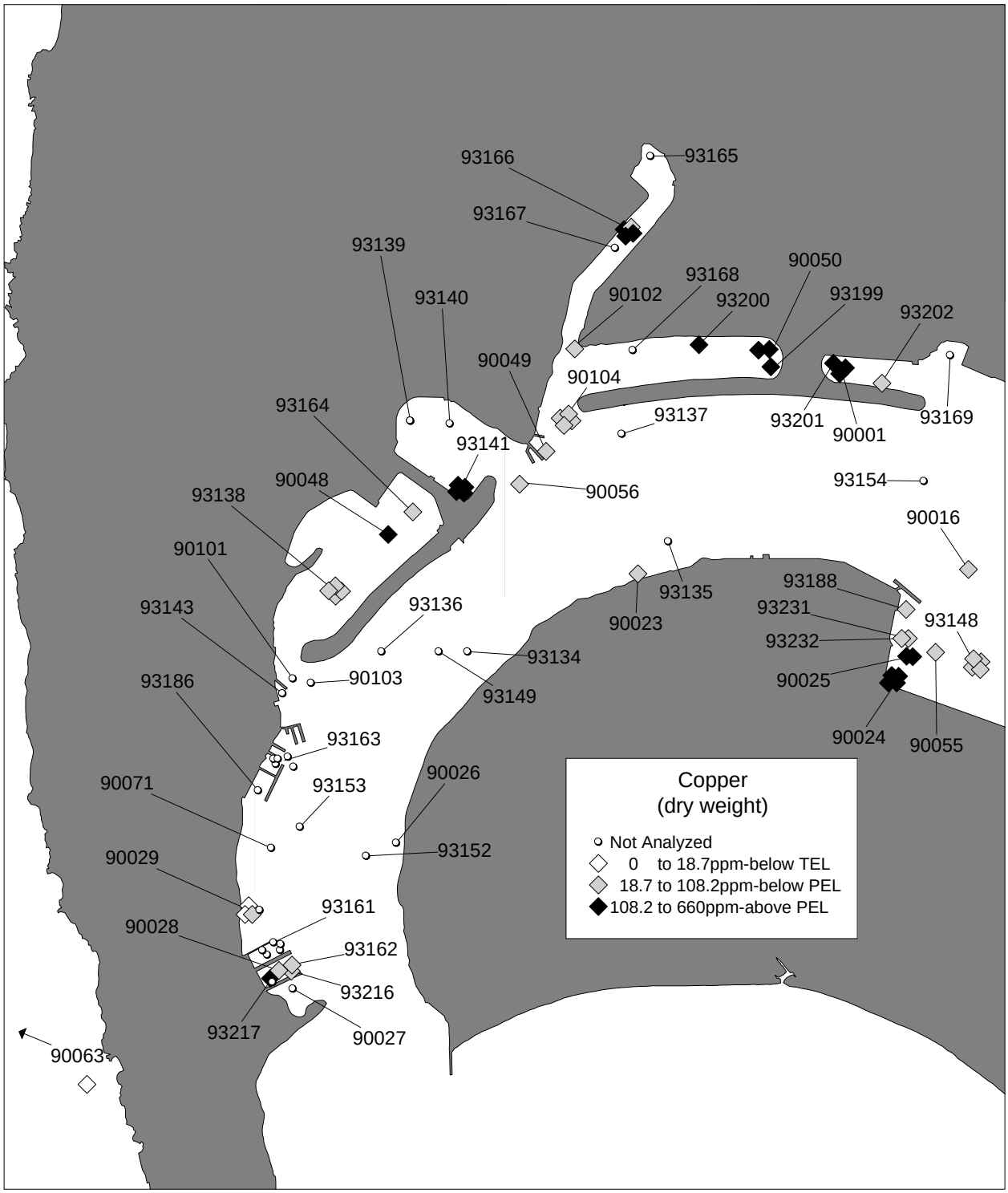


Figure 6b
Copper Concentrations in Sediment
Mid San Diego Bay

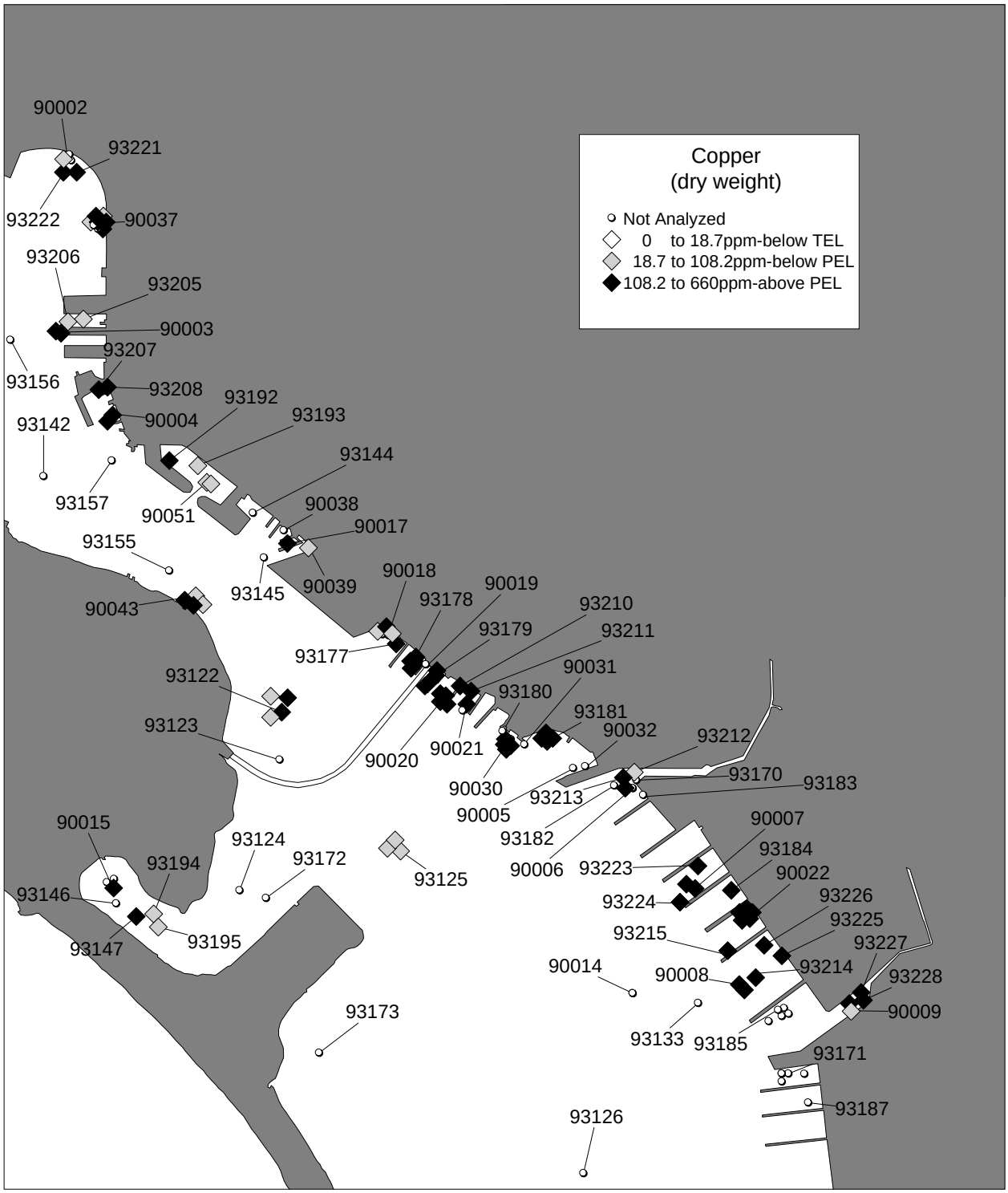


Figure 6c
Copper Concentrations in Sediment
South San Diego Bay

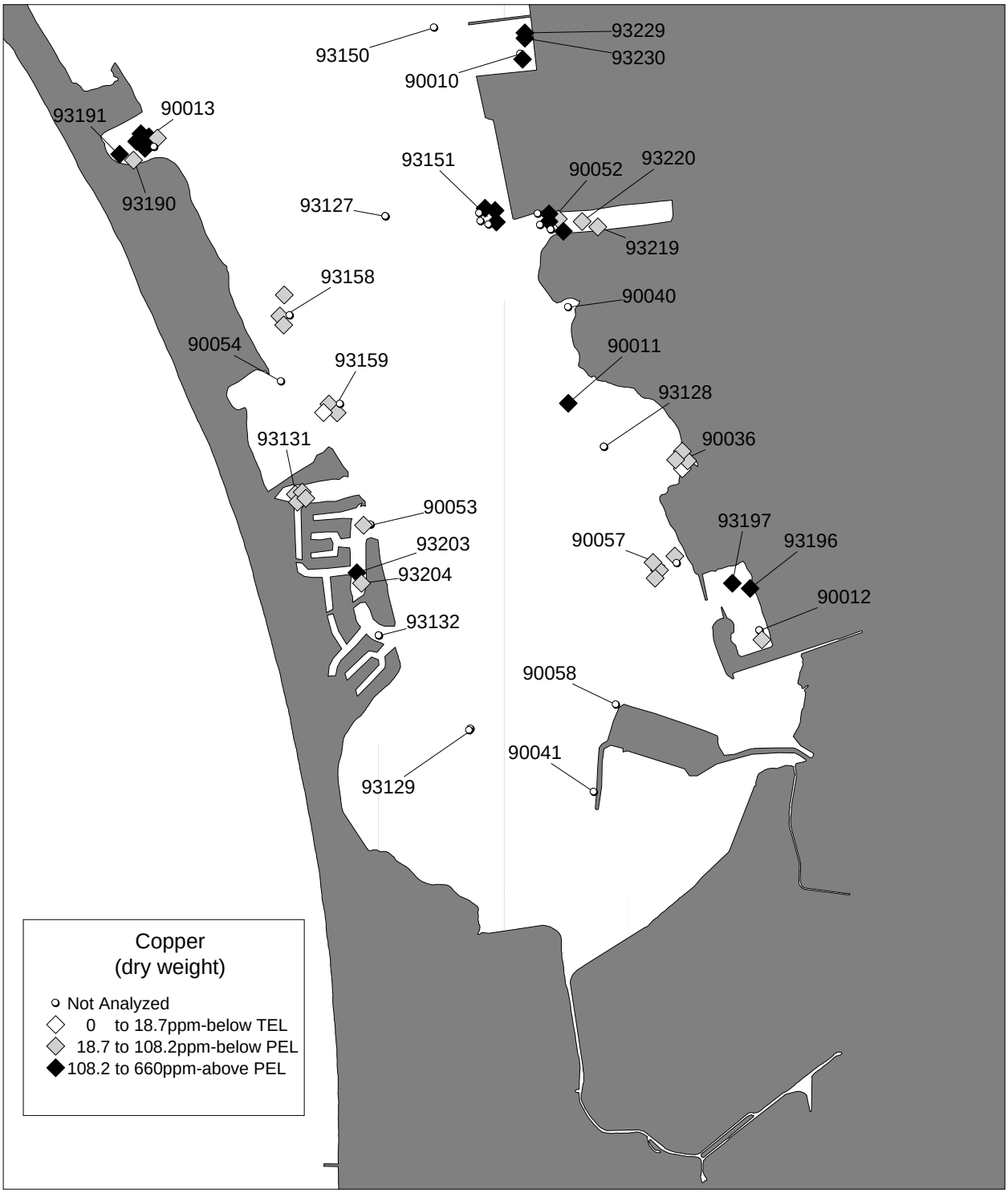
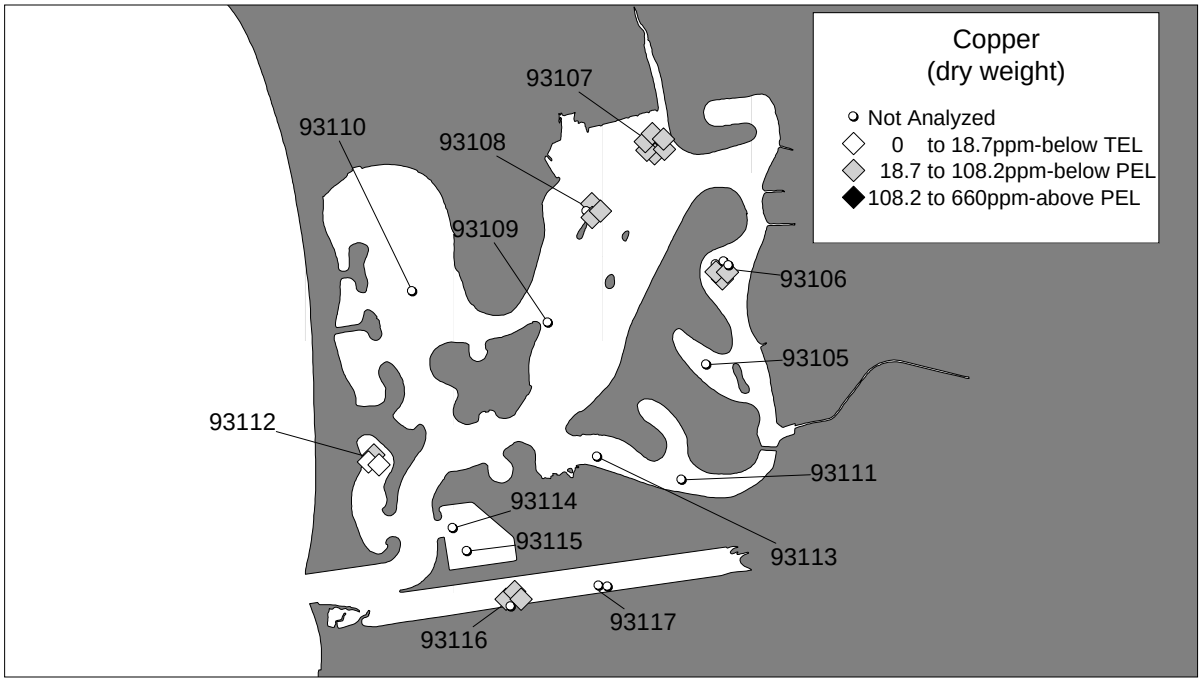


Figure 6d
Copper Concentrations in Sediment
Mission Bay and San Diego River Estuary



Tijuana River Estuary

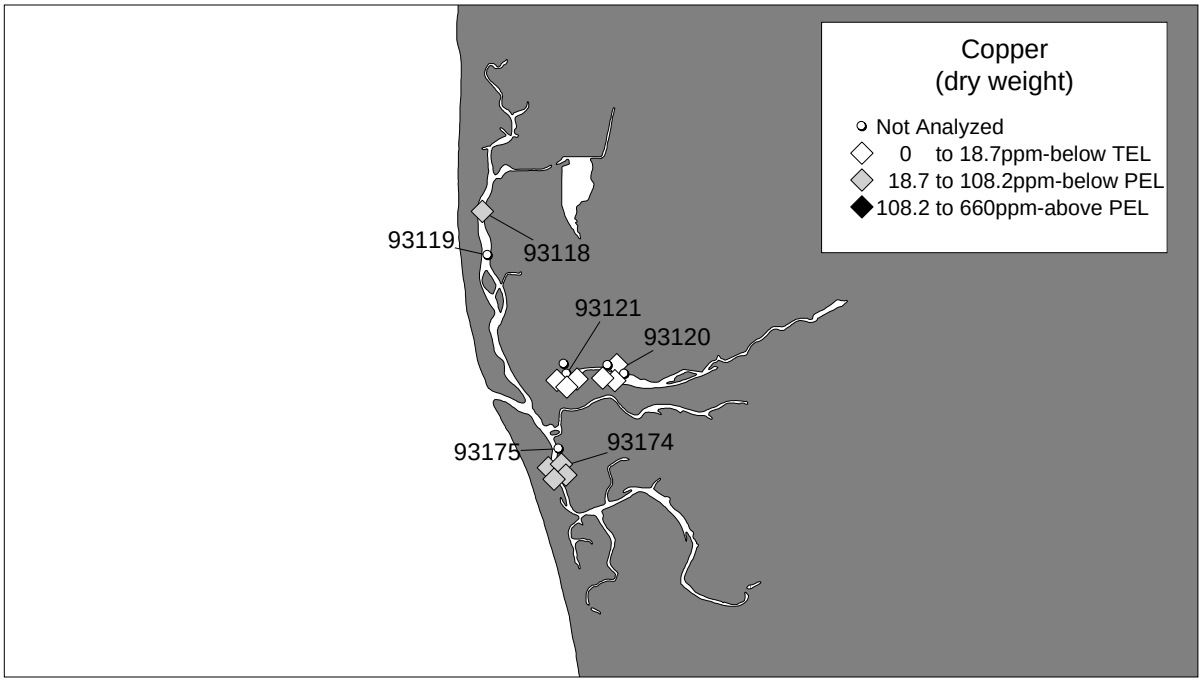


Figure 7a
Zinc Concentrations in Sediment
North San Diego Bay

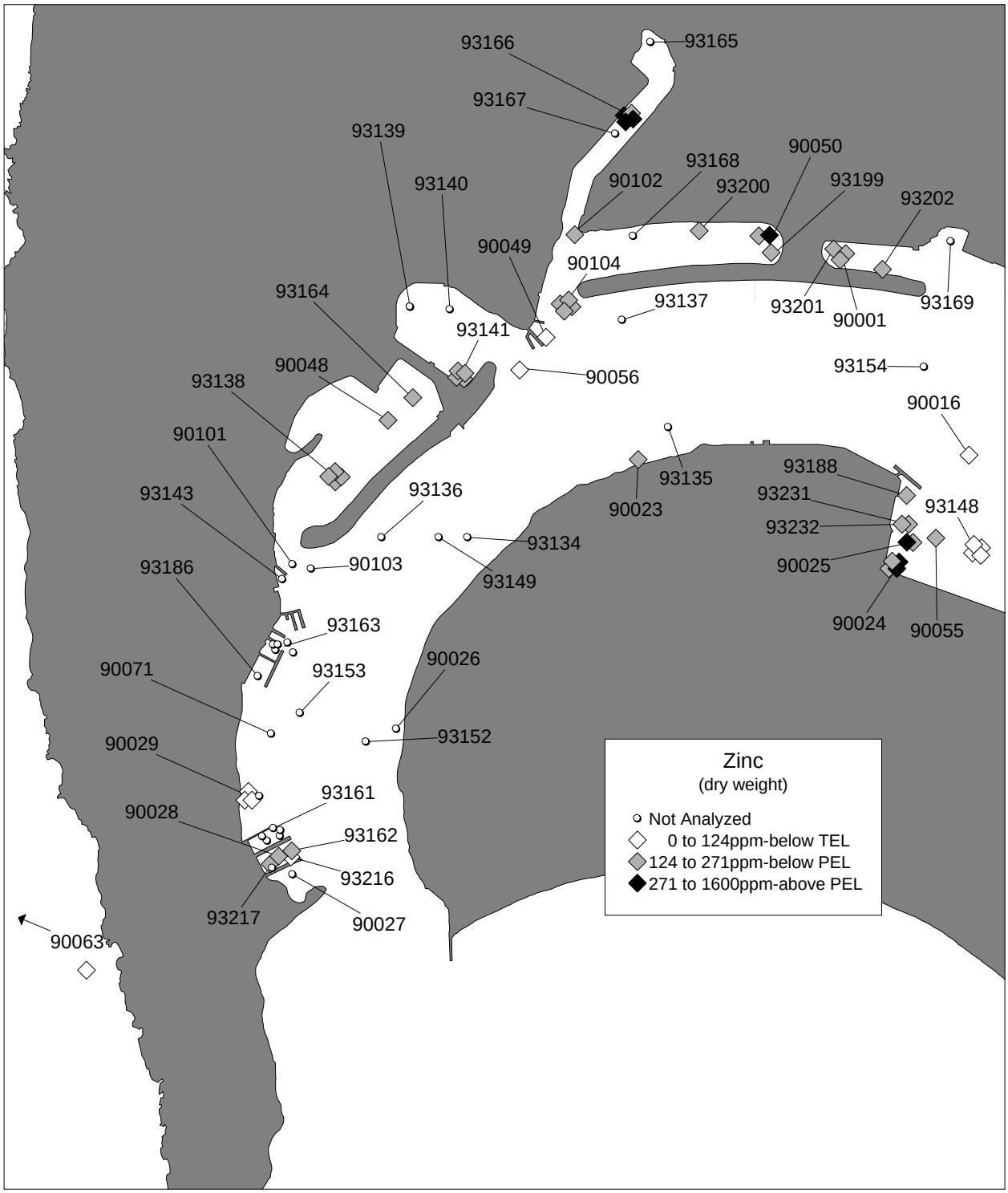


Figure 7b
Zinc Concentrations in Sediment
Mid San Diego Bay

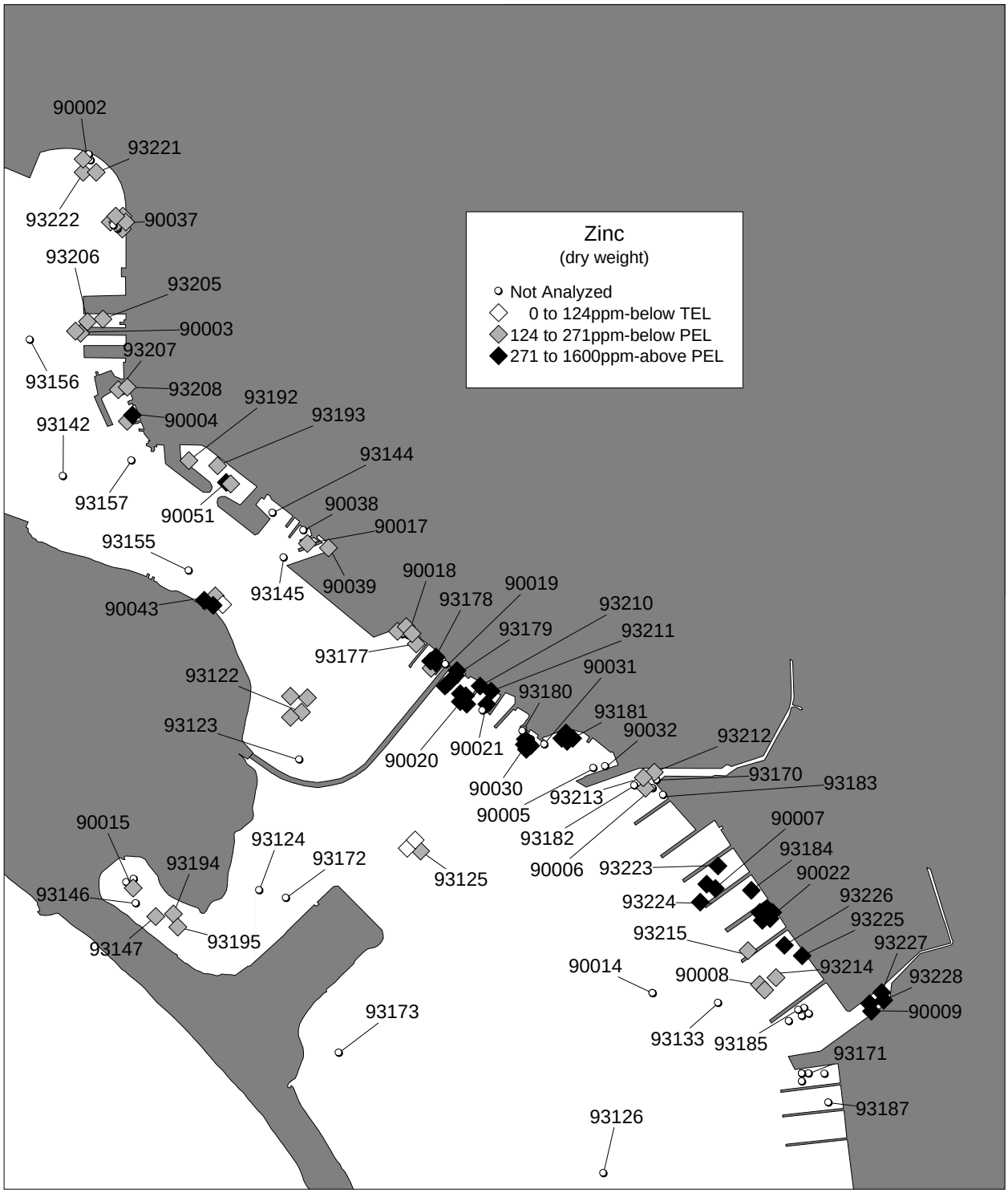


Figure 7c
Zinc Concentrations in Sediment
South San Diego Bay

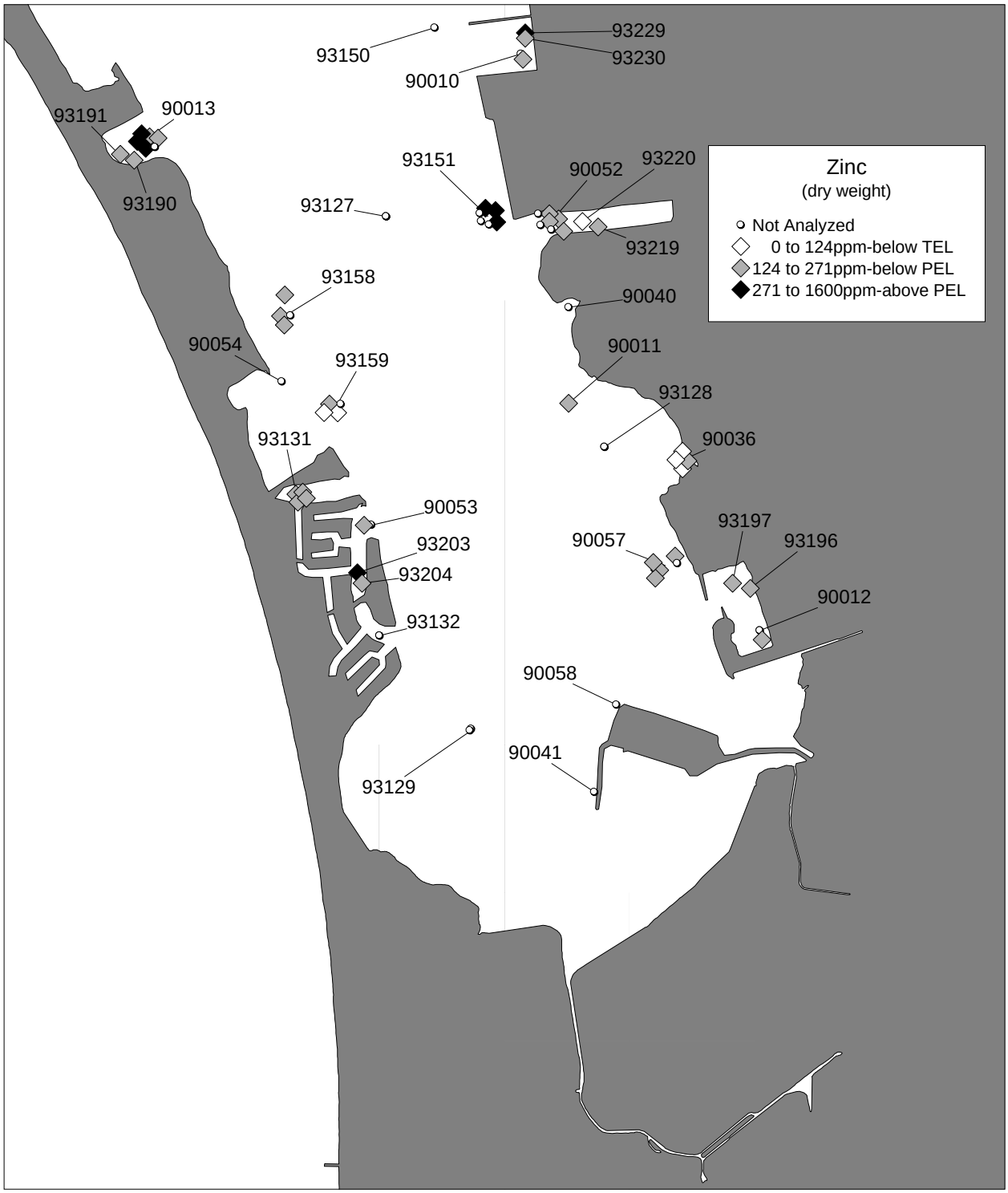
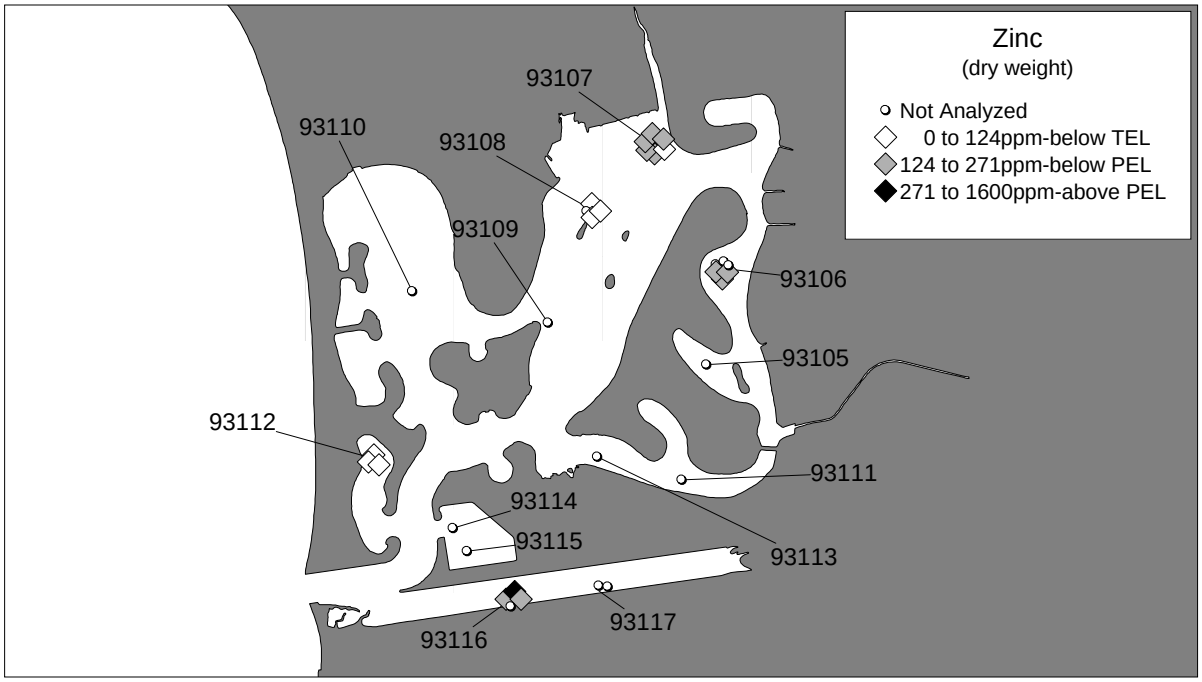


Figure 7d
Zinc Concentrations in Sediment
Mission Bay & San Diego River Estuary



Tijuana River Estuary

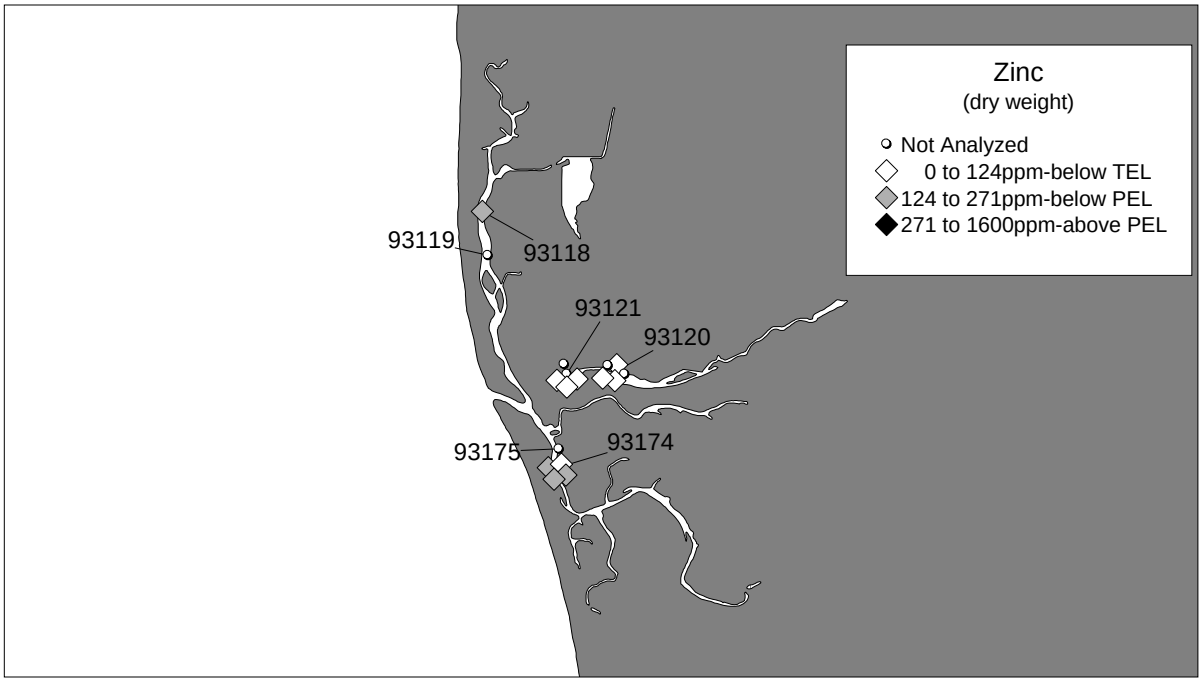


Figure 8a
Mercury Concentrations in Sediment
North San Diego Bay

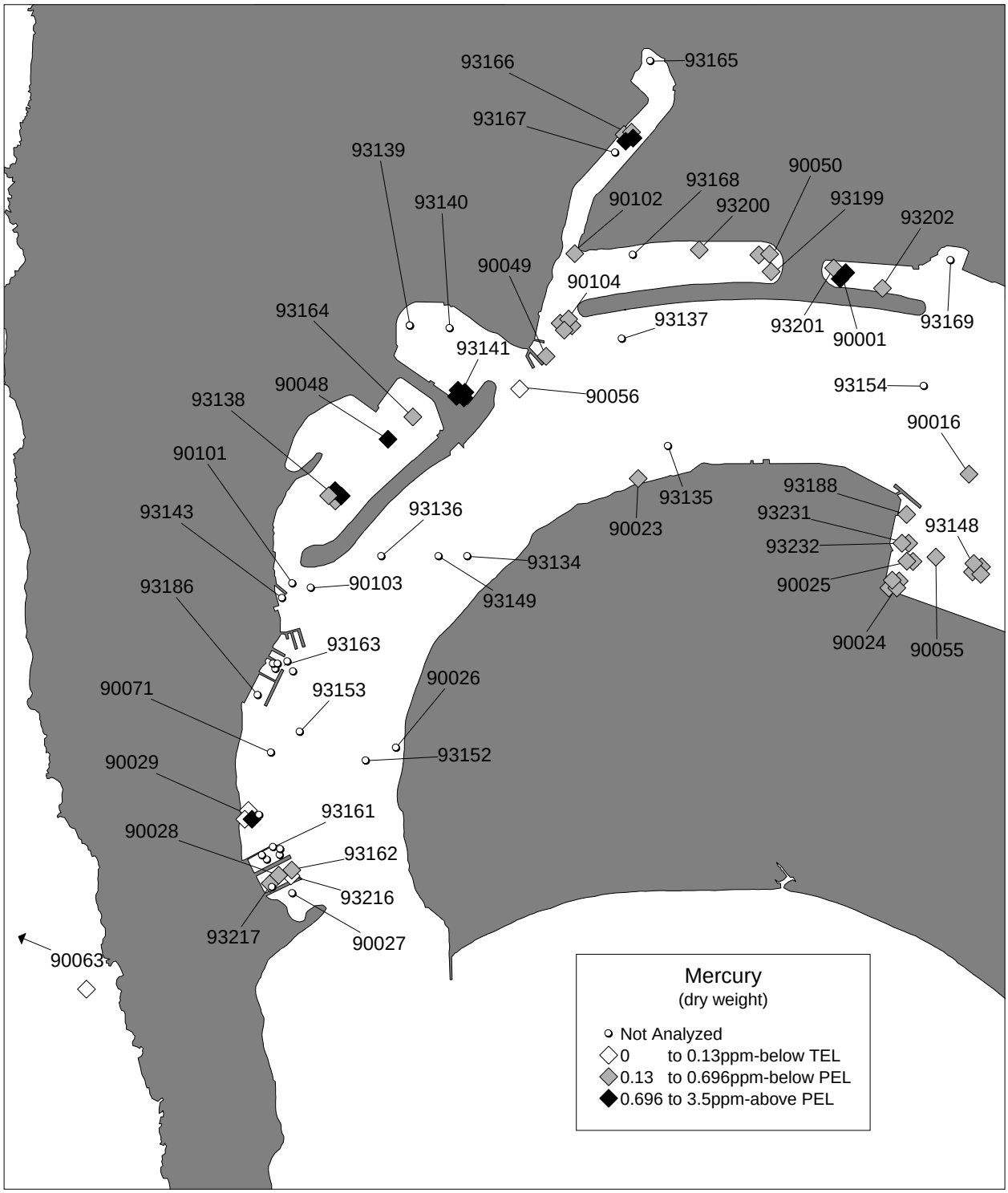


Figure 8b
Mercury Concentrations in Sediment
Mid San Diego Bay

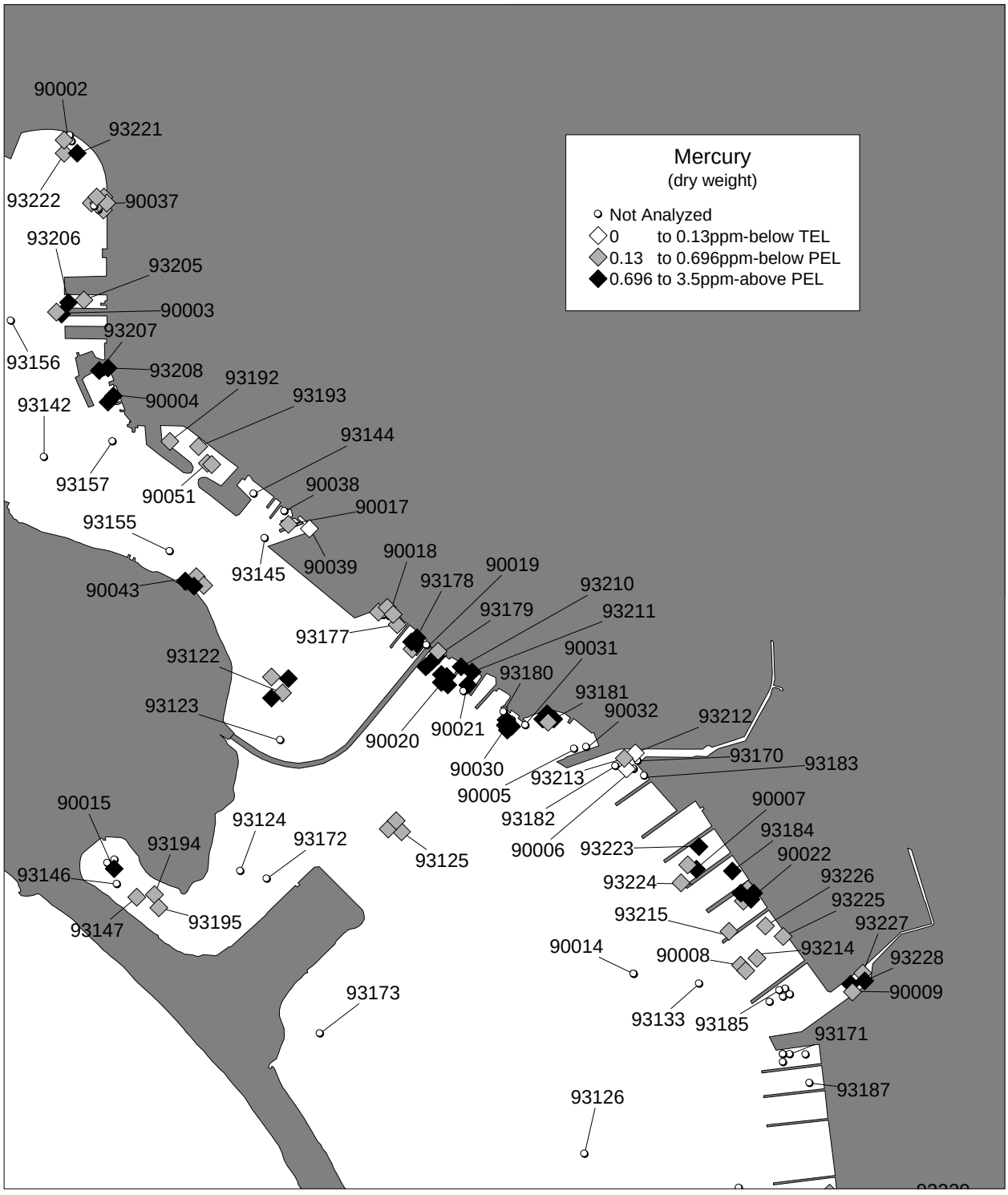


Figure 8c
Mercury Concentrations in Sediment
South San Diego Bay

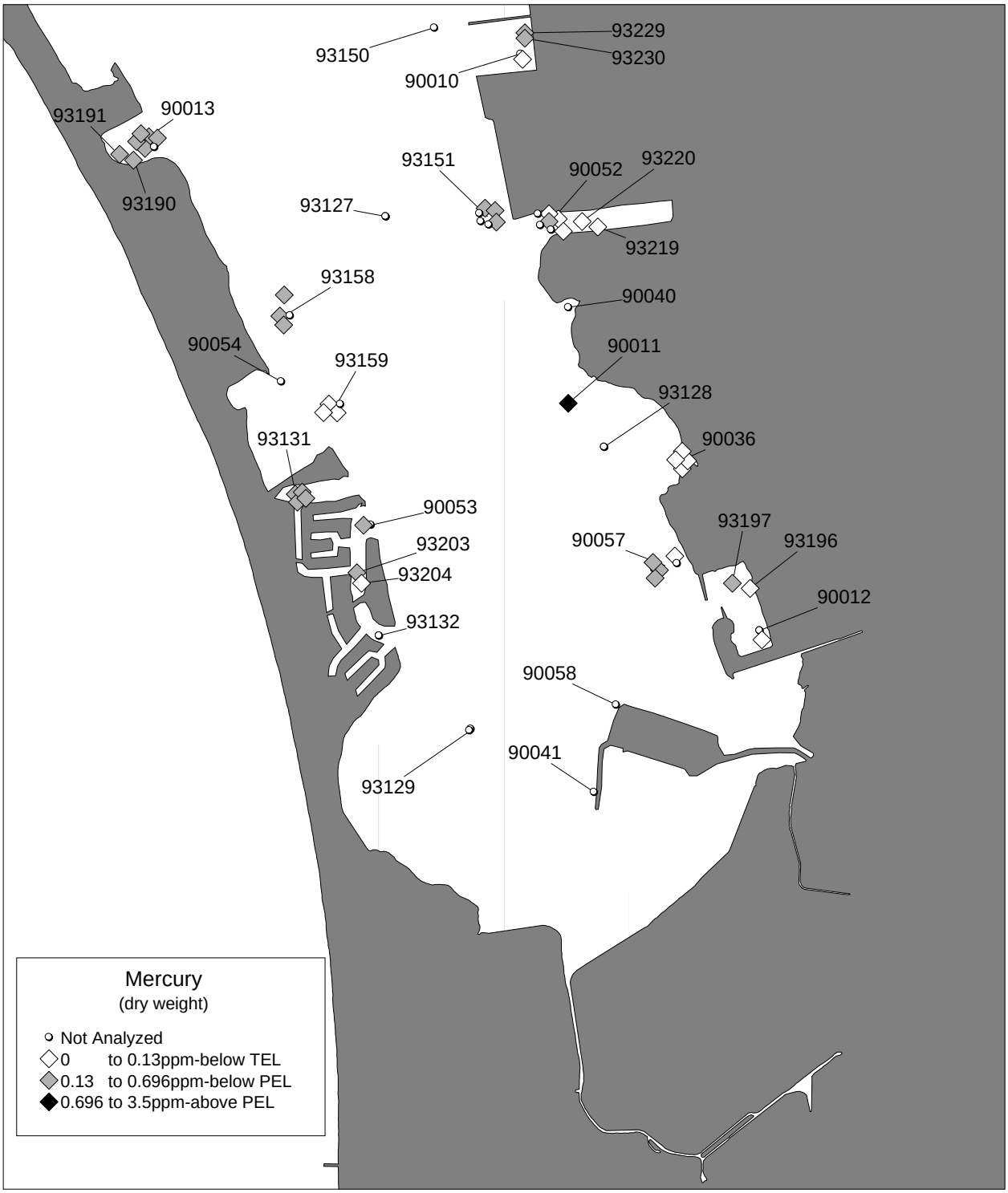
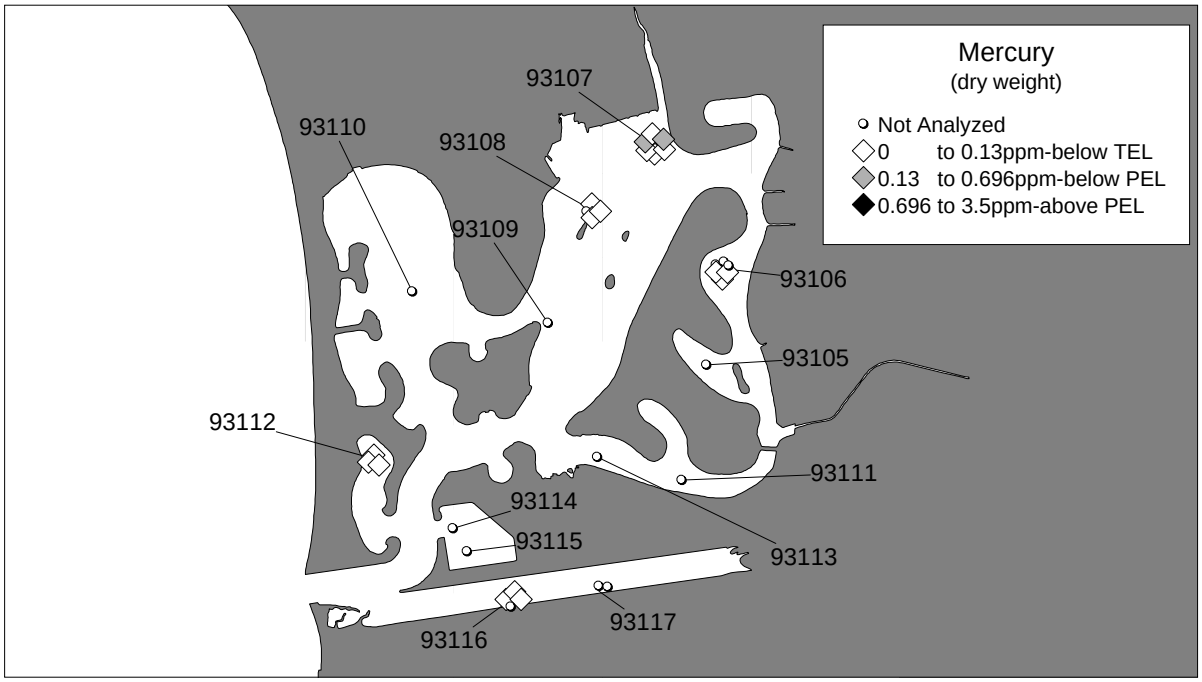


Figure 8d
Mercury Concentrations in Sediment
Mission Bay & San Diego River Estuary



Tijuana River Estuary

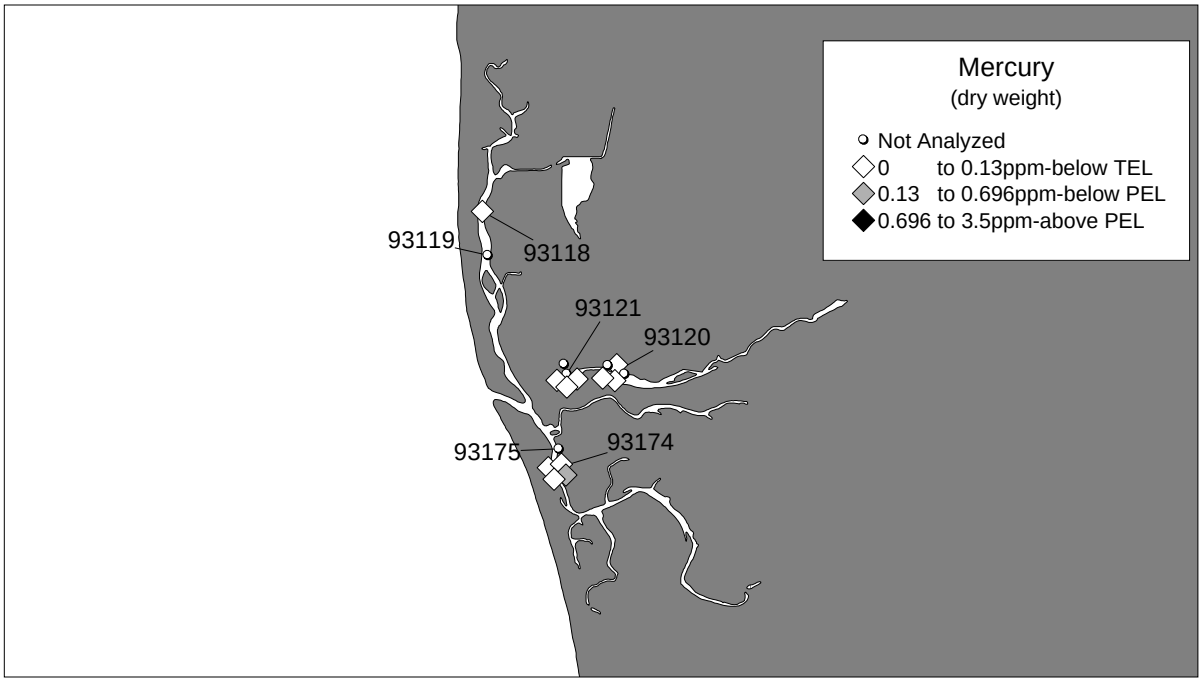


Figure 9a
High Molecular Weight PAH Concentrations in Sediment
North San Diego Bay

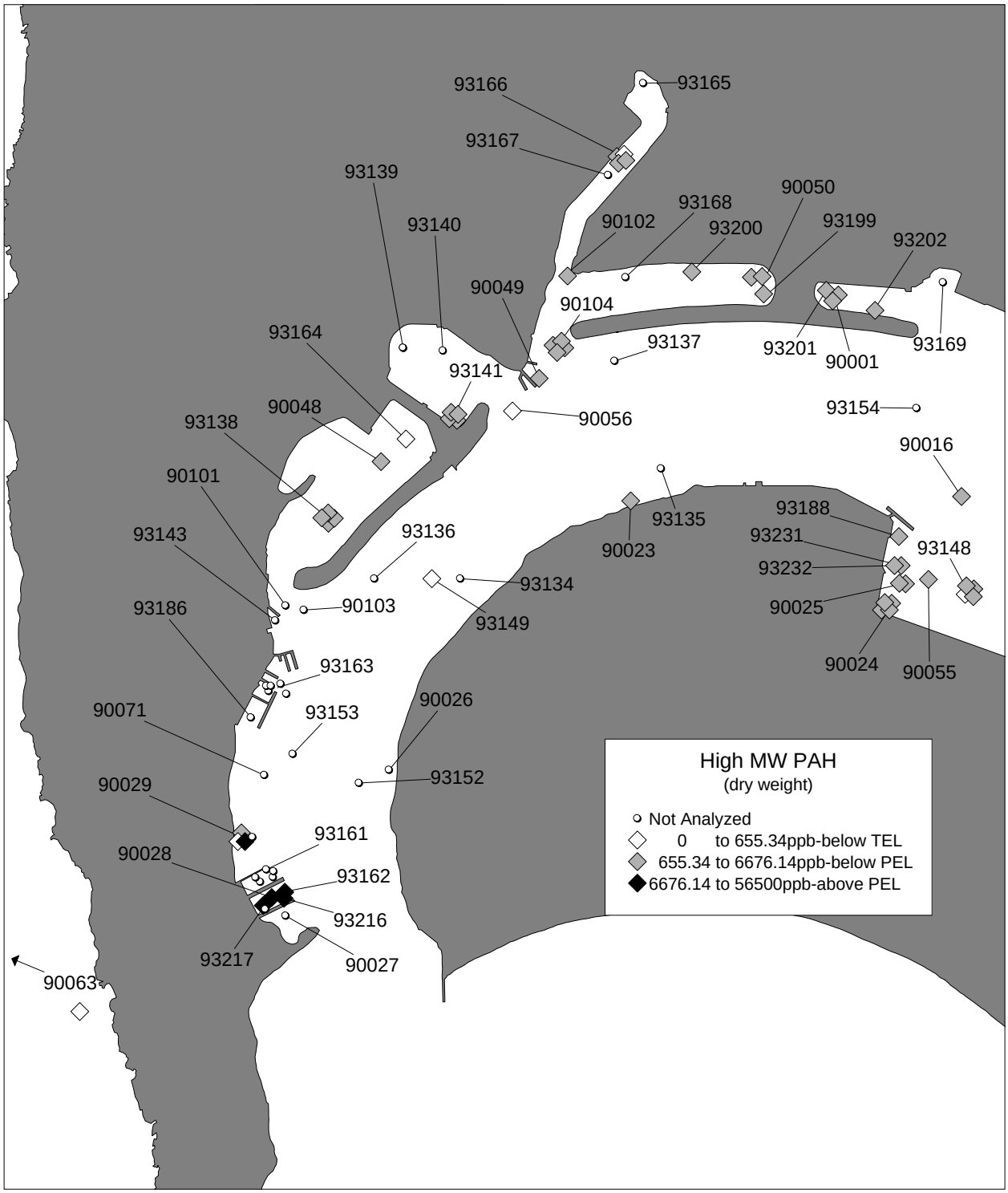


Figure 9b
High Molecular Weight PAH Concentrations in Sediment
Mid San Diego Bay

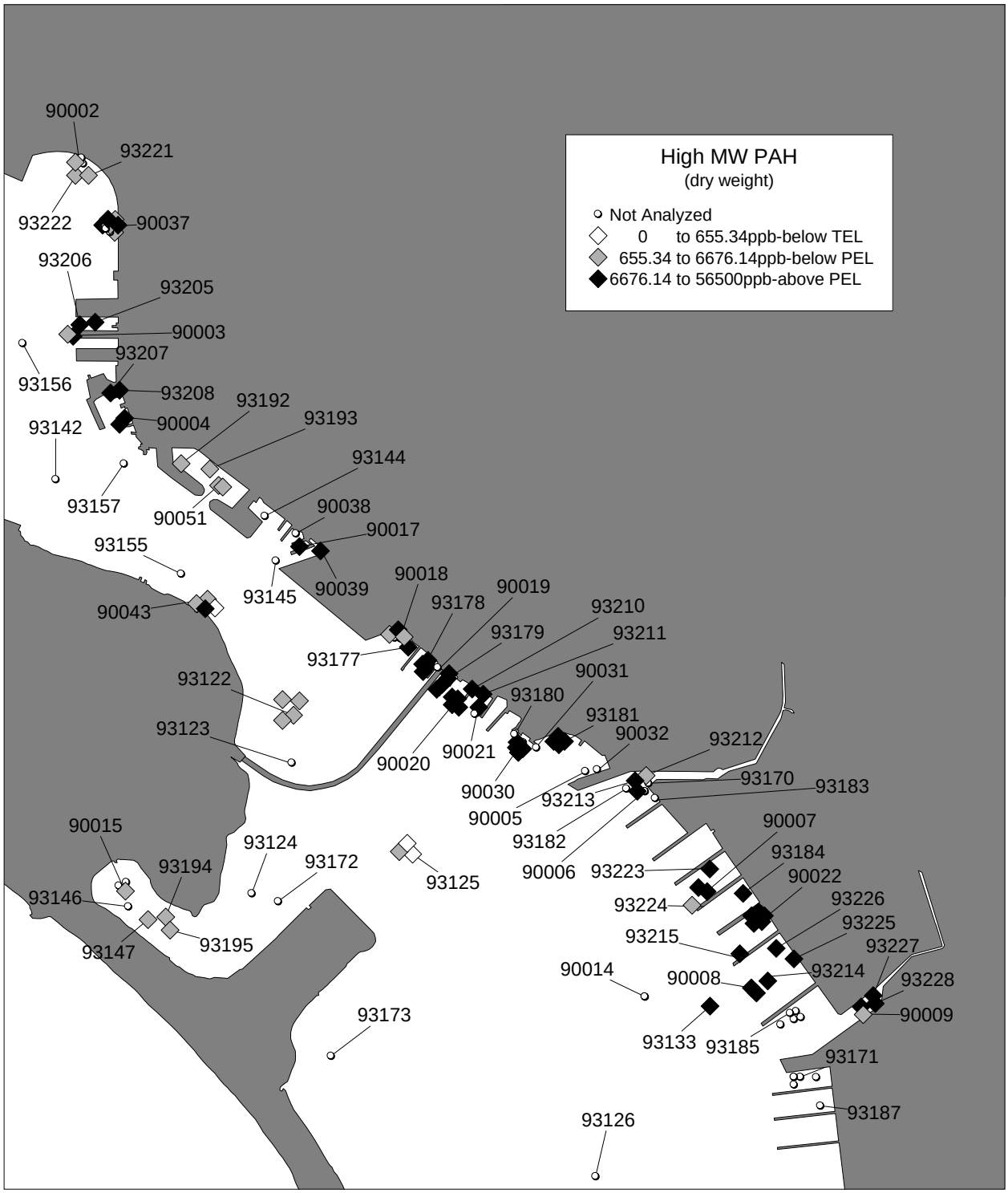


Figure 9c
High Molecular Weight PAH Concentrations in Sediment
South San Diego Bay

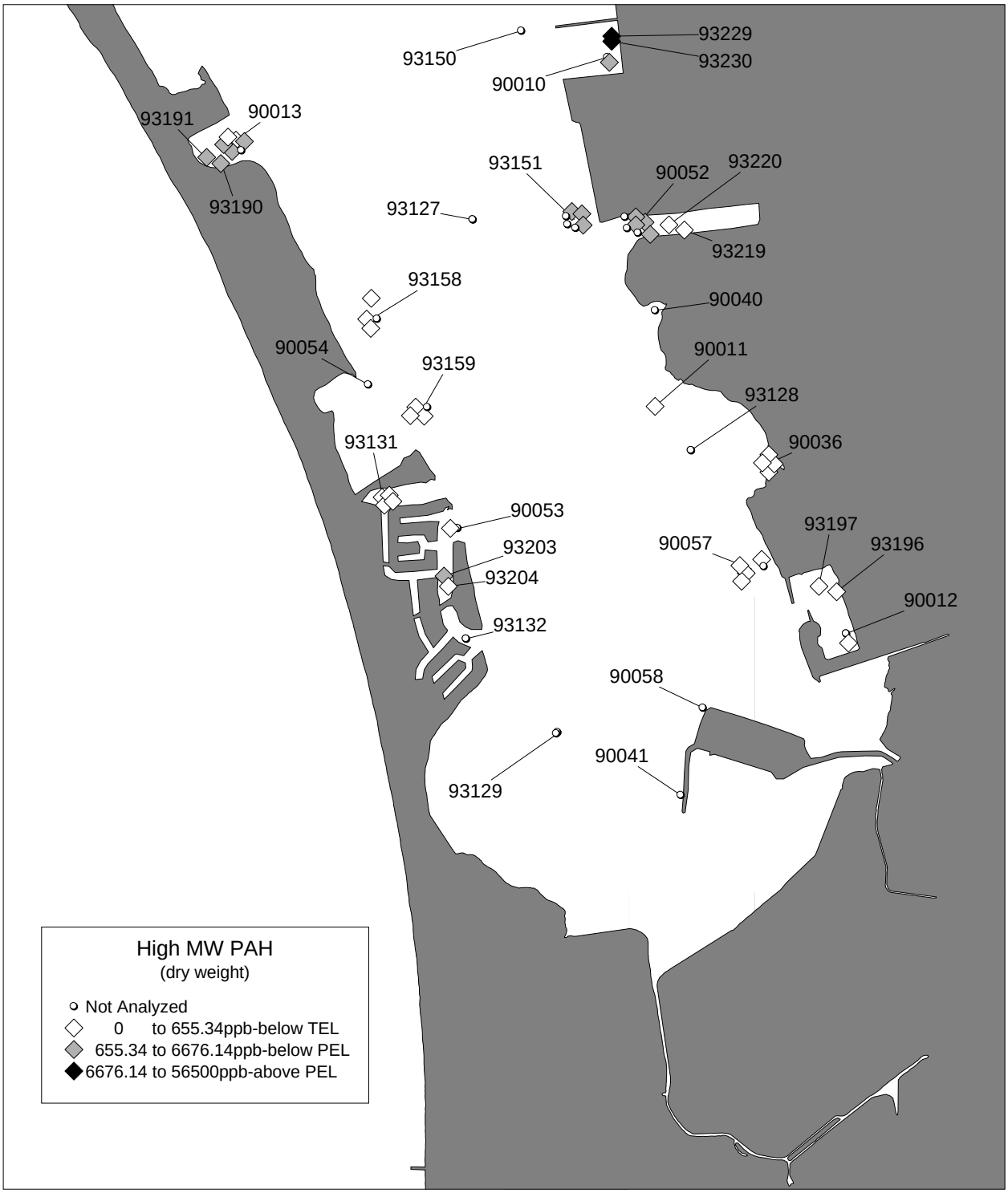
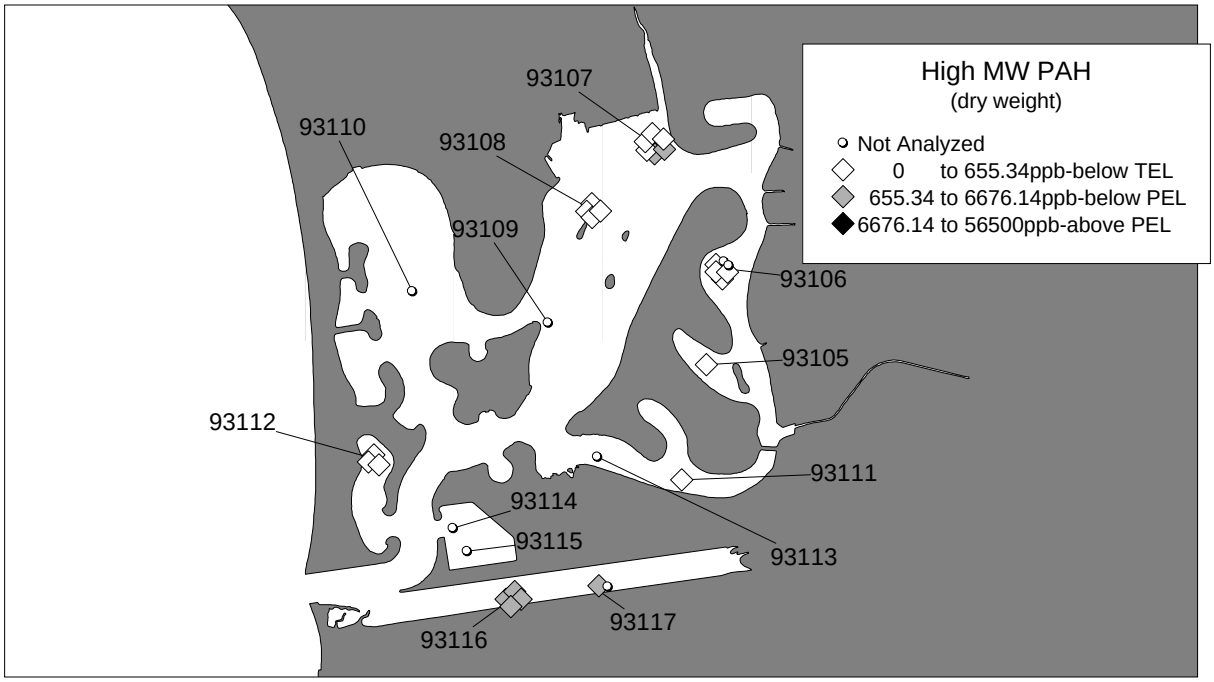


Figure 9d
High Molecular Weight PAH Concentrations in Sediment
Mission Bay and San Diego River Estuary



Tijuana River Estuary

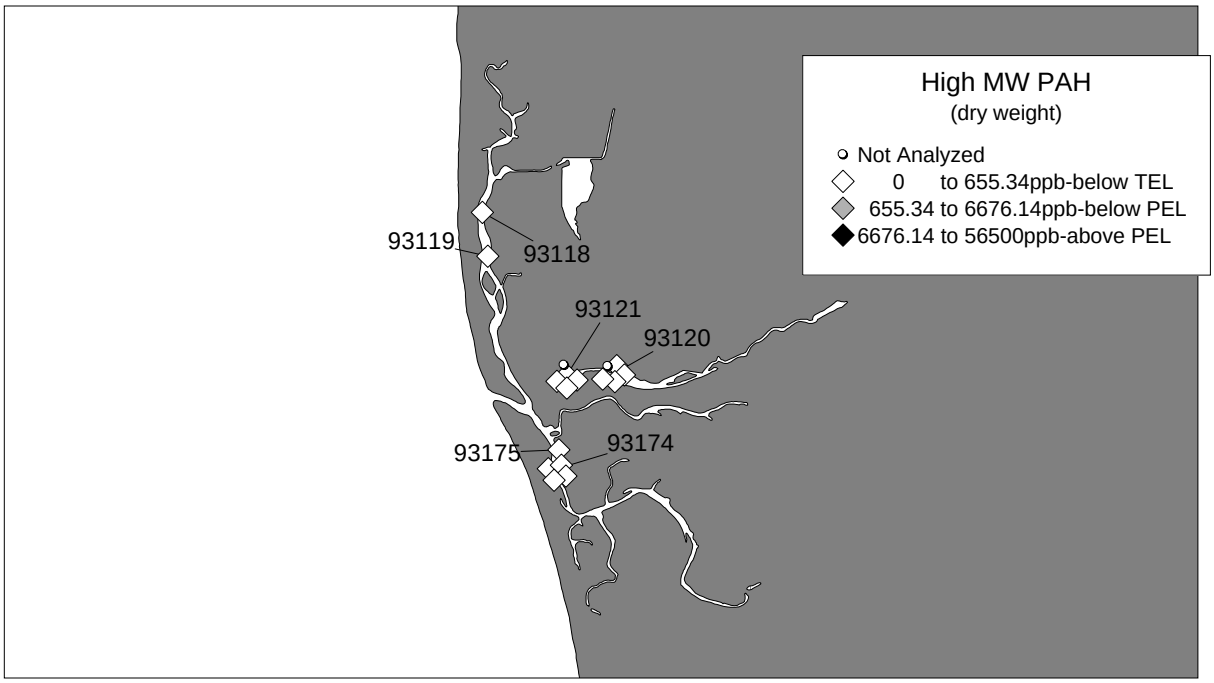


Figure 10a
Low Molecular Weight PAH Concentrations in Sediment
North San Diego Bay

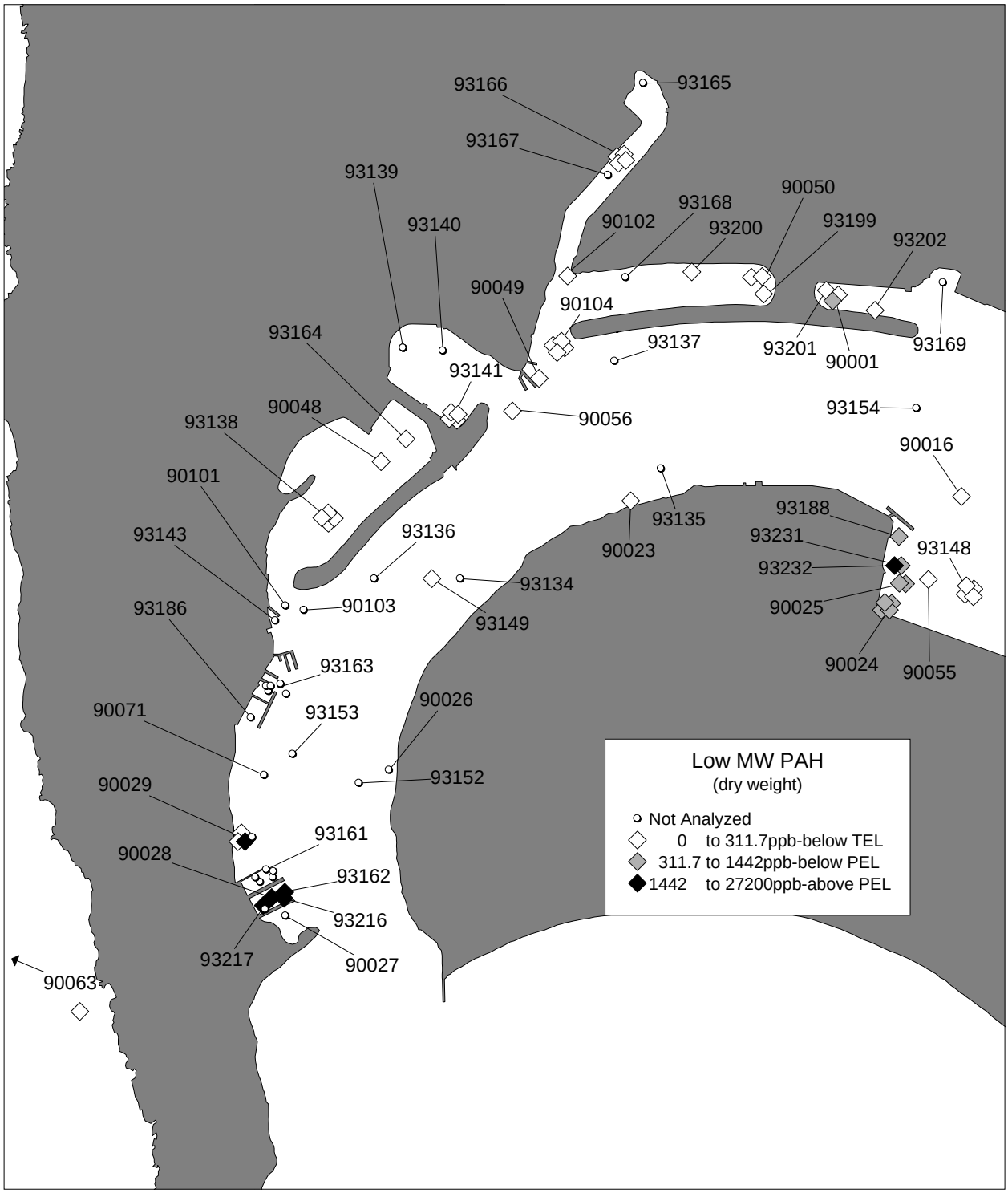


Figure 10b
Low Molecular Weight PAH Concentrations in Sediment
Mid San Diego Bay

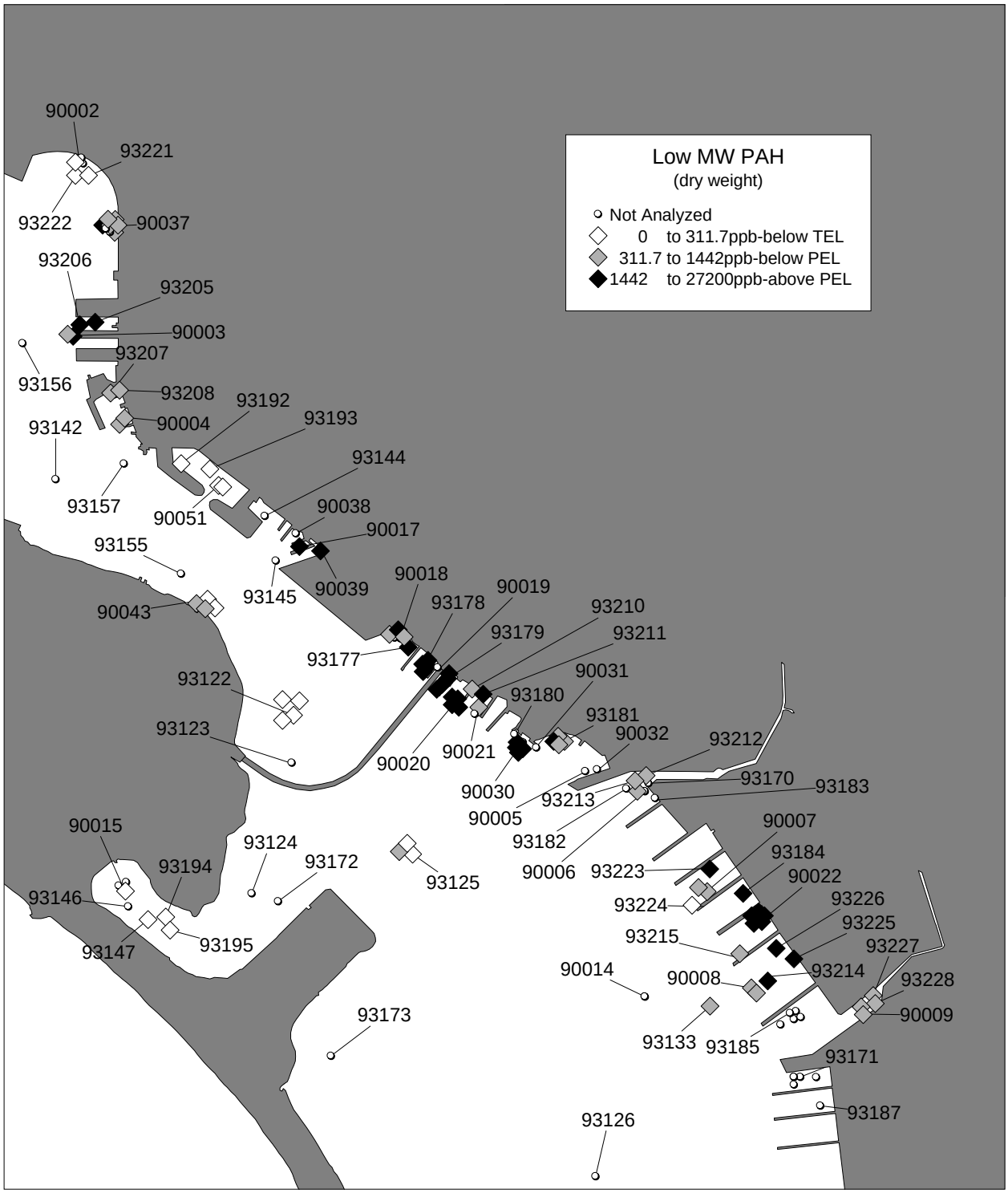


Figure 10c
Low Molecular Weight PAH Concentrations in Sediment
South San Diego Bay

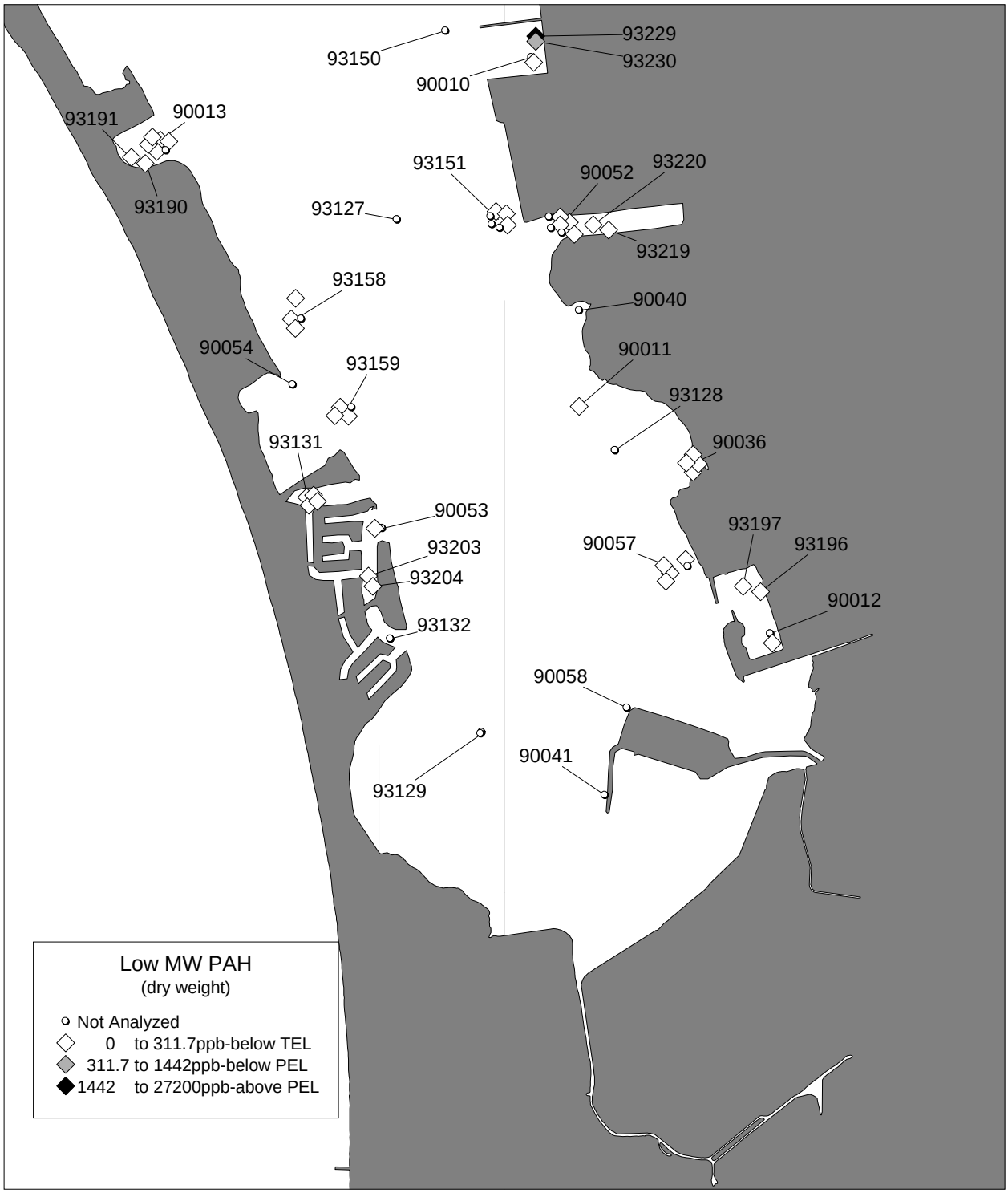
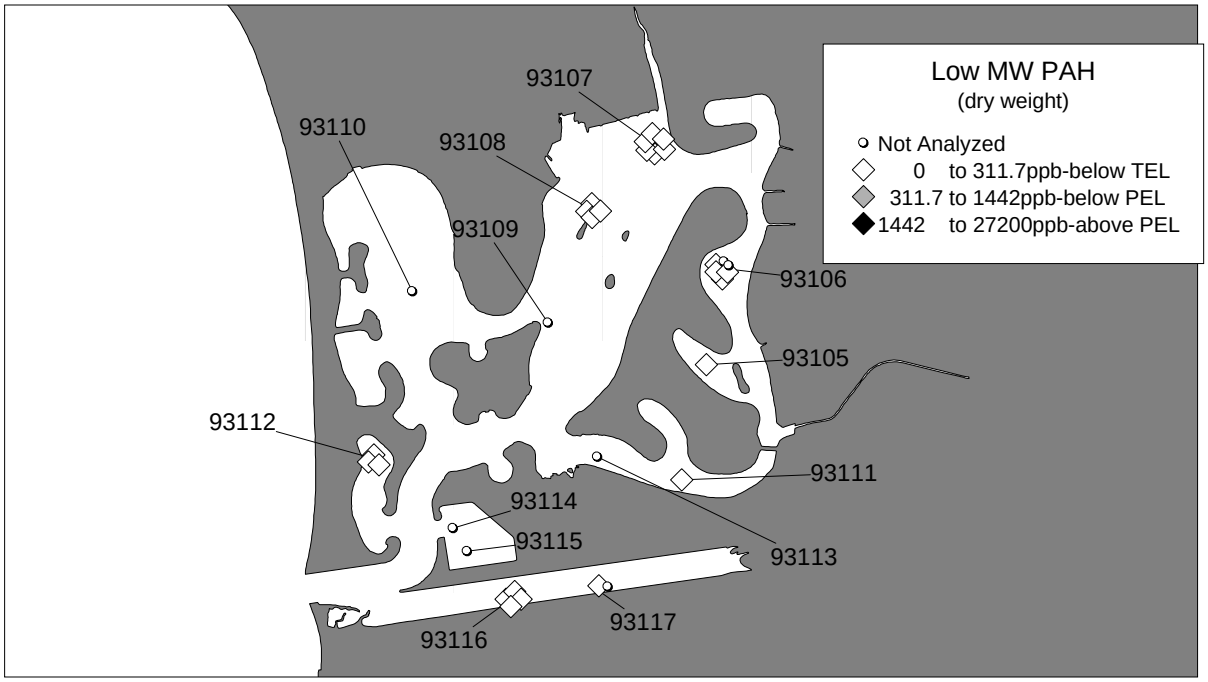
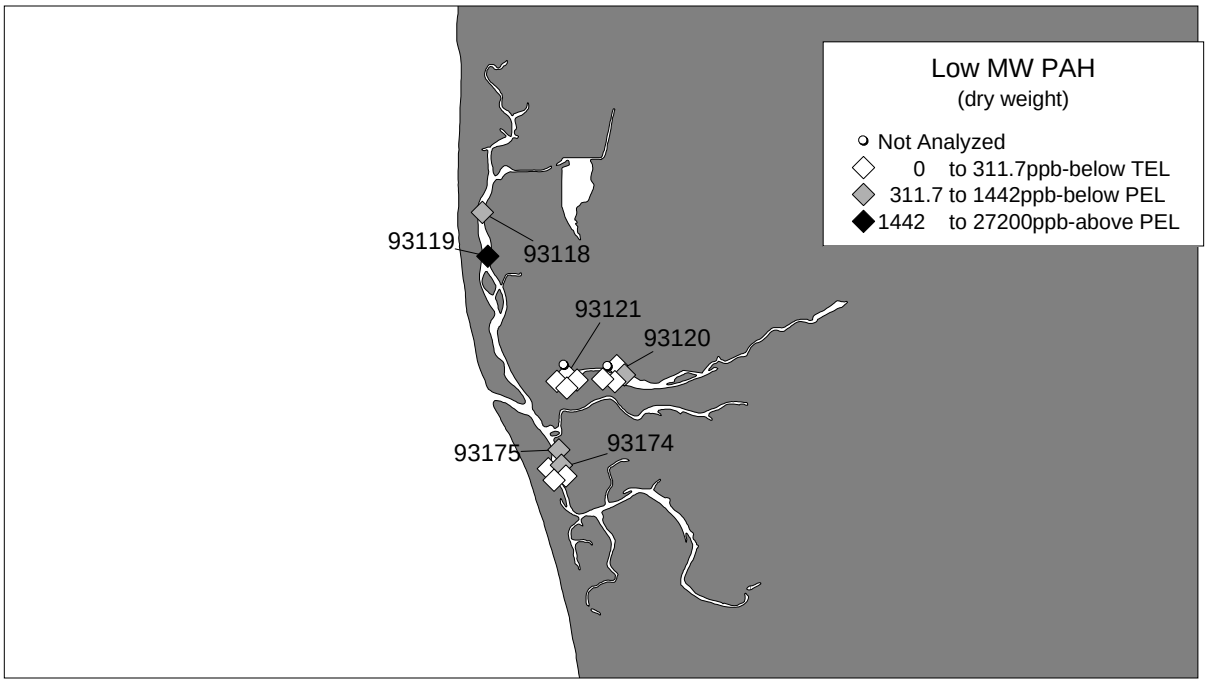


Figure 10d
Low Molecular Weight PAH Concentrations in Sediment
Mission Bay and San Diego River Estuary



Tijuana River Estuary



biphenyl. There are 209 numerically designated individual compounds, called congeners (*i.e.*, PCB #101), based on the possible chlorine substitution patterns. Mixtures of various PCB congeners have been manufactured in the U.S. since 1929 (Phillips, 1987) and are used commercially under the trade name Aroclor. Each PCB mixture has a number designation (*i.e.*, Aroclor 1254) with the last two numbers indicating the percentage of chlorine in the mixture. PCB mixtures were used extensively in the U.S. prior to 1979 for industrial applications which required fluids with thermal stability, fire and oxidation resistance and solubility in organic compounds (Hodges, 1977). PCBs have proven to be extremely persistent in the environment and have demonstrated a variety of adverse carcinogenic and non-carcinogenic effects (USEPA, 1993c). These substances have a high potential to accumulate in the tissues of aquatic organisms and can represent significant hazards to consumers of aquatic species (Moore and Walker, 1991). Total PCB (the sum of 18 congeners, Appendix B - Section VII) pollution is most prominent in sediments along the naval shipyard waterfront (Figure 11(a-d)), although several locations along the downtown waterfront and small boat harbors also show total PCB values in excess of the PEL (>188.79 μg/kg) and ERM (>180 μg/kg).

Chlordane is a multipurpose insecticide which has been used extensively in home and agricultural applications for the control of termites and other insects. Although use of this compound ended in the mid-70s, its persistence in sediments of the region is apparent. Total chlordane is the summation of major constituents of technical grade chlordane and its metabolite (Appendix B - Section VII). Chlordane pollution is extensive along the north shore of San Diego Bay, the San Diego River, and the most northerly station in Mission Bay (Figure 12(a-d)). Areas which receive storm runoff, such as Chollas Creek, Seventh St. Channel, and urban storm drains appear to be the most heavily contaminated (PEL (>4.79 μg/kg) or ERM (>6 μg/kg)).

ERM and PEL Summary Quotients

In this report, comparisons of the data to effects-based numerical guidelines were made to assess how sediment pollution in the San Diego Bay Region compares to sediment pollution on a national scale. Additionally, these guidelines were used to identify chemicals of concern for sediment quality management within the San Diego Bay Region. Rankings and comparisons were made in this report using summary ERM-quotients (ERMQ) and PEL-quotients (PELQ). Summary quotients are summations of chemical concentrations for chemicals listed in Table 5, divided by their respective ERM or PEL value, and then divided by total number of chemicals used. In samples where levels of measured chemicals were below the analytical method detection limit (MDL), a value of one-half the MDL was used for summations. Methods and analytes used for summations and averaging are given in Appendix B-Section VII. This was a simple approach for addressing overall chemical pollution where there were multiple pollutants at a station, and was in addition to the standard chemical by chemical

Figure 11a
Total PCB Concentrations in Sediment
North San Diego Bay

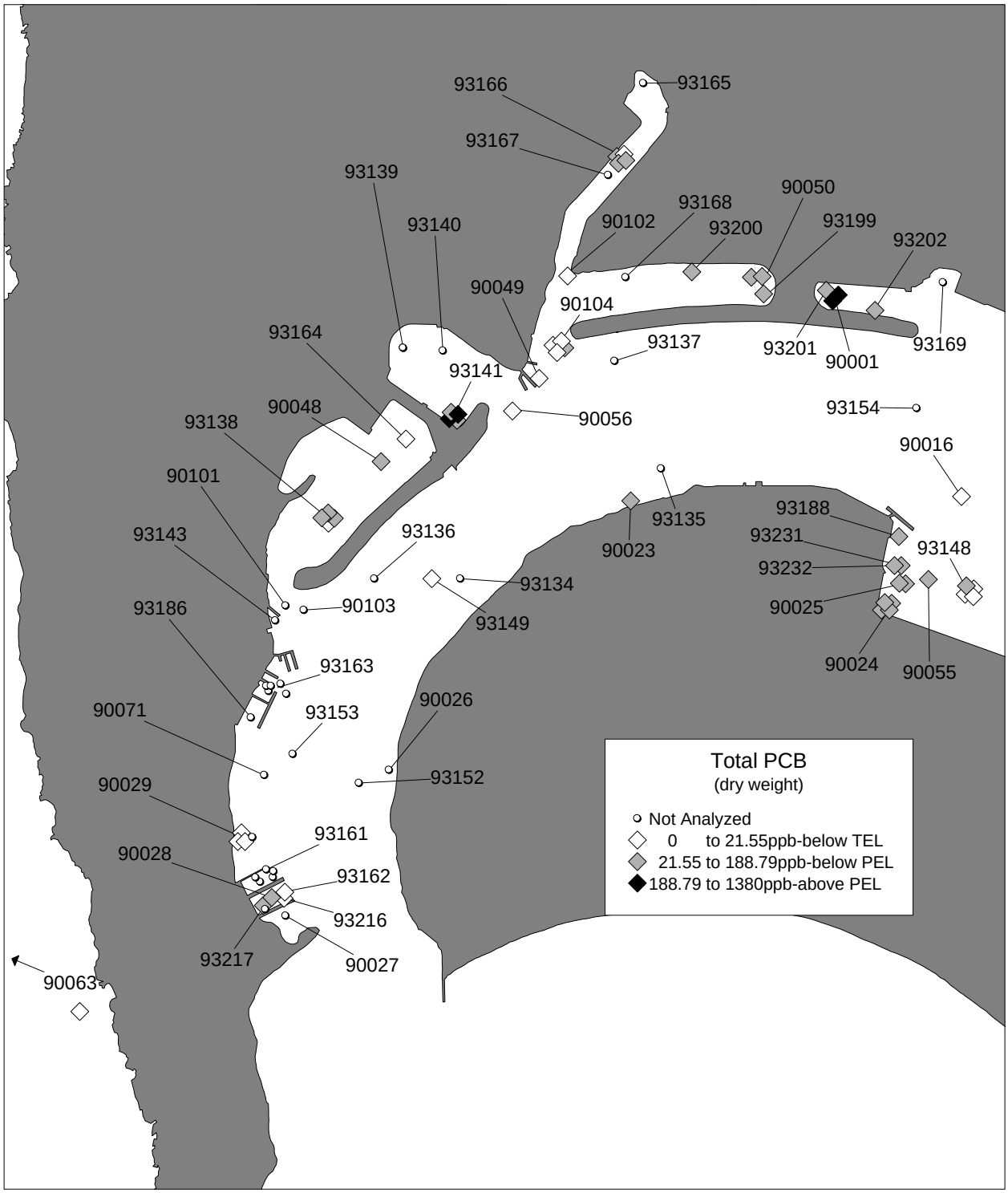


Figure 11b
Total PCB Concentrations in Sediment
Mid San Diego Bay

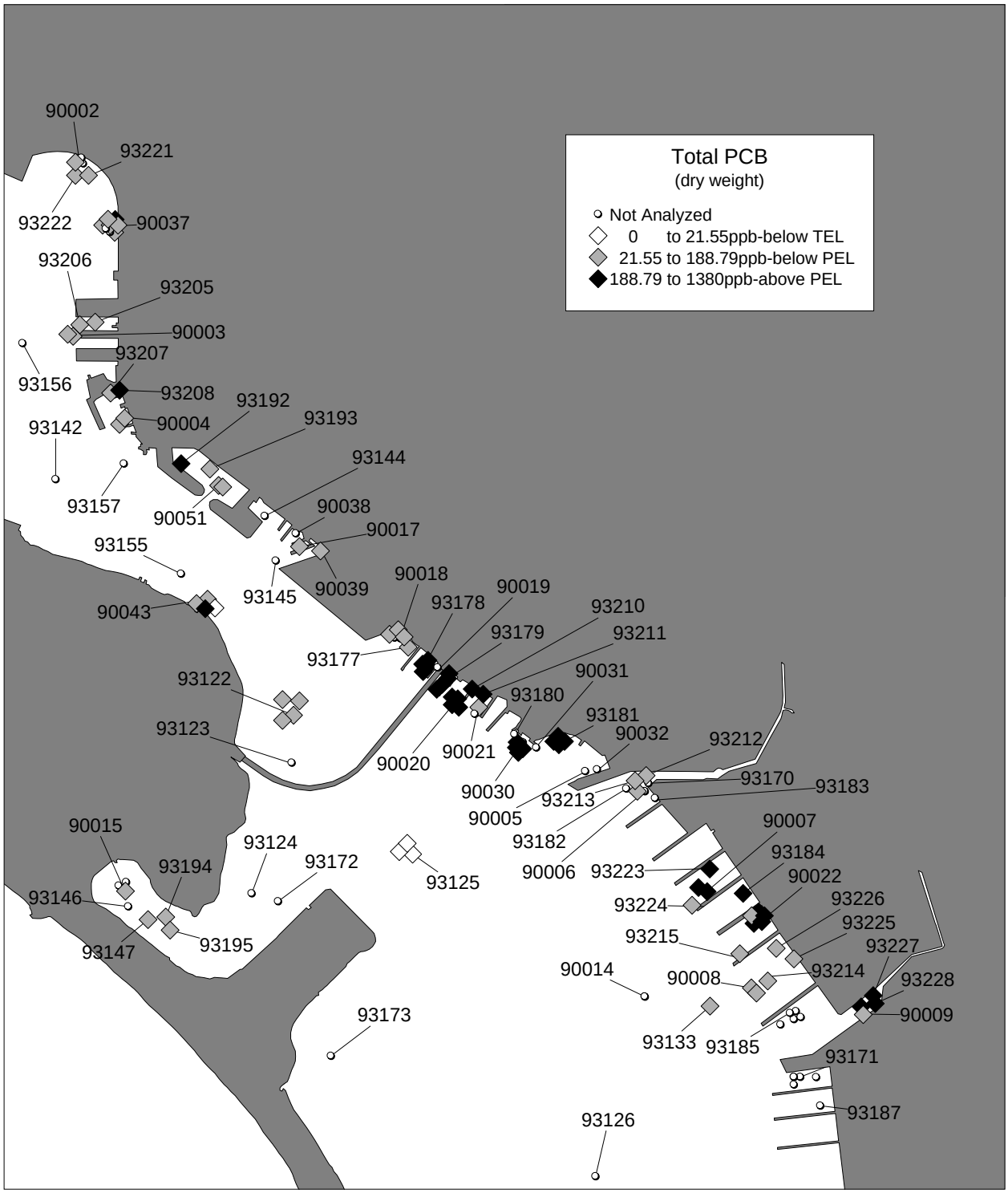


Figure 11c
Total PCB Concentrations in Sediment
South San Diego Bay

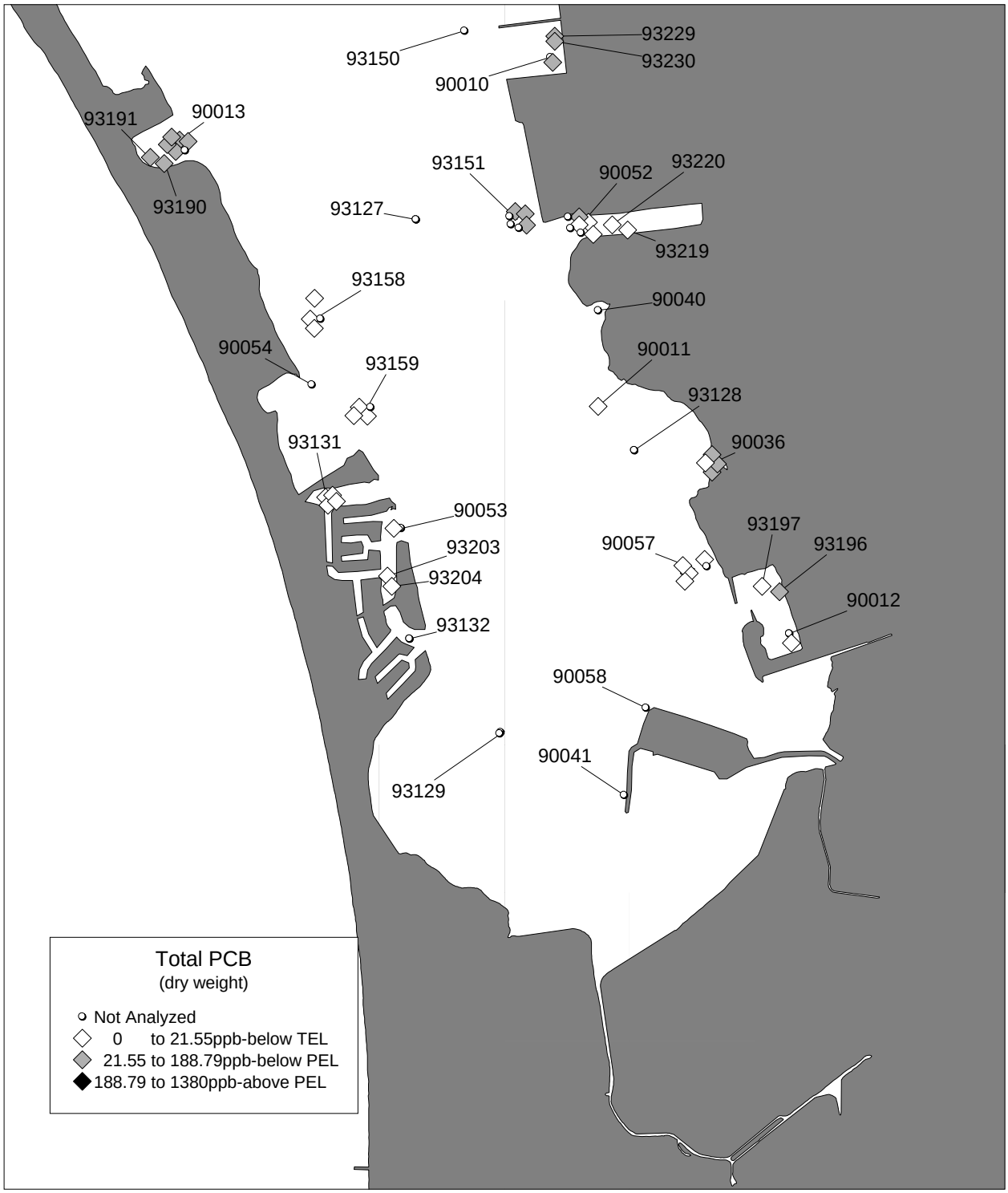
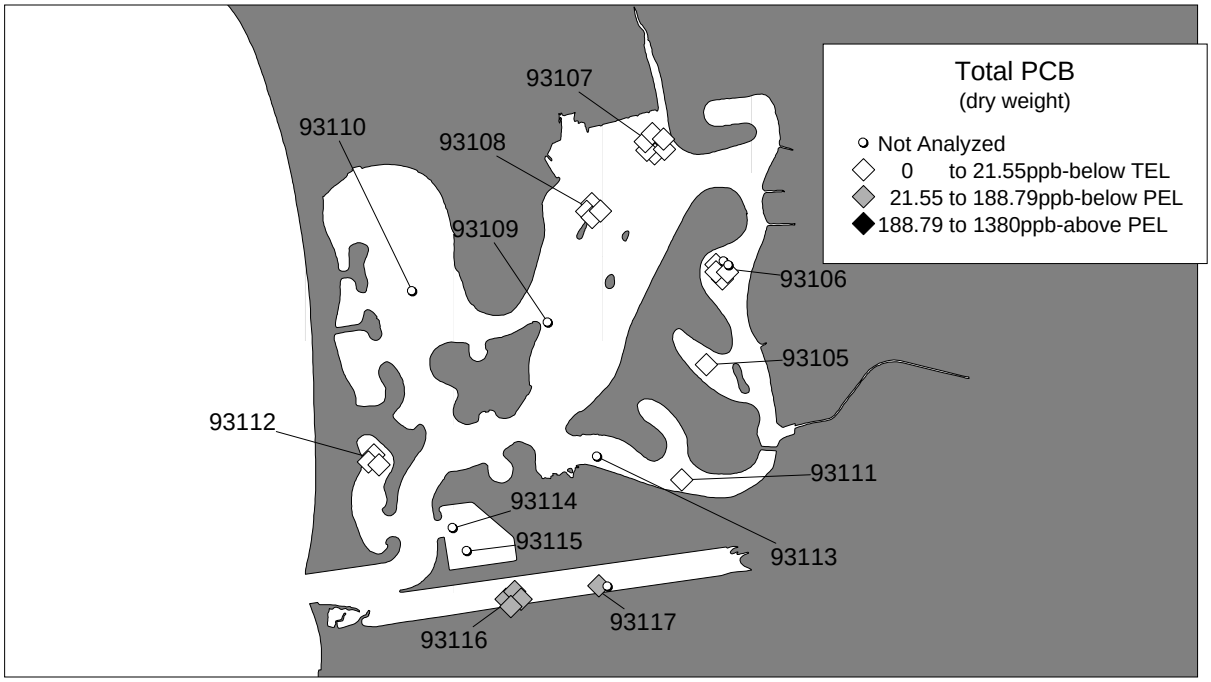


Figure 11d
Total PCB Concentrations in Sediment
Mission Bay and San Diego River Estuary



Tijuana River Estuary

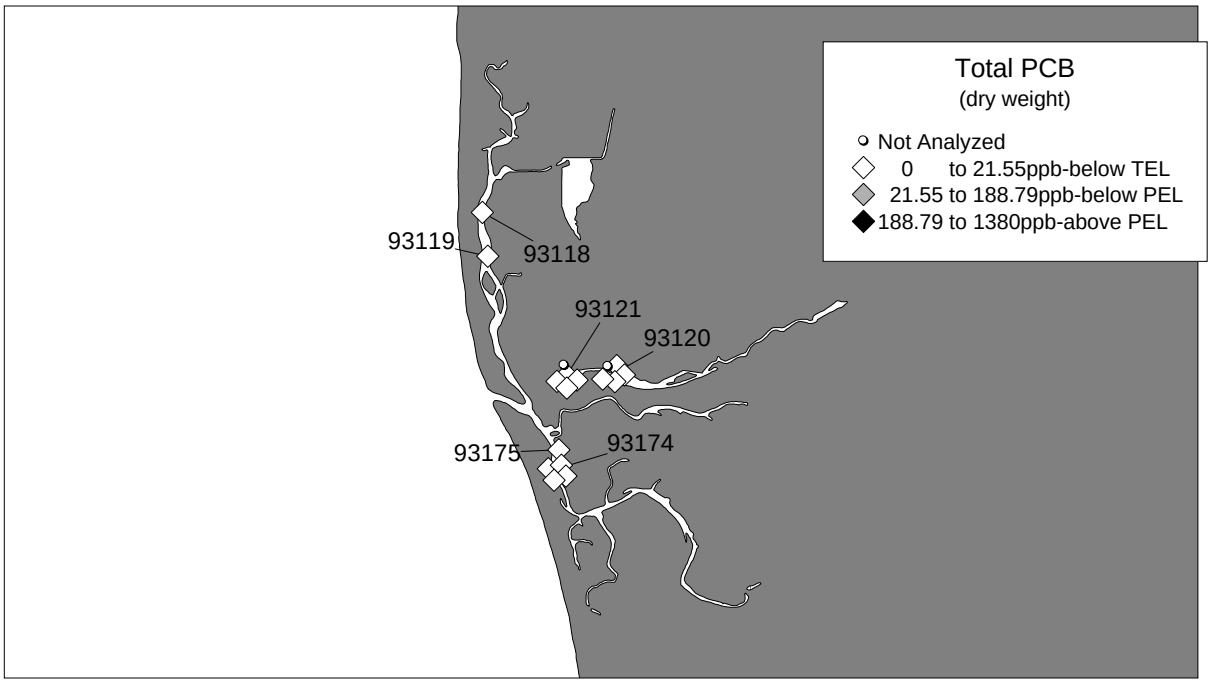


Figure 12a
Total Chlordane Concentrations in Sediment
North San Diego Bay

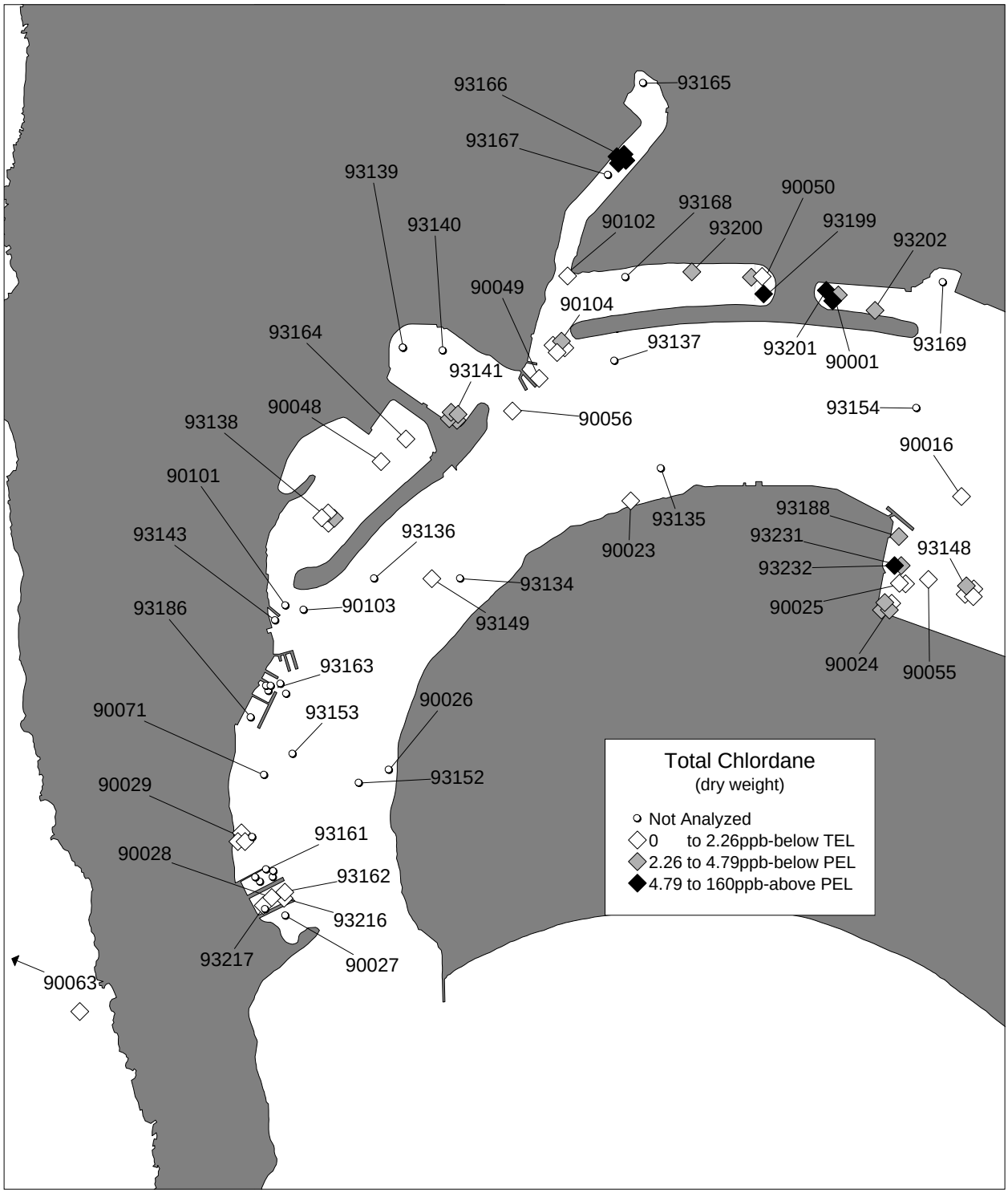


Figure 12b
Total Chlodane Concentrations in Sediment
Mid San Diego Bay

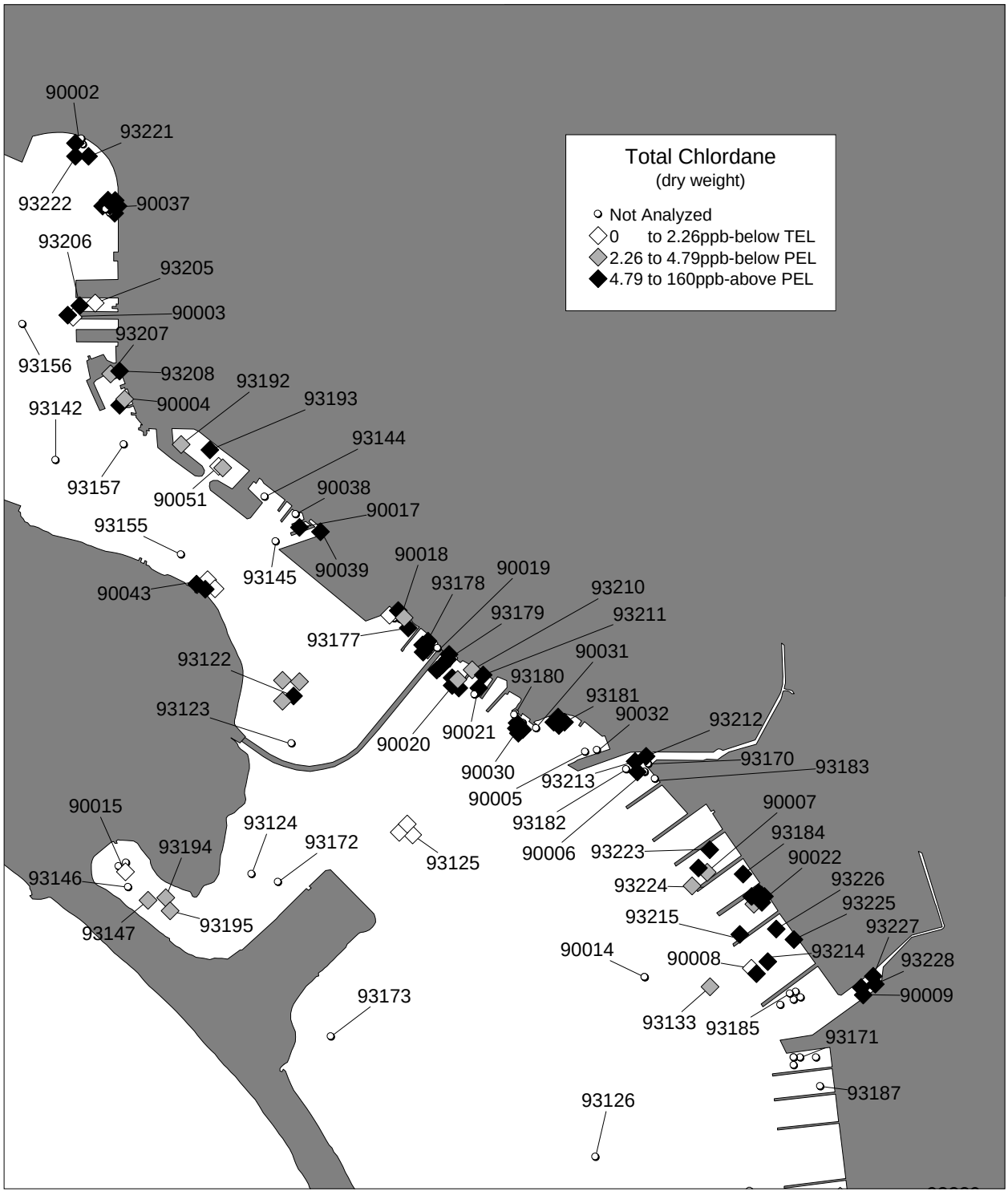


Figure 12c
Total Chlordane Concentrations in Sediment
South San Diego Bay

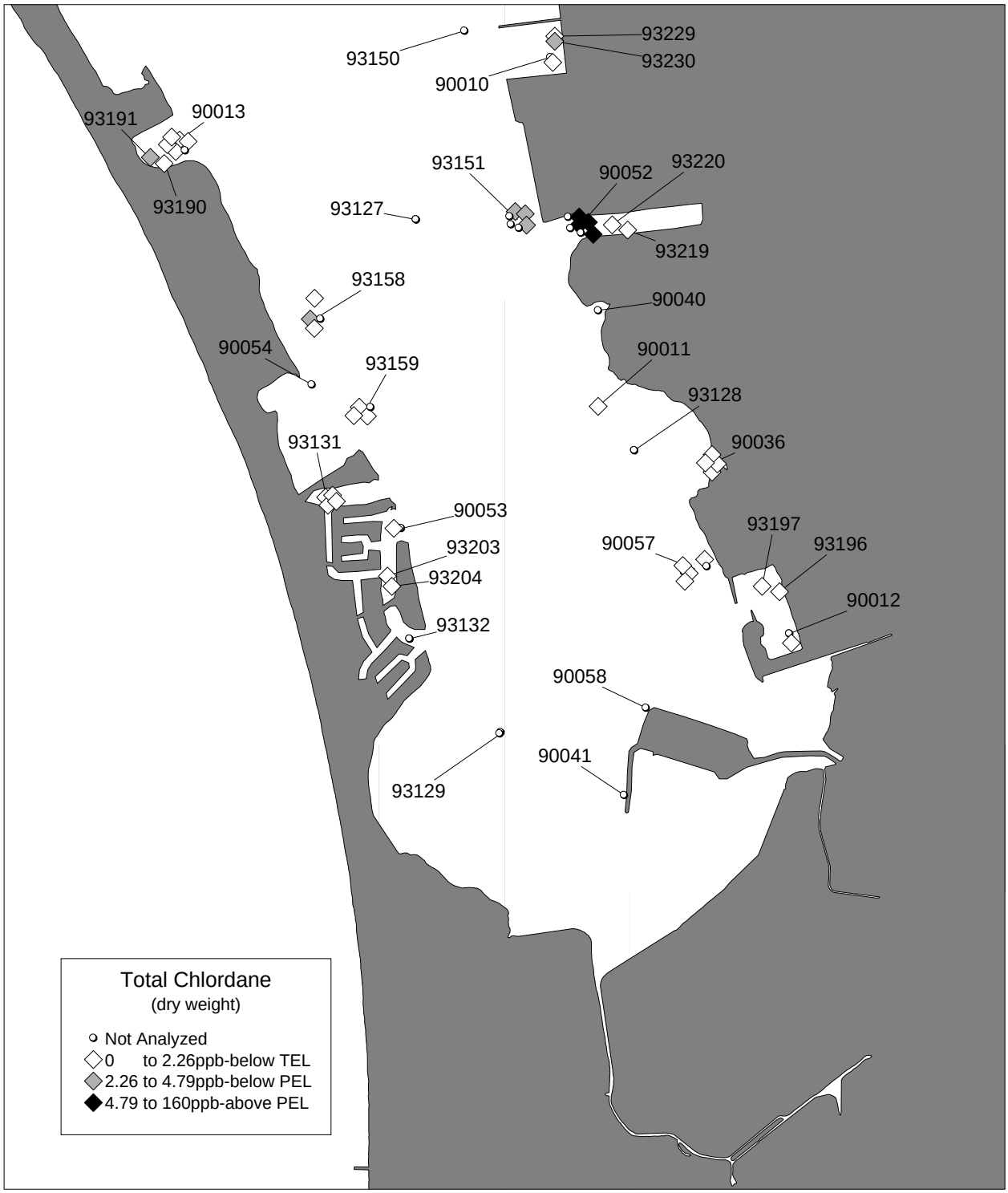
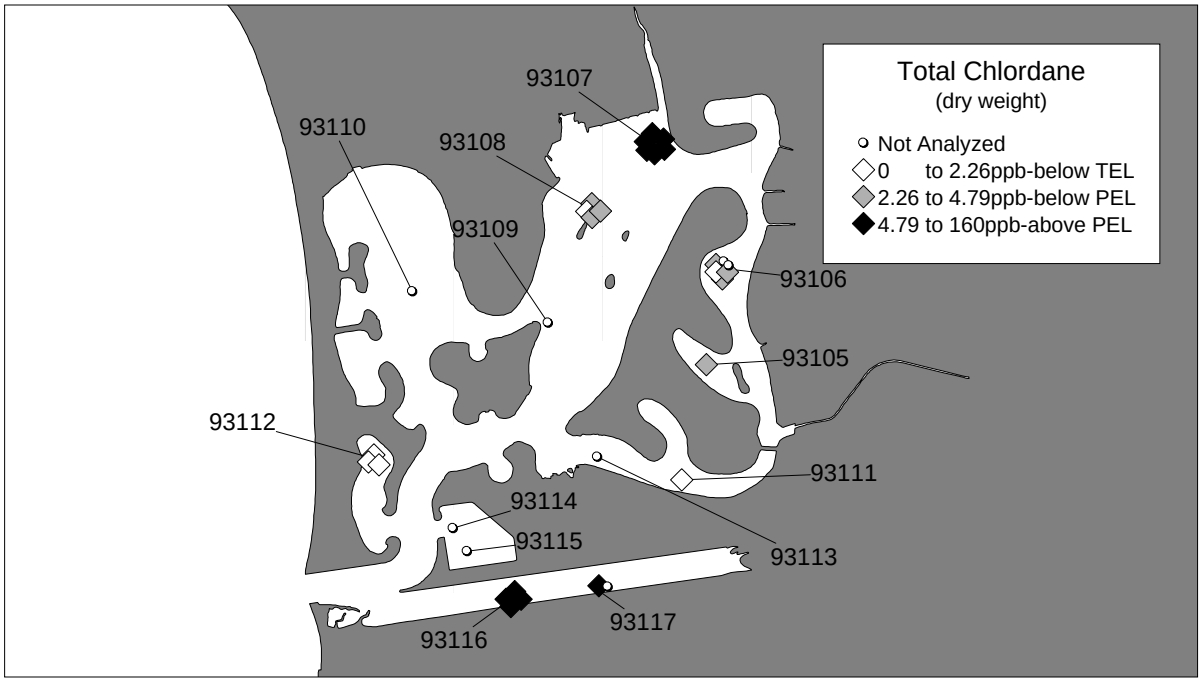
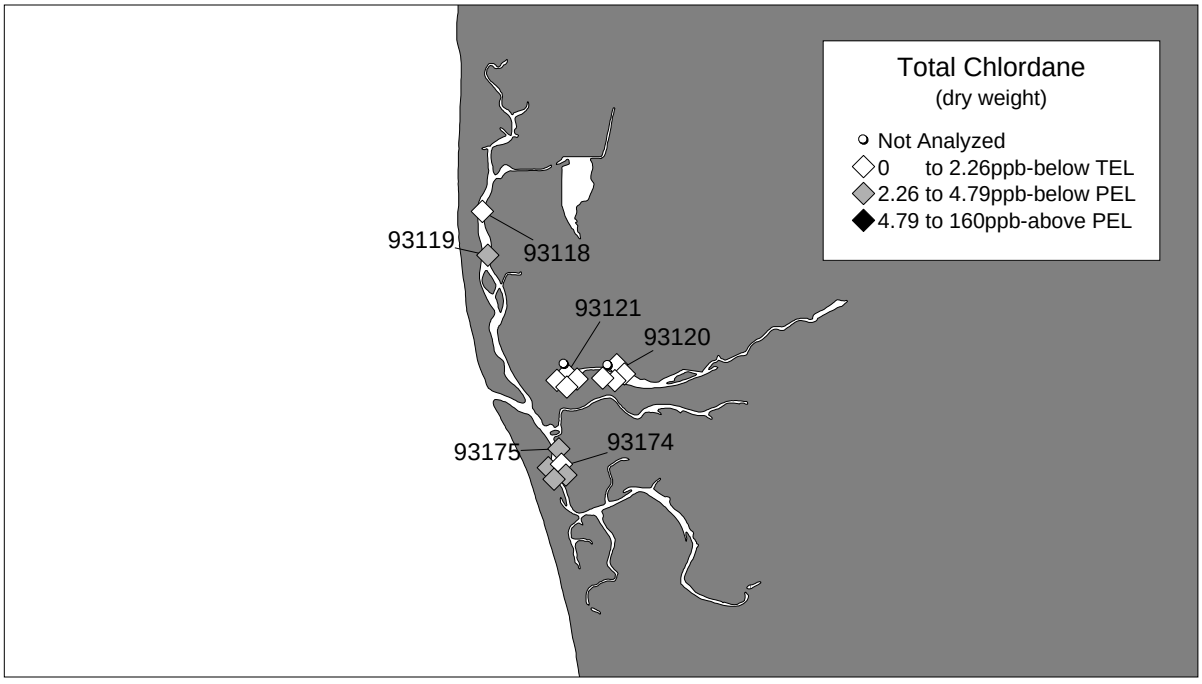


Figure 12d
Total Chlordane Concentrations in Sediment
Mission Bay and San Diego River Estuary



Tijuana River Estuary



approach discussed earlier. This approach considered not only the presence of guideline exceedances, but the number and degree of multiple exceedances.

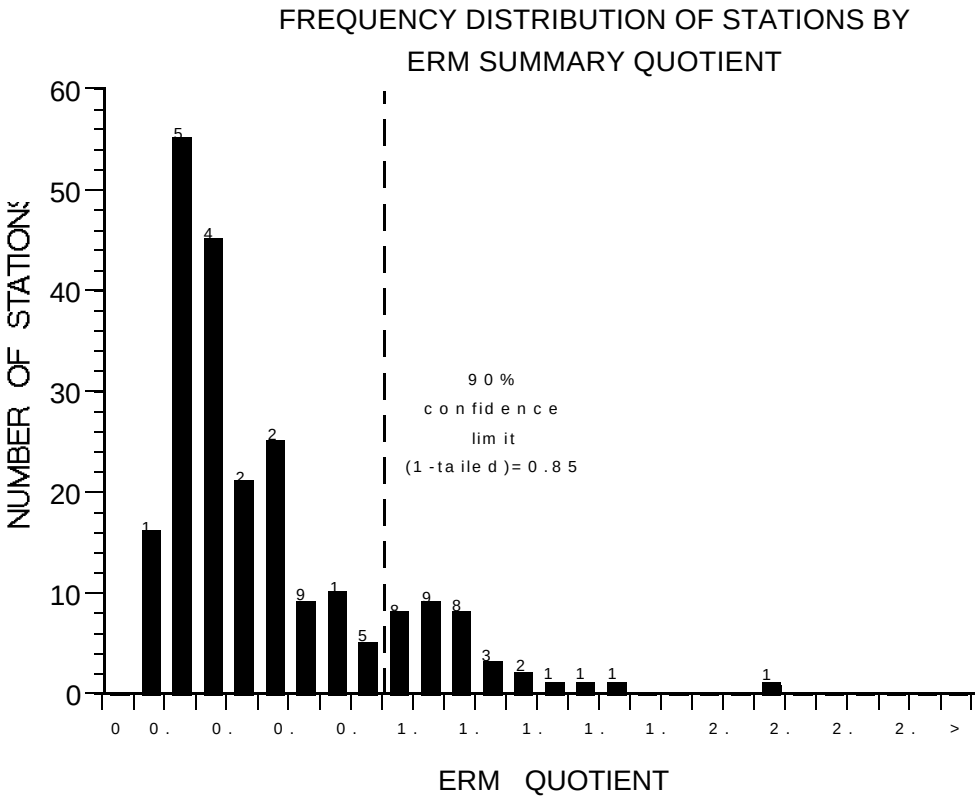
Based upon analyses of the national NS&T and EMAP database, the incidence of toxicity has been shown to increase with increasing summary ERM and PEL quotients (Long, Field and MacDonald, in prep). Synergistic effects are possible, but not implied by the quotient summations, therefore, this method should be recognized only as a ranking scheme meant to better focus management efforts on interpretation of ambient sediment chemistry data.

Interpretations using ERM and PEL summary quotients were limited to statistical analysis within this dataset because the approach has not been formally presented in other reports, therefore, outside comparisons are unavailable at this time. The 90% confidence interval from a 1-tailed t-distribution was chosen as an arbitrary threshold level for evaluating the data set. For the 220 stations on which chemical analysis was performed, stations with an ERMQ>0.85 or a PELQ>1.29 were found to fall above this confidence interval (Figure 13). Although these values of 0.85 and 1.29 cannot be considered threshold levels with proven ecological significance, they can be used for within bay comparative purposes. Forty-one stations exhibited ERM or PEL quotient levels exceeding the confidence interval cutoffs. Of these forty-one stations, twelve received benthic community analysis, all which were determined to have degraded communities in the analysis discussed later (Figure 14). All 41 stations were tested for *Rhepoxynius* toxicity, of which 29% demonstrated significant toxicity, at the 48% limit established by the reference envelope method discussed later. This difference in biological response to pollutants, between benthic community structure and bioassays, may be explained by long term exposure to pollutants in the benthic community relative to short term (10 day) pollutant exposure in bioassay tests. Use of the ERM and PEL quotients appear to give a worthwhile representation of overall chemical pollution and are used later in this report for station rankings and characterizations.

Distribution of Benthic Community Degradation

Data Analyses and Interpretation

The identification of benthic degraded and undegraded habitat (as determined by macrobenthic community structure) was conducted using a cumulative, weight-of-evidence approach. Tests were employed without prior knowledge or integration of results from laboratory exposures or chemical analyses. Analyses were performed to identify relationships between community structure within and between each station or site. This included diversity/evenness indices, analyses of habitat and species composition, construction of dissimilarity matrices for pattern testing, assessment of indicator species and development of a benthic index, cluster and ordination (multidimensional scaling) analyses. Initially, a triangular correlation matrix was produced



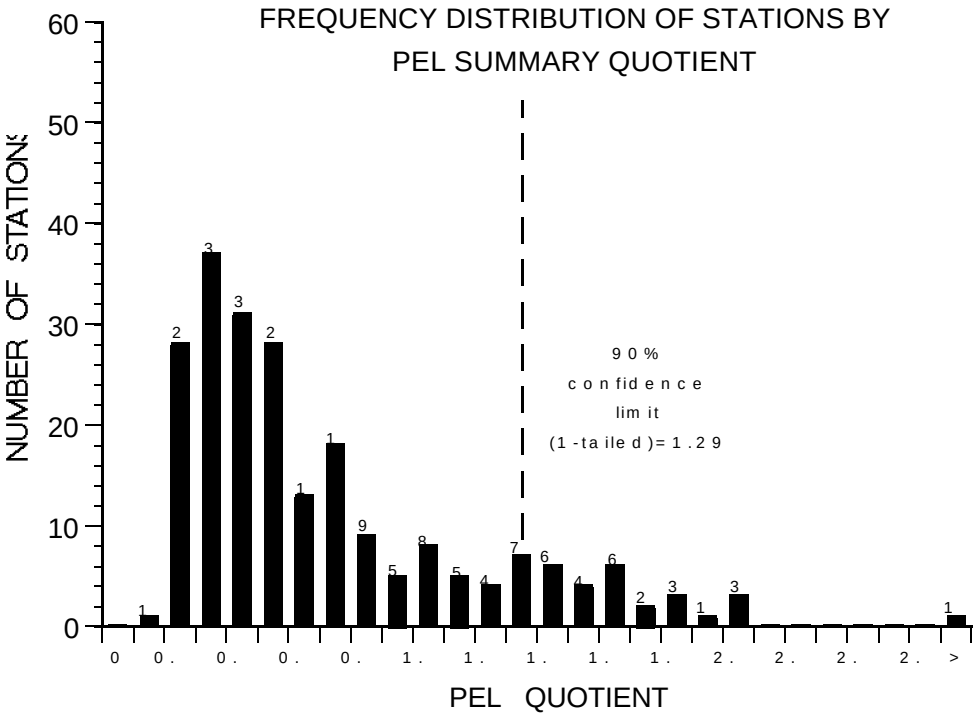


Figure 13. Histogram of the number of stations by ERM or PEL summary quotient group. Vertical dashed line indicates 90% confidence limit of the mean.

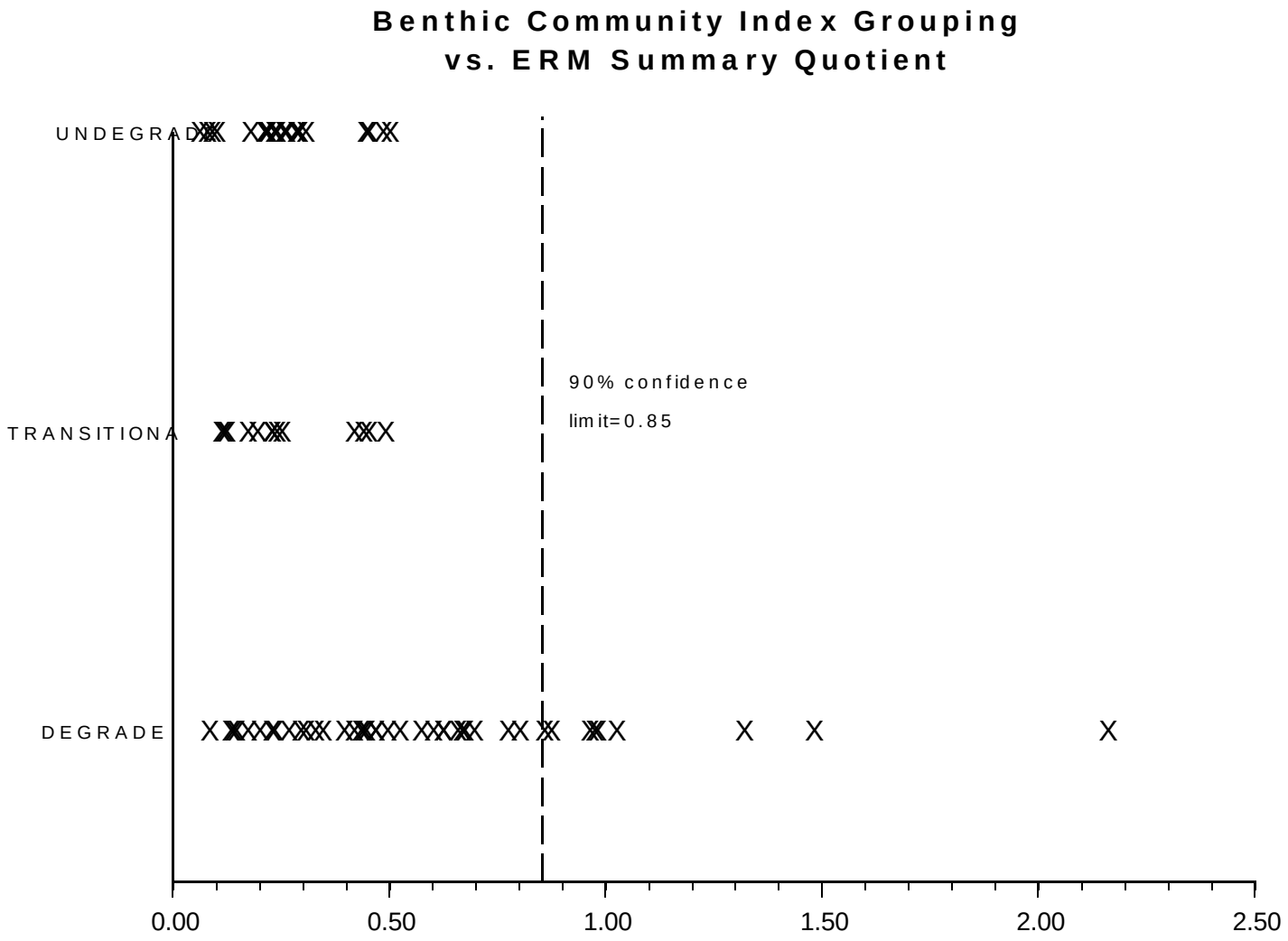


Figure 14. Benthic index grouping vs. ERM summary quotient value. Each data point represents one station (n=75).

from species density data from each site using the Systat® statistical program. From this matrix several tests for association of variables were performed. The tests employed are common in marine and estuarine benthic community analyses and are well-documented in the literature (Field *et al.,* 1982; Pearson *et al* 1983; Swartz *et al.,* 1985; Gray, 1989; Clark and Ainsworth, 1993). Classification analysis was employed to demonstrate site-related community patterns such as species dominance. Cluster analysis is a multivariate procedure for detecting natural groupings in data, and, for our purposes, data were grouped by average similarities in total composition and species abundance (Krebs, 1989). The average-linkage method calculates similarity between a pair of cluster groups as the average similarity among entities in the two groups. Species information is used to compute similarity index values. Grouped stations were clustered at a conservative distance limit of 50-60% similarity, however, this level was purely arbitrary. Because classification analyses have the tendency to force data into artificially distinct groups, another method (*e.g.*, multi-dimensional scaling) was used to confirm the validity of group clusters and site similarity. Ordination analysis was useful because it enables one to see multidimensional gradients in data rather than just groupings (Smith, personal communication).

Multi-dimensional scaling (MDS) is used extensively in the analyses of benthic communities, particularly in estuarine and marine pollution studies. MDS is a procedure for fitting a set of points in space such that the distance between points correspond to a given set of dissimilarities. This technique is more flexible than principal co-ordinate analyses when handling the large number of zero counts generally characteristic of species-samples matrices. Nonmetric MDS analyses were performed using Systat®. For a detailed account of MDS statistical procedures, see Clarke and Ainsworth (1993) and Warwick and Clarke (1993). Inferences from the resultant ordination are also presented. It is important to note that, as with cluster analyses, MDS results are not definitive and must be used in conjunction with additional ecological information. MDS results are based on total species number and numbers of individuals. Inferences from the resultant ordination are also presented.

After classification and ordination patterns were determined, the raw data were reevaluated to assess which species may have influenced the observed patterns. Indicator species were then selected on the basis of a literature review (*i.e.,* distribution, life history strategies and habitat preference), by recommendations from other experienced benthic taxonomists, and review of the raw data. Initially, community analyses were conducted as a per "site" comparison. Later, it was decided analyses also be expanded to a per "station" comparison to produce a more definitive data set for the reference pool. The extended analysis of station variability was performed using the benthic index.

Benthic assemblages have many attributes which make them reliable and sensitive indicators of the ecological condition in estuarine environments. The following procedure summarizes the construction and application of the benthic index used to reliably discriminate between degraded and undegraded conditions at sites in the San Diego Bay Region. Although there are problems with trying to simplify complex biological communities, we attempted to develop a quantitative method which creates a partition between degraded and undegraded areas. Polluted sites can not be conclusively identified using results from benthic community analyses alone, but these analyses impartially describe "environmentally stressed" areas. This benthic index is based on species (indicators), and group (general taxa) information. The index also evaluates community parameters, such as species richness, and abundance or presence of pollution indicators, which identify the extremes of the community characteristics. Sites are ranked according to these extremes and are represented by a single value. In general, decreasing numbers of species, increasing numbers of individuals, and decreasing diversity values are common responses observed near polluted areas. These trends are incorporated into the index. One of the important restrictions with the existing method is it evaluates this limited San Diego Bay benthic data set when dividing groups for categorization. Construction and subsequent validation of this simplified benthic index are loosely based on criteria developed by several agencies, including USEPA-EMAP and SCCWRP. However, the benthic index developed by USEPA-EMAP (Weisberg *et al.*, 1993) included several environmental variables in its construction (*e.g.* dissolved O_2), while the index for San Diego Bay data used only biological parameters. Briefly, the following major steps were followed in constructing and validating this benthic index:

1. Degraded and undegraded (*i.e.,* reference condition) stations were identified on the basis of measured environmental and biological variables.
2. A list of "candidate" parameters was developed using species abundance data. The list included metrics having ecological relevance (*e.g.,* species diversity indices, etc.) which were used to discriminate between degraded and reference areas.
3. A value for each candidate parameter (*i.e.,* diversity, abundance, taxonomic composition) was calculated for each station (*e.g.,* total species per station, total individuals per station, total crustaceans species per station, total number of polychaete individuals, total amphipods per station, etc.).
4. Range of values per metric was determined (lowest to highest value).
5. Quartiles from that range were determined.
6. Ranking within quartiles were assigned: upper quartile=2, lower quartile=0, middle quartile=1. These calculations were applied to the metrics from step 3.

7. The index was defined by values of 0, 1, or 2. A value of 0 defines the degraded (detectable stress) stations(s), and 2 identifies environmentally undegraded stations(s). Stations with an index value of 1 are considered transitional communities, which are neither degraded nor reference stations. Transitional stations have species or other parameters which indicate both degraded and undegraded habitats. These stations are investigated further to determine the cause of ambiguity of the transitional status.

8. Relative abundance of indicator species (both degraded and undegraded habitat indicators) per station is assessed.

A primary concern regarding the benthic index is how well it fulfills the objective of discriminating among degraded and undegraded estuarine conditions. This simplified version forms the basis for ongoing iterative procedures involved in construction of an index. This index will include a variety of indicator values (Bascom *et al.*, 1978; Kerans *et al.*, 1994; EcoAnalysis *et al.*, 1995) for future applications of the assessment of benthic community structure. The following sections report results of benthic community analyses based solely on composition and abundance of macrobenthic species from sediment cores throughout San Diego Bay and its vicinity. Environmental parameters (*e.g.*, total organic carbon levels and sediment grain size range) and other factors capable of influencing benthic composition were examined, but not evaluated in conjunction with the data presented here. Those data are examined later in sections which address correlative analyses.

In this study, bioeffects are required to be demonstrated in relation to properly selected reference sites and to occur in association with significant pollutant levels. The following evidence for undegraded (possible reference) and degraded (possible contaminated) sites was based on benthic community "quality" at each site and station. Benthic community structure was evaluated as an indicator of environmentally degraded or undegraded areas and not as a pollution or contamination indicator. Benthic reference sites were determined predominantly by analyses of specific indicator species and groups (*e.g.*, amphipods). These species are generally not found in polluted or disturbed areas.

The intention of this section is to clearly describe the condition of macrobenthic communities from sampling areas. Definitions of degraded, transitional, and undegraded used in this section are adopted from several papers (Bascom *et al.*, 1978; Pearson and Rosenberg, 1978; Schindler, 1987; Swartz *et al.*, 1985; Underwood and Peterson, 1988). Although the boundaries set in Bascom *et al.* (1978) were based on food supply and not on toxicants, the same general principles apply to this study. In benthic analyses, the term "degraded" does not refer to a

community response to significant levels of toxic chemicals. Degraded areas are those which contain significant numbers of opportunistic species, in the absence of non-opportunistic species, and have relatively low species diversity. Correlations are later used to determine if community profiles are influenced by chemistry or by natural environmental disturbances. Sites and stations which are categorized as "undegraded" have high species diversity, high proportional abundance of amphipods and other crustaceans, while noting there are a few exceptions to this rule (*e.g., Grandidierella japonica*, etc.). Undegraded areas generally contain species which are known to be sensitive to pollutants. Transitional sites and stations are those which are not confidently partitioned into the other two categories. These areas may solicit further study. Overall, an integration of data from laboratory exposures, chemical analyses, and benthic community assessments provide strong complementary evidence of the degree of pollution-induced degradation in aquatic communities. The following data analyses were conducted on a per site basis using sample replicates (n=5) at each sampling location (Table 6). An analysis also was performed using per station data (n=1) and is presented later in this section. Tests included classification and ordination analyses, diversity measurements, construction of a benthic index, and assessment of indicator species. One cautionary note is each of the benthic community and population condition tests are subject to effects of not only the pollutants measured in this study, but many other confounding natural factors, such as depth, salinity, sediment texture, and/or predation.

Abundance and Diversity

There were 7,232 individuals, representing 198 macrobenthic species, collected from 375 benthic cores during sampling legs 20 through 23 of the San Diego Bay confirmation phase (Table 7). Mean number of species was calculated from 5 replicates per site (Table 8). Polychaetes comprised the majority of specimens in samples. Great numbers of mollusks in sites within West Basin, Downtown Piers, and Glorietta Bay were due to the bivalve *Musculista senhousei* which was collected as large aggregates. Echinoderms were found at only 6 of the 25 sites, and were significantly ($p>0.01$) greater at the Mission Bay A3 site (640.0±216.6) and the Mission Bay A8 site (213.3±53.3) compared to all other sites. Holothurians comprised the majority of echinoderms found at these sites, although ophiuroids were also present. Colonial species were not present. Diversity ranged from 9 to 46 benthic species per site in collected samples. Significant differences in species diversity were not as distinct as with other indices and no trends were obvious. Results shown in Table 9 indicate most communities in this study were relatively diverse and even. Simpson's diversity index (D') which emphasizes more common species, and Shannon-Weaver (H') which puts statistical weight on rare species, showed differences in the range of diversity values. Chula Vista Yacht Basin was the only site which showed a moderately high level of dominance as

Table 6. Benthic samples from the San Diego Bay region.

Site-Station Name	Replicate Number	Station No.	IDORG No.
10 Swartz (West Basin)	1	90050.0	837
10 Swartz (West Basin)	2	93199.0	838
10 Swartz (West Basin)	3	93200.0	839
10 Swartz (West Basin)	4	^	837.1
10 Swartz (West Basin)	5	^	837.2
11 Swartz (East Basin)	1	90001.0	840
11 Swartz (East Basin)	2	93201.0	841
11 Swartz (East Basin)	3	93202.0	842
11 Swartz (East Basin)	4	^	840.1
11 Swartz (East Basin)	5	^	840.2
12 Swartz (Downtown Anch)	1	90002.0	878
12 Swartz (Downtown Anch)	2	93221.0	879
12 Swartz (Downtown Anch)	3	93222.0	880
12 Swartz (Downtown Anch)	4	^	878.1
12 Swartz (Downtown Anch)	5	^	878.2
14 Swartz (Downtown Piers)	1	90003.0	846
14 Swartz (Downtown Piers)	2	93205.0	847
14 Swartz (Downtown Piers)	3	93206.0	848
14 Swartz (Downtown Piers)	4	^	846.1
14 Swartz (Downtown Piers)	5	^	846.2
15 Swartz (G St Pier Marina)	1	90004.0	849
15 Swartz (G St Pier Marina)	2	93207.0	850
15 Swartz (G St Pier Marina)	3	93208.0	851
15 Swartz (G St Pier Marina)	4	^	849.1
15 Swartz (G St Pier Marina)	5	^	849.2
16 Swartz (Intercont. Marina)	1	90051.0	818
16 Swartz (Intercont. Marina)	2	93192.0	819
16 Swartz (Intercont. Marina)	3	93193.0	820
16 Swartz (Intercont. Marina)	4	^	818.1
16 Swartz (Intercont. Marina)	5	^	818.2
23 Swartz (Naval Base 07)	1	90006.0	865
23 Swartz (Naval Base 07)	2	93212.0	866
23 Swartz (Naval Base 07)	3	93213.0	867
23 Swartz (Naval Base 07)	4	^	865.1
23 Swartz (Naval Base 07)	5	^	865.2
25 Swartz (Naval base/ SY 010)	1	90007.0	887
25 Swartz (Naval base/ SY 010)	2	93223.0	888
25 Swartz (Naval base/ SY 010)	3	93224.0	889
25 Swartz (Naval base/ SY 010)	4	^	887.1
25 Swartz (Naval base/ SY 010)	5	^	887.2
27 Swartz (Naval Base /SH 013)	1	90008.0	890
27 Swartz (Naval Base /SH 013)	2	93225.0	891
27 Swartz (Naval Base /SH 013)	3	93226.0	892
27 Swartz (Naval Base /SH 013)	4	^	890.1
27 Swartz (Naval Base /SH 013)	5	^	890.2
28 Swartz (7th St Channel Q1)	1	90009.0	893
28 Swartz (7th St Channel Q1)	2	93227.0	894
28 Swartz (7th St Channel Q1)	3	93228.0	895
28 Swartz (7th St Channel Q1)	4	^	893.1
28 Swartz (7th St Channel Q1)	5	^	893.2
31 Swartz (Marine Terminal R3)	1	90010.0	896
31 Swartz (Marine Terminal R3)	2	93229.0	897
31 Swartz (Marine Terminal R3)	3	93230.0	898
31 Swartz (Marine Terminal R3)	4	^	896.1
31 Swartz (Marine Terminal R3)	5	^	896.2
32 Swartz (Sweetwater Ch)	1	90052.0	875
32 Swartz (Sweetwater Ch)	2	93219.0	876
32 Swartz (Sweetwater Ch)	3	93220.0	877
32 Swartz (Sweetwater Ch)	4	^	875.1
32 Swartz (Sweetwater Ch)	5	^	875.2
34 Swartz (CV Yacht Basin)	1	90012.0	824
34 Swartz (CV Yacht Basin)	2	93196.0	825
34 Swartz (CV Yacht Basin)	3	93197.0	826
34 Swartz (CV Yacht Basin)	4	^	824.1
34 Swartz (CV Yacht Basin)	5	^	824.2
35 Swartz (Coronado Cays)	1	90053.0	843
35 Swartz (Coronado Cays)	2	93203.0	844
35 Swartz (Coronado Cays)	3	93204.0	845
35 Swartz (Coronado Cays)	4	^	843.1
35 Swartz (Coronado Cays)	5	^	843.2
37 Swartz (Marina)	1	90013.0	815
37 Swartz (Marina)	2	93190.0	816
37 Swartz (Marina)	3	93191.0	817
37 Swartz (Marina)	4	^	815.1
37 Swartz (Marina)	5	^	815.2
41 Swartz (Glorietta Bay)	1	90015.0	821
41 Swartz (Glorietta Bay)	2	93194.0	822
41 Swartz (Glorietta Bay)	3	93195.0	823
41 Swartz (Glorietta Bay)	4	^	821.1
41 Swartz (Glorietta Bay)	5	^	821.2
K Swartz (Naval Base 04)	1	90021.0	862
K Swartz (Naval Base 04)	2	93210.0	863
K Swartz (Naval Base 04)	3	93211.0	864
K Swartz (Naval Base 04)	4	^	862.1
K Swartz (Naval Base 04)	5	^	862.2
Mission Bay A4	1	93108.0	859
Mission Bay A4	2	93108.0	860
Mission Bay A4	3	93108.0	861
Mission Bay A4	4	93108.0	859.1
Mission Bay A4	5	93108.0	859.2
Mission Bay A8	1	93112.0	856
Mission Bay A8	2	93112.0	857
Mission Bay A8	3	93112.0	858
Mission Bay A8	4	93112.0	856.1
Mission Bay A8	5	93112.0	856.2
Mission Bay A3	1	93107.0	853
Mission Bay A3	2	93107.0	854
Mission Bay A3	3	93107.0	855
Mission Bay A3	4	93107.0	853.1
Mission Bay A3	5	93107.0	853.2
NSB-M1 (Sub Base C2)	1	90028.0	871
NSB-M1 (Sub Base C2)	2	93216.0	872
NSB-M1 (Sub Base C2)	3	93217.0	873
NSB-M1 (Sub Base C2)	4	^	871.1
NSB-M1 (Sub Base C2)	5	^	871.2
P Swartz (Naval Base 012)	1	90022.0	868
P Swartz (Naval Base 012)	2	93214.0	869
P Swartz (Naval Base 012)	3	93215.0	870
P Swartz (Naval Base 012)	4	^	868.1
P Swartz (Naval Base 012)	5	^	868.2
San Diego River B1	1	93116.0	881
San Diego River B1	2	93116.0	882
San Diego River B1	3	93116.0	883
San Diego River B1	4	93116.0	881.1
San Diego River B1	5	93116.0	881.2
SDNI- N5 (Carrier Base V2)	1	90025.0	899
SDNI- N5 (Carrier Base V2)	2	93231.0	1000
SDNI- N5 (Carrier Base V2)	3	93232.0	1001
SDNI- N5 (Carrier Base V2)	4	^	899.1
SDNI- N5 (Carrier Base V2)	5	^	899.2
Stormdrain EM (Grape St.)	1	90037.0	827
Stormdrain EM (Grape St.)	2	90037.0	828
Stormdrain EM (Grape St.)	3	90037.0	829
Stormdrain EM (Grape St.)	4	90037.0	827.1
Stormdrain EM (Grape St.)	5	90037.0	827.2
Long Beach Outer Harbor	1	40018.3	884
Long Beach Outer Harbor	2	40018.3	885
Long Beach Outer Harbor	3	40018.3	886
Long Beach Outer Harbor	4	40018.3	884.1
Long Beach Outer Harbor	5	40018.3	884.2
Lower Main Channel	1	40004.2	830
Lower Main Channel	2	40004.2	831
Lower Main Channel	3	40004.2	832
Lower Main Channel	4	40004.2	830.1
Lower Main Channel	5	40004.2	830.2
Off Cabrillo Beach	1	40010.0	1006
Off Cabrillo Beach	2	40010.0	1007
Off Cabrillo Beach	3	40010.0	1008
Off Cabrillo Beach	4	40010.0	1006.1
Off Cabrillo Beach	5	40010.0	1006.2
Palos Verdes (Swartz 6)	1	40031.2	1002
Palos Verdes (Swartz 6)	2	40031.2	1003
Palos Verdes (Swartz 6)	3	40031.2	1004
Palos Verdes (Swartz 6)	4	40031.2	1002.1
Palos Verdes (Swartz 6)	5	40031.2	1002.2
West Basin Entrance	1	40009.1	834
West Basin Entrance	2	40009.1	835
West Basin Entrance	3	40009.1	836
West Basin Entrance	4	40009.1	834.1
West Basin Entrance	5	40009.1	834.2

Table 7. Species list of macroinvertebrates from the San Diego Bay region benthic samples

Acmira catherinae	Gastropoda	*Fabricinuda limicola*	Polychaeta	*Orchomene pacifica*	Gammaridea
Acmira horikoshii	Gastropoda	*Glycera americana*	Polychaeta	*Orchomene sp.*	Gammaridea
Acuminodeutopus heteruropus	Amphipoda	*Glycera nana*	Polychaeta	*Paracerceis sculpta*	Isopoda
Aglaja sp.	Gastropoda	*Gnathia crenulatifrons*	Isopoda	*Paradexamine sp.*	Amphipod
Alpheus californiensis	Decapoda	*Goniada brunnea*	Polychaeta	*Paramage scutata*	Polychaeta
Amaeana occidentalis	Polychaeta	*Goniada sp(p).*	Polychaeta	*Paranthura elegans*	Isopoda
Ampelisca brevisimulata	Gammaridea	*Grandidierella japonica*	Gammaridea	*Paraprionospio pinnata*	Polychaeta
Ampelisca cristata	Gammaridea	*Harmothoe hirsuta*	Polychaeta	*Parasterope barnesi*	Ostracoda
Ampelisca hancocki	Gammaridea	*Harmothoe imbricata*	Polychaeta	*Parougia caeca*	Polychaeta
Ampharete labrops	Polychaeta	*Heptacarpus cf taylori*	Decapoda	*Parvilucina tenuisculpta*	Bivalvia
Amphicteis scaphobranchiata	Polychaeta	*Heptacarpus sp. A*	Decapoda	*Pectinaria californiensis*	Polychaeta
Amphideutopus oculatus	Amphipoda	*Hesperonoe sp(p).*	Polychaeta	*Pennatulacea*	Anthozoa
Amphilochidae	Gammaridea	*Heterophoxus oculatus*	Gammaridea	*Pherusa capulata*	Polychaeta
Ampithoe sp.	Gammaridea	unidentified holothuroid	Holothuroidea	*Pherusa sp(p).*	Polychaeta
unid. anemone	Anthozoa	*Hyale frequens*	Gammaridea	*Pholoe glabra*	Polychaeta
Aphelochaeta monilaris	Polychaeta	*Hydroides pacificus*	Polychaeta	unidentified phoronida	Phoronida
Aphelochaeta multifilis	Polychaeta	*insect larva*	Arthropoda	*Photis sp.*	Gammaridea
Aphelochaeta sp(p).	Polychaeta	*Laevicardium substriatum*	Bivalvia	*Pista alata*	Polychaeta
Apistobranchus sp(p).	Polychaeta	*Laonice cirrata*	Polychaeta	*Pista sp(p).*	Polychaeta
Apoprionospio pygmaea	Polychaeta	*Leitoscoloplos pugettensis*	Polychaeta	*Pleustidae*	Gammaridea
Armandia brevis	Polychaeta	*Lembos sp.*	Gammaridea	*Podarkeopsis glabra*	Polychaeta
Asteropella slatteryi	Ostracoda	*Leptochelia dubia*	Tanaidacea	*Podarkeopsis perkinsi*	Polychaeta
Autolytus sp(p).	Polychaeta	*Leptognathia sp.*	Tanaidacea	*Podocerus cristatus*	Gammaridea
unidentified bivalve	Bivavia	*Levinsenia gracilis*	Polychaeta	*Poecilochaetus johnsoni*	Polychaeta
Brania brevipharyngea	Polychaeta	*Listriella goleta*	Gammaridea	*Polydora cornuta*	Polychaeta
Bulla sp.	Gastropoda	*Lophopanopeus bellus diegensis*	Decapoda	*Polydora nuchalis*	Polychaeta
Campylaspis rubromaculata	Cumacea	Lumbrineridae, unident.	Polychaeta	*Polydora socialis*	Polychaeta
Capitella capitata complex	Polychaeta	*Lyonsia californica*	Bivalvia	*Polyophthalmus pictus*	Polychaeta
Caprella californica	Caprellida	*Lysippe labiata*	Polychaeta	*Pontogeneia rostrata*	Gammaridea
Caulleriella sp(p).	Polychaeta	*Macoma cf yoldiformis*	Bivalvia	*Praxillella pacifica*	Polychaeta
Chaetozone corona	Polychaeta	*Macoma nausta*	Bivalvia	*Prionospio heterobranchia*	Polychaeta
Chone mollis	Polychaeta	*Macoma sp.*	Bivalvia	*Prionospio lighti*	Polychaeta
Cirratulidae, unident.	Polychaeta	*Mactra californica*	Bivalvia	*Prionospio sp(p).*	Polychaeta
Cirratulus sp(p).	Polychaeta	*Malmgreniella macginitiei*	Polychaeta	*Prionospio steenstrupi*	Polychaeta
Cirriformia luxuriosa	Polychaeta	*Marphysa disjuncta*	Polychaeta	*Pseudopolydora paucibranchiata*	Polychaeta
Collisela depicta	Gastropoda	*Mayerella banksia*	Amphipoda	*Rhynchospio glutaea*	Polychaeta
Compsomyax subdiaphana	Bivalvia	*Mediomastus californiensis*	Polychaeta	*Rudilemboides stenopropodus*	Amphipoda
Cooperella subdiaphana	Bivalvia	*Megalomma pigmentum*	Polychaeta	*Scleroplax granulata*	Decapoda
Corophium acherusicum	Gammaridea	*Melinna oculata*	Polychaeta	*Scolelepis quinquedentata*	Polychaeta
Corophium heteroceratum	Gammaridea	*Metasychis disparidentata*	Polychaeta	*Scoletoma erecta*	Polychaeta
Cossura candida	Polychaeta	*Microjassa litotes*	Gammaridea	*Scoletoma tetraura*	Polychaeta
Crepidula fornicata	Gastropoda	*Monoculodes hartmanae*	Gammaridea	*Scoloplos acmeceps*	Polychaeta
Crucibulum spinosum	Gastropoda	*Monticellina dorsobranchialis*	Polychaeta	*Scyphoproctus sp(p).*	Polychaeta
Cryptomya californica	Bivalvia	*Monticellina sp. C*	Polychaeta	*Serolis carinata*	Isopoda
Cylichnella inculta	Gastropoda	*Monticellina tesselata*	Polychaeta	*Sigambra tentaculata*	Polychaeta
Cylichnella sp.	Gastropoda	*Munnogonium californiensis*	Isopoda	*Siliqua lucida*	Bivalvia
Diastylis sp.	Cumacea	*Musculista senhousei*	Bivalvia	unidentified spionid	Polychaeta
Diopatra sp(p).	Polychaeta	*Myriochele sp. M*	Polychaeta	*Spiophanes berkeleyorum*	Polychaeta
Diopatra tridentata	Polychaeta	*Mysella sp.*	Bivalvia	*Spiophanes missionensis*	Polychaeta
Diplocirrus sp(p).	Polychaeta	unidentified mysid	Mysidacea	*Sthenelais tertiaglabra*	Polychaeta
Dorvillea longicornis	Polychaeta	*Nassarius perpinguis*	Gastropoda	*Sthenelanella uniformis*	Polychaeta
Drilonereis falcata minor	Polychaeta	*Neanthes acuminata*	Polychaeta	*Streblosoma sp. B*	Polychaeta
Elasmopus rapax	Amphipoda	*Neastacilla californica*	Isopoda	*Streblospio benedicti*	Polychaeta
Eranno lagunae	Polychaeta	*nemertean*	Nemertea	*Sulcoretusa xystrum*	Gastropoda
Eteone californica	Polychaeta	*Neotrypaea californiensis*	Decapoda	*Synchelidium rectipalmum*	Gammaridea
Eteone sp(p).	Polychaeta	*Nephtys caecoides*	Polychaeta	*Synchelidium sp.*	Gammaridea
Euchone limnicola	Polychaeta	*Nephtys cornuta*	Polychaeta	*Tagelus subteres*	Bivalvia
Euclymeninae spp. indet.	Polychaeta	Nereididae, unident.	Polychaeta	*Tellina modesta*	Bivalvia
Eudorella pacifica	Cumacea	*Nereis procera*	Polychaeta	*Tenonia priops*	Polychaeta
Euphilomedes carcharodonta	Ostracoda	*Notomastus tenuis*	Polychaeta	Terebellidae, unident.	Polychaeta
Euphilomedes producta	Ostracoda	*Nuculana taphria*	Bivalvia	*Terebellides californica*	Polychaeta
Eupolymnia sp(p).	Polychaeta	*Odontosyllis phosphorea*	Polychaeta	*Theora fragilis*	Bivalvia
Exogone lourei	Polychaeta	*Odostomia sp.*	Gastropoda	*Trachycardium quadragenarium*	Bivalvia
Exogone molesta	Polychaeta	*oligochaeta*	Oligochaeta	*Turbonilla sp.*	Gastropoda
Exogone sp(p)	Polychaeta	*Olivella baetica*	Gastropoda	*Urocaris infraspinis*	Decapoda
Exogone uniformis	Polychaeta	unidentified ophiuroid	Ophioroidea	*Zeuxo normani*	Tanaidacea

Table 8. Mean densities and standard error of higher taxonomic groups at each site in San Diego Bay. Total area sampled (0.04m2) at each site was from 5 replicate cores.

SITES	ID ORG #	Polychaetes mean #/m2 ± SE	Mollusks mean #/m2 ± SE	Crustaceans mean #/m2 ± SE	Echinoderms mean #/m2 ± SE
10 Swartz (West Basin)	837	4,986.5 ± 481.8	2,213.3 ± 1,211.5	5,199.9 ± 792.2	
11 Swartz (East Basin)	840	5,599.9 ± 1,654.0	640.0 ± 319.4	7,946.5 ± 2,605.1	26.7 ± 26.7
14 Swartz (Downtown Piers)	846	4,213.2 ± 822.5	2,453.3 ± 1,865.5	1,146.6 ± 449.4	
15 Swartz (G St Pier Marina)	849	4,106.6 ± 694.6	1,040.0 ± 508.4	1,120.0 ± 123.6	
16 Swartz (Intercont. Marina)	818	3,893.2 ± 824.5	1,146.6 ± 629.1	2,853.3 ± 905.9	
23 Swartz (Naval Base 07)	865	5,119.9 ± 1,427.1	106.7 ± 77.7	373.3 ± 154.3	
25 Swartz (Naval base/ SY 010)	887	2,639.9 ± 932.7	53.3 ± 53.3	53.3 ± 32.7	
27 Swartz (Naval Base /SH 013)	890	2,373.3 ± 268.0	133.3 ± 73.0	293.3 ± 165.5	
28 Swartz (7th St Channel Q1)	893	2,000.0 ± 944.7	80.0 ± 53.3	26.7 ± 26.7	
31 Swartz (Marine Terminal R3)	896	4,373.2 ± 1,827.4	746.6 ± 225.5	853.3 ± 466.8	
32 Swartz (Sweetwater Ch)	875	5,066.5 ± 1,224.2	213.3 ± 181.8	1,013.3 ± 459.2	
34 Swartz (CV Yacht Basin)	824	10,426.4 ± 2,264.4	373.3 ± 154.3	800.0 ± 332.0	
35 Swartz (Coronado Cays)	843	4,986.5 ± 1,506.5	320.0 ± 171.8	3,199.9 ± 370.0	26.7 ± 26.7
37 Swartz (Marina)	815	4,399.9 ± 1,141.5	426.7 ± 160.0	1,626.6 ± 351.2	
41 Swartz (Glorietta Bay)	821	10,106.4 ± 532.3	5,066.5 ± 2,724.3	1,493.3 ± 816.9	
K Swartz (Naval Base 04)	862	2,799.9 ± 480.7	906.6 ± 208.3	853.3 ± 293.9	
NSB-M1 (Sub Base C2)	871	4,266.6 ± 668.0	1,013.3 ± 149.7	1,146.6 ± 200.4	53.3 ± 53.3
P Swartz (Naval Base 012)	868	4,799.9 ± 808.8	533.3 ± 279.7	533.3 ± 245.8	
SDNI- N5 (Carrier Base V2)	899	7,733.1 ± 2,003.5	1,946.6 ± 512.2	2,000.0 ± 511.2	
12 Swartz (Downtown Anch)	878	3,893.2 ± 760.6	1,333.3 ± 865.1	2,159.9 ± 586.3	
Mission Bay A3	853	1,600.0 ± 152.0	1,440.0 ± 330.4	533.3 ± 242.2	640.0 ± 216.6
Mission Bay A4	859	2,186.6 ± 422.9	213.3 ± 149.7	933.3 ± 467.6	53.3 ± 32.7
Mission Bay A8	856	11,573.0 ± 761.7	320.0 ± 90.4	3,599.9 ± 1,096.2	213.3 ± 53.3
San Diego River B1	881	2,426.6 ± 1,062.0	26.7 ± 26.7	800.0 ± 173.8	
Stormdrain EM (Grape St.)	827	4,239.9 ± 534.0	53.3 ± 53.3	3,813.2 ± 1,345.6	

Table 9. Macrobenthic community variables at sites in San Diego bay. Biological parameters derived from 5 replicate samples per site Physical measurements are from an average of the 3 stations.

SITES	depth (m)	silt:clay (%)	TOC	Total no. of species	Mean no. indiv./m2	Simpson's diversity D	inverse (1/D) diversity	V' evennness	Shannon-W diversity H'	J' evenness	habitat
32 Swartz (Sweetwater Ch)	6	64.49	0.97	31	6,426.5	0.161	6.211	0.005	3.514	0.709	E-sandy
11 Swartz (East Basin)	3	52.71	1.33	35	14,586.3	0.124	8.065	0.004	3.719	0.725	S,Sb
16 Swartz (Intercont. Marina)	4	59.68	1.04	32	8,106.5	0.086	11.628	0.003	4.037	0.807	S,Sb
37 Swartz (Marina)	3	92.77	1.45	29	6,586.5	0.101	9.901	0.003	3.833	0.789	S,Sb
Stormdrain EM (Grape St.)	8	82.47	1.97	33	8,239.8	0.071	14.085	0.002	4.152	0.823	E,Sb
10 Swartz (West Basin)	3	75.36	1.46	34	12,399.7	0.094	10.638	0.003	3.910	0.769	S,Sb
14 Swartz (Downtown Piers)	11	54.59	1.30	37	7,919.8	0.088	11.364	0.002	4.112	0.789	E
15 Swartz (G St Pier Marina)	5	77.25	4.08	33	6,586.5	0.074	13.514	0.002	4.194	0.831	E
41 Swartz (Glorietta Bay)	5	50.00	1.05	28	16,879.6	0.163	6.135	0.006	3.296	0.686	S,Sb
K Swartz (Naval Base 04)	5	62.79	2.23	21	4,586.6	0.129	7.752	0.006	3.481	0.793	E,N
SDNI- N5 (Carrier Base V2)	7	65.80	1.81	46	11,839.7	0.075	13.333	0.002	4.342	0.786	E,N
12 Swartz (Downtown Anch)	5	73.73	1.83	31	7,439.8	0.094	10.638	0.003	3.985	0.804	E
23 Swartz (Naval Base 07)	8	55.09	1.74	29	5,706.5	0.124	8.065	0.004	3.621	0.745	E,N
25 Swartz (Naval base/ SY 010)	9	71.89	1.92	20	2,799.9	0.141	7.092	0.007	3.324	0.769	E,N
27 Swartz (Naval Base /SH 013)	10	71.16	1.90	21	2,826.6	0.111	9.009	0.005	3.631	0.827	E,N
31 Swartz (Marine Terminal R3)	6	61.51	1.58	32	6,079.8	0.142	7.042	0.004	3.634	0.727	E
34 Swartz (CV Yacht Basin)	3	90.40	1.39	33	11,866.4	0.368	2.717	0.011	2.474	0.490	S
35 Swartz (Coronado Cays)	3	82.29	1.39	30	8,613.1	0.103	9.709	0.003	3.847	0.784	S,N
NSB-M1 (Sub Base C2)	10	62.67	1.64	43	6,746.5	0.101	9.901	0.002	4.087	0.753	E,N
P Swartz (Naval Base 012)	10	69.63	2.07	28	5,866.5	0.108	9.259	0.004	3.744	0.779	E,N
Mission Bay A4 REF	2	65.70	1.63	37	3,599.9	0.069	14.493	0.002	4.460	0.856	M
28 Swartz (7th St Channel Q1)	7	45.97	1.73	15	2,159.9	0.178	5.618	0.012	3.156	0.808	nd
Mission Bay A8 REF	5	36.99	0.89	44	15,866.3	0.085	11.765	0.002	4.109	0.753	M
Mission Bay A3 REF	3	93.21	2.98	27	5,653.2	0.130	7.692	0.005	3.516	0.739	M
San Diego River B1 REF	1	76.19	2.31	9	3,466.6	0.332	3.012	0.037	2.081	0.656	M
					Value range=	0-1	1-s	0-1	<5, max=log S	0-1	

E=exposed, S=sheltered, Sb=small boats, N=navy, C=channel, M=Mission Bay

shown by the evenness index (J'=0.490). This was due to an abundance of *Mediomastus californiensis* and *Leitoscoloplos pugettensis* polychaetes. Compared to all other sites, Chula Vista had a significantly lower density of crustaceans. The Mission Bay A4 site had moderately high species diversity but comparatively low species abundance.

Cluster and Ordination Analyses

Cluster analyses produced the dendrogram (Figure 15) of station affinities, based on mean root-root transformed abundance of the 198 macrobenthic species, using Pearson's correlation of similarity and group-average sorting. A root-root transformation, reduced the weighting of abundant species (Field *et al.*, 1982). The similarity level, although arbitrary, was designated somewhat conservatively near 50%. The resulting classification of assemblages reflect general patterns of benthic species composition, domination, and evenness (*e.g.*, sites along the 0.00 line would be identical in species composition and abundance). Six major groups were delineated from the hierarchical clusters, which were defined by an overall dominant species. Group I, which included only a single site (32 Swartz, Sweetwater Channel) was co-dominated by the tube-building tanaid *Zuexo normandi* and polychaete worm *Leitoscoloplos pugettensis*. Groups IV, V and VI were all dominated by the polychaete worm species *L. pugettensis*, *Prionospio heterobranchia*, and co-dominants *P. heterobranchia* and oligochaetes, respectively. Amphipods (*Acuminodeutopus heteruropus*) were the most abundant group in cluster II. The seemingly ubiquitous bivalve *Musculista senhousei* was the numerically important species in Group III. When plotted, these biologically-based clusters provide a qualitative assessment of the pattern of physical data and visually demonstrate the relationship of one site to another. To put the relationship of samples into a more general perspective, the level of similarity found between San Diego Bay site samples and those from Los Angeles Harbor was between 5-10% (Figure 16), revealing the benthos of these northerly areas should not be used comparatively, due to differences in habitats and biotic response. Although tidally influenced, the species composition of the San Diego River B1 site was also found to be highly dissimilar to other San Diego Bay samples, presumably due to habitat differences.

In addition to conventional methods, non-metric multi-dimensional scaling (MDS) using a weighted Spearman rank correlation coefficient dissimilarity matrix was used to determine similarity in species composition between stations. Non-metric MDS can handle large numbers of zeros, missing data, and unequal replication. MDS seeks a representation of individuals in a space of low dimensionality where the distances between individuals in ordination space optimally represent their dissimilarities in variable space (Kenkel and Orloci, 1986). Typically, transformed biotic and abiotic data are initially analyzed separately, then combined to assess common MDS spatial patterns. The resulting ordination for biotic variables is demonstrated here.

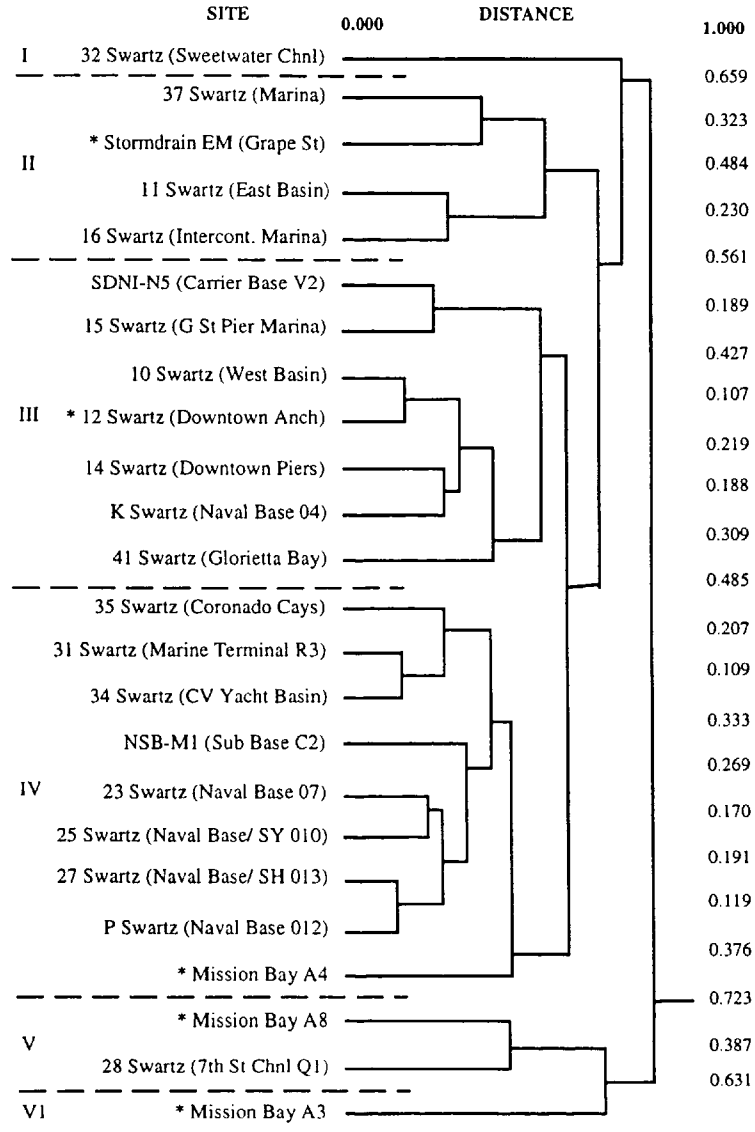


Figure 15. Numerical classification of mean abundance data of 198 macrobenthic species. Clusters are derived from Pearson correlation matrix data and group-average sorting. Six major clusters are shown, each dominated by 1-2 species.

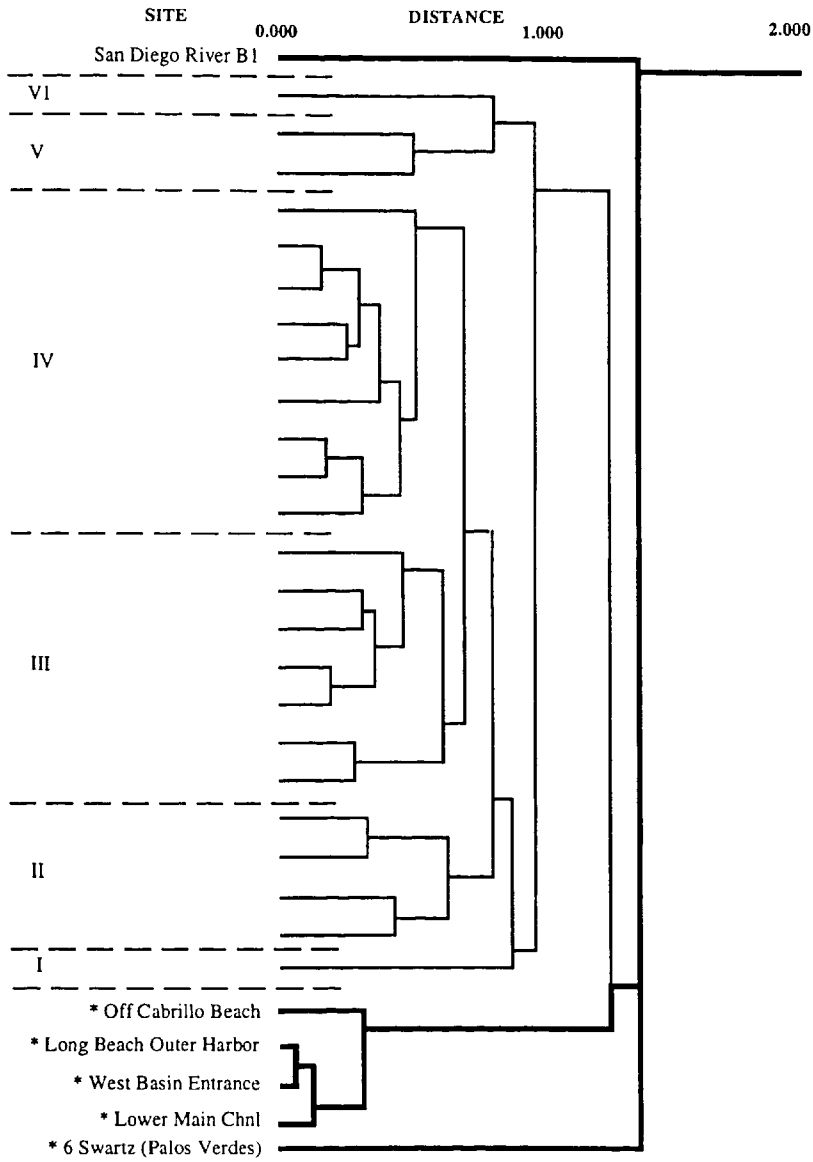


Figure 16. Numerical classification of mean abundance data from San Diego Bay and vicinity and Los Angeles Harbor.

PLOT	VARIABLE/SITE	CORRELATION CLUSTER NO.	PLOT	VARIABLE/SITE	CORRELATION CLUSTER NO.
A	West Basin, Swartz 10	III	N	Marina, Swartz 37	II
B	East Basin, Swartz 11	II	O	Glorietta Bay, Swartz 41	III
C	Downtown Piers, Swartz 14	III	P	Naval Base 04, Swartz K	III
D	G St Pier Marina, Swartz 15	III	Q	Sub Base C2, NSB-M1	IV
E	Intercont. Marina, Swartz 16	II	R	Naval Base 012, Swartz P	IV
F	Naval Base 07, Swartz 23	IV	S	Carrier Base V2, SDNI-N5	III
G	Naval Base/ SY 010, Swartz 25	IV	T	San Diego River B1	nd
H	Naval Base/ SH 013, Swartz 27	IV	U	Stormdrain EM, Grape St	II
I	7th Channel Q1, Swartz 28	V	V	Downtown Anch, Swartz 12	III
J	Marine Terminal R3, Swartz 31	IV	W	Mission Bay A3	VI
K	Sweetwater Channel, Swartz 32	I	X	Mission Bay A4	IV
L	CV Yacht Basin, Swartz 34	IV	Y	Mission Bay A8	V
M	Coronado Cays, Swartz 35	IV			

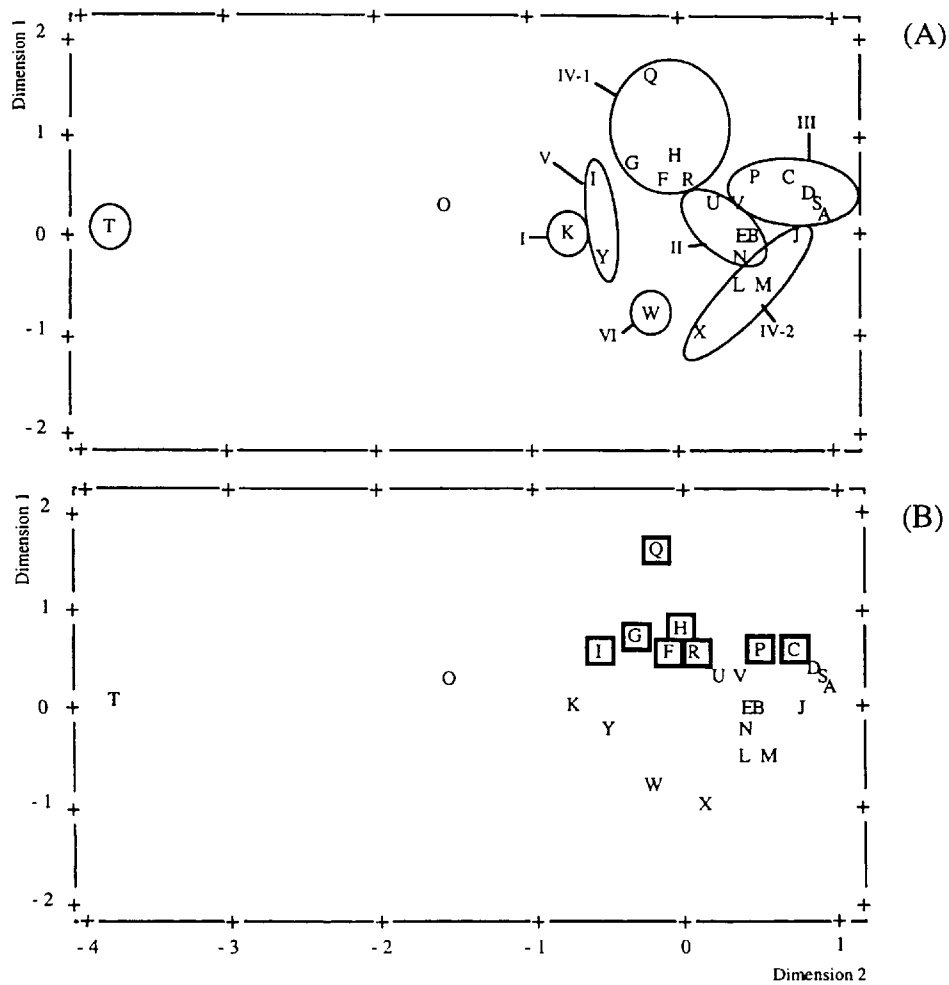


Figure 17. Multidimensional scaling (ms) ordination of site samples from San Diego Bay based on the abundance matrix of 198 macrobenthic species. (A) Clusters deliniated and numbered in Figure 15 dendogram are shown here as circled groups. (B) Qualitative assessment of the relation of chemistries >ERM levels (site codes surrounded by boxes) to ms biotic configuration.

displays the 2-dimensional representation resulting from multidimensional scaling, using the same matrix data applied to classification analysis. Letters surrounded by each circle represent the partitioned cluster groups delineated in the cluster hierarchy. The configuration was not altered when the outlier (T) was removed. The x- and y-axes represent scores for the first and second ordination axes. These scores are based on species diversity data and abundance and composition data.

When sites with chemistry values which exceeded ERM levels were assessed on the MDS plot in a qualitative, cursory manner as shown in Figure 17b (shown with squares), the sites clustered together. When interpreted along the axis gradient, these data suggested dimension 1 likely defined the pollution gradient, where the top quadrant within the plot identified the most contaminated sites (*i.e.*, Q or H). This is assuming the plot configuration is affected by toxic pollution alone and not by any organic enrichment. The y-axis may represent responses to a salinity gradient or change in sediment grain size. These analyses are especially revealing when environmental variables (*e.g*, TOC, grain size, water depth, total PAHs, individual metals, etc.) and biota are scaled together to determine which variables influence the configuration. However, even in the absence of these parallel plots, patterns are apparent from the correlations illustrated in other sections of this report.

Indicator Species

Despite the numerous studies performed in San Diego Bay, there have been no analyses of the fauna as bioindicators (SCCWRP-Diener, personal communication). Indicator species are assessed to determine which species are responsible for the separation of groups in classification and ordination analyses (Field *et al.*, 1982). Indicator species used in this study were selected on the basis of overall abundance in the San Diego Bay data set, literature review which determined distribution, known life histories and habitat preference, and discussions with ecologists experienced with Southern California marine biota and marine habitats. Species indicative of control or reference sites were derived from frequency of occurrence data. The presence or absence of specific polychaetes in sediments provided one valuable indication of the condition or health (Pocklington and Wells, 1992) of the benthic communities in San Diego Bay. The presence of *Capitella capitata* or *Streblospio benedicti*, in the absence of other species, is widely accepted as pollution indicators. Sensitive species like *Harmothoe imbricata* are represented at sites Carrier Base V2 and Mission Bay A8, and are typically found in uncontaminated areas. Additionally, *Nereidae* are accepted as indicators of early successional phases of environmental recovery (Pearson and Rosenberg, 1978) and are evident at site Carrier Base V2. *Mediomastus* polychaetes are found throughout the bay and have been considered to be identifiers of environmentally stressed areas. However, this species was found at the majority of sites. Another common species found in 16 out of 25 station samples was *Diplocirrus* sp.

which had not been found in previous studies in San Diego Bay (SCCWRP, personal communication). *Dipolocirrus* sp. was significantly ($p>0.05$) abundant at the Mission Bay A8 site. This unusual species is thought to have been introduced from the arctic region (G. Ruff, personal communication).

The benthic index discussed later was used to rank and calculate site partitions using the following indicator species: *Capitella capitata* (polychaete), *Armandia brevis* (polychaete), *Dorvillea longicornis* (polychaete), *Heterophoxus oculatus* (gammarid amphipod), and *Diastylis* sp. (cumacean). The polychaete worm *C. capitata* is widely accepted as a pollution indicator. *Diastylis* sp. ("sand-licker") feeds on nutrients adhered to sand grains and its presence indicates a relatively clean sample. Although it can tolerate moderately contaminated sediments, *H. oculatus* is a burrower and is considered an indicator of clean sediment.

One of the limitations in benthic community assessment is that patterns are more apparent where there is a strong gradient of pollutants, or when samples are selected from areas with distinctively low and high pollutant signals. There are limitations to what can be surmised from analyses of abundance of specific species, and selection of indicator species are highly site specific (Swartz *et al*., 1985). However, these species, combined with information from ordination and other supplemental analyses, make it apparent that these are important as ecologically relevant data. Many species used to assess environmental quality are used because they respond quickly to changes in environmental conditions. (Pocklington and Wells, 1992). Therefore, a station designated in the initial phases of sample collection as a having reference conditions, based on toxicity test or chemical analysis results, could be removed from the reference station list based on subsequent benthic community analyses.

Benthic Index

Benthic communities, and occasionally single benthic species, have been used to elucidate the severity of human disturbance to nearshore marine and estuarine environments. It is possible to develop a comparable disturbance classification for species and use a simple numerical infaunal index with these species. Distinct pollution gradients are rare in most embayments because of confounding environmental gradients and historical changes. Still, an index has the best potential to quantitatively assess benthic community responses to disturbance. Some benthic indices are based on *a priori* information and are developed using test sites representing the extremes within a range of environmental conditions which adversely affect benthos. In contrast, the index developed and used in this study was based solely on information which characterized the benthic community, such as specific indicator species and community parameters (species richness, abundance, presence of pollution indicator species, etc.). This elementary index approach may be best for this study because San Diego Bay encompasses a variety of habitats, each of which may

require a very specific set of index variables (SCCWRP-Diener, personal communication). Note that identification of degraded and undegraded sites here resulted from evaluation of a limited data set, without site comparison to an existing known reference. The index was used within this limited data set to designate the partition between degraded, undegraded and transitional areas.

Site and Station Application of Benthic Index

Table 10 shows the results of benthic index application to data from sampling sites in legs 20-23. Sites (25 sites with 5 replicates each) were ranked and partitioned into 9 degraded, 3 undegraded and 13 transitional sites using 8 biotic parameters. Due to spatial differences in sampling of the benthic replicates at the 25 sites, the benthic index was also applied to individual stations (n=75). When benthic community structure was evaluated "by site", 5 replicates were used. Replicates 1, 2 and 3 were sampled at numbered stations locations (Table 6) where associated toxicity and chemistry data could be directly compared. When later analyses were expanded to a "by station" evaluation, the 4th and 5th replicates were not included in the per station assessment. These replicates were randomly sampled within the "site" for benthic community analysis only and did not receive synoptic chemistry and toxicity analysis. While the results did not alter the degraded and undegraded determination of sites assessed "by site", it did separate stations within the initial "transitional" status into one of the three categories (*e.g.*, degraded, transitional or undegraded). Station analyses heavily emphasized benthic index, amphipod abundance, species diversity and crustacean numbers.

As part of analytical procedure, the BPTCP Scientific Planning and Review Committee (SPARC) recommended additional emphasis on the use of amphipod abundance and overall species diversity as indicators of degraded and undegraded areas. These parameters were assessed and incorporated into the "station evaluation" versions of the benthic index. Species number and abundance of amphipods were calculated from the proportions of total species and total individuals, respectively. The resultant categorization of stations into one of the three partitions (*e.g.*, degraded, transitional, undegraded) did not change, so the assessment of amphipods further supported the partition derived from previous analyses. The density of all amphipods was significantly more abundant at the following stations: West Basin (90050, 93199, 93200), East Basin (90001, 93201), Downtown Anchorage (93221, 93222), Coronado Cays (90053, 93203), Sweetwater Channel (93220), Mission Bay A8 (93112), Carrier Base V2 (90025) and Grape St. Stormdrain (90037). No amphipods were found at stations 14 Downtown Piers (90003), Naval Base O7 (93212), Naval Base/SY O10 (93223, 93224), Naval Base/SH O13 (93225, 93226), 7th St. Channel Q1 (90009, 93227, 93228), Marine Terminal R3 (93229), K Swartz Naval Base O4 (93210), Sub Base C2 (93216, 93217), and Naval Base O12 (93215). Stations with abundant amphipods but dominated by *Grandidierella japonica* were evaluated with caution, because *G. japonica* has been found to be tolerant of high

Table 10. Results of Benthic Index application on San Diego Bay data. Benthic community condition based on mean abundance of 5 replicate samples per site. Community status indicates allocation of a station to an Index partition: 2-undegraded sites, 1=transitional sites, 0=degraded sites.

SITES (5 replicates)	Community Status	SITES (5 replicates)	Community Status
10 Swartz (West Basin)	1	35 Swartz (Coronado Cays)	1
11 Swartz (East Basin)	2	37 Swartz (Marina)	2
12 Swartz (Downtown Anch)	1	41 Swartz (Glorietta Bay)	1
14 Swartz (Downtown Piers)	0	K Swartz (Naval Base 04)	1
15 Swartz (G St Pier Marina)	1	Mission Bay A3	1
16 Swartz (Intercont. Marina)	1	Mission Bay A4	1
23 Swartz (Naval Base 07)	0	Mission Bay A8	2
25 Swartz (Naval base/ SY 010)	0	NSB-M1 (Sub Base C2)	0
27 Swartz (Naval Base /SH 013)	0	P Swartz (Naval Base 012)	0
28 Swartz (7th St Channel Q1)	0	San Diego River B1	0
31 Swartz (Marine Terminal R3)	1	SDNI- N5 (Carrier Base V2)	1
32 Swartz (Sweetwater Ch)	1	Stormdrain EM (Grape St.)	1
34 Swartz (CV Yacht Basin)	0		

sediment toxicity (Slattery and Swartz, personal communication). Final benthic community evaluation of 75 stations (Table 11) resulted in the designation of 23 undegraded, 43 degraded and 9 transitional stations. A map of the distribution of degraded, transitional and undegraded stations is shown in Figure 18(a-d). Degraded stations were found at the submarine base in North San Diego Bay. Commercial shipping, storm drainages and the naval shipyard waterfronts all had degraded communities in the Mid San Diego Bay. In South San Diego Bay, industrial and small boat locations exhibited benthic community degradation. In Mission Bay the stations near Rose Inlet and in the San Diego River were found to be degraded.

Chemically clean sites, as determined by ERM and PEL summary quotients and lack of ERM and PEL guideline exceedances, were reexamined to expand the undegraded list from possible "borderline" transitional stations. Stations 93194 and 93231 appropriately fit this category (Table 4) and were used as undegraded stations in the construction of the reference envelope for toxicity determination, discussed earlier.

As shown earlier in Figure 14, the relationship between benthic community conditions and elevated chemical conditions (as determined by using ERM and PEL Summary Quotients) was quite dramatic. Benthic communities were always found to be degraded when chemical levels were elevated (ERMQ>0.85), where both analyses were performed at a station.

Distribution Of Toxicity

The results of all toxicity tests conducted as part of this study are presented in tables in Appendix D. These tables show means and standard deviations for each toxicity test response (e.g. percent survival of amphipods; percent normal development of larval sea urchins) for three to five replicates of each sample tested. Associated ammonia and hydrogen sulfide concentrations are also presented in Appendix D.

Toxicity Testing Quality Assurance/Quality Control Evaluation

All toxicity test data produced for this report were evaluated for acceptability using the Quality Assurance guidelines described in the BPTCP Quality Assurance Project Plan (QAPP; Stephenson *et al.*, 1994). Toxicity data reported here met all test acceptability standards for each protocol, with the following exceptions. Of the solid phase tests with amphipods, two samples (Station 93120- IDORG# 702 and Station 93107- IDORG# 721) were tested with only one laboratory replicate, due to a lack of sufficient sample volume. Survival in those two samples was 90% and 85%, respectively, indicating a lack of toxicity. All amphipod samples tested in Leg 15 (Appendix D) have the following QA qualification. The test protocol requires five replicates of a control sample to be tested concurrently with test samples. In some early sampling legs of this study, 15 laboratory replicates of the control sediment were tested, to

Table 11. Benthic Index results showing the recalculation of San Diego Bay data based on individual stations. Replicates 4 and 5 in the site evaluation were not included (see text). Community status indicates allocation of a station to an Index partition: 2=undegraded stations, 1=transitional stations, 0=degraded stations.

IDORG	Station #	Station name	Community Status	IDORG	Station #	Station name	Community Status	IDORG	Station #	Station name	Community Status
837	90050	10 Sw (West Basin)	2	892	93226	27 Sw (Naval Base /SH 013)	0	854	93107	Mission Bay A3	0
838	93199	10 Sw (West Basin)	2	893	90009	28 Sw (7th St Channel Q1)	0	855	93107	Mission Bay A3	1
839	93200	10 Sw (West Basin)	2	894	93227	28 Sw (7th St Channel Q1)	0	859	93108	Mission Bay A4	1
840	90001	11 Sw (East Basin)	2	895	93228	28 Sw (7th St Channel Q1)	0	860	93108	Mission Bay A4	2
841	93201	11 Sw (East Basin)	2	896	90010	31 Sw (Marine Terminal R3)	0	861	93108	Mission Bay A4	1
842	93202	11 Sw (East Basin)	2	897	93229	31 Sw (Marine Terminal R3)	0	856	93112	Mission Bay A8	2
878	90002	12 Sw (Downtown Anch)	0	898	93230	31 Sw (Marine Terminal R3)	0	857	93112	Mission Bay A8	2
879	93221	12 Sw (Downtown Anch)	2	875	90052	32 Sw (Sweetwater Ch)	1	858	93112	Mission Bay A8	2
880	93222	12 Sw (Downtown Anch)	2	876	93219	32 Sw (Sweetwater Ch)	1	871	90028	NSB-M1 (Sub Base C2)	0
846	90003	14 Sw (Downtown Piers)	0	877	93220	32 Sw (Sweetwater Ch)	0	872	93216	NSB-M1 (Sub Base C2)	0
847	93205	14 Sw (Downtown Piers)	0	824	90012	34 Sw (CV Yacht Basin)	0	873	93217	NSB-M1 (Sub Base C2)	0
848	93206	14 Sw (Downtown Piers)	0	825	93196	34 Sw (CV Yacht Basin)	0	868	90022	P Sw (Naval Base 012)	0
849	90004	15 Sw (G St Pier Marina)	0	826	93197	34 Sw (CV Yacht Basin)	0	869	93214	P Sw (Naval Base 012)	0
850	93207	15 Sw (G St Pier Marina)	0	843	90053	35 Sw (Coronado Cays)	2	870	93215	P Sw (Naval Base 012)	0
851	93208	15 Sw (G St Pier Marina)	0	844	93203	35 Sw (Coronado Cays)	2	881	93116	San Diego River B1	0
818	90051	16 Sw (Intercont. Marina)	1	845	93204	35 Sw (Coronado Cays)	0	882	93116	San Diego River B1	0
819	93192	16 Sw (Intercont. Marina)	1	815	90013	37 Sw (Marina)	2	883	93116	San Diego River B1	0
820	93193	16 Sw (Intercont. Marina)	1	816	93190	37 Sw (Marina)	2	899	90025	SDNI- N5 (Carrier Base V2)	2
865	90006	23 Sw (Naval Base 07)	0	817	93191	37 Sw (Marina)	2	1000	93231	SDNI- N5 (Carrier Base V2)	2
866	93212	23 Sw (Naval Base 07)	0	821	90015	41 Sw (Glorietta Bay)	1	1001	93232	SDNI- N5 (Carrier Base V2)	2
867	93213	23 Sw (Naval Base 07)	0	822	93194	41 Sw (Glorietta Bay)	2	827	90037	Stormdrain EM (Grape St.)	0
887	90007	25 Sw (Naval base/ SY 010)	0	823	93195	41 Sw (Glorietta Bay)	2	828	90037	Stormdrain EM (Grape St.)	0
888	93223	25 Sw (Naval base/ SY 010)	0	862	90021	K Sw (Naval Base 04)	0	829	90037	Stormdrain EM (Grape St.)	2
889	93224	25 Sw (Naval base/ SY 010)	0	863	93210	K Sw (Naval Base 04)	0				
890	90008	27 Sw (Naval Base /SH 013)	0	864	93211	K Sw (Naval Base 04)	0				
891	93225	27 Sw (Naval Base /SH 013)	0	853	93107	Mission Bay A3	0				

Figure 18a
Benthic Community Analyses
North San Diego Bay

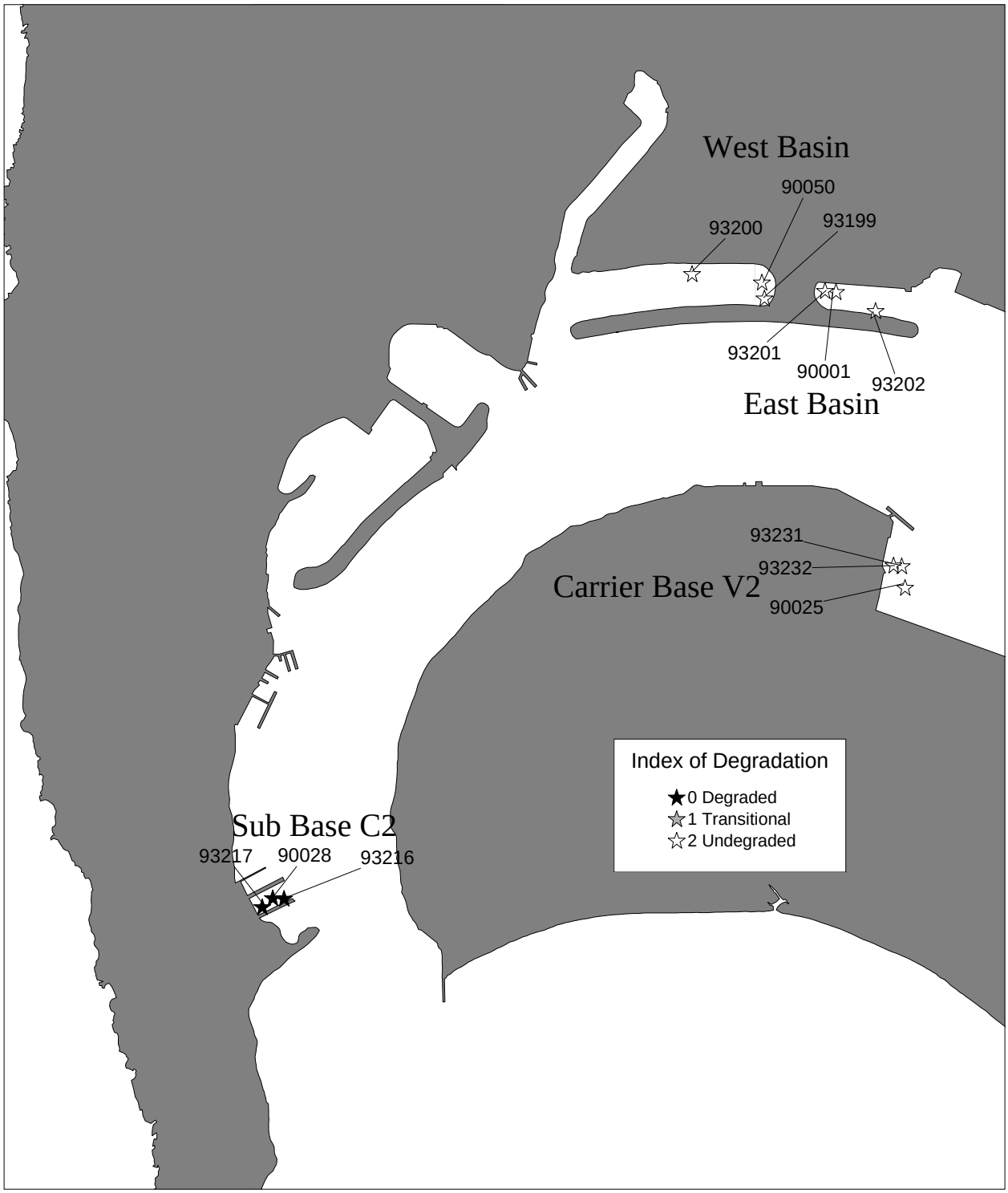


Figure 18a
Benthic Community Analyses
North San Diego Bay

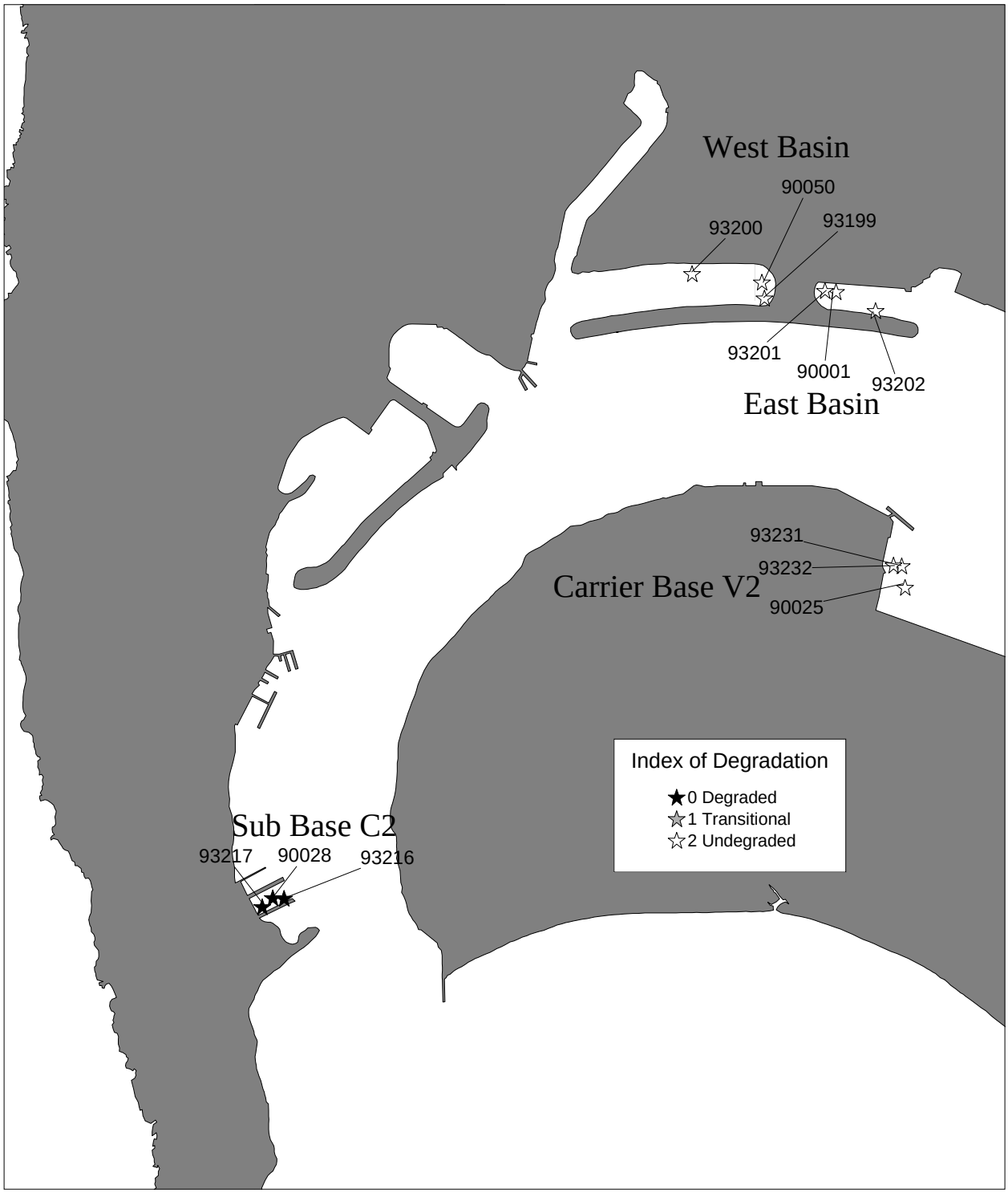


Figure 18b
Benthic Community Analyses
Mid San Diego Bay

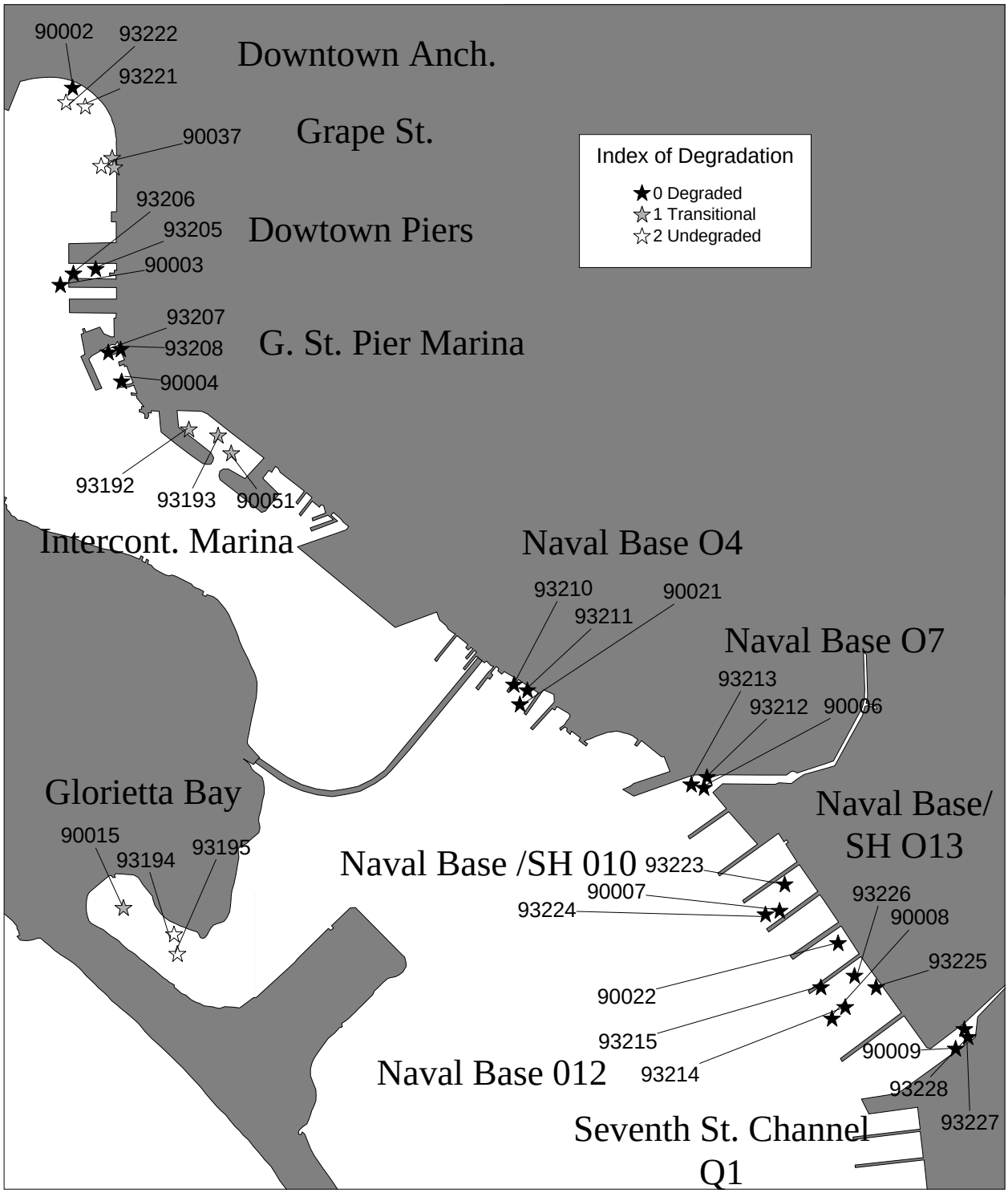


Figure 18c
Benthic Community Analyses
South San Diego Bay

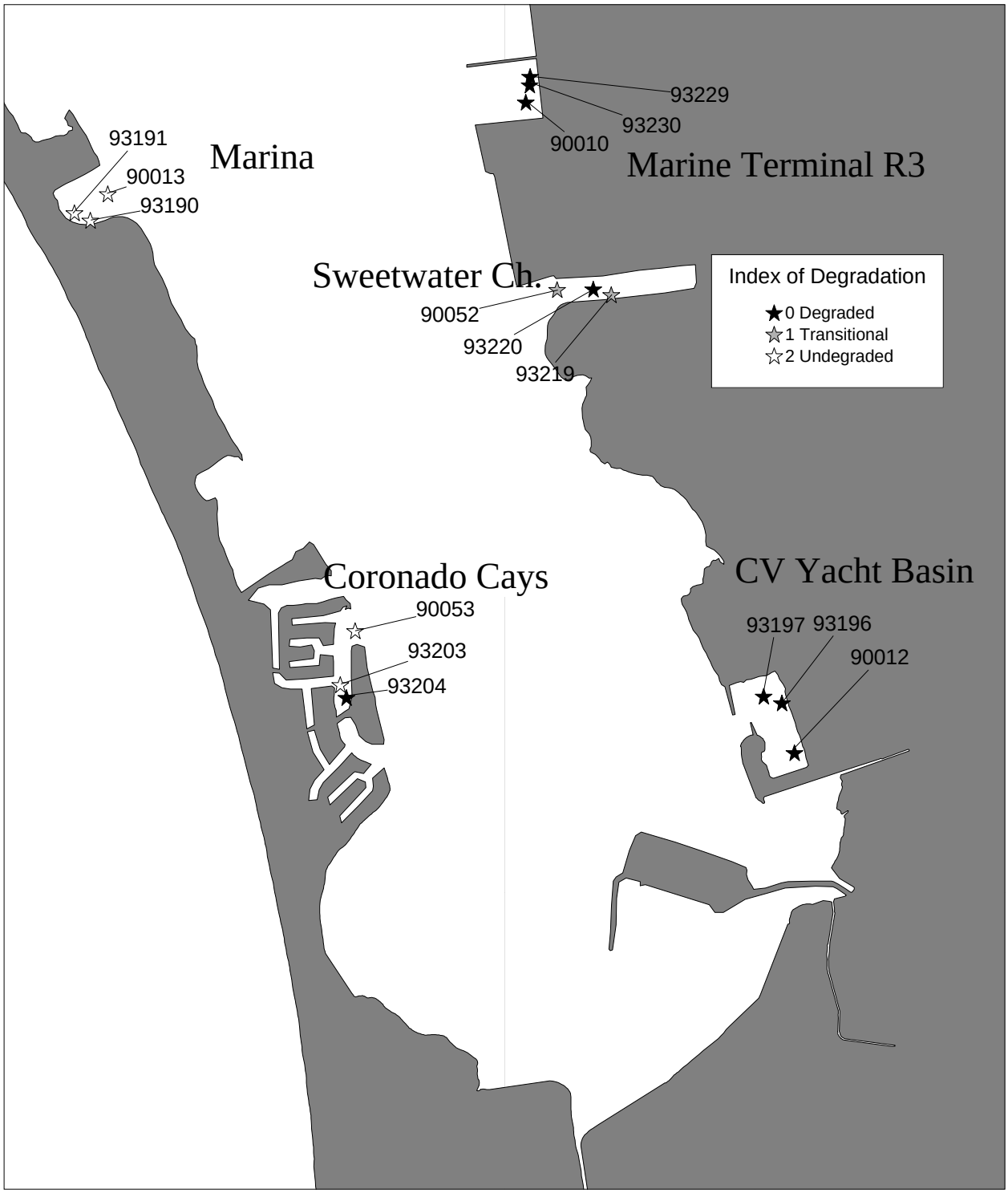
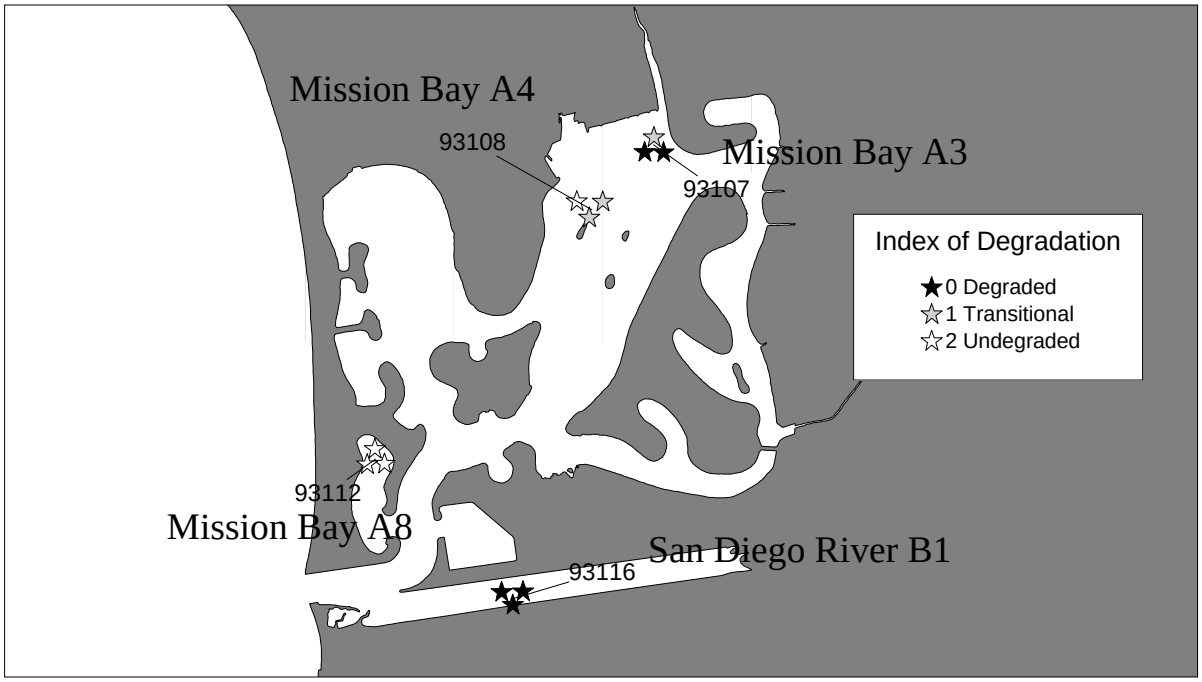


Figure 18d
Benthic Community Analyses
Mission Bay and San Diego River Estuary



allow use of alternative statistical procedures. Of the fifteen control replicates in Leg 15, two had 75% survival, which is below the 80% criterion given in the protocol. In tests using the *Neanthes arenaceodentata* (hereafter *Neanthes*) protocol on solid phase sediments, all samples tested in Leg 21 used sediment that was held in the laboratory three days beyond the fourteen-day specified holding time. These QA exceptions in solid phase tests have been judged by the toxicity project officers to not adversely affect interpretation of toxicity results. These and lesser departures from acceptable standards are recorded in the Quality Assurance Evaluative Reports accompanying each dataset for this study. Quality Assurance Evaluative Reports for toxicity testing are available for review from the SWRCB. Minor departures not mentioned above included elevated dissolved oxygen measurements in overlying water and other variations in water quality measurement that were considered to have little probability of affecting the outcome of the respective toxicity test.

There were no deviations from quality assurance criteria, other than minor deviations in measurement of water quality parameters as cited above, in any of the abalone, mussel, or sea urchin larval development tests in pore water or water column samples (subsurface water).

Sea urchin fertilization tests were conducted on over 300 pore water samples. Many of these were retested because of poor response in brine controls. Bay *et al.* (1993) discussed commonly observed problems using the *Strongylocentrotus purpuratus* (hereafter *Strongylocentrotus*) fertilization test in samples requiring salinity adjustment with hypersaline brine. Through numerous repeated tests, acceptable brine control results were produced for all but one sample. However, as described in BPTCP QA reports to the SWRCB, an additional control for the storage effects of frozen pore water samples in Teflon bottles was included in later tests. These additional controls, which were not required by the original QAPP, indicated that toxicity may be associated with frozen sample storage in Teflon bottles. Because all pore water samples for fertilization tests were stored frozen in Teflon bottles, we have no assurance the data from any of these fertilization tests is truly indicative of sample toxicity. Any toxicity observed in the fertilization tests may be wholly or partially due to storage effects. For this reason, we retested all samples from legs 15-23 with the sea urchin larval development test, unless those samples had already been tested with the development test. The urchin larval development test has been unaffected by storage artifacts, as indicated by response in frozen storage bottle controls. While sea urchin fertilization data are reported in Appendix D, they were not used in any further data analysis for this report. The use of fertilization data, for determination of toxicity, was therefore not considered prudent considering the possibility of false positive results related to sample storage.

Areal Extent of Toxicity Based on the EMAP Approach

The Cumulative Distribution Frequency (CDF) analyses indicated that 56% of the total area sampled was toxic to *Rhepoxynius abronius* (hereafter *Rhepoxynius*) (Table 12, Figure 19). The sea urchin larval development test of undiluted (100%), 50%, and 25% pore water indicated 74%, 54%, and 29% percent of the total study area was toxic, respectively (Table 12, Figure 20). A number of samples were toxic to both sea urchins and amphipods. Samples representing 36%, 27%, or 14% of the study area were toxic to *Rhepoxynius* in solid phase sediment and to sea urchin larvae in 100%, 50%, or 25% pore water, respectively. The percentage of area toxic was based on comparisons with laboratory controls using the EMAP statistical approach described in the methods section. These analyses utilized data from random stations within the stratified sampling blocks, and did not include data from stations utilizing the non-random, directed sampling design (Figure 21a-d, Figure 22a-d).

The curves on the CDF plots indicate the magnitude of toxicity throughout the Region. Each point on the CDF plot represents a single sample. The distribution of the amphipod data (Figure 19) show there were few samples with survival less than 40%, a greater number of samples with survival between 40% and 80%, and about half of all samples with survival greater than 80%. NOAA surveys of Tampa Bay, Florida and EMAP surveys of the Mid-Atlantic coast region (Virginian Province) produced CDF curves for amphipod mortality data further right on the scale and much steeper than the San Diego Bay Region plot, and had more than 90% of samples with greater than 90% survival in both regions (Long *et al*., 1994; Schimmel *et al*., 1991).

The CDF plot of San Diego Bay Region sea urchin larval development test data (Figure 20) shows a cluster of samples with 0% normal larval development, a smaller number of samples with intermediate response, and a cluster of samples with percent normal development roughly equal to that observed in controls. The 25% pore water dilutions had a majority of samples resulting in percent normal larval development roughly equal to controls. As pore water concentration increased to 50% and 100% pore water, the distribution of samples shifted toward the more toxic end of the scale, and the 100% pore water tests had a majority of samples resulting in 0% normal larval development. A similar pattern was observed in sea urchin fertilization tests of pore water from Tampa Bay, Florida (NOAA, 1994). As with the amphipod data, the San Diego distribution is shifted further to the left, indicating higher overall toxicity observed from San Diego Bay Region samples.

Toxicity Based on Reference Envelope Approach

Using the *Rhepoxynius* data and a p-value of 1%, a lower reference envelope tolerance bound of 48% survival was calculated, indicating that samples with survival values below 48% are significantly more toxic than samples representative of less

Table 12. Percent of total area sampled determined to be toxic with each toxicity test protocol. Sample toxicity is based on the EMAP statistical approach using two criteria for any given sample: significant difference from the control using a separate variance t-test and an alpha of 0.05 and a sample mean value less than 80% of the control value. Calculations for cumulative distribution frequency (CDFs) used to compute the percent of area toxic are explained in text and presented in Appendix F. Total study area was 47 square kilometers.

Toxicity Test and Pore Water Dilution	**Percent of Total Area Determined to be Toxic**
Rhepoxynius abronius Survival in Solid Phase	56%
Strongylocentrotus purpuratus Development in:	
100% (undiluted) Pore Water	74%
50% Pore Water	54%
25% Pore Water	29%

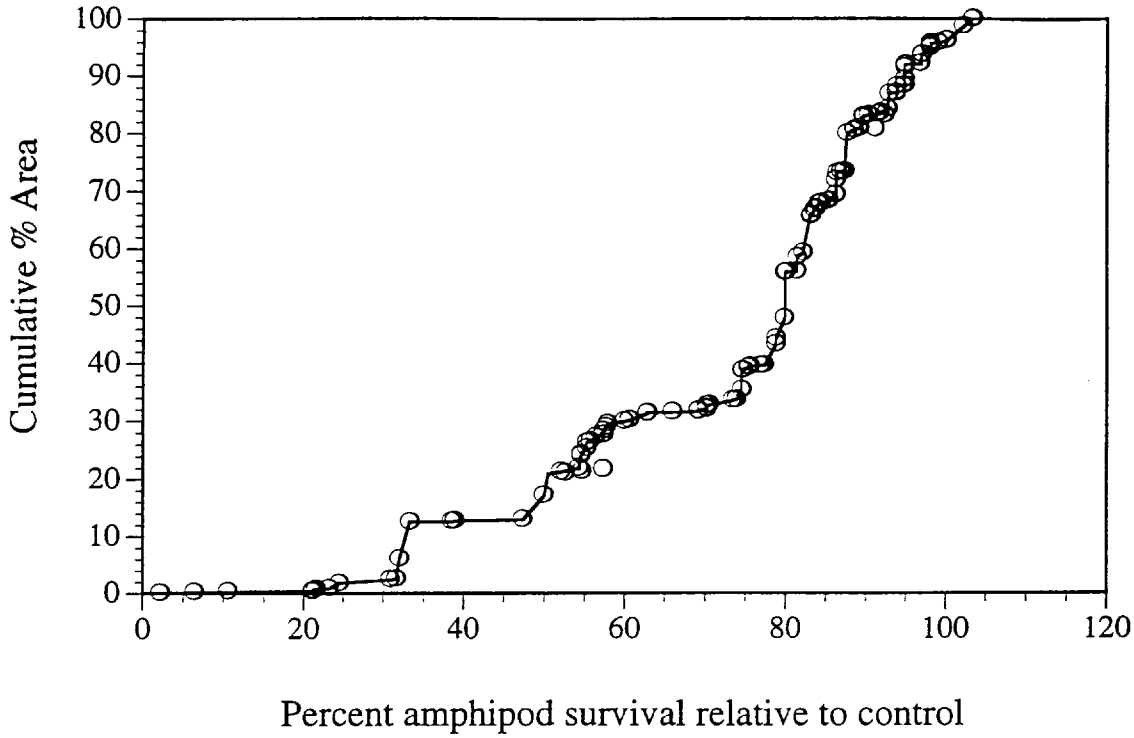


Figure 19. Cumulative distribution frequency of percent *Rhepoxynius* survival against percent of total area sampled. Data points correspond to individual samples.

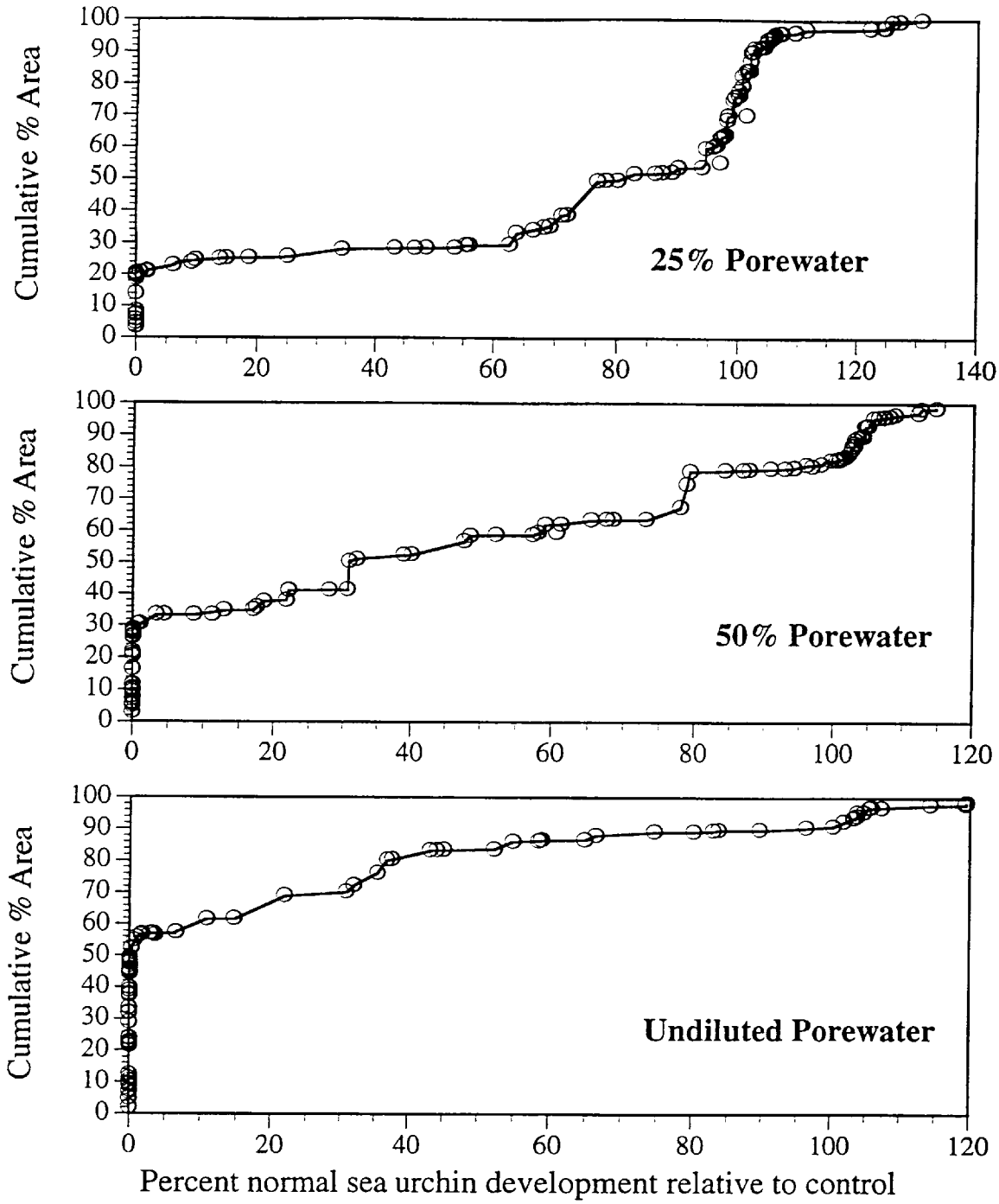


Figure 20. Cumulative distribution frequency of percent normal sea urchin larval development in 25%, 50%, and undiluted porewater against percent of total area sampled. Data points correspond to individual samples.

Figure 21a
Amphipod Toxicity Using Lab Controls
for Randomly Sampled Stations
North San Diego Bay

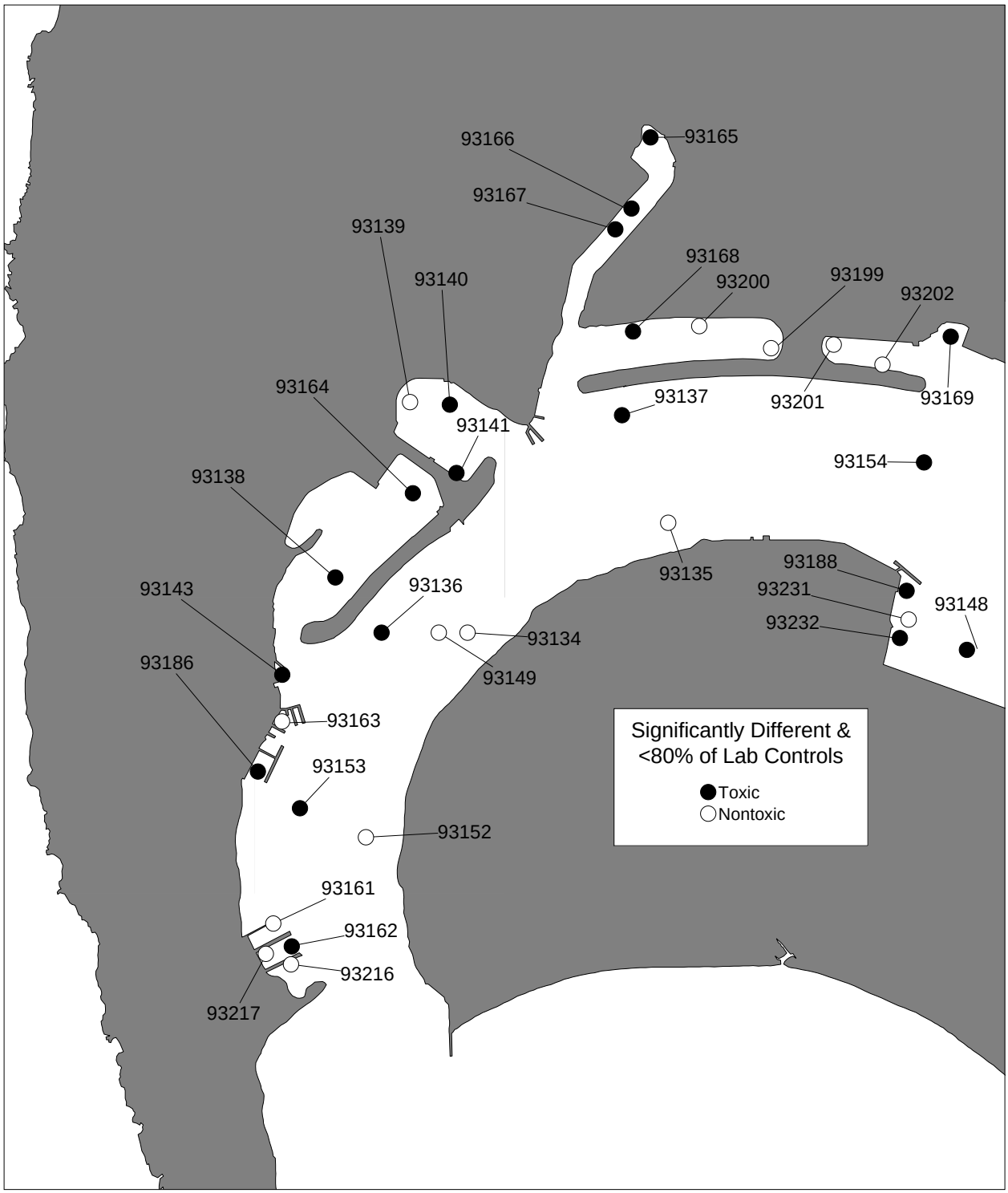


Figure 21b
Amphipod Toxicity Using Lab Controls
for Randomly Sampled Stations
Mid San Diego Bay

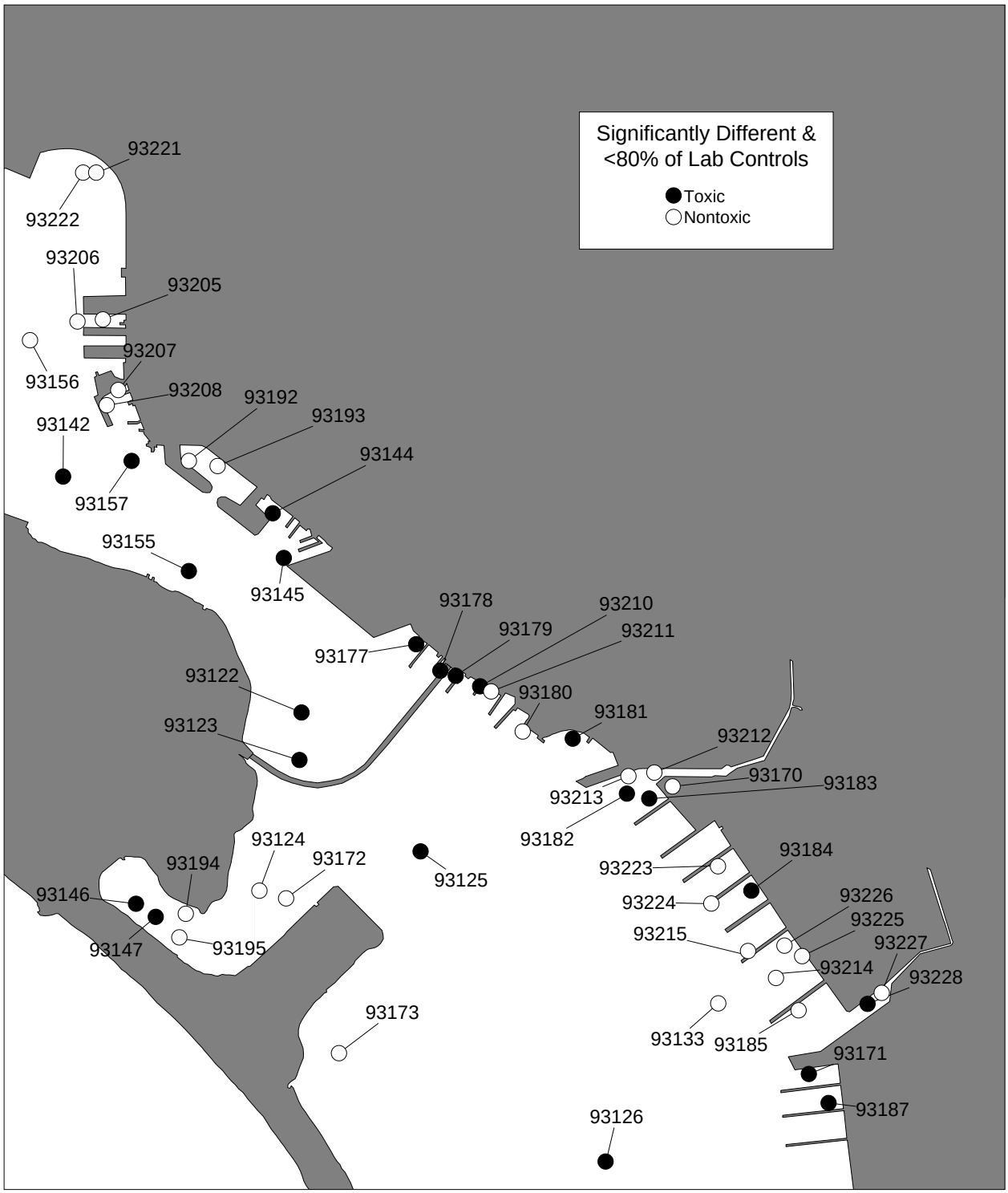


Figure 21c
Amphipod Toxicity Using Lab Controls
for Randomly Sampled Stations
South San Diego Bay

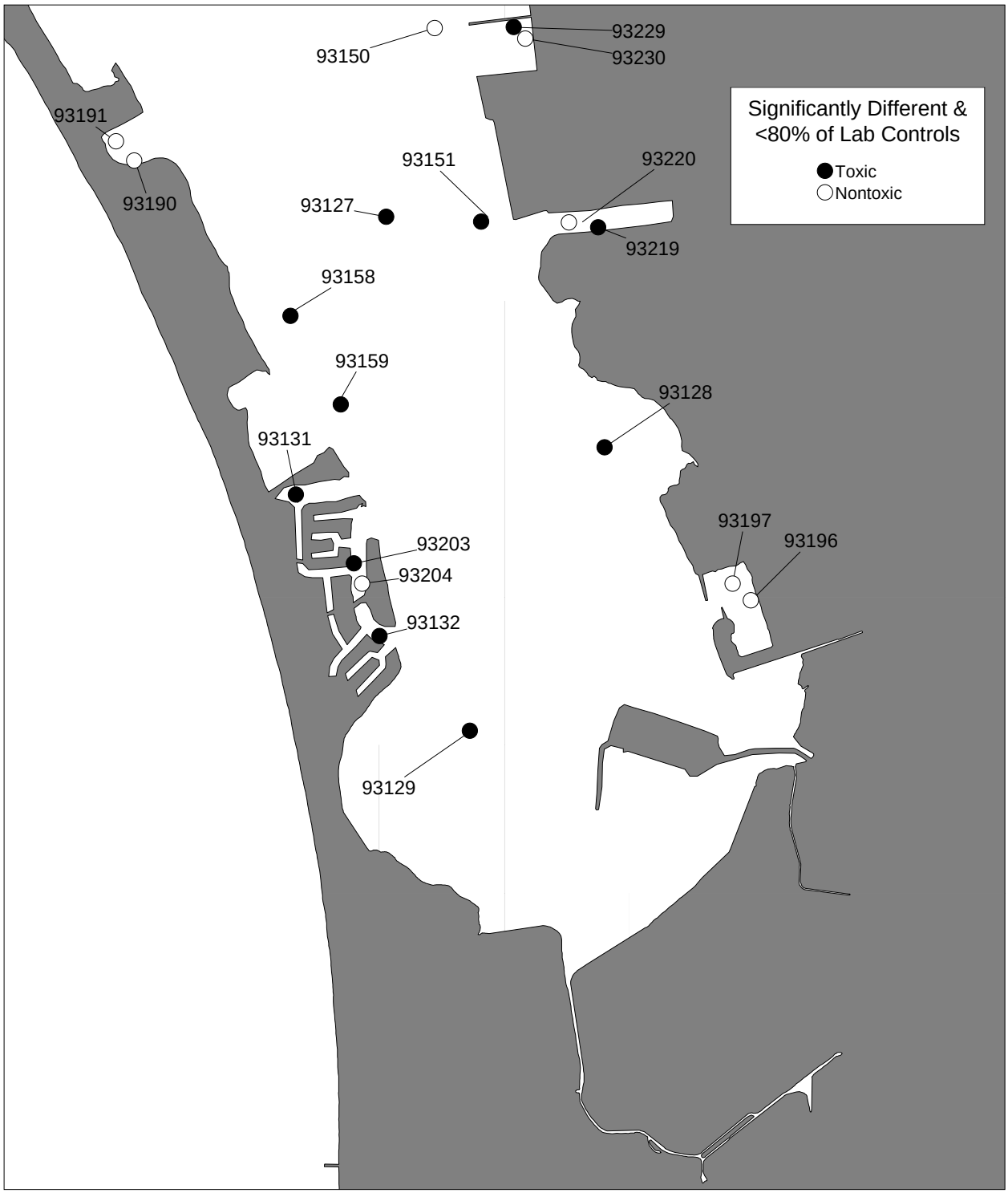
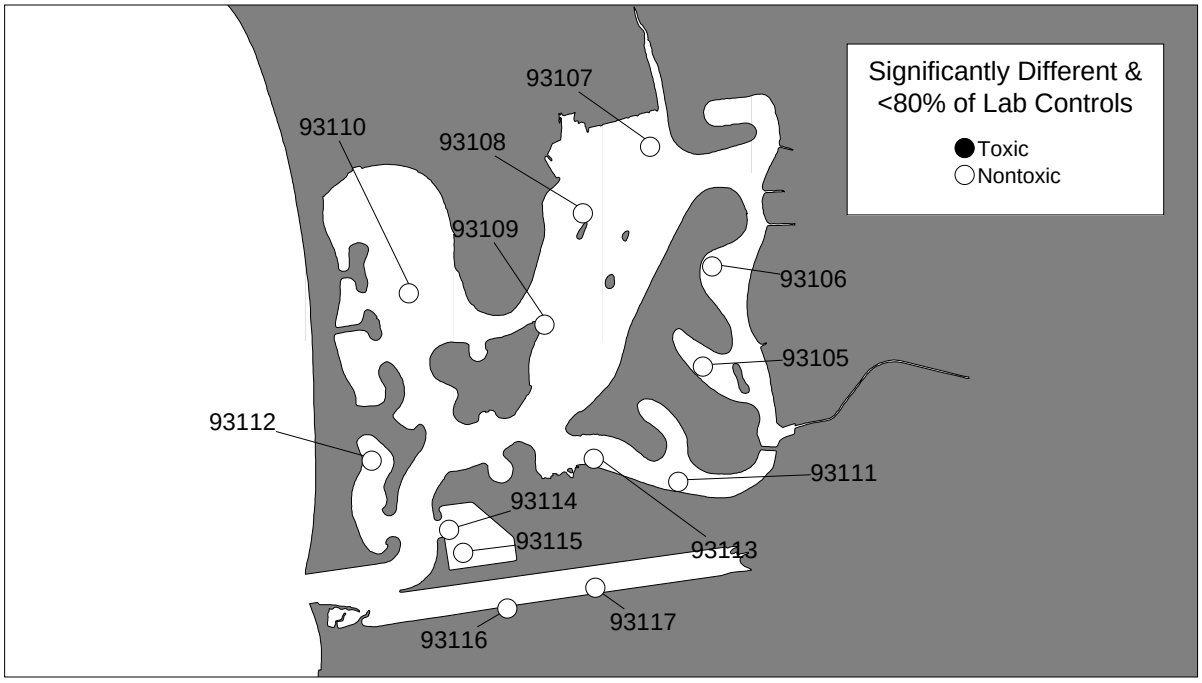


Figure 21d
Amphipod Toxicity Using Lab Controls
for Randomly Sampled Stations
Mission Bay and San Diego River Estuary



Tijuana River Estuary

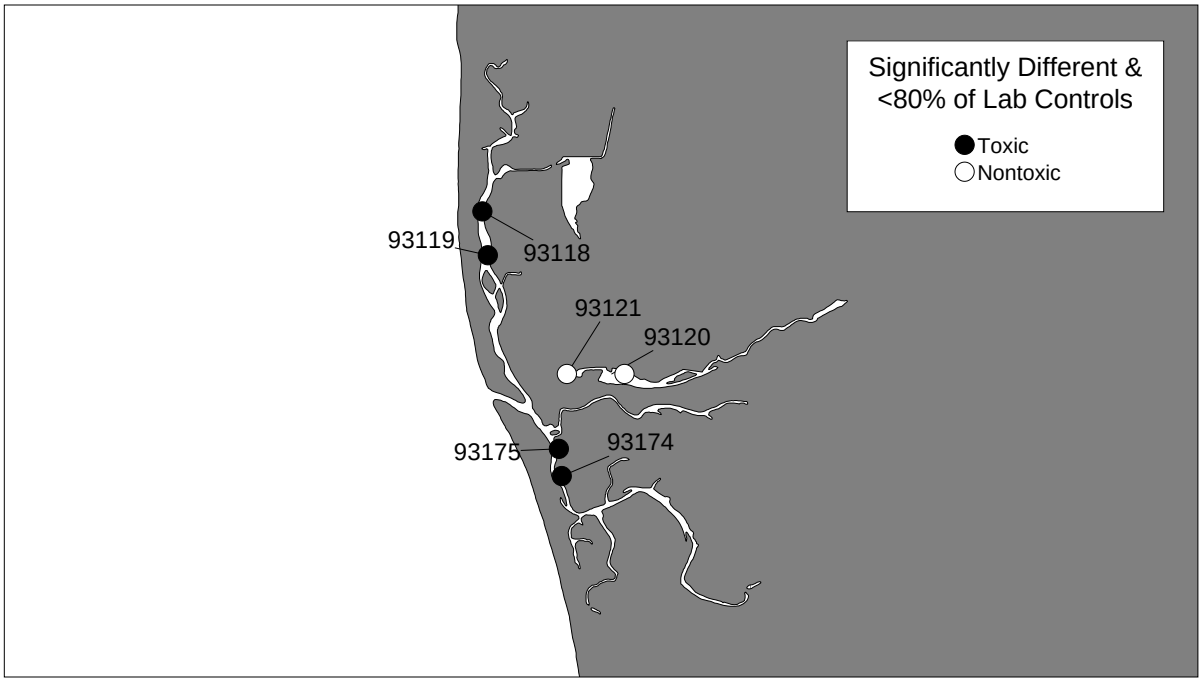


Figure 22a
Urchin Development Toxicity Using Lab Controls
for Randomly Sampled Stations
North San Diego Bay

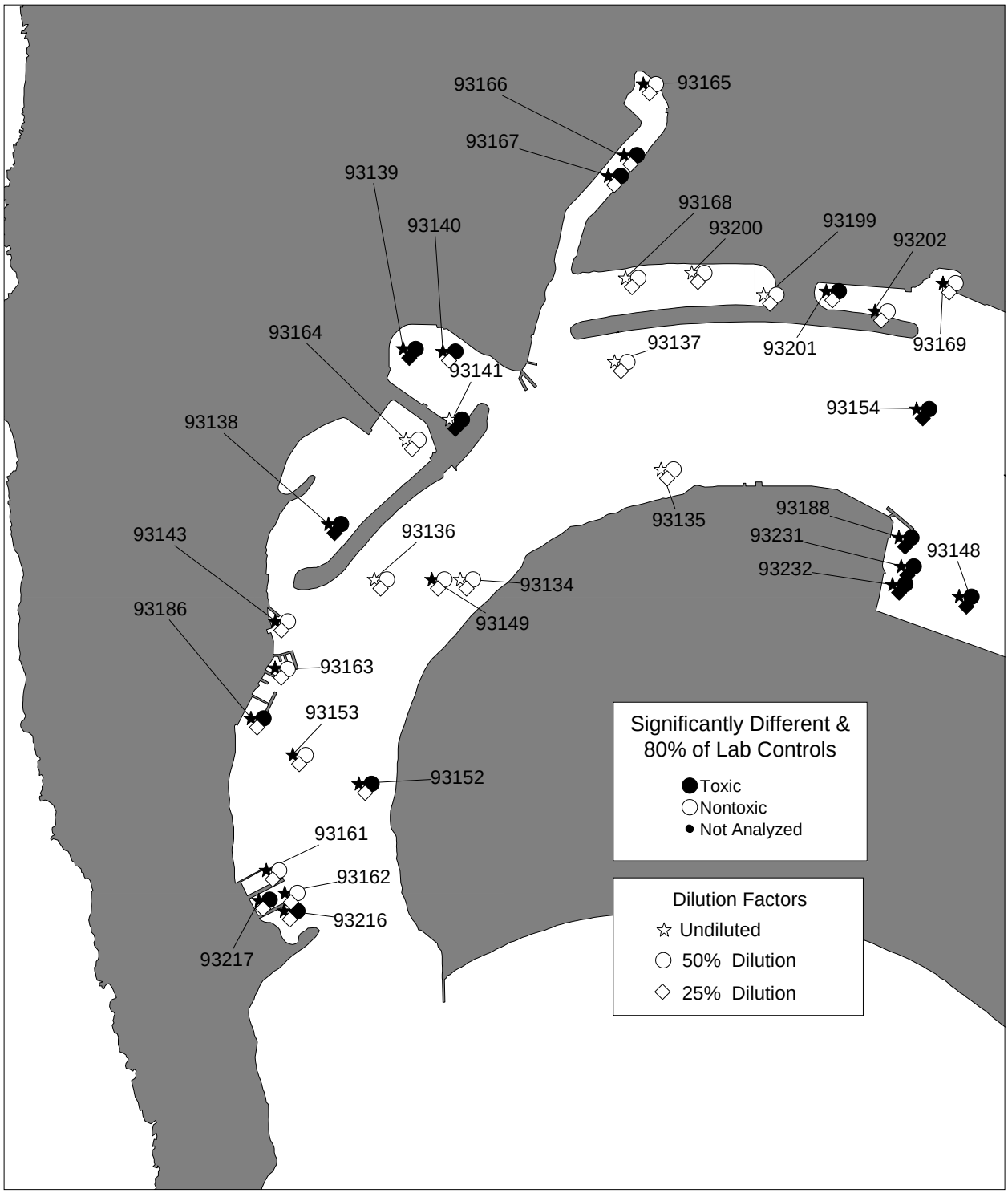


Figure 22b
Urchin Development Toxicity Using Lab Controls for Randomly Sampled Stations Mid San Diego Bay

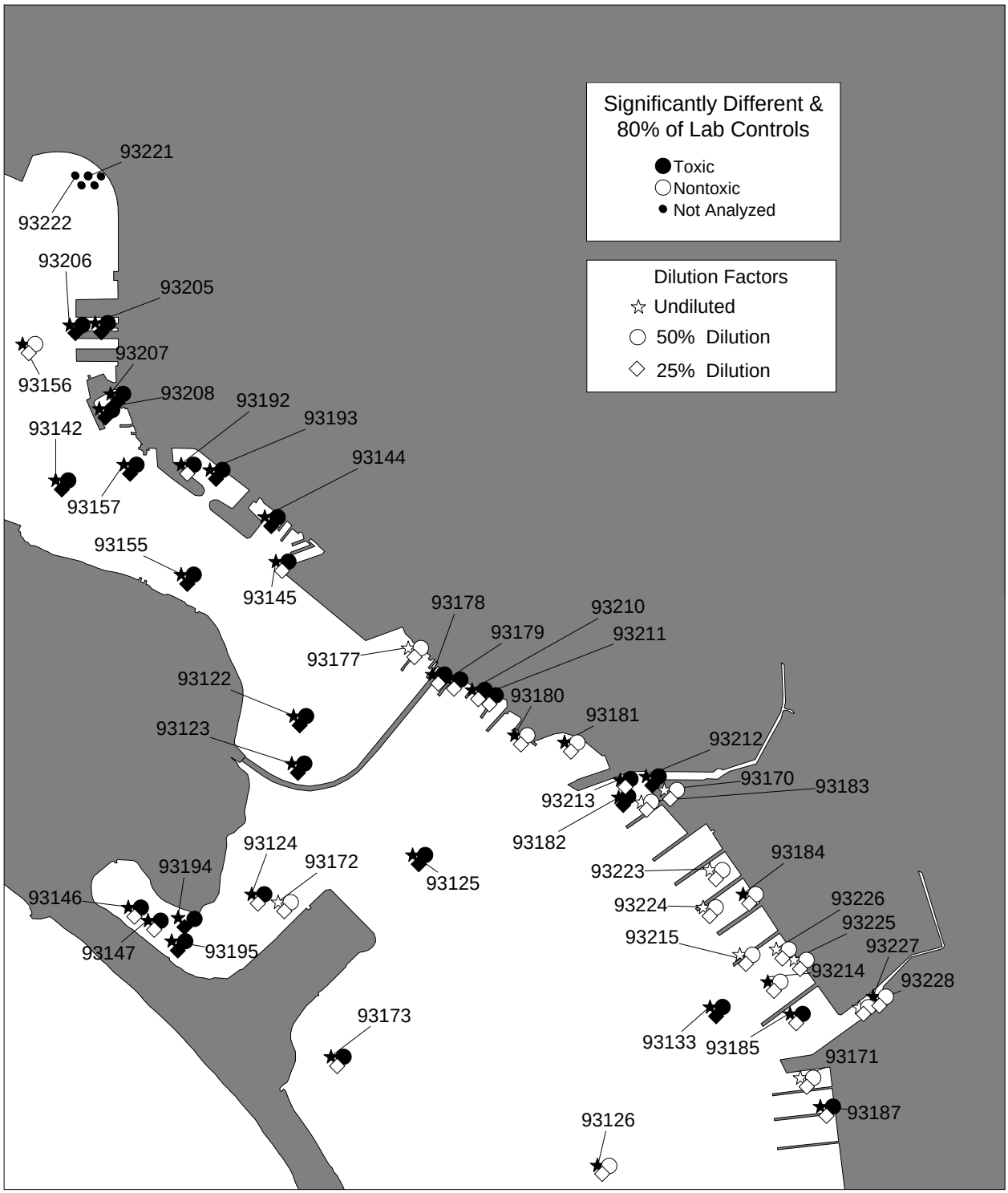


Figure 22c
Urchin Development Toxicity Using Lab Controls for Randomly Sampled Stations South San Diego Bay

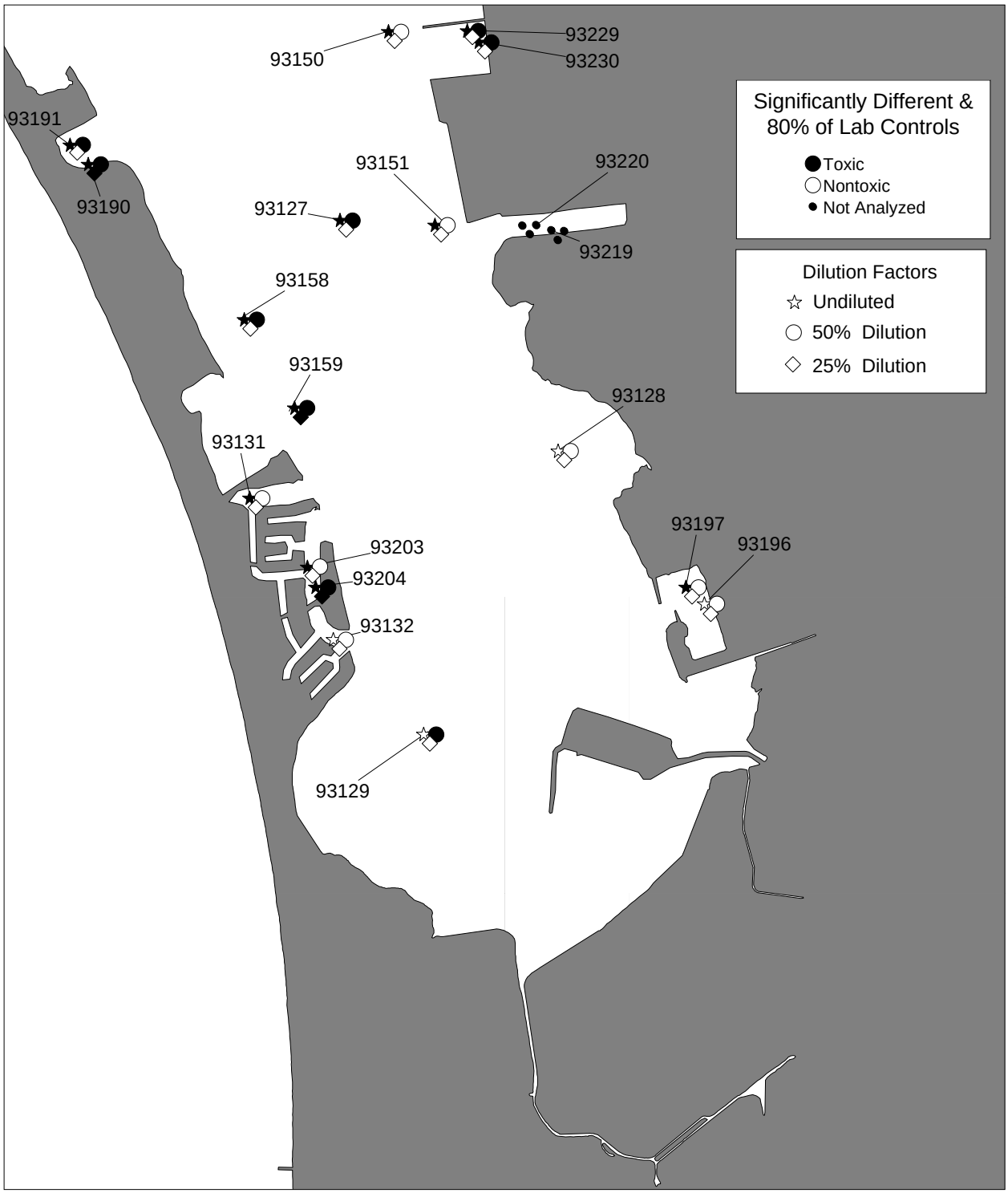
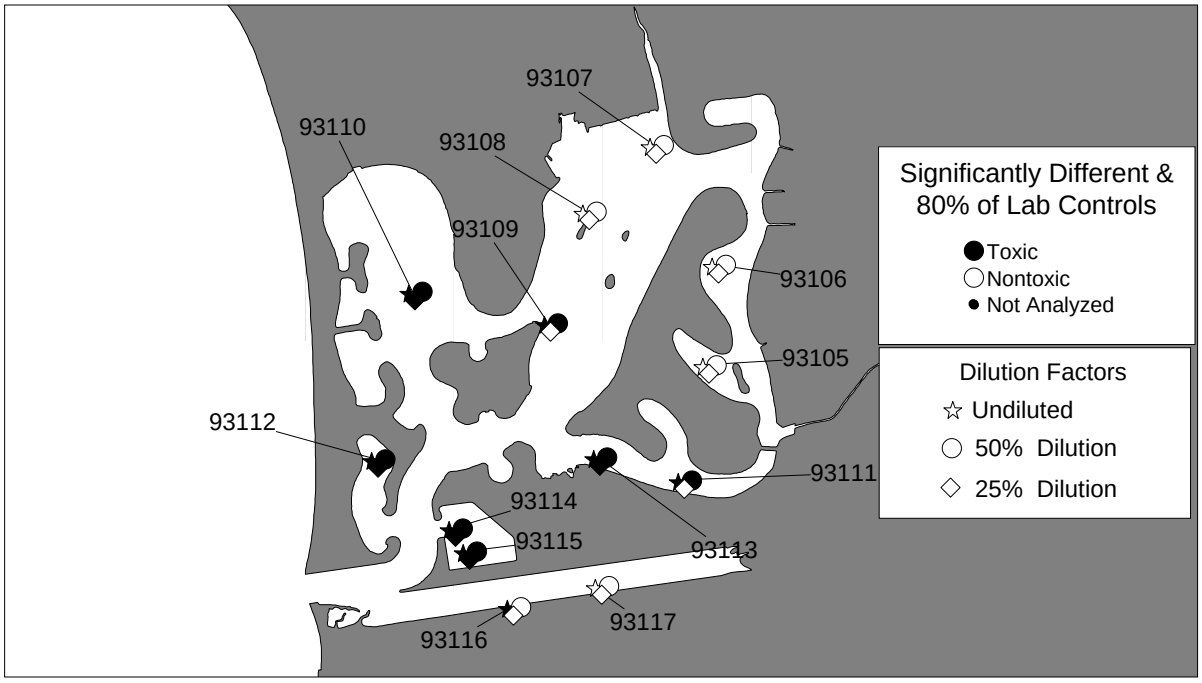
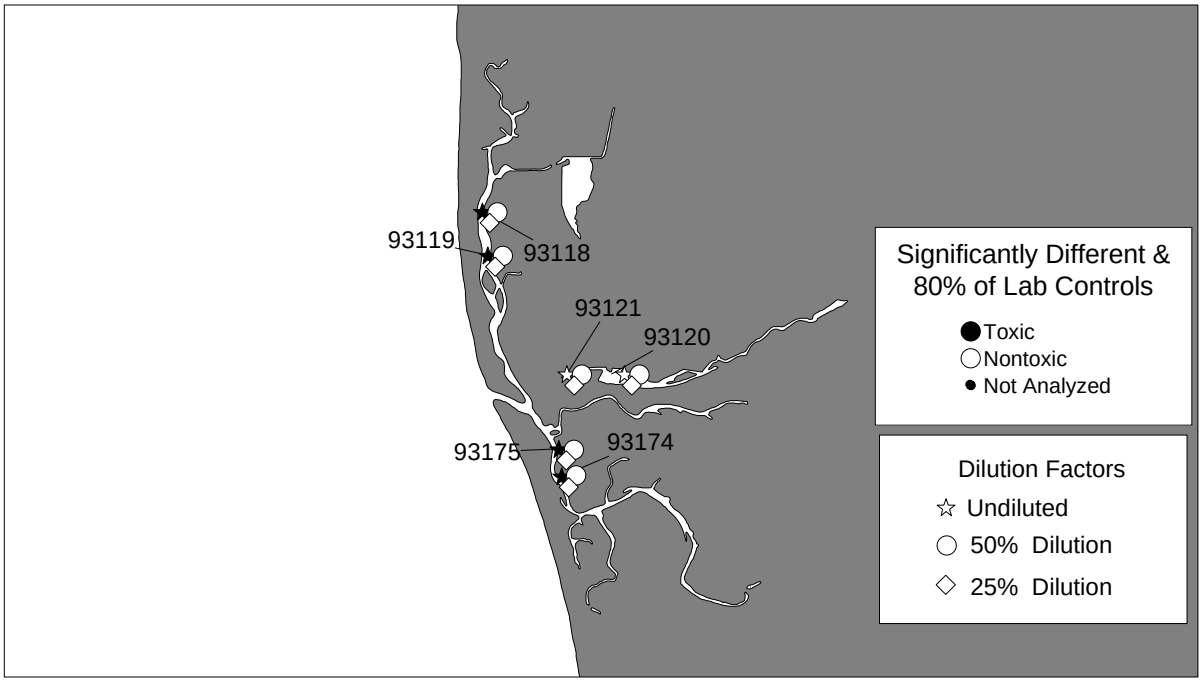


Figure 22d
Urchin Development Toxicity Using Lab Controls
for Randomly Sampled Stations
Mission Bay and San Diego River Estuary



Tijuana River Estuary



contaminated ambient conditions in the San Diego Bay Region. There is a 95% probability that samples with survival values less than 48% are more toxic than the most toxic 1% of samples from the reference site population. Of 350 samples tested with the *Rhepoxynius* test (from both random and non-randomly selected stations), 61 samples were found to be toxic using the reference envelope analysis (Figure 23a-d). Toxicity based on the reference envelope approach is used later in this report for prioritizing stations of concern.

Strongylocentrotus pore water data from reference stations produced a lower mean value and greater variability than was found for the amphipod solid phase data (Table 4). The variability in pore water data from sea urchin larval development tests produced a reference site distribution extending across the range from 0 to 100% normal development. A p-value of 1% (see Methods Section) produced a tolerance bound (reference envelope edge) which was below zero, indicating no distinctions could be made between reference and toxic stations. The high degree of variability in the pore water results from the reference sites may be related to the sensitivity of this test to measured or unmeasured toxicants, and/or may reflect artifacts related to pore water extraction and handling. Potential artifacts and sources of variability related to pore water testing are discussed below.

Comparison of Toxicity Test Protocols

Solid phase toxicity tests using the amphipod *Rhepoxynius* provided a wide range of response, from 0 to 98% survival. Amphipod survival ranged from 68-98 % for the eleven reference stations, suggesting that relatively high *Rhepoxynius* survival is a consistent feature of sites with relatively low chemical concentrations and undegraded benthic communities. The *Rhepoxynius* test identified multiple toxic samples, which indicated adequate sensitivity. Of the two solid phase protocols used in this study, the *Rhepoxynius* test provided the best test performance in terms of convenience, consistency, and sensitivity.

Solid phase toxicity tests which used the polychaete *Neanthes* were less sensitive than the *Rhepoxynius* test, and usually indicated no toxicity in samples that were toxic to test organisms using other protocols. In all instances where a sediment sample was toxic to *Neanthes* (survival or growth - relative to controls), it was also toxic to *Rhepoxynius*, whereas many samples that were toxic to *Rhepoxynius* were not toxic to *Neanthes* test. Because the *Neanthes* test demonstrated considerably less sensitivity than the *Rhepoxynius* test, the *Neanthes* test was not recommended for continued use in this program.

Two pore water tests, using *Strongylocentrotus* fertilization and larval development protocols, were performed on three concentrations of pore water samples to evaluate their usefulness

Figure 23a
Amphipod Toxicity Using Reference Envelope
for All Stations
North San Diego Bay

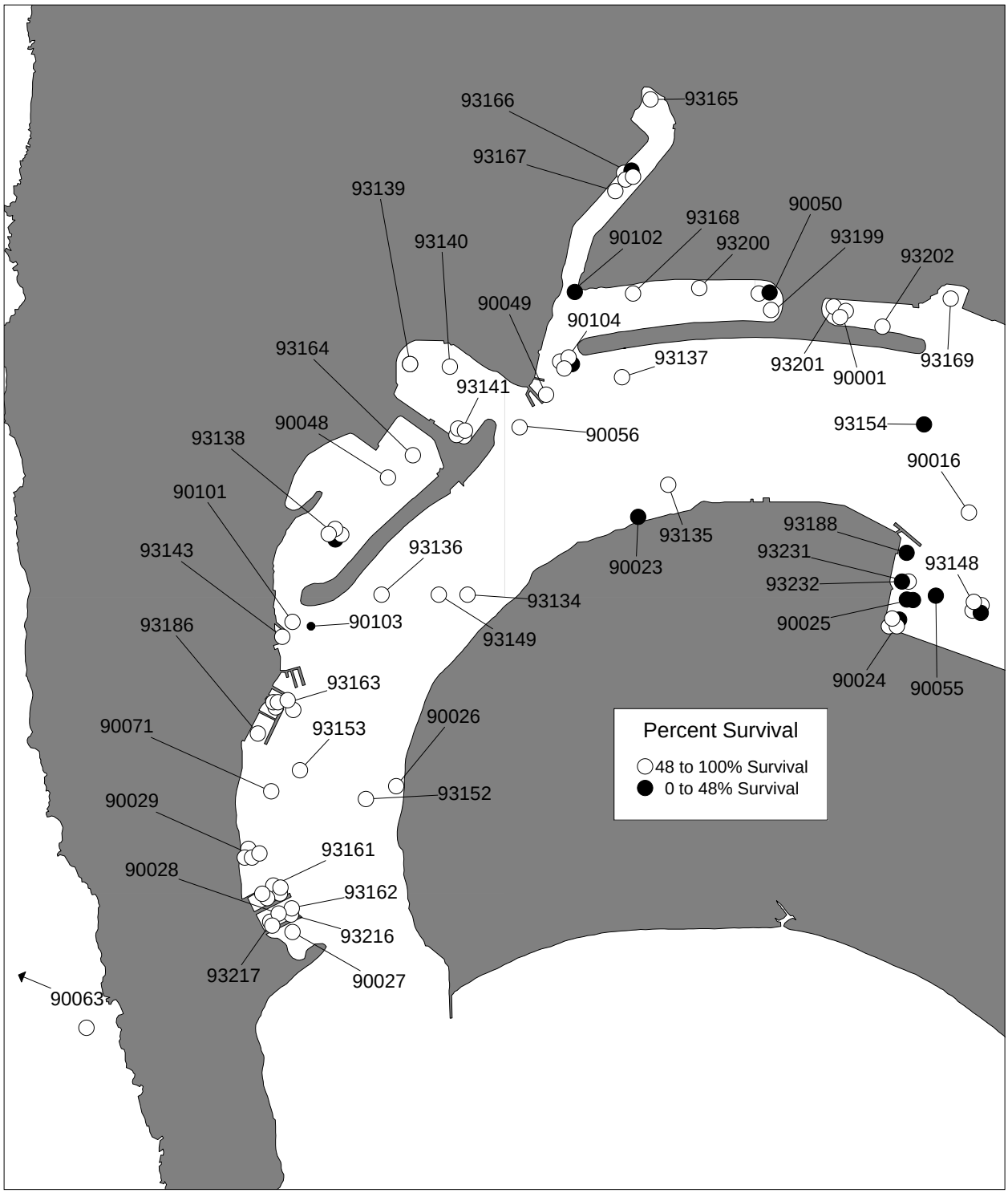


Figure 23b
Amphipod Toxicity Using Reference Envelope for All Stations
Mid San Diego Bay

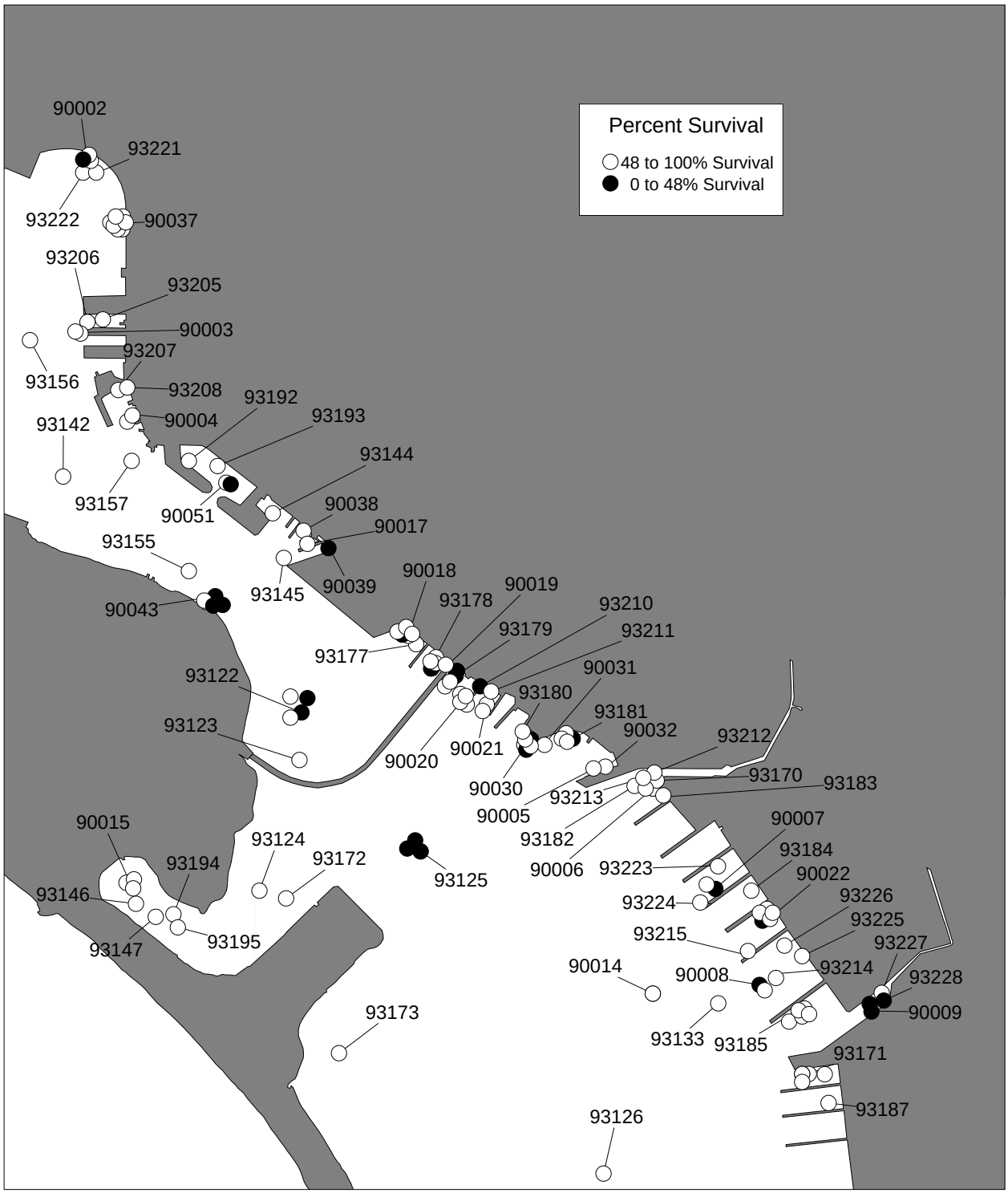


Figure 23c
Amphipod Toxicity Using Reference Envelope
for All Stations
South San Diego Bay

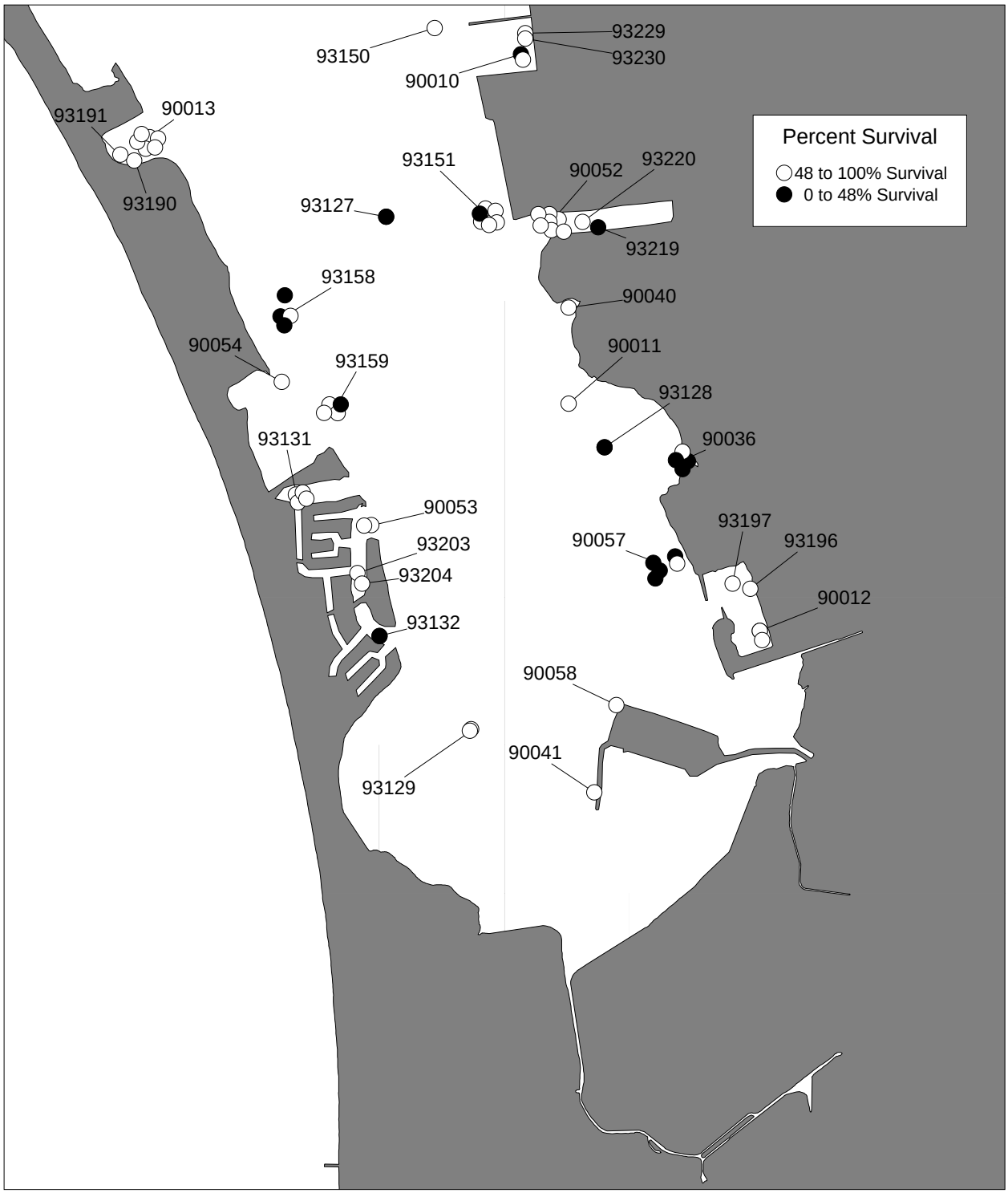
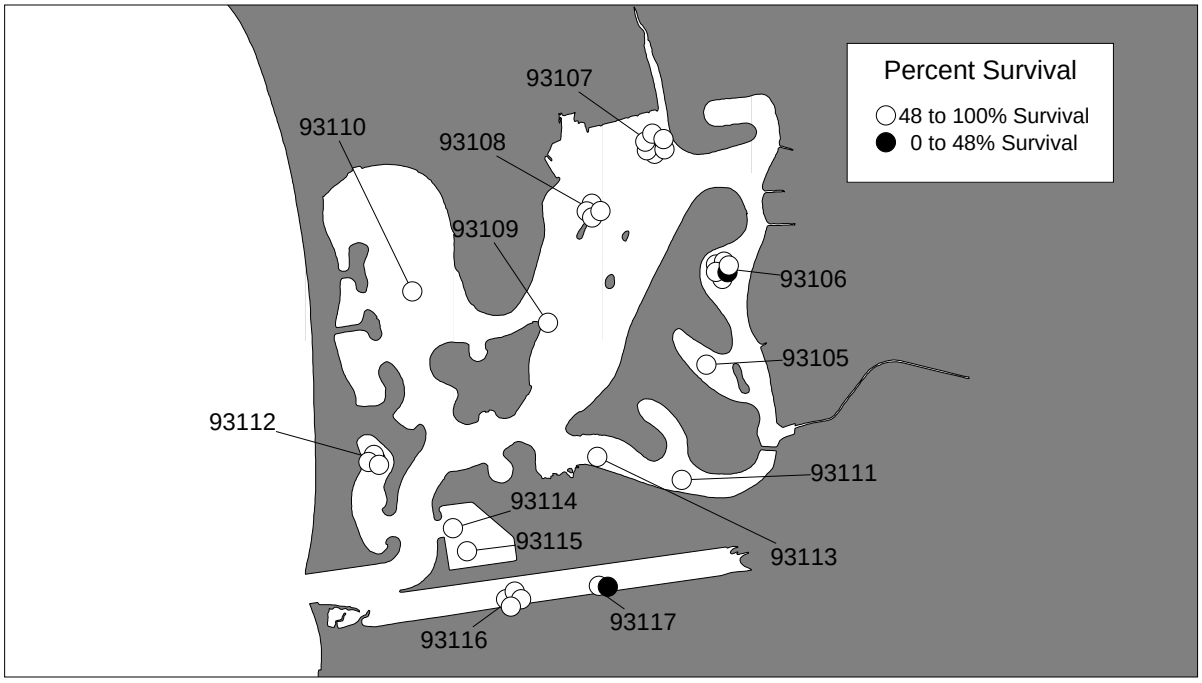
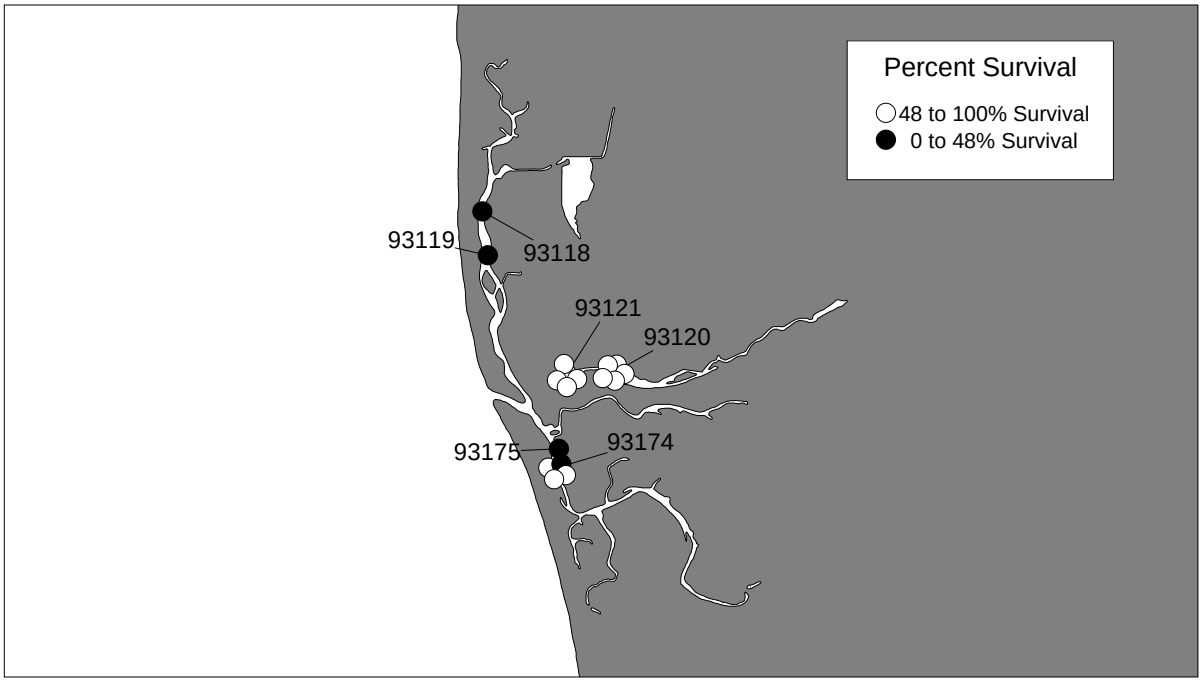


Figure 23d
Amphipod Toxicity Using Reference Envelope
for All Stations
Mission Bay and San Diego River Estuary



Tijuana River Estuary



as components of the BPTCP. Results indicated these tests were extremely sensitive to pollutants and/or other pore water constituents in the study area, particularly at the 100% porewater concentration. It is reasonable to expect that pore water sea urchin tests, which measure sublethal effects on sensitive early life stages, would be more sensitive than the amphipod solid phase tests, which measure adult mortality. It is also likely that all three protocols respond differently to different contaminants. The high sensitivity of the sea urchin protocols has been observed in other studies assessing pore water toxicity (Burgess *et al.*, 1993; Carr and Chapman, 1992; Long *et al.*, 1990).

Rhepoxynius solid phase test results agreed with *Strongylocentrotus* development (100% and 50%) pore water results in 61 of 117 concurrently tested samples (52%). For the 25% pore water dilution, results agreed in 48% of samples. The three dilutions for the *Strongylocentrotus* tests agreed with each other 56% of the time. In all but two cases, *Strongylocentrotus* results differed from each other because samples were less toxic as pore water was increasingly diluted. In one case the 50% pore water was toxic when the 100% and 25% were not, and in another case, the 50% and 25% were toxic when the 100% was not.

Carr and Chapman (1992) noted that sensitive toxicity test protocols are necessary to adequately characterize the toxicity of potentially contaminated sediments. Pore water tests provide the following advantages: allow the use of a variety of sensitive sublethal toxicity test protocols which have not yet been developed for solid phase tests; eliminate interference from physical factors such as sediment grain size; and allow test organisms to be directly exposed to the aqueous sediment fraction, the probable primary route of pollutant exposure to organisms (Adams *et al.*, 1985; DiToro, 1990). In addition, pore water is currently the only sediment matrix suitable for toxicity identification evaluations that may be useful in identifying toxicants responsible for observed sediment toxicity.

Despite the need to evaluate pore water toxicity, logistical issues of pore water extraction and handling are still a focus of current research (Carr *et al.*, 1995). Among the samples associated with high toxicity in the sea urchin pore water tests were a number from the selected reference stations. These stations had non-degraded benthic communities, relatively low concentrations of pollutants, and ammonia concentrations below levels expected to have an observable effect. The wide range in pore water toxicity at the reference stations was unexpected, and prevented identification of toxic sites using the reference envelope approach. Pore water properties and sampling manipulations that may have affected pore water test results are discussed later.

Samples of water collected one meter above the sediment surface were tested for toxicity at a number of stations. These subsurface water samples were tested as one of the suite of

screening bioassays conducted on suspected areas of water quality impairment. Sixty-five subsurface water samples were tested with the red abalone (*Haliotis rufescens*) larval shell development protocol. Of these, eleven samples were significantly toxic, indicating degradation of the water column in 17% of the stations tested. Water column testing has not been a consistent component of the BPTCP, and will probably be reserved for special investigations. The abalone test appears appropriate for this application.

The bivalve (*Mytilus sp.)* larval shell development test was used to test eight subsurface water samples and three pore water samples. This test was used only in cases where salinity was less than 30 or 26 parts per thousand, the low end of salinity ranges for abalone and sea urchin larval development tests, respectively. Because seawater salinities in the San Diego Bay region were usually in the acceptable range for abalone and sea urchins, the bivalve test was used sparingly. None of the subsurface water samples tested with mussels were significantly toxic, and one of three pore water samples tested with mussels was significantly toxic. This protocol is well established as a sensitive test method, and has the advantage of a relatively wide salinity range. In situations where the salinity range precludes the use of abalone or sea urchins, the bivalve test is an acceptable alternative.

The presence of mitotic aberrations in anaphase cells (cytogentic abnormalities) of *Strongylocentrotus* were determined in some samples. Cells undergoing mitosis were analyzed for chromosomal abnormalities. This porewater test is appropriate for identifying samples containing genotoxic compounds, which may affect reproductive capacity in a wide variety of organisms. Though the test is useful for specific applications, it proved time-consuming for assessing large numbers of samples. Most porewater samples that demonstrated increased aberration rates also were significantly toxic in larval development tests. Since the larval development test was considerably easier to quantify and was being used routinely as part of the study, the mitotic aberration endpoint was discontinued for logistical reasons. It would be useful in specific applications where the effects of genotoxic compounds must be assessed.

Evaluation of Utilization of Pore Water as a Test Medium for the BPTCP

The diffusive flux of dissolved chemicals through the sediment water interface into the overlying water column is a major component of sediment diagenesis and chemical cycles. Bioassay testing of the filtered pore water is an attempt to address exposure of animals living in the sediment matrix, or near the sediment/water interface, to chemicals not associated with the particulate phase. Equilibrium-partitioning theory predicts pore water is the controlling exposure medium in the toxicity of sediments to infaunal organisms (Adams *et al.*, 1985; DiToro, 1990). To accurately interpret pore water test results, it is

important to determine how manipulations of pore water during extraction and handling may have affected observed toxicity. The BPTCP utilized a low pressure (<200psi) squeezing extraction technique with filtration to 0.45 um, and subsequent freezing of pore water samples, prior to testing. There has been some debate regarding appropriate pore water extraction methods and sample manipulations for the purposes of toxicity testing (Carr et al., 1995; Schults et al., 1992). Squeezing techniques allow pore water to be selectively filtered, thus eliminating particulates.

Suspected artifacts from the squeezing technique may include chemical disequilibria through physical disruption of weakly charged ion/particulate associations or lysing of cell walls with resultant changes in concentration of dissolved and particulate organic carbon or other organic components. There is also concern that filtration has a profound effect on observed toxicity. Pore size and filter material can cause variability in measured chemical concentrations (Schults, *et al.*, 1992). Many scientists are now using centrifugation to obtain pore water from sediment for toxicity testing, because this method may be less subject to toxicity artifacts than squeezing (Lange *et al*., 1992; Giesy *et al.*, 1990).

Toxicity has been observed to decrease in bedded sediments which are tested after freezing and thawing, with observed changes assumed to be related to the release of soluble organic carbon through disruption of natural lattices, clay aggregates and organic matter (Schuytema *et al.*, 1989). Although solids are removed from pore water samples, there remain some soluble organic carbon concerns due to disruption of colloidal aggregations in the pore water, however centrifugation of pore water samples prior to freezing helps minimize this effect (Carr and Chapman, 1995). There are other unresolved concerns related to the toxicity testing of sediment pore waters which require additional study. These include sediment sample handling and storage conditions prior to testing, oxygen contamination, storage time of pore water samples prior to testing (Lange *et al.*, 1992) and sorption kinetics in toxicity test containers and extraction devices (Pittinger, 1988).

Dose responses from the three pore water dilutions demonstrate decreasing toxicity with increasing pore water dilution, confirming that some factor associated with pore water was causing toxicity. However, considering the uncertainty of introduced artifacts during sample manipulations, the ability to discriminate more severely impacted sediments from less severely impacted sediments (a primary goal of the BPTCP) is clearly compromised. As a result of this uncertainty, toxicity testing using pore water as the test medium was suspended in August, 1993, pending further method evaluation. Pore water extraction methods and pore water sample handling have been under evaluation by the BPTCP since that time, with preliminary results indicating that centrifugation and refrigerated (not frozen) sample storage may be the preferable methods when testing this matrix. Recent method comparison research of Carr and Chapman (1995) supports

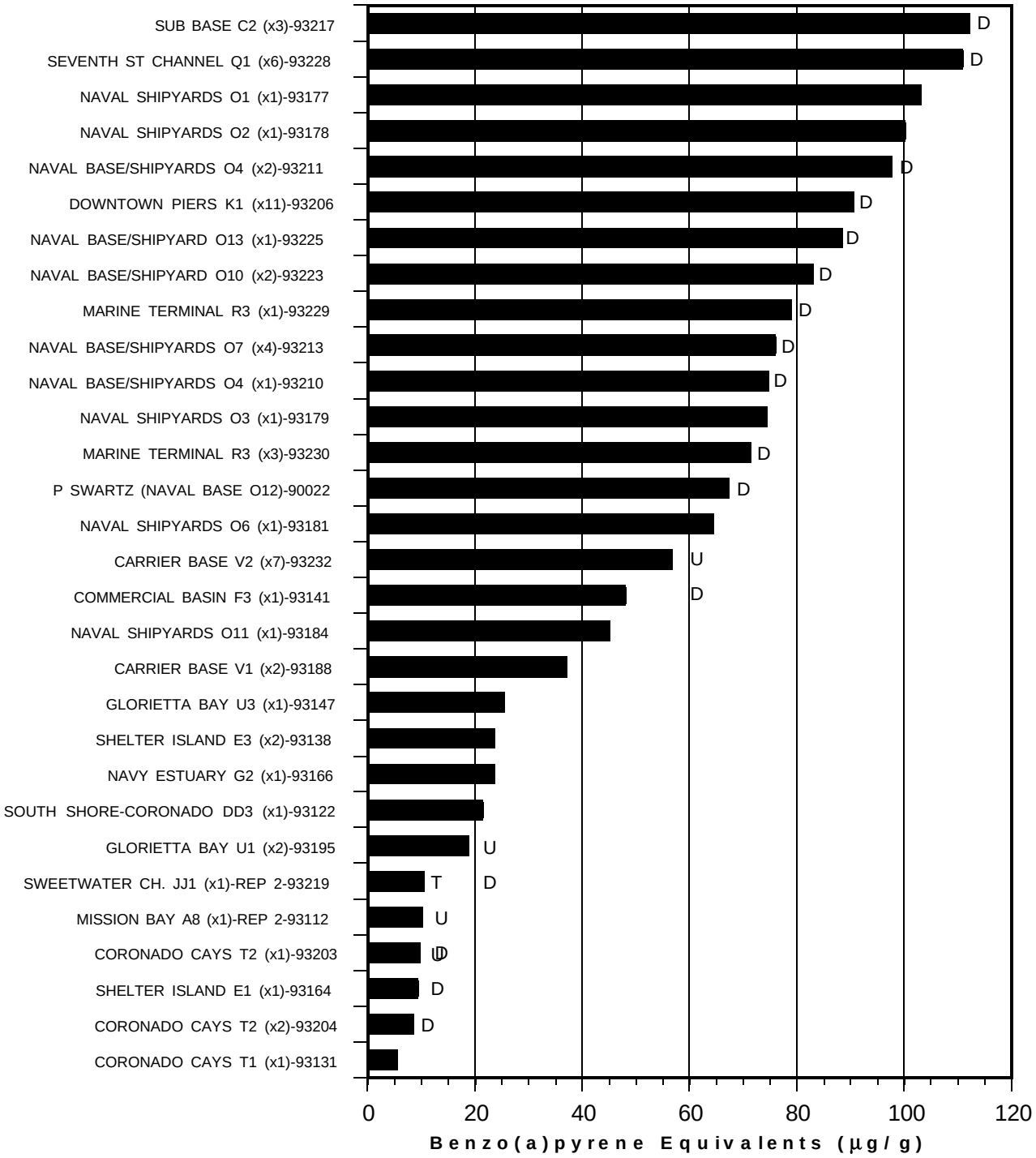
the use of squeezing technique yet concludes that in situations where hydrophobic organic compounds are a concern (as they are in this program), centrifugation is the method of choice for maximizing the sensitivity of the toxicity test. Sample storage and holding times were critical for all methods evaluated and require further investigation (Schults *et al.*, 1992).
As pore water test methods, test organism selection, and the interpretation of results continue to evolve, they will be evaluated for use by the BPTCP. Because test sensitivity is necessary for accurate sediment characterization, the *Strongylocentrotus* pore water larval development toxicity test protocol should continue to be included in BPTCP. At present, pore water toxicity data by themselves are difficult to interpret. If pore water toxicity tests are used in conjunction with solid phase toxicity tests, chemical measurements and benthic community evaluations, they can provide useful additional information when using a weight of evidence approach toward site characterization.

Distribution of P450 Reporter Gene System Response

Induction of the CYP1A1 gene on the human chromosome is produced by such compounds as dioxins, furans, dioxin-like PCB congeners (coplanar), and several high molecular weight polycyclic aromatic hydrocarbons. This induction and resulting production of the detoxifying enzyme, P450, infers that these xenobiotics are present at levels that are potentially toxic, carcinogenic, or mutagenic to organisms. The P450 Reporter Gene System (RGS) assay can measure the response of human (101L) cells to organic extracts when a firefly plasmid at the CYP1A1 site produces the enzyme luciferase. A luminometer is used to quantify the luciferase as a function of concentration and potency of the organics in the extract. Solvent extracts (using standard extraction methods EPA 3510, 3450 or 3550) of water, aquatic sediments, soils and tissues can be tested in the assay system, with a measured response in 16 hours (Anderson *et al.,* 1996).

Findings of the P450 Reporter Gene System (RGS) assay of sediment extracts from 30 stations are summarized in Figure 24, where the RGS responses (in 101L cells) are expressed as μg/g (ppm) of benzo(a)pyrene equivalents (BaPEq). The Mission Bay A8 (93112) station, Coronado Cays T2 (93203, 93204) stations, Shelter Island E1 & E3 (93138, 63164) and the Sweetwater Channel stations produced baseline responses in the range of 5.3 to 10.4 μg/g BaPEq. Figure 24 shows that all Naval Shipyard stations, the Commercial Basin station, the Marine Terminal and Downtown piers, as well as Seventh Street and the Sub Base stations all produced strong RGS responses. These responses suggest that benthic fish and invertebrates living in contact with these sediments have a high probability of P450 enzyme levels above background, which could result in chronic toxicity, and/or damage to tissues and reproductive potential.
http://www.norcalsetac.org/meetings.htm
Examination of the relationship between RGS response to sediment extracts and total PAHs concentration in sediments demonstrates

Figure 24. P450 Responses to Extracts of Sediments From San Diego Bay



P450-RGS response (expressed as benzo(a)pyrene equivalents) and benthic community index. Stations with degraded benthic communities are shown with a "D" label. Undegraded are shown with "UD," and transitional stations are shown with "T." Benthic community analysis was not performed on unlabeled stations.

a strong correlation ($r^2 = 0.86$) between the two measures (Figure 25). This is expected, because samples significantly contaminated with PAHs and/or other compounds (coplanar PCBs) have been shown to produce induction of the CYP1A1 gene and the RGS response (Anderson *et al.*, 1995).

Figures 9a-d show stations with high molecular weight PAHs at the PEL (6676 ng/g) and above in black. Examination of these data demonstrated that RGS responses above 60 μg/g BaPEq were always associated with total PAHs at levels above the PEL. This comparison with the PEL suggested that sediment samples with RGS responses above 60 μg/g BaPEq also had a high probability of demonstrating a toxic biological effect, based on sediment quality guidelines. Interestingly, stations identified by RGS to contain significant amounts of inducing organic compounds (> 60μg/g BaPEq) were also found to have degraded benthic communities, at all stations where both analyses were performed. Toxicity test results did not demonstrate a similar strong association with the RGS response.

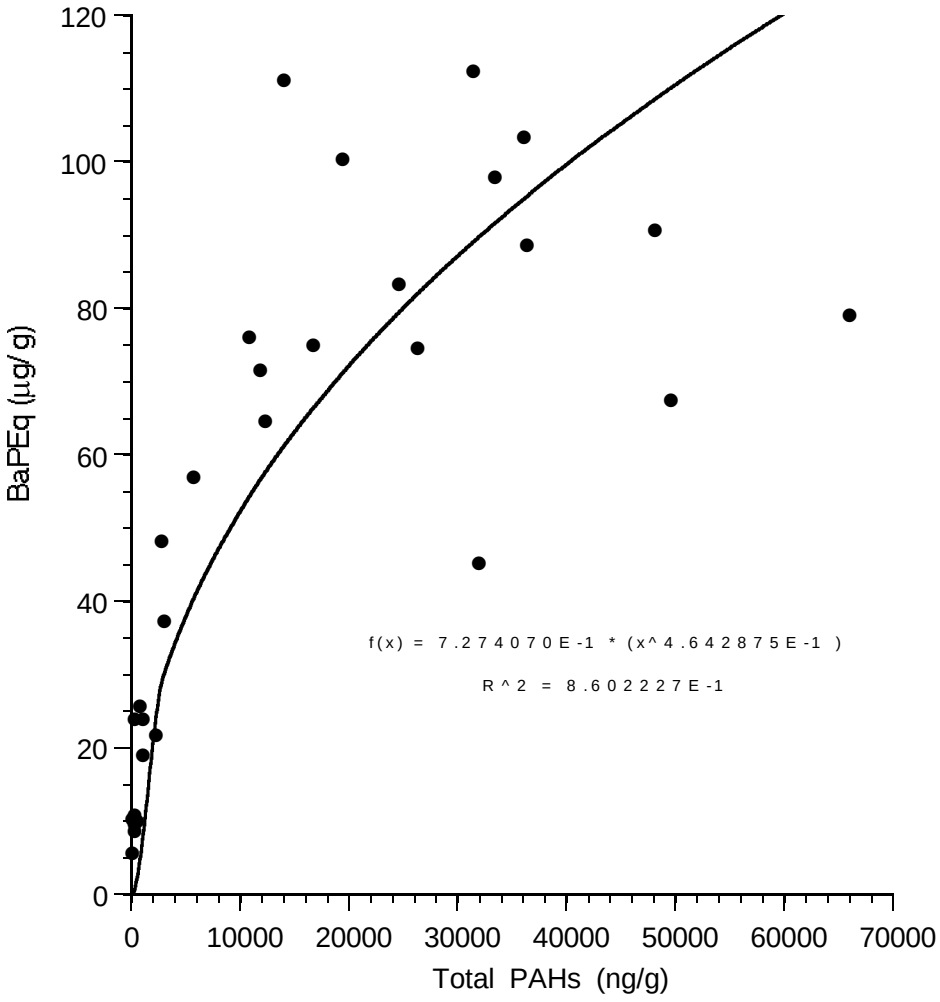
The P450 Reporter Gene System proved to be effective for rapidly (16 hr test) and inexpensively assessing the magnitude of PAHs at selected stations in the San Diego Bay Region. It further proved useful by demonstrating a RGS response threshold above which benthic community degradation was expected. This method may be appropriate as a screening test at additional locations when benthic community degradation and contamination from multiple PAHs, coplanar PCBs, dioxins and furans is suspected. The bioeffects branch of NOAA has utilized this assay in investigations of coastal studies in southern California, Charleston Harbor, S.C., Sabine Lake and Galveston Bay, Texas, and Biscane Bay Florida. In concert with other chemical and biological measures, this method provides additional convincing evidence for the assessment of overall pollution at sites of chemical concern.

Determination of Relationships Between Toxicity and Chemistry

Linear regression was used to describe the relationship between toxicity and chemical concentrations. The dependent variable values are assumed to be normally distributed around the predicted values on the regression line. If this assumption has been met, then a significance test evaluating the null hypothesis (slope of the regression equation is equal to zero), is performed. In addition to a significant probability ($p < 0.05$), the coefficient of determination (r^2) is also an indication of regression strength. The coefficient of determination value represents the proportion of total variance of the dependent variable which can be explained by the independent variable, with a r^2 value of greater than 0.60 being significant. Regression is preferable to non-parametric tests because there is greater power to detect significant relationships with this method (Zar, 1984).

Linear regressions were used to assess the relationship between *Rhepoxynius* (amphipod) mean survival and chemical concentration.

Figure 25. Total PAHs vs P450-RGS Response Expressed as Benzo(a)pyrene Equivalents



Systat® v.5.04 was used for all analyses. The arcsine (square root) transformation is utilized to equalize variance over the entire range of proportions. Chemistry data were checked for normality and transformed using Log(x+1), when necessary (Zar, 1984). Examination of residuals reveal homogeneity of variances exists when these transformations are performed and therefore, the statistical assumptions of a regression can be met. The coefficient of determination (r^2) was reported only when the linear regression was significant ($p<0.05$).

Regressions using amphipod data and chemical concentrations for all stations were analyzed. Testing the degree of dependence of amphipod survival on individual chemical concentrations yielded several regressions which are significant, however, there were no r^2 values greater than 0.072 (Table 13).

To investigate dependence of amphipods on chemistry within specific areas of the Bay, all stations were grouped into one of six specific areas (Appendix B). Groupings were performed to combine stations with similar physical characteristics or uses. These six groups were military use areas (Navy), commercial basins for shipping and industrial activities, small boat harbors and marinas, Mission Bay, rivers (San Diego and Tijuana), and "other" stations, which generally were in open areas removed from San Diego Bay shorelines. The area into which each station was grouped is reported in Appendix B. These regressions were used to test the degree of relationship between amphipod survival and specific areas in the San Diego Bay Region.

Regressions using the navy station group were significant for some chemical groups although no regression had an r^2 value greater than 0.272 (Table 14). In commercial basins, low and high molecular weight PAHs, several metals and one PCB compound were significant, but all had low r^2 values (Table 15). In the small boat harbor group, several PAH and PCB compounds and one pesticide were significant, however, no r^2 values were greater than 0.167 (Table 16). In river stations low molecular weight PAHs were strongly correlated with amphipod survival (Table 17), producing the most significant regressions of the statistical analysis. These regression results from the river stations were somewhat misleading, however, because PAH levels were low relative to most stations in San Diego Bay and to ERM guidelines. For regressions using the "other" station designations, several metals and PCB compounds and one PAH, were significant (Table 18) yet, r^2 values were never better than 0.265. When testing the six station groups, there were no significant regressions for chemistry or amphipods within the Mission Bay group. This was expected because of the low chemical concentrations, therefore no table is shown.

Ammonia, hydrogen sulfide and grain size are suspected non-anthropogenic contributors to toxicity, and have been discussed previously by Ankley *et al.*(1990), Knesovich *et al.* (In Press), and DeWitt *et al.* (1988). To investigate whether these natural

Table 13. Linear regression of amphipod survival dependence on chemistry concentrations for all stations (chemistry with * and all PCB and PAH compounds were Log (x+1) transformed, r^2 is presented when $p<0.05$, ns=nonsignificant).

Metal	n	p	r^2	Pesticide	n	p	r^2	PCB	n	p	r^2	PAH	n	p	r^2
Aluminum	217	0.000	0.047	ALDRIN	229	ns		PCB8	229	0.008	0.031	ACY	198	ns	
Antimony	217	0.015	0.027	CCHLOR*	229	ns		PCB15	78	ns		ACE	229	ns	
Arsenic	217	ns		TCHLOR*	198	ns		PCB18	229	0.001	0.049	ANT	229	ns	
Cadmium*	217	0.000	0.06	ACDEN	217	ns		PCB27	78	ns		BAA	229	ns	
Chromium	217	ns		GCDEN	186	ns		PCB31	78	0.018	0.072	BAP	229	ns	
Copper	217	ns		CLPYR	165	0.011	0.039	PCB44	229	ns		BBF	198	ns	
Iron*	217	ns		Total CHLR	229	ns		PCB49	78	ns		BKF	198	ns	
Manganese	217	ns		DACTH	186	0.000	0.049	PCB52	229	ns		BGP	198	ns	
Nickel	217	ns		OPDDD	229	0.000	0.060	PCB66	229	ns		BEP	229	ns	
Silver	217	0.023	0.024	PPDDD	229	0.000	0.057	PCB70	78	ns		BPH	229	ns	
Selenium	217	ns		OPDDE	229	ns		PCB74	78	ns		CHR	229	ns	
Tin	217	0.000	0.049	PPDDE	229	ns		PCB87	109	ns		DBA	229	ns	
Zinc	217	ns		OPDDT	229	ns		PCB95	78	ns		DMN	229	0.012	0.028
				Total DDT	229	ns		PCB97	78	ns		FLA	229	ns	
				DICLB	186	ns		PCB99	78	ns		FLU	229	ns	
				DIELDRIN	229	ns		PCB101	229	ns		IND	198	ns	
				HCHG	229	ns		PCB105	229	ns		MNP1	229	ns	
				HEPTACHL	229	0.000	0.068	PCB110	78	ns		MNP2	229	ns	
				HCB	229	ns		PCB118	229	ns		MPH1	229	ns	
				METHOXY	217	0.04	0.020	PCB128	229	ns		NPH	198	ns	
				MIREX	229	ns		PCB132	78	ns		PHN	229	ns	
				CNONA	186	ns		PCB138	229	ns		PER	229	ns	
				TNONA	217	ns		PCB149	78	ns		PYR	229	ns	
				TBT	217	ns		PCB153	229	ns		LMW PAH	229	ns	
								PCB156	78	ns		HMW PAH	229	ns	
								PCB157	78	ns		Total PAH	229	ns	
								PCB158	78	ns					
								PCB170	229	ns					
								PCB174	78	ns					
								PCB177	78	ns					
								PCB180	229	ns					
								PCB183	78	ns					
								PCB187	78	ns					
								PCB194	78	ns					
								PCB195	229	ns					
								PCB201	78	ns					
								PCB203	78	ns					
								PCB206	229	ns					
								PCB209	229	ns					
								Total PCB	229	ns					

Table 14. Linear regression of amphipod survival dependence on chemistry concentrations in navy stations (all chemistry data were Log (x+1) transformed, r^2 is presented when $p<0.05$, ns=nonsignificant). All PAH compound regressions were not significant and therefore not shown.

Metal	n	p	r^2	Pesticide	n	p	r^2	PCB	n	p	r^2
Aluminum	65	0.024	0.078	ALDRIN	65	ns		PCB 15	25	ns	
Antimony	65	ns		CCHLOR	65	ns		PCB 18	65	0.024	0.078
Arsenic	65	ns		OPDDD	65	ns		PCB 27	25	ns	
Cadmium	65	0.021	0.082	PPDDD	65	ns		PCB 31	25	0.007	0.272
Chromium	65	ns		TCHLOR	57	ns		PCB 44	65	ns	
Copper	65	ns		OPDDE	65	ns		PCB 49	25	ns	
Iron	65	ns		PPDDE	65	ns		PCB 52	65	ns	
Lead	65	0.014	0.092	OPDDT	65	ns		PCB 66	65	0.026	0.077
Manganese	65	ns		PPDDT	65	0.011	0.098	PCB 70	25	0.017	0.222
Mercury	65	0.022	0.081	Total DDT	65	ns		PCB 74	25	0.013	0.240
Silver	65	ns		ACDEN	65	ns		PCB 87	33	ns	
Nickel	65	ns		Total CHLR	65	ns		PCB 97	25	ns	
Selenium	65	ns		DIELDRIN	65	ns		PCB 95	25	ns	
Tin	65	0.000	0.215	HCHG	65	ns		PCB 99	25	ns	
Zinc	65	ns		HEPTACH	65	0.001	0.168	PCB 101	65	ns	
				HCB	65	ns		PCB 105	65	0.020	0.084
				METHOXY	65	ns		PCB 110	25	ns	
				CNONA	57	ns		PCB 118	65	ns	
				TNONA	65	ns		PCB 128	65	0.029	0.073
				TBT	65	ns		PCB 132	25	ns	
								PCB 138	65	ns	
								PCB 149	25	ns	
								PCB 153	65	ns	
								PCB 156	25	ns	
								PCB 158	25	ns	
								PCB 170	65	ns	
								PCB 174	25	ns	
								PCB 177	25	ns	
								PCB 180	65	ns	
								PCB 183	25	ns	
								PCB 187	25	ns	
								PCB 194	25	ns	
								PCB 195	65	ns	
								PCB 201	25	ns	
								PCB 203	25	ns	
								PCB 206	65	ns	
								PCB 209	65	ns	
								TTLPCB	65	ns	

Table 15. Linear regression of amphipod survival dependence on chemistry concentrations in commercial basin stations (all chemistry data were Log (x+1) transformed, r^2 is presented when $p<0.05$, ns=nonsignificant). All pesticide compound regressions were not significant and therefore not shown.

Metal	n	p	r^2	PAHs	n	p	r^2	PCBs	n	p	r^2
Aluminum	44	0.000	0.266	ACY	37	0.024	0.137	PCB 8	44	ns	
Antimony	44	ns		ACE	44	0.016	0.130	PCB 15	19	ns	
Arsenic	44	0.007	0.163	ANT	44	0.001	0.216	PCB 18	44	ns	
Cadmium	44	0.006	0.168	BAA	44	0.018	0.127	PCB 31	19	ns	
Chromium	44	0.026	0.112	BAP	44	0.010	0.146	PCB 44	44	ns	
Copper	44	ns		BBF	37	0.008	0.187	PCB 49	19	ns	
Iron	44	ns		BKF	37	0.009	0.180	PCB52	44	ns	
Lead	44	ns		BGP	37	0.009	0.180	PCB 66	44	ns	
Manganese	44	ns		BEP	44	0.020	0.123	PCB 70	19	ns	
Mercury	44	ns		BPH	44	ns		PCB 74	19	ns	
Nickel	44	ns		CHR	44	0.016	0.130	PCB 87	26	ns	
Silver	44	ns		DBA	44	0.014	0.135	PCB 95	19	ns	
Selenium	44	ns		DMN	44	ns		PCB 99	19	ns	
Tin	44	ns		FLA	44	0.025	0.114	PCB 101	44	ns	
Zinc	44	ns		FLU	44	0.008	0.158	PCB 105	44	ns	
				IND	37	0.005	0.207	PCB 110	19	ns	
				MNP1	44	ns		PCB118	44	ns	
				MNP2	44	0.013	0.137	PCB 128	44	ns	
				MPH1	44	0.039	0.097	PCB 132	19	ns	
				NPH	37	0.004	0.218	PCB 138	44	ns	
				PHN	44	0.023	0.116	PCB 149	19	ns	
				PER	44	0.019	0.124	PCB 153	44	ns	
				PYR	44	0.025	0.114	PCB 156	19	ns	
				TMN	37	ns		PCB 157	19	ns	
				HMW PAH	44	0.008	0.156	PCB 170	44	ns	
				LMW PAH	44	0.007	0.158	PCB 174	19	ns	
				Total PAH	44	0.006	0.168	PCB 177	19	ns	
								PCB 180	44	ns	
								PCB 183	19	ns	
								PCB 194	19	ns	
								PCB 195	44	ns	
								PCB 201	19	ns	
								PCB 203	19	ns	
								PCB 206	44	ns	
								PCB 209	44	0.000	0.091
								Total PCB	44	ns	

Table 16. Linear regression of amphipod survival dependence on chemistry concentrations in small boat stations (all chemistry data were Log (x+1) transformed, r^2 is presented when $p<0.05$, ns=nonsignificant). All metal concentration regressions were not significant and therefore not shown.

PAHs	n	p	r^2	PCBs	n	p	r^2	Pesticide	n	p	r^2
ACY	39	ns		PCB 5	22	ns		CCHLOR	44	ns	
ACE	44	ns		PCB 18	44	ns		TCHLOR	39	ns	
ANT	44	ns		PCB 31	22	ns		Total CHLR	44	ns	
BAA	44	ns		PCB 44	44	ns		OPDDD	44	ns	
BAP	44	ns		PCB 49	22	ns		PPDDD	44	ns	
BBF	39	ns		PCB 52	44	ns		OPDDE	44	ns	
BKF	39	ns		PCB 66	44	ns		PPDDE	44	ns	
BGP	39	0.015	0.150	PCB 70	22	ns		OPDDT	44	ns	
BEP	44	0.038	0.099	PCB 74	22	ns		PPDDT	44	ns	
CHR	44	ns		PCB 87	27	ns		Total DDT	44	ns	
DBA	44	0.043	0.094	PCB 95	22	ns		CNONA	39	ns	
FLA	44	0.009	0.153	PCB 97	22	ns		TNONA	44	0.047	0.091
FLU	44	0.034	0.102	PCB 101	44	ns		TBT	44	ns	
IND	39	0.035	0.114	PCB 105	44	ns					
MNP2	44	ns		PCB 110	22	ns					
MPH1	44	ns		PCB 118	44	ns					
NPH	39	ns		PCB 128	44	ns					
PHN	44	0.040	0.097	PCB 132	22	ns					
PER	44	ns		PCB 138	44	0.036	0.100				
PYR	44	0.006	0.167	PCB 149	22	ns					
LMW PAH	44	0.050	0.089	PCB 153	44	0.041	0.096				
HMW PAH	44	0.030	0.108	PCB 156	22	ns					
Total PAH	44	0.030	0.108	PCB 157	22	ns					
				PCB 170	44	ns					
				PCB 174	22	ns					
				PCB 177	22	ns					
				PCB 180	44	ns					
				PCB 183	22	ns					
				PCB 187	22	ns					
				PCB 194	22	ns					
				PCN 195	44	ns					
				PCB 201	22	ns					
				PCB 203	22	ns					
				PCB 206	44	ns					
				Total PCB	44	0.049	0.089				

Table 17. Linear regression of amphipod survival dependence on chemistry concentrations in river stations (all chemistry data were Log (x+1) transformed, r^2 is presented when $p<0.05$, ns=nonsignificant). All metal, pesticide, and PCB compound regressions were not significant and therefore not shown.

PAHs	n	p	r2
ACY	18	ns	
ACE	20	0.028	0.240
ANT	20	ns	
BAA	20	ns	
BAP	20	ns	
BBF	18	ns	
BKF	18	ns	
BGP	18	ns	
BEP	20	ns	
BPH	20	0.000	0.646
CHR	20	ns	
DBA	20	ns	
DMN	20	0.000	0.672
FLA	20	ns	
FLU	20	0.000	0.692
IND	18	ns	
MNP1	20	0.000	0.669
MNP2	20	0.000	0.634
MPH1	20	0.000	0.714
NPH	18	ns	
PHN	20	0.005	0.358
PER	20	ns	
PYR	20	ns	
TMN	18	0.000	0.591
LMW PAH	20	0.000	0.607
HMW PAH	20	ns	
Total PAH	20	ns	

Table 18. Linear regression of amphipod survival dependence on chemistry concentrations in "other" stations (all chemistry data were Log (x+1) transformed, r^2 is presented when $p<0.05$, ns=nonsignificant). All pesticide compound regressions were not significant and therefore not shown.

Metal	n	p	r^2	PAHs	n	p	r^2	PCBs	n	p	r^2
Aluminum	35	ns		ACY	28	ns		PCB 5	37	ns	
Antimony	35	0.002	0.255	ACE	37	ns		PCB 18	37	ns	
Arsenic	35	ns		ANT	37	ns		PCB 44	37	ns	
Cadmium	35	ns		BAA	37	ns		PCB 52	37	ns	
Chromium	35	0.017	0.161	BAP	37	ns		PCB 66	37	ns	
Copper	35	0.023	0.147	BBF	28	ns		PCB 87	9	ns	
Iron	35	0.009	0.188	BKF	28	ns		PCB 101	37	0.033	0.124
Lead	35	0.019	0.155	BGP	28	ns		PCB 105	37	ns	
Manganese	35	ns		BEP	37	ns		PCB 118	37	0.033	0.124
Mercury	35	ns		BPH	37	ns		PCB 128	37	ns	
Nickel	35	ns		CHR	37	ns		PCB 138	37	ns	
Silver	35	0.003	0.232	DBA	37	ns		PCB 153	37	0.017	0.151
Selenium	35	ns		DMN	37	ns		PCB 170	37	ns	
Tin	35	0.046	0.159	FLA	37	ns		PCB 180	37	ns	
Zinc	35	0.003	0.232	FLU	37	ns		PCB 195	37	ns	
				IND	28	ns		PCB 206	37	ns	
				MNP1	37	ns		PCB 209	37	ns	
				MNP2	37	ns		Total PCB	37	0.049	0.106
				MPH1	37	ns					
				NPH	28	0.005	0.265				
				LPHN	37	ns					
				PER	37	ns					
				PYR	37	ns					
				TMN	28	ns					
				LMW PAH	37	ns					
				HMW PAH	37	ns					
				Total PAH	37	ns					

factors influenced the effects of anthropogenic chemicals in test sediments from the San Diego Bay Region, data were adjusted to exclude tests where unionized ammonia was greater than O.4 mg/L in overlying water and/or hydrogen sulfide was greater than 0.06 mg/L. The 0.4 mg/L ammonia threshold value is based on the NOEC value for the EPA test protocols for marine amphipods (USEPA, 1994) and the 0.06 mg/L hydrogen sulfide threshold value is based on data presented by Knesovich *et al*. (In Press). A general trend is seen by DeWitt *et al.* (1988), in which survival decreases with increasing fines. However, because this trend was not apparent in the San Diego Bay Region and no clear cutoff has been conclusively demonstrated, data were not adjusted to exclude samples with a high percentage of fines. NH_3 and H_2S adjusted amphipod data were compared to the thirty two chemicals or chemical groups, for which PEL values have been derived, and to ERM and PEL summary quotients. Regressions were significant for cadmium, chromium, copper, nickel, silver, zinc, DDT, dieldrin, acenapthene, and the ERM and PEL summary quotients (Table 19). By eliminating high ammonia concentrations (>0.4 mg/L) and high hydrogen sulfide concentrations (0.06 mg/L), regressions do improve slightly, however r^2 values are generally low. It is prudent though to recognize that these natural factors may confound interpretation of toxicity results and that caution should be exercised when elevated ammonia or hydrogen is noted.

In summary, simple linear regressions provide few clues to understanding the relationship between amphipod survival in the toxicity tests and measured single chemical concentrations. When viewing scatter plots, it remains difficult to convincingly argue that there is, or should be, a linear toxic response to increasing chemical concentrations in natural settings. In industrialized settings such as San Diego Bay, where multiple pollutants are common, co-variation and possible synergistic effects within a group of multiple pollutants further confound the separation of effects to single pollutants. A single multiple regression or a variable selection technique may statistically better describe the relationship between toxicity and multiple chemicals, but these were not performed in this analysis.

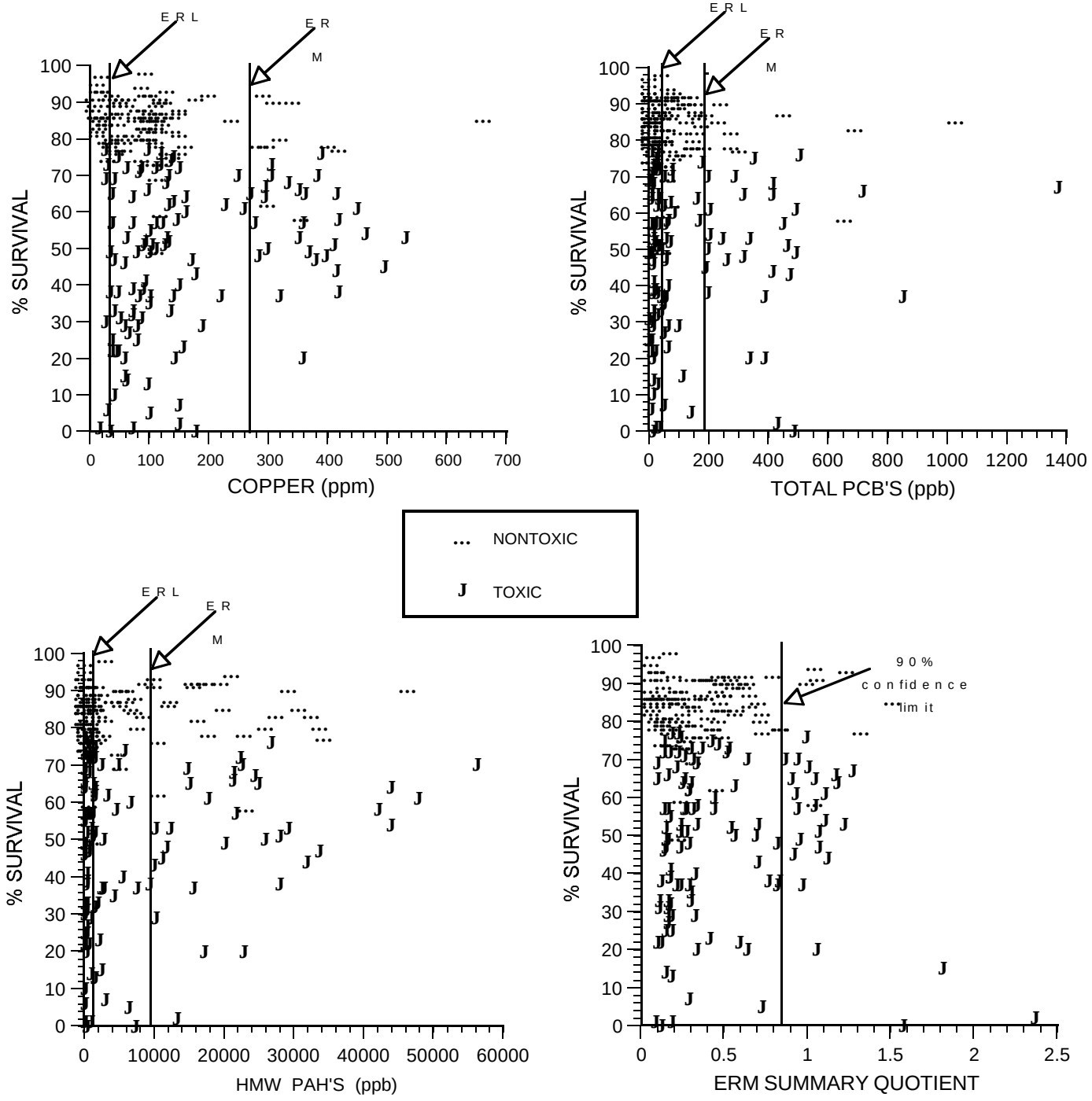
Figure 26 is typical of chemical vs. toxicity scatter plots seen throughout the region, with considerable scatter at low chemical concentrations and a gradual decrease in survival at elevated chemical concentrations. Because regressions did not generally support a linear toxic response to chemical pollutants, it is suspected that most organisms are tolerant of pollutants until a threshold is exceeded. This threshold effect appears well demonstrated in the San Diego Bay Region's benthic communities setting, as illustrated in Figure 14.

Although it was less evident for acute toxicity tests, where high amphipod survival was observed even at elevated chemical levels (Figure 26), a distinct response pattern still emerges. When the EMAP approach for determination of toxicity (significantly different from controls and less than 80% of controls) was used, 28 of 39 (72%) sediment samples were toxic when copper

Table 19. Linear regression of amphipod survival dependence on chemical analytes for which PEL levels have been developed. Amphipod data has overlying unionized ammonia values >0.4 ppm and hydrogen sulfide values >0.06 ppb removed (all chemical data are Log (x+1) transformed. r^2 is presented when $p<0.05$, ns= nonsignificant).

ANALYTE	n	p	r2
Metal			
Arsenic	193	ns	
Cadmium	193	0.000	0.074
Chromium	193	0.028	0.025
Copper	193	0.014	0.031
Lead	176	ns	
Nickel	193	0.003	0.044
Mercury	193	ns	
Silver	193	0.008	0.036
Zinc	193	0.001	0.057
Pesticide			
Total Chlordane	193	ns	
PPDDE	193	ns	
PPDDT	193	0.000	0.068
Total DDT	193	0.008	0.036
Dieldrin	193	0.023	0.027
Lindane	193	ns	
PAH			
ACY	170	ns	0.031
ACE	193	ns	
ANT	193	ns	
BAA	193	ns	
BAP	193	ns	
CHR	193	ns	
DBA	193	ns	
FLA	193	ns	
FLU	193	ns	
MNP2	193	ns	
NPH	170	ns	
PHN	193	ns	
PYR	193	ns	
LMW PAH	193	ns	
HMW PAH	193	ns	
Total PAH	193	ns	
PCB			
Total PCB	193	ns	
Summary Quotients			
PELQ	184	0.050	0.020
ERMQ	184	0.014	0.033

Figure 26. Amphipod Survival vs ERM Summmary Quotient or Chemical Level



concentrations exceeded the ERM value whereas only about 7 of 28 samples (25%) were toxic when copper concentrations were below the ERL value. This was also seen with total PCBs with 73% of the samples being toxic when PCB concentrations exceeded the ERM value and only 53% toxic below the ERL. Because it is suspected that toxicity in urban bays is caused by exposure to complex mixtures of chemicals comparisons to ERM summary quotients (multiple chemical indicators) were made. The highest incidence of toxicity (>78%) is found in samples with elevated ERM summary quotients (>0.85), supporting the theory that the effects of elevated levels of multiple pollutants may elucidate the toxic response. This pattern of increased incidence of toxicity when chemical concentrations exceed established sediment quality guidelines or the summary quotient 90% confidence interval seems to support the threshold response theory for amphipod bioassays in the San Diego Bay Region.

Guideline thresholds are quantitatively estimated from large national or statewide data sets, as described earlier, but the applicability of calculated values may be limited in specific water bodies. Use of unique guidelines for the San Diego Bay Region, which account for local physical, chemical and biological conditions, would be optimal when evaluating data. However, without substantial additional data, chemical specific thresholds for the San Diego Bay region cannot be accurately determined. Currently the most useful tools for addressing the relationship between toxicity and chemical concentration appears to be threshold approaches, such as the ERM/ERL and TEL/PEL guidelines.

Station Specific Sediment Quality Assessments

One of the primary goals of the BPTCP is to establish state guidelines under which contaminated or toxic stations can be designated "toxic hot spots". These guidelines are currently being developed based on data collected throughout the state. Although final guidelines are contingent upon further data analysis, the "toxic hot spot" definition currently utilized by the BPTCP, requires that one or more of the following criteria must be met:

1. The water or sediment exhibits toxicity associated with toxic pollutants, based on toxicity tests acceptable to the SWRCB or the RWQCB. To determine whether toxicity exists, recurrent measurements (at least two separate sampling dates) should demonstrate an effect.

2. Significant degradation in biological populations and/or benthic communities associated with presence of elevated levels of toxic pollutants.

3. The site exceeds water or sediment quality objectives for toxic pollutants which are contained in appropriate water quality control plans, or exceeds water quality criteria promulgated by the U.S. Environmental Protection Agency.

4. The tissue toxic pollutant levels of organisms collected from the site exceed levels established by the United States Food and Drug Administration (FDA) for protection of human health, or the National Academy of Sciences (NAS) for the protection of human health or wildlife.

Because tissue residues were not analyzed in this study, criteria are limited to the first three. Satisfying any one of these criteria can designate a site a "toxic hot spot". Satisfying more than one criterion and the severity demonstrated within each criterion determines the weighting for which qualitative rankings can be made. In this report, stations were not designated as "toxic hot spots", because this designation is still under evaluation and development by the BPTCP. Instead, stations were prioritized for further evaluation for hot spot status. This priority was classified as high, moderate, low, or no action and may be used by State and Regional Water Board staff to direct further investigations at these stations. Each station receiving a high to low priority ranking meets one or more of the first three criteria established above. Those meeting all three criteria were designated as the highest priority for further action.

Stations were evaluated for repeat toxicity (criterion 1) using the reference envelope method, the most conservative measure developed. Only those stations which demonstrated amphipod survival less than 48% in repeated tests, without confounding ammonia, hydrogen sulfide or grain size effects, were considered to exhibit repeat toxicity hits. Because only one critical value could be determined for any of the dilutions of the pore water bioassays, pore water toxicity results were not evaluated for repeat toxicity when prioritizing stations.

Stations with repeat toxicity and elevated chemistry and/or degraded benthic communities, were assigned a moderate or high priority. Stations with repeat toxicity, but lacking elevated chemistry or degraded benthic communities, were assigned a low priority (Tables 20 and 21- REPEAT TOXICITY HITS).

Stations with only a single toxicity hit were also considered a moderate or high priority, when associated with elevated chemistry and/or degraded benthic communities. Stations with a single toxicity hit, but lacking elevated chemistry or degraded benthic communities, were assigned a low priority. (Tables 20 and 21- SINGLE TOXICITY HITS).

Nineteen stations demonstrated repeat or single toxicity hits but were given a "no action" recommendation at this time (Tables 20 and 21). These stations had measured hydrogen sulfide or ammonia concentrations which confounded interpretation of the bioassay test results. Chemistry levels were low, or not analyzed, and the benthic community was undegraded or transitional, where sampled. These results provided little or no evidence that these stations should be prioritized for hot spot status. A toxicity identification evaluation (TIE) should be considered for these

TABLE 20

FUTURE INVESTIGATION PRIORITY LIST FOR THE SAN DIEGO BAY REGION

Stations With Synpotic Chemical, Toxicological and Benthic Community Analyses

STANUM	STATION	IDORG	LEG	H2S	NH3	% AMPHI. SURVIVAL	>4X ERM OR >5.9X PEL	ERMQ	PELQ	BENTHICS	COMMENTS	PRIORITY
	REPEAT TOXICITY											
90009.0	28 SWARTZ (7TH ST CHANNEL Q1)	893	23	nd	0.016	5.00	Chlordane	0.732	0.990	DEGRADED	TOXICITY, ELEVATED CHEM, BENTHIC HIT	HIGH
93228.0	SEVENTH ST CHANNEL Q1 (x6)	895	23	nd	0.010	2.00	Chlordane	**2.373**	**3.082**	DEGRADED	TOXICITY, ELEVATED CHEM, BENTHIC HIT	HIGH
90025.0	SDNI-N5 (CARRIER BASE V2)	899	23	nd	**0.643**	37.00		0.294	0.454	UNDEGRADED	NH3>0.4	NO ACTION
93232.0	CARRIER BASE V2 (x7)	1001	23	nd	**0.773**	35.00		0.300	0.481	UNDEGRADED	NH3>0.4	NO ACTION
	SINGLE TOXICITY											
90002.0	12 SWARTZ(DOWNTOWN ANCH)-REP 1	878	22	nd	**1.836**	15.00	Chlordane	**1.818**	**2.444**	DEGRADED	TOXICITY (NH3>0.4), ELEVATED CHEM, BENTHIC HIT	HIGH
93210.0	NAVAL BASE/SHIPYARDS O4 (x1)	863	22	0.0023	**0.775**	37.00		**0.975**	1.157	DEGRADED	TOXICITY (NH3>0.4), ELEVATED CHEM, BENTHIC HIT	HIGH
90051.0	16 SWARTZ (INTERCONT. MARINA)	818	20	0.0010	**3.340**	1.00		0.190	0.301	TRANSITIONAL	NH3>0.4	LOW
93219.0	SWEETWATER CH JJ1 (x1)-REP 2	876	22	nd	0.319	31.00		0.115	0.188	TRANSITIONAL		LOW
	DEGRADED BENTHICS											
90007.0	25 SWARTZ (NAVAL BASE/SY O10)	887	23	nd	0.014	86.00		0.702	1.025	DEGRADED		LOW
93223.0	NAVAL BASE/SHIPYARD O10 (x2)	888	23	nd	0.016	79.00		0.847	**1.308**	DEGRADED	ELEVATED CHEM	MODERATE
93224.0	NAVAL BASE/SHIPYARD O10(x6)	889	23	nd	0.010	90.00	Zinc	0.623	0.994	DEGRADED	ELEVATED CHEM	MODERATE
93211.0	NAVAL BASE/SHIPYARDS O4 (x2)	864	22	nd	0.158	86.00	Antimony, Copper, PCB	**1.509**	**1.945**	DEGRADED	ELEVATED CHEM	MODERATE
90021.0	K SWARTZ (NAVAL BASE O4)	862	22	nd	0.060	93.00		0.626	0.961	DEGRADED		LOW
90006.0	23 SWARTZ (NAVAL BASE O7)	865	22	nd	0.054	92.00	Chlordane	**1.056**	**1.487**	DEGRADED	ELEVATED CHEM	MODERATE
93212.0	NAVAL BASE/SHIPYARDS 07 (x1)	866	22	nd	0.026	91.00	Chlordane	0.589	0.847	DEGRADED	ELEVATED CHEM	MODERATE
93213.0	NAVAL BASE/SHIPYARDS O7 (x4)	867	22	nd	0.010	94.00	Chlordane	**1.230**	**1.730**	DEGRADED	ELEVATED CHEM	MODERATE
93227.0	SEVENTH ST CHANNEL Q1 (x5)	894	23	nd	0.076	79.00	Chlordane	0.837	1.175	DEGRADED	ELEVATED CHEM	MODERATE
93206.0	DOWNTOWN PIERS K1 (x11)	848	21	nd	0.048	95.00	PAHs	**1.042**	**1.956**	DEGRADED	ELEVATED CHEM	MODERATE
90004.0	15 SWARTZ (G ST. PIER MARINA)	849	21	nd	0.220	77.00		0.494	0.736	DEGRADED		LOW
93207.0	G ST PIER MARINA L1 (x4)	850	21	nd	0.173	89.00		0.454	0.674	DEGRADED		LOW
90022.0	P SWARTZ (NAVAL BASE O12)	868	22	nd	0.061	91.00	PAHs	**1.001**	**1.522**	DEGRADED	ELEVATED CHEM	MODERATE
93214.0	NAVAL BASE/SHIPYARDS O12 (x3)	869	22	nd	0.031	93.00		0.465	0.710	DEGRADED		LOW
93215.0	NAVAL BASE/SHIPYARDS O12 (x4)	870	22	nd	0.017	88.00		0.361	0.578	DEGRADED		LOW
90008.0	27 SWARTZ (NAVAL BASE/SH O13)	890	23	nd	0.008	92.00		0.419	0.665	DEGRADED		LOW
93225.0	NAVAL BASE/SHIPYARD O13 (x1)	891	23	0.0213	0.013	81.00		0.719	1.130	DEGRADED		LOW
93226.0	NAVAL BASE/SHIPYARD O13 (x3)	892	23	nd	0.019	91.00		0.642	1.033	DEGRADED		LOW
90010.0	31 SWARTZ (MARINE TERMINAL R3)	896	23	nd	0.077	86.00		0.145	0.254	DEGRADED		LOW
93229.0	MARINE TERMINAL R3 (x1)	897	23	nd	0.109	70.00	PAHs	**0.876**	**1.504**	DEGRADED	ELEVATED CHEM	MODERATE
93230.0	MARINE TERMINAL R3 (x3)	898	23	nd	0.056	63.00		0.449	0.737	DEGRADED		LOW
93116.0	SAN DIEGO RIVER B1 (x4)-REP 1	881	22	nd	0.216	92.00		0.282	0.381	DEGRADED		LOW
93116.0	SAN DIEGO RIVER B1 (x4)-REP 2	882	22	nd	0.098	92.00	Chlordane	0.540	0.770	DEGRADED	ELEVATED CHEM	MODERATE
93116.0	SAN DIEGO RIVER B1 (x4)-REP 3	883	22	nd	0.162	78.00	Chlordane	0.728	1.026	DEGRADED	ELEVATED CHEM	MODERATE
90028.0	NSB-M1 (SUB BASE C2)	871	22	nd	0.078	84.00	PAHs	0.577	1.038	DEGRADED	ELEVATED CHEM	MODERATE
93216.0	SUB BASE C2 (x1)	872	22	nd	0.079	93.00		0.201	0.351	DEGRADED		LOW
93217.0	SUB BASE C2 (x3)	873	22	nd	0.074	81.00		0.472	0.818	DEGRADED		LOW
90012.0	34 SWARTZ (C.V. YACHT BASIN)	824	20	0.0002	0.334	57.00		0.135	0.243	DEGRADED		LOW
93196.0	CHULA V. YACHT BASIN S1 (x1)	825	20	0.0003	0.260	78.00		0.236	0.426	DEGRADED		LOW
93197.0	CHULA V. YACHT BASIN S1 (x3)	826	20	0.0003	0.165	79.00		0.177	0.308	DEGRADED		LOW
90003.0	14 SWARTZ (DOWNTOWN PIERS)	846	21	nd	0.084	70.00		0.314	0.483	DEGRADED		LOW
93205.0	DOWNTOWN PIERS K1 (x9)	847	21	nd	0.167	84.00	PAHs	0.329	0.552	DEGRADED	ELEVATED CHEM	MODERATE
93107.0	MISSION BAY A3 (x1)-REP 1	853	21	nd	0.075	57.00		0.311	0.429	DEGRADED		LOW
93107.0	MISSION BAY A3 (x1)-REP 2	854	21	nd	0.046	77.00		0.364	0.483	DEGRADED		LOW
93204.0	CORONADO CAYS T2 (x2)	845	21	nd	0.062	82.00		0.140	0.234	DEGRADED		LOW
93220.0	SWEETWATER CH. JJ1 (x8)-REP 3	877	22	nd	0.129	81.00		0.088	0.150	DEGRADED		LOW
93208.0	G ST. PIER MARINA L1 (x5)	851	21	nd	0.064	83.00		0.728	1.047	DEGRADED		LOW
	CHEMISTRY-Individual Chemicals											
93107.0	MISSION BAY A3 (x1)-REP 3	855	21	nd	0.145	73.00	Chlordane	0.535	0.724	TRANSITIONAL	ELEVATED CHEM	MODERATE
93221.0	DOWNTOWN ANCH. J1 (x1)-REP 2	879	22	nd	0.143	83.00	Chlordane	0.564	0.803	UNDEGRADED	ELEVATED CHEM	LOW
STANUM	**STATION**	**IDORG**	**LEG**	**H2S**	**NH3**	**% AMPHI. SURVIVAL**	**>4X ERM OR >5.9X PEL**	**ERMQ**	**PELQ**	**BENTHICS**	**COMMENTS**	**PRIORITY**
	REPEAT TOXICITY HITS											
90009.0	28 SWARTZ	158	7	not analyzed	0.002	0.00	Chlordane, DDT	**1.570**	**1.839**	not analyzed	ELEVATED CHEM, SITE DEGRADED IN LEG 23	HIGH
93179.0	NAVAL SHIPYARDS O3 (x1)	797	19	not analyzed	**0.539**	20.00		**1.056**	**1.534**	not analyzed	ELEVATED CHEM, ADJACENT SITE DEGRADED	HIGH
93179.0	NAVAL SHIPYARDS O3 (x1)-REP 1	1122	27	0.0003	0.059	44.00		**1.119**	**1.525**	not analyzed	ELEVATED CHEM, ADJACENT SITE DEGRADED	HIGH
90043.0	CORONADO WHARF	192	12	not analyzed	**0.884**	29.00		0.169	0.249	not analyzed	NH3>0.4	NO ACTION
90043.0	CORONADO WHARF-REP 1	1156	28	0.0016	**0.423**	33.00		0.113	0.187	not analyzed	NH3>0.4	NO ACTION
90043.0	CORONADO WHARF-REP 2	1157	28	0.0030	0.224	43.00		0.703	0.996	not analyzed		LOW
90030.0	BF SCHROEDER SITE F	179	12	not analyzed	0.066	47.00	PAHs	**1.067**	**1.788**	not analyzed	ELEVATED CHEM	MODERATE
90030.0	BF SCHROEDER SITE F	749	16	not analyzed	0.204	43.00		not analyzed	not analyzed	not analyzed		LOW

TABLE 21

FUTURE INVESTIGATION PRIORITY LIST FOR THE SAN DIEGO BAY REGION

Stations Without Synpotic Chemical, Toxicological and Benthic Community Analyses

STANUM	STATION	IDORG	LEG	H2S	NH3	% AMPHI. SURVIVAL	>4X ERM OR >5.9X PEL	ERMQ	PELQ	BENTHICS	COMMENTS	PRIORITY
	REPEAT TOXICITY											
90009.0	28 SWARTZ	158	7	not analyzed	0.002	0.00	Chlordane, DDT	**1.570**	**1.839**	not analyzed	ELEVATED CHEM, SITE DEGRADED IN LEG 23	HIGH
93179.0	NAVAL SHIPYARDS O3 (x1)	797	19	not analyzed	**0.539**	20.00		**1.056**	**1.534**	not analyzed	ELEVATED CHEM, ADJACENT SITE DEGRADED	HIGH
93179.0	NAVAL SHIPYARDS O3 (x1)-REP 1	1122	27	0.0003	0.059	44.00		**1.119**	**1.525**	not analyzed	ELEVATED CHEM, ADJACENT SITE DEGRADED	HIGH
90043.0	CORONADO WHARF	192	12	not analyzed	**0.684**	29.00		0.169	0.249	not analyzed	NH3>0.4	NO ACTION
90043.0	CORONADO WHARF-REP 1	1156	28	0.0016	**0.423**	33.00		0.113	0.187	not analyzed	NH3>0.4	NO ACTION
90043.0	CORONADO WHARF-REP 2	1157	28	0.0030	0.224	43.00		0.703	0.996	not analyzed		LOW
90030.0	BF SCHROEDER SITE F	179	12	not analyzed	0.066	47.00	PAHs	**1.067**	**1.768**	not analyzed	ELEVATED CHEM	MODERATE
90030.0	BF SCHROEDER SITE F	749	16	not analyzed	0.204	43.00		not analyzed	not analyzed	not analyzed		LOW
93122.0	SOUTH SHORE-CORONADO DD3 (x1)	725	16	not analyzed	**0.740**	23.00		0.416	0.617	not analyzed	NH3>0.4	NO ACTION
93122.0	S.S.- CORONADO DD3 (x1) REP 1	1013	24	nd	**0.463**	33.00		0.306	0.471	not analyzed	NH3>0.4	NO ACTION
90036.0	STORM DRAIN- ROHR CHANNEL	185	5	not analyzed	**0.894**	27.00		0.162	0.253	not analyzed	NH3>0.4	NO ACTION
90036.0	STORMDRAIN EA (ROHR CH.) REP 3	1024	24	nd	0.119	1.00		0.090	0.144	not analyzed		LOW
90036.0	STORMDRAIN EA (ROHR CH.) REP 1	1022	24	**0.0679**	0.136	0.00		0.131	0.174	not analyzed	H2S> 0.06	NO ACTION
93125.0	SILVER STRAND FF4 (x4) REP 1	1016	24	nd	**0.514**	38.00		0.121	0.199	not analyzed	NH3>0.4	NO ACTION
93125.0	SILVER STRAND FF4 (x4) REP 2	1017	24	nd	**0.720**	22.00		0.102	0.171	not analyzed	NH3>0.4	NO ACTION
93125.0	SILVER STRAND FF4 (x4) REP 3	1018	24	**1.2744**	**0.484**	22.00		0.125	0.210	not analyzed	H2S> 0.06, NH3>0.4	NO ACTION
93158.0	SOUTH BAY GG1 (x1) REP 1	1035	24	nd	0.043	33.00		0.163	0.265	not analyzed		LOW
93158.0	SOUTH BAY GG1 (x1) REP 2	1036	24	nd	0.108	39.00		0.175	0.277	not analyzed		LOW
93158.0	SOUTH BAY GG1 (x1) REP 3	1037	24	nd	0.072	46.00		0.141	0.233	not analyzed		LOW
90024.0	SDNI-N1	173	7	not analyzed	**0.684**	40.00		0.323	0.506	not analyzed	NH3>0.4, SITE UNDEGRADED IN LEG 23	NO ACTION
90025.0	SDNI-N5	174	7	not analyzed	**0.925**	7.00		0.295	0.489	not analyzed	NH3>0.4, SITE UNDEGRADED IN LEG 23	NO ACTION
93188.0	CARRIER BASE V1 (x2)	806	19	not analyzed	**2.593**	37.00		0.220	0.349	not analyzed	NH3>0.4 SITE UNDEGRADED IN LEG 23	NO ACTION
90057.0	5 SDG&E	206	12	not analyzed	0.011	25.00		0.147	0.249	not analyzed		LOW
90057.0	5 SDG&E REP 1	1019	24	nd	0.046	41.00		0.176	0.290	not analyzed		LOW
90057.0	5 SDG&E REP 2	1020	24	0.0132	0.011	39.00		0.172	0.283	not analyzed		LOW
90057.0	5 SDG&E REP 3	1021	24	nd	0.032	31.00		0.169	0.281	not analyzed		LOW
	SINGLE TOXICITY											
90007.0	25 SWARTZ	156	7	not analyzed	0.004	37.00	Mercury	0.820	1.088	not analyzed	ELEVATED CHEM, SITE DEGRADED IN LEG 23	MODERATE
90008.0	27 SWARTZ	157	7	not analyzed	0.010	29.00		0.333	0.564	not analyzed	SITE DEGRADED IN LEG 23	MODERATE
90022.0	P SWARTZ	171	7	not analyzed	0.008	38.00		0.771	1.207	not analyzed	SITE DEGRADED IN LEG 22	MODERATE
93181.0	NAVAL SHIPYARDS O6 (x1)	799	19	not analyzed	0.042	45.00		**0.920**	**1.382**	not analyzed	ELEVATED CHEM	MODERATE
90010.0	31 SWARTZ	159	6	not analyzed	**1.291**	39.00		not analyzed	not analyzed	not analyzed	NH3>0.4, SITE DEGRADED IN LEG 23	LOW
90039.0	CL	188	12	not analyzed	0.090	38.00	Chlordane, DDT	0.835	1.156	not analyzed	ELEVATED CHEM	MODERATE
93178.0	NAVAL SHIPYARDS O2 (x1)	796	19	not analyzed	0.350	20.00		0.647	0.936	not analyzed		LOW
93166.0	NAVY ESTUARY G2 (x1)	779	18	not analyzed	**1.129**	20.00		0.336	0.501	not analyzed	NH3>0.4	NO ACTION
93118.0	TIJUANA R. ESTUARY HH1 (x2)	713	15	0.0005	0.187	30.00	DDE	not analyzed	not analyzed	not analyzed	ELEVATED CHEM	MODERATE
90018.0	D DE LAPPE	748	16	not analyzed	0.039	19.00		not analyzed	not analyzed	not analyzed		LOW
90023.0	NM SANDBAG	172	7	not analyzed	0.378	32.00		0.173	0.302	not analyzed		LOW
90050.0	10 SWARTZ	199	7	not analyzed	0.004	47.00		0.240	0.416	not analyzed		LOW
90055.0	43 SWARTZ	204	7	not analyzed	0.075	37.00		0.238	0.372	not analyzed		LOW
90102.0	HARBOR BRIDGE 71A	256	7	not analyzed	0.113	14.00		0.149	0.243	not analyzed		LOW
90104.0	WEST BASIN ENTRANCE (71C) REF	275	12	not analyzed	**1.046**	13.00		0.192	0.314	not analyzed	NH3>0.4	NO ACTION
93106.0	MISSION BAY A2 (x1)-REP 2	1102	27	0.0007	0.106	25.00		0.190	0.275	not analyzed		LOW
93117.0	SAN DIEGO RIVER B2 (x2)	1029	24	0.0125	0.110	0.00		not analyzed	not analyzed	not analyzed		LOW
93119.0	TIJUANA R. ESTUARY HH1 (x1)	714	15	0.0015	0.224	22.00	DDE, DDT	0.599	0.726	not analyzed	ELEVATED CHEM	MODERATE
93127.0	SOUTH BAY GG2 (x1)	1028	24	nd	0.096	47.00		not analyzed	not analyzed	not analyzed		LOW
93128.0	SOUTHBAY GG5 (x1)	1033	24	nd	0.031	27.00		not analyzed	not analyzed	not analyzed		LOW
93132.0	CORONADO CAYS T3 (x1)	1025	24	nd	0.004	47.00		not analyzed	not analyzed	not analyzed		LOW
93138.0	SHELTER ISLAND E3 (x2)	741	16	not analyzed	0.020	29.00		0.185	0.282	not analyzed		LOW
93148.0	CHANNEL-CORONADO Y1 (x2)	751	16	not analyzed	**0.525**	47.00		0.151	0.225	not analyzed	NH3>0.4	NO ACTION
93154.0	NORTH SHORE-MOUTH CC4 (x1)	763	17	not analyzed	**0.836**	31.00		not analyzed	not analyzed	not analyzed	NH3>0.4	NO ACTION
93159.0	SOUTH BAY GG3 (x1)	768	17	not analyzed	**0.675**	21.00		not analyzed	not analyzed	not analyzed	NH3>0.4	NO ACTION
93174.0	TIJUANA R. ESTUARY HH3 (x2)	787	18	not analyzed	0.282	6.00		not analyzed	not analyzed	not analyzed		LOW
93175.0	TIJUANA R. ESTUARY HH3 (x3)	788	18	not analyzed	0.141	10.00	DDE, DDT	not analyzed	not analyzed	not analyzed	ELEVATED CHEM	MODERATE

sites to confirm the source of toxicity as non-anthropogenic. Stations were evaluated for benthic community condition using the benthic index discussed earlier (Table 11). Stations determined to be degraded, with elevated chemistry and/or toxicity, were assigned a moderate or high priority. Stations determined to be degraded, but which did not demonstrate elevated chemistry or toxicity, were assigned a low priority. Transitional and undegraded stations were not considered a priority unless chemical or toxicity results initially prioritized the stations. (Table 20- DEGRADED BENTHICS)

Stations were evaluated for elevated chemistry (criterion 3) using an ERM Summary Quotient >0.85 or a PEL Summary Quotient >1.29. In the earlier discussion of ERM and PEL summary quotients, it was determined these values are statistically above the 90% confidence interval of summary quotients from all stations analyzed. These quotients were used to identify stations where multiple pollutants were near or above established ERM and PEL guidelines (Table 22-CHEMISTRY-Summary Quotients). As shown in Figure 14, 100% of the stations analyzed for benthics were found to be degraded when chemical analysis demonstrated an ERMQ above 0.85. Although the eighteen stations in Table 22 (CHEMISTRY-Summary Quotients) did not have benthic community analysis performed, it is likely these stations will demonstrate degraded benthic communities, when analyzed. In consideration of this concern, all stations with elevated chemistry, based on ERM summary quotients above 0.85, were assigned a moderate priority ranking.

In situations where high summary quotient values were not found, but where any single chemical concentration exceeded four times (4x) its associated ERM or 5.9 times (5.9x) its associated PEL, the station was also considered to exhibit elevated chemistry. The 4x and 5.9x cutoffs were not statistically determined using the 90% confidence interval as they were with the summary quotients. Values for individual chemical quotients were not normally distributed and transformations did not improve distributions, so statistical determination of confidence limits was not appropriate. Instead, a qualitative examination of the data set indicated that only in the top 10th percentile of chemical measurements do values exceed four times their respective ERM or 5.9 times their respective PEL (Tables 20 and 22- CHEMISTRY-Individual Chemicals). These cutoffs were used to help identify stations where any single chemical was extremely elevated. Stations with elevated individual chemical quotients and evidence of benthic community degradation were assigned a moderate ranking. Stations which exhibited elevated chemistry, but showed no biological effects, were assigned a low priority.

Stations which satisfied all three of the criteria were considered a triad hit and are given the highest priority ranking. These stations demonstrated toxicity in the bioassay tests, benthic community degradation and elevated chemistry. Four stations (representing three sites) fell in this category: the Seventh Street Channel (90009-leg 23 and 93228), 12 Swartz

TABLE 22

FUTURE INVESTIGATION PRIORITY LIST FOR THE SAN DIEGO BAY REGION

Stations Without Synoptic Chemical, Toxicological and Benthic Community Analyses

STANUM	STATION	IDORG	LEG	H2S	NH3	% AMPHI. SURVIVAL	>4X ERM OR >5.9X PEL	ERMQ	PELQ	BENTHICS	COMMENTS	PRIORITY
	CHEMISTRY-Summary Quotients											
90020.0	G DE LAPPE	169	12	not analyzed	0.020	49.00		**0.964**	1.255	not analyzed	ELEVATED CHEM	MODERATE
90020.0	G DE LAPPE-REP 1	1104	27	0.0006	0.086	65.00		**1.051**	**1.411**	not analyzed	ELEVATED CHEM	MODERATE
90020.0	G DE LAPPE-REP 2	1105	27	0.0007	0.087	59.00		**1.043**	**1.401**	not analyzed	ELEVATED CHEM	MODERATE
90020.0	G DE LAPPE-REP 3	1106	27	0.0009	0.049	57.00		**0.947**	**1.293**	not analyzed	ELEVATED CHEM	MODERATE
90030.0	BF SCHROEDER SITE F-REP 1	1144	28	0.0012	0.192	70.00		**0.948**	**1.419**	not analyzed	ELEVATED CHEM	MODERATE
90030.0	BF SCHROEDER SITE F-REP 2	1145	28	0.0025	**0.616**	76.00	PAHs	**1.000**	**1.537**	not analyzed	ELEVATED CHEM	MODERATE
90030.0	BF SCHROEDER SITE F-REP 3	1146	28	0.0013	0.017	68.00		**1.007**	**1.438**	not analyzed	ELEVATED CHEM	MODERATE
93178.0	NAVAL SHIPYARDS O2 (x1)-REP 1	1119	27	0.0022	0.185	61.00		**0.934**	**1.294**	not analyzed	ELEVATED CHEM	MODERATE
93178.0	NAVAL SHIPYARDS O2 (x1)-REP 2	1120	27	nd	0.145	66.00	PCBs	**1.170**	**1.618**	not analyzed	ELEVATED CHEM	MODERATE
93178.0	NAVAL SHIPYARDS O2 (x1)-REP 3	1121	27	0.0007	0.168	67.00	PCBs	**1.269**	**1.651**	not analyzed	ELEVATED CHEM	MODERATE
90022.0	P SWARTZ-REP 1	1107	27	0.0003	0.061	58.00	PAHs	**1.042**	**1.549**	not analyzed	ELEVATED CHEM	MODERATE
90022.0	P SWARTZ-REP 2	1108	27	0.0008	0.073	61.00	PAHs	**1.109**	**1.770**	not analyzed	ELEVATED CHEM	MODERATE
90022.0	P SWARTZ-REP 3	1109	27	0.0008	0.038	54.00	PAHs	**1.107**	**1.724**	not analyzed	ELEVATED CHEM	MODERATE
93179.0	NAVAL SHIPYARDS O3 (x1)-REP 2	1123	27	nd	0.049	51.00		**1.071**	**1.462**	not analyzed	ELEVATED CHEM	MODERATE
93179.0	NAVAL SHIPYARDS O3 (x1)-REP 3	1124	27	nd	0.115	78.00	Antimony	**1.330**	**1.658**	not analyzed	ELEVATED CHEM	MODERATE
93184.0	NAVAL SHIPYARDS O11 (x1)	802	19	not analyzed	0.070	53.00	DDT	**1.226**	**1.774**	not analyzed	ELEVATED CHEM	MODERATE
90017.0	C DELAPPE	166	6	not analyzed	**0.840**	64.00	PAHs	**1.183**	**1.943**	not analyzed	ELEVATED CHEM	MODERATE
93181.0	NAVAL SHIPYARDS O6 (x1)-REP 3	1112	27	0.003	0.037	65.00		**0.904**	**1.362**	not analyzed	ELEVATED CHEM	MODERATE
	CHEMISTRY-Individual Chemicals											
93162.0	SUB BASE C3 (x1)	775	18	not analyzed	**0.585**	53.00	PAHs	0.347	0.596	not analyzed	ELEVATED CHEM	LOW
90037.0	STORMDRAIN EM(GRAPE ST.)-REP 3	1161	29	0.0012	0.290	85.00	Chlordane	0.656	0.934	not analyzed	ELEVATED CHEM	LOW
93141.0	COMMERCIAL BASIN F3 (x1)-REP 3	1170	29	0.0004	0.057	70.00	Mercury	0.650	0.905	not analyzed	ELEVATED CHEM	LOW
93116.0	SAN DIEGO RIVER B1 (x4)	711	15	**0.0893**	0.137	88.00	Chlordane	0.659	0.913	not analyzed	ELEVATED CHEM, SITE DEGRADED IN LEG 22	MODERATE
93120.0	TIJUANA R. ESTUARY HH2 (x1)	715	15	0.0002	0.087	85.00	DDE	0.321	0.358	not analyzed	ELEVATED CHEM	LOW
93121.0	TIJUANA R. ESTUARY HH2 (x5)	716	15	0.0016	0.010	85.00	DDE	0.287	0.314	not analyzed	ELEVATED CHEM	LOW
93174.0	TIJUANA R. EST. HH3 (x2)-REP 3	1152	28	0.0044	0.084	80.00	DDE	0.325	0.395	not analyzed	ELEVATED CHEM	LOW
93177.0	NAVAL SHIPYARDS O1 (x1)	795	19	not analyzed	0.023	50.00	PAHs	0.694	1.204	not analyzed	ELEVATED CHEM	LOW

Downtown Anchorage (90002) and Naval Base/Shipyards O4 (93210). Three stations were given a high priority ranking although not all conditions of the triad were met (Seventh Street Channel (90009-leg 7) and Naval Shipyards O3 (93179- legs 19 & 27)). These stations demonstrated repeated toxicity and elevated chemistry but no benthic analyses were performed. However, benthic data for stations analyzed in the same proximity, or later sampling of the station, led to the concern that these sites would have been found degraded, if analyzed. In addition, chemical summary quotients at these three stations were at levels which suggest probable benthic community degradation, as discussed earlier. These concerns warranted upgrading these three stations from a moderate priority to a high priority. Forty three stations were given moderate priorities and 57 were given low priorities, based on the methods of prioritization previously discussed. Prioritized stations are mapped in Figure 27(a-d).

Stations were prioritized to assist SWRCB and RWQCB staff in meeting sediment quality management objectives for San Diego Bay. These recommendations were based on scientific evaluation of data collected between 1992 and 1994. They are intended to focus future efforts toward scientifically and economically responsible characterization of locations which have a high probability of causing adverse effects to aquatic life. This report should be evaluated in conjunction with all available information and additional research when management and policy decisions are made by SWRCB and RWQCB staff.

Possible Sources of Pollutants at Prioritized Stations

A brief description is given, where additional information was available, of factors which may have contributed to elevated chemical levels, toxicity, or benthic community degradation at the prioritized stations. Descriptions are given in order of geographic distribution, proceeding from north (Mission Bay) to south (Tijuana River Estuary).

In Mission Bay only one location was given the moderate priority ranking (station 93116). This station was located in the San Diego River flood control channel and demonstrated high total chlordane concentrations (36.1 ppb). Chlordane is not expected to undergo significant hydrolysis, oxidation, or direct photolysis in water, thus it may persist in soils for extended periods of time (Howard, 1991). Cohen *et al.* (1990) conducted a study on chlordane in soil samples near golf courses and found unusually high concentrations of chlordane (4.75-4310 ppb). Station 93116 is located directly down river from a golf course, therefore, runoff from this facility could be a chlordane source. Station 93107, in the mouth of Rose Inlet (northern Mission Bay), received a moderate priority listing, based on high chlordane concentrations. Its location is also near a golf course.

One site in North San Diego Bay (Point Loma area) received a moderate priority recommendation; stations 90028 (Submarine Base). This station had degraded benthic communities, high

Figure 27a
Future Investigation Priority List
North San Diego Bay

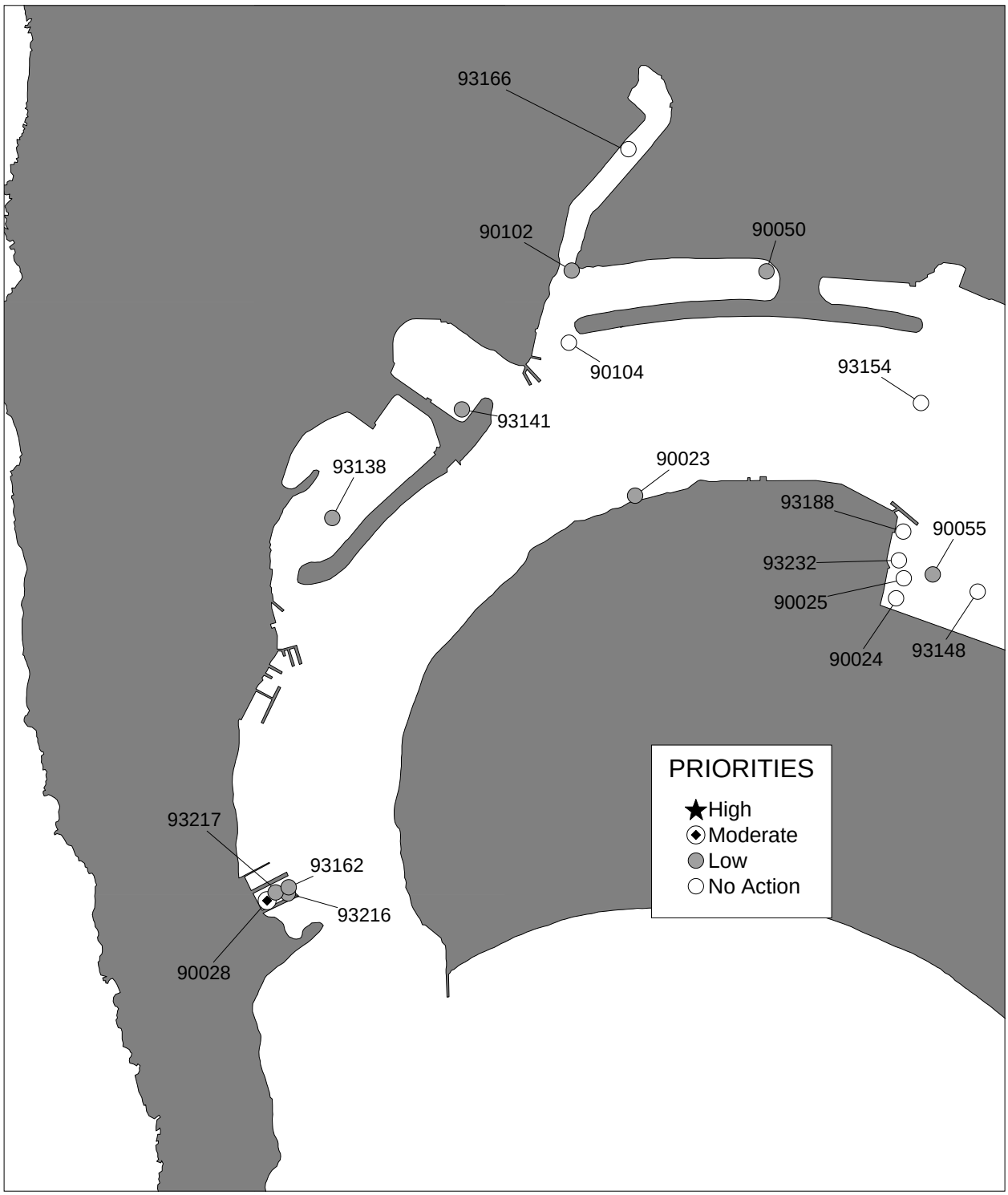


Figure 27b
Future Investigation Priority List
Mid San Diego Bay

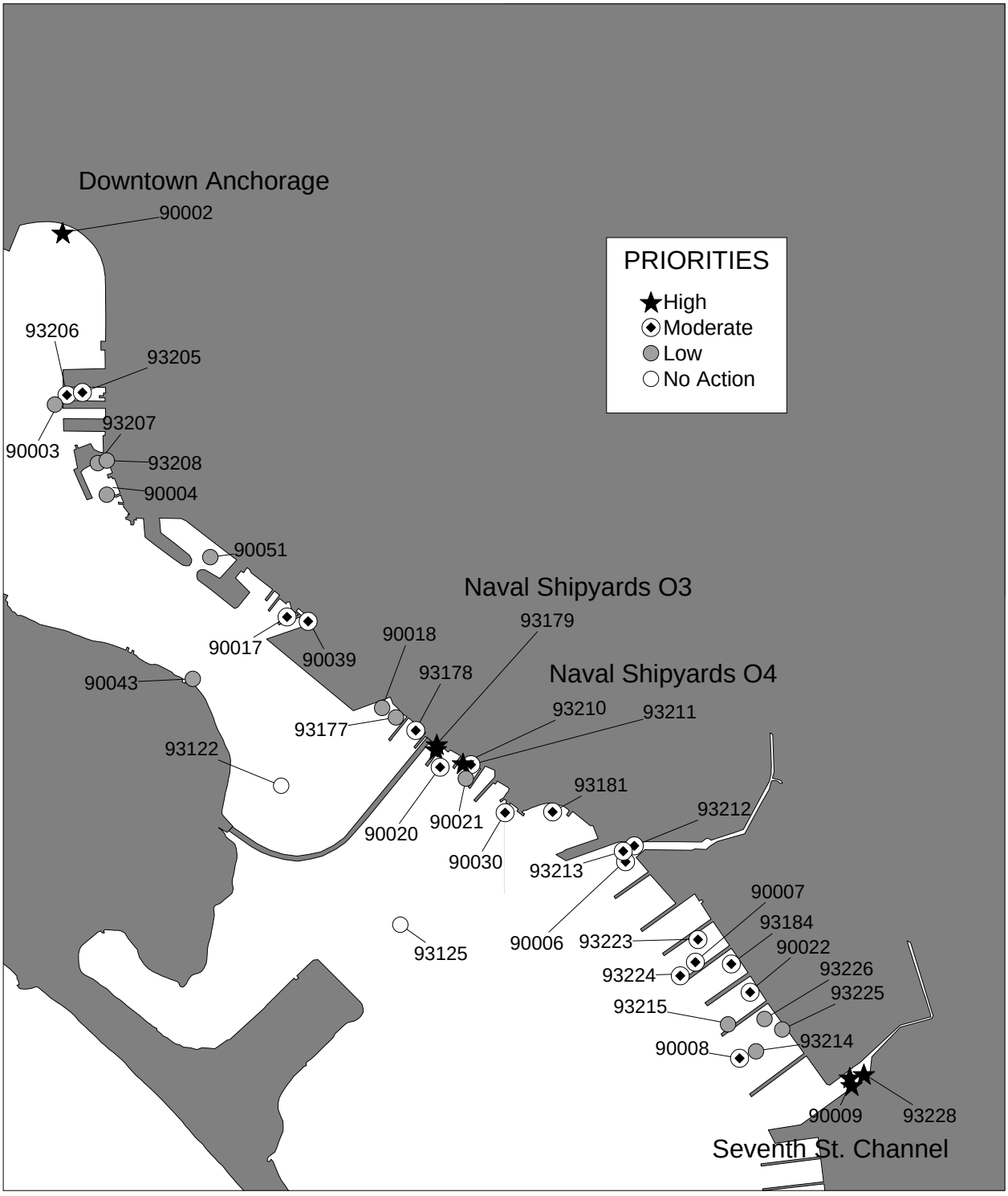


Figure 27c
Future Investigation Priority List
South San Diego Bay

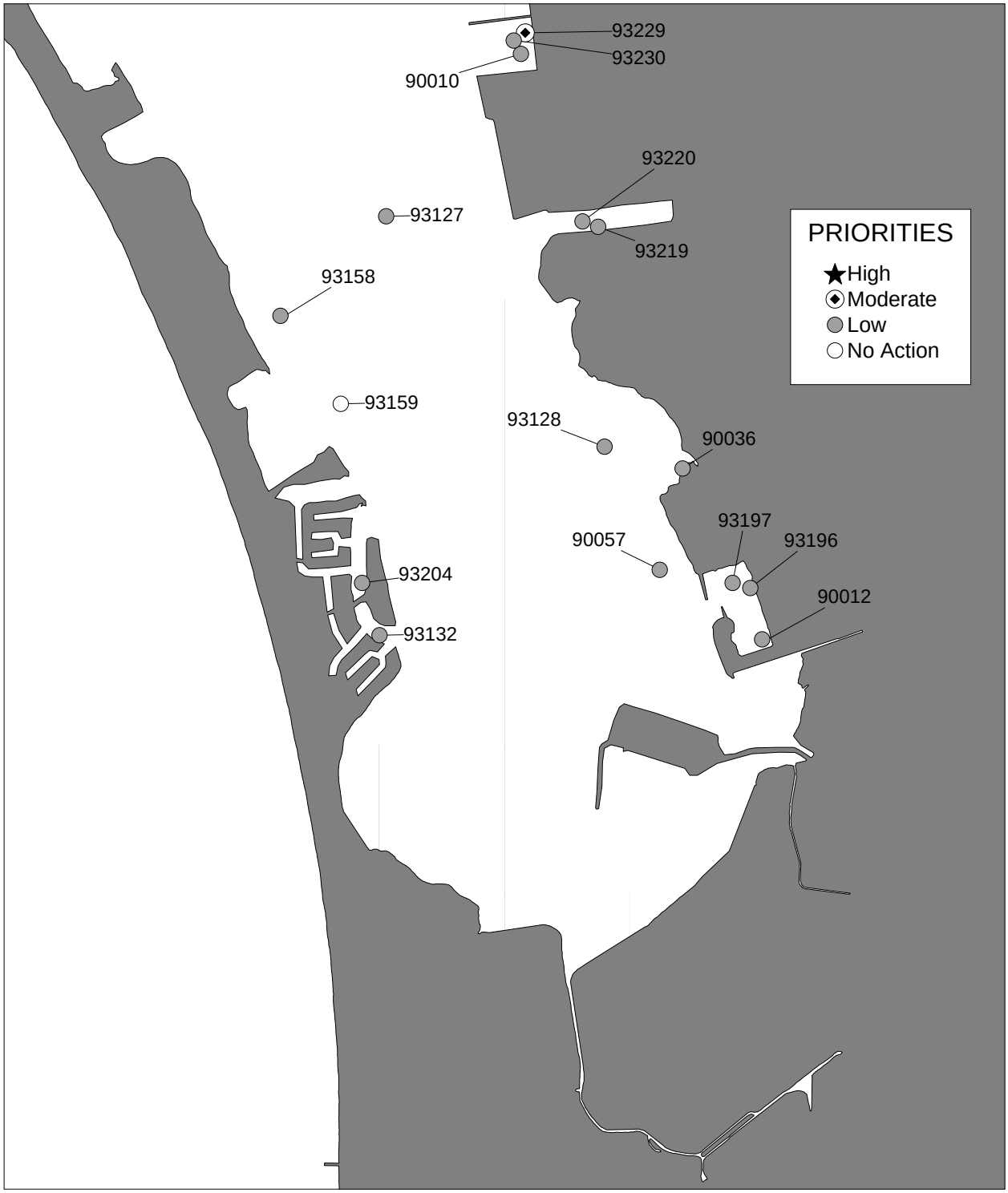
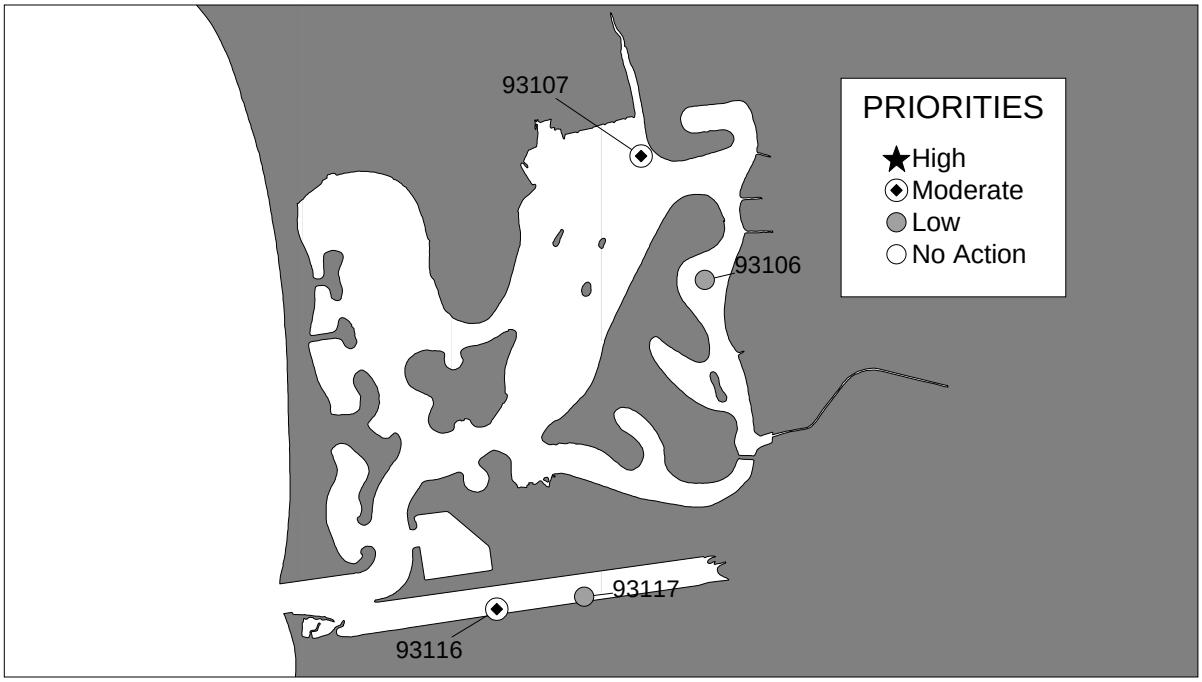


Figure 27d
Future Investigation Priority List
Mission Bay and San Diego River Estuary



Tijuana River Estuary

concentrations of low and high molecular weight PAHs, and moderate levels of metals. Historically the Naval Complex at Point Loma has received plating waste, sewage, and sludge containing high concentrations of metals and chlorinated hydrocarbons (Johnston *et al.*, 1989). Although it is difficult to identify the source of high concentrations of PAHs at these stations, Lung (1983) suggests ground water gradients promote groundwater flow towards San Diego Bay, thus potentially allowing PAHs in the nearby soil to migrate to the Bay. A number sites investigated by the Navy (Eakes and Smith, 1986), which were previously used for waste oil and drum disposal, are located onshore adjacent to and immediately north of stations 93216, 93217 and 90028. Migration of pollutants from these onshore sites is likely. Minor spills during fueling operations at the submarine base are also possible.

Station 90002 (Downtown Anchorage), located in the northern end of mid San Diego Bay, was one of the stations which received a high priority recommendation. High concentrations of metals and chlordane were present, as well as a degraded benthic community. This station also had a low survival for *Rhepoxynius* in solid phase toxicity tests. Perhaps the most obvious explanation for these data would be the presence of a large storm drain and numerous smaller storm drains, which empty into the Bay near this station. These storm drains drain parking lots, light industrial and commercial areas (Conway and Gilb, 1990). Another possible source for observed toxicity and chemistry is runoff from nearby San Diego International Airport. Results from the State Mussel Watch Program 1987-1993 indicate elevated levels of both metals and pesticides in mussel tissue and sediments in this area. Elevated levels of metals could have originated from anti-fouling paints on private boats anchored near the station (90002). The area around this station becomes a modified eddy during ebb tide and may serve to recirculate pollutants, creating a pollutant sink and preventing chemicals from being flushed out of the area (Peeling, 1974).

Located just south of station 90002, stations 93205 and 93206 (Downtown Piers) were given moderate priority ratings based on high chlordane and PAHs concentrations, and degraded benthic communities. Located between the B street pier and the Broadway pier, elevated levels of pollutants can most likely be attributed to sources similar to those described above. Commercial shipping is likely an additional contributor to the observed PAH signal in this area.

Two stations, 90017 and 90039 (located immediately north of the 10th avenue marine terminal), were assigned moderate priority rankings based on high concentrations of chlordane, metals, and PAHs at each of these stations. Campbell Industries operate five ship repair piers and four dry-docking facilities in this area. Sandblasting, painting, and other ship repair activities are probably the cause of the elevated levels of copper, zinc and mercury. High concentrations of metals have historically been detected at this site (Barry, 1972). The 10th avenue Marine

Terminal berths 1 and 2 are also located in this area (station 90039). Ships are loaded and unloaded at this site and supplied with fuel from four steel storage tanks located near the berths. Increased levels of PAHs and metals detected in this area may be related to the cargo transfer facility.

In addition to the ship repair facilities and cargo transfer areas, there is a large storm drain system which is directly south of the 10th and Imperial Trolley station. The system drains approximately eleven square kilometers of residential (including Balboa Park) and industrial areas before emptying into the Bay. The elevated levels of chlordane and PAHs at both of the sites could have additional sources from within this drainage system.

Immediately south of the Coronado Bridge was station 93179 (Naval Shipyards-O3) which was designated as a high priority site for future investigations. To the north and south of this site are numerous stations assigned a moderate prioritization. The predominant activity in this area is ship building and repair (NASSCO, Continental Maritime, Southwest Marine), thus indicating the probable source of high levels of metals, PCBs and PAHs found at stations sampled in this area. A stormdrain, which drains an industrial area and empties into the Bay immediately adjacent to the bridge, is the likely chlordane source to the area. Runoff from the bridge itself could also be viewed as a potential source of PAHs and metals in the Bay. The California State Mussel Watch Program (1995) has sampled extensively in this area of San Diego Bay and found chemistry values for mussels and sediment to be comparable to the current study. This area has also been extensively sampled in other studies resulting in similar conclusions (de Lappe, 1989; Martin, 1985; Anderson, 1989). Toxicity, chemical pollution and benthic community degradation are extensive in this area and warrant further site characterizations.

Stations 93212, 93213, and 90006 (Naval Shipyards-O7) were located near the 28th Street pier and were each given a moderate priority ranking. Chollas Creek empties into the Bay near this site, carrying with it runoff from a large urban area. This creek is believed to carry high concentrations of PAHs into the Bay (McCain *et al.*, 1992) and is the likely source of high chlordane levels at the site.

Numerous low, moderate and high priority sites were located in the Naval Station between the 28th Street pier and 7th Street channel. This area demonstrated toxicity, high metal and chemistry concentrations and degraded benthic communities. The area is predominantly used for ship repair, outfitting, and conversion. Sand blasting, painting, and the changing of zinc electrolysis plates are some of the specific activities conducted in this area and are likely the main sources of metals found in the sediments.

Station 93227 was located in the 7th Street Channel at the southern end of the San Diego Naval Station. This site was given

the high priority ranking based on high metal, chlordane and PAH concentrations, as well as toxicity and degraded benthic communities. Repeated sampling of this site resulted in similar findings. Paleta Creek runs directly into 7th Street channel with numerous drains located in the immediate area emptying into the creek and bay. Also, a large stormdrain is present which drains a residential area east of Interstate 5 and the Naval station adjacent to the channel.

The Navy has used 7th Street channel and the surrounding area for a variety of activities. Excess materials (solid waste, ships stores, and waste hydraulic fluids) from decommissioned ships were disposed of in the ship repair basins. Overflow from salvage yards, lube and hydraulic oil wastes, and paint sludge from nearby Naval repair facilities were often taken to the area's wet docks for disposal. In the late 1970's trucks and heavy equipment returning form Vietnam were routinely decontaminated by spraying with diesel fuel and dunking (by crane) into Paleta Creek. It is estimated that approximately 75,000 to 360,000 gallons of petroleum based material were disposed of at this site during its period of operation (1945-1973).

The 7th Street channel is located near a Navy salvage yard which has stormdrains emptying directly into the channel. In 1976, soil samples retrieved from the area contained PCB concentrations high enough to result in the upper eight inches of soil being removed as contaminated waste and the entire area paved. Although the Navy has attempted to deal with this historic pollution in the area, further investigations were requested by a Naval initial assessment team in 1986 (Eakes and Smith, 1986). Furthermore, the California State Mussel Watch program has stations located in the area and concluded 7th Street channel had some of the highest chemical concentrations in San Diego Bay (State Mussel Watch Program, 1995).

The Marine terminal site (stations 90010, 93230 and 93229) demonstrated elevated copper and PAH levels and a degraded benthic community. Moderate and low priorities were assigned to these stations even though a portion of this area is currently undergoing cleanup activities. Due to the large amount ore spillage at the PACO copper loading facility, this area should continue to be monitored after cleanup activities are completed.

The southern portion of San Diego Bay, from 7th Street channel to the Otay River, did not receive any moderate or high priority rankings. Although this result could give the impression south San Diego Bay is in not polluted, it is important to note some stations still demonstrated high metals concentrations. The Sweetwater channel area (station 93220), and other sites in the South San Diego Bay had high concentrations of copper, most likely reflecting the input from the copper ore loading facility (Martin, 1985). Three stations in the Chula Vista area and one in Coronado Cays received low priority rankings due to elevated levels of metals and degraded benthic communities. Each of these stations were located within marinas where numerous private boats

are berthed. Increased levels of metals detected in this area are probably from anti-fouling paint scrapings or zinc electrolysis blocks used on virtually all boats. Few studies have concentrated sampling in the South San Diego Bay, presumably due to reduced shipping activity and population.

Stations from the Tijuana River Estuary demonstrated elevated concentrations of DDT and DDE, as well as toxicity to amphipods. This resulted in a number of stations receiving moderate and low prioritizations. The presumed sources of this pesticide were wastewater discharges from Mexico, into the Tijuana River (California State Coastal Conservancy, 1989).

Comparison of Pollution with Other Water Bodies

Numerous studies comparing San Diego Bay with other bays and harbors have been conducted (NOAA, 1991; Grovenhoug *et al.*, 1987; Goldberg *et al.*, 1978). In one such study, Robertson (1989) analyzed sediments for a number of organic pollutants at approximately 200 sites around the coasts of the United States. Results ranked San Diego Bay seventh highest in the country for total concentrations of PCBs. Interestingly, San Diego Bay did not rank high in comparison to the rest of the country for any other organic pollutant, although results from the current study clearly showed elevated concentrations (relative to ERMs and PELs) of total PAHs, chlordane, and certain trace metals throughout the Bay.

In a similar study, Johnston (1990) evaluated 367 waste disposal sites at 58 Navy and Marine Corps bases located throughout the country. Each of the bases, or areas of activity, were located in the coastal zone and were reviewed to characterize the pollutants, disposal methods, and potential impact to the surrounding aquatic environment. Four sites were chosen in San Diego Bay: Naval Station San Diego (located immediately south of the seventh street channel), Naval Amphibious Base (near Glorietta Bay), Naval Training Center, and Naval Complex Point Loma. Although these sites were not ranked or compared with sites in other parts of the country, the types of contamination listed were somewhat similar for each of the sites described. Paint, oil, and solvent contamination was reported at all of the sites in addition to some site specific forms of contamination(*i.e.* sandblasting grit disposal area at the Naval Amphibious Base and drum disposal area at the Naval Complex Point Loma).

San Diego Bay has also been compared to other bodies of water on a regional scale. In a SCCWRP project funded by the State Board, Anderson and Gossett (1987) analyzed PAHs in sediments collected at stations between Santa Monica Bay and San Diego Bay and found the Seventh Street (Paleta Creek) and Chollas Creek stations to contain the highest levels of these hydrocarbons. In a follow-up State Board/SCCWRP study Anderson *et al.* (1988) compared ten coastal sites in southern California for concentrations of trace metals, PAHs, chlorinated hydrocarbons and toxicity. Samples from San Diego Bay were shown to have the highest concentrations of

metals, PAHs, and hydrocarbons of all stations sampled, and were the most toxic in two out of three toxicity tests used. Anderson *et al.* (1988) identified the Seventh Street Channel station as the most polluted area in the San Diego Bay Region. This conclusion is corroborated by the current study which also found sampling stations in the Seventh Street Channel to be the most polluted and most toxic stations in the region. Flegal and Sanudo-Wilhelmy (1993) showed total dissolved trace metal (Ag, Cd, Co, Cu, Ni, and Pb) concentrations in San Diego Bay are comparable to levels of trace element pollution in south San Francisco Bay. Specifically, copper was found in elevated concentrations in both bays. The current study found copper to be the predominant trace element pollutant in San Diego Bay. Flegal and Sanudo-Wilhelmy concluded that unlike south San Francisco Bay, elevated trace metal concentrations in San Diego Bay could not be directly linked to point-source inputs, because all wastewater discharges to San Diego Bay were terminated in 1964. Copper based anti-fouling paints and urban runoff are currently the most likely sources of copper. Elevated concentrations of copper in San Diego Bay have also been reported in other studies (Zirino *et al.*, 1978).

It is also important to analyze available site specific data within San Diego Bay from previous studies. In the current study, commercial and naval shipyards located near the Coronado Bridge consistently demonstrated high concentrations of pollutants, a high incidence of toxicity, and benthic community degradation. Shipbuilding activity, in addition to storm drains and creeks, appear to be the primary sources of organic and trace metal pollutants in these areas (Conway and Gilb, 1990). Secondary sources of contamination may include runoff from the Coronado Bridge (San Diego Interagency Water Quality Panel, 1989) and polluted fill in the area (Peter Michael, San Diego Regional Water Quality Control Board, personal communication). This is supported by the conclusions of McCain (1992) who found several major sources of pollutants in the central portion of San Diego Bay.

Specific organic pollutants such as PCBs have been historically identified in certain parts of the bay. In one of the earliest studies of PCBs in San Diego Bay, Young and Heesen (1977) identified PCBs in mussel tissues. The highest measured concentrations occurred in Commercial Basin (Shelter Island). Subsequent studies have also shown elevated levels of PCBs in the Shelter Island area, as well as near Harbor Island and numerous other spots throughout the Bay (Stephenson *et al.*, 1980; Martin, 1985). Similar results were obtained from sediment samples in the current study in which high concentrations of PCBs were reported from areas near the Coronado Bridge, west Commercial Basin and East Basin near Harbor Island. The Regional Water Quality Control Board has identified a 60 inch storm drain as the main source of PCBs into the East Basin site. Cleanup and Abatement Orders, regarding PCBs, have been issued to boatyards in and around Shelter Island and Harbor Island (San Diego Interagency Water Quality Panel, 1994).

Tributyltin (TBT), an organic based biocide, was widely used as an antifoulant on ships and small craft until 1988 (Richard and Lillebo, 1988). Although TBT is highly efficient at killing fouling organisms it is also acutely toxic to non-target organisms, making it a continuing concern in the San Diego Bay Region. Toxic effects have been observed in concentrations as low as 1 ng/L (Henderson, 1988). Long term monitoring of U.S. harbors indicates that among naval bases, San Diego has relatively low concentrations of TBT (Kram *et al.*, 1989; Seligman *et al.*, 1990). These studies focused on comparisons between U.S. Naval facilities (i.e. Pearl harbor, Norfolk harbor) where use of TBT anti-fouling paints is not restricted on vessels over 25 meters in length (Organotin Antifouling Paint Control Act, 1988). Because San Diego Bay is a multi-use port, where smaller non-naval vessels must conform to the 1988 legislation, TBT values are expectedly lower than harbors which solely contain large naval vessels. In the current study, TBT values were highest in naval and commercial basin areas, similar to the findings of Seligman *et al.* (1990). Although both studies found elevated levels of TBT in commercial and naval sites, data from the current study indicates an overall decline in TBT sediment concentrations at these locations. This is most likely a reflection of restrictive legislation on TBT use in antifouling paints. Given the historical use of antifouling paints in San Diego Bay, continued monitoring is recommended, although results from the current study were encouraging.

Limitations

The two step sampling design of this study relied on an initial "screening phase" to give a broad assessment of toxicity in the San Diego Bay Region. Subsequent toxicity test, chemical analysis and benthic community analysis were performed only on selected stations ($\approx$ 40% of the screened stations) which demonstrated toxicity during the screening phase, or were considered candidates as reference stations. The remaining stations, from the screening phase, did not receive additional testing or analysis. Therefore, statistical analyses, comparisons to chemical specific screening values, identification of undegraded and degraded habitats, and prioritized rankings could not be performed on all stations sampled. Currently these stations fall under a no action recommendation, but it should be understood that for these stations a weight-of-evidence evaluation was not performed, due to the absence of chemical and/or benthic community data.

In determination of toxicity for the reference envelope approach, values must be chosen for alpha and the percentile (p) to calculate the edge of the reference envelope (L) using the following equation:

$$L = X_r - [\, g_{a,p,n} * S_r \,]$$

The values of alpha and p are chosen to express the degree of certainty desired when classifying a sample as toxic. In this study values of alpha=.05 and p=1 were used to distinguish the most toxic samples which have a 95% certainty of being in the most toxic 1% (Figure 4). This calculation resulted in a determination of toxicity for the *Rhepoxynius* test when samples had a mean survival of less than 48%. If the value of p was chosen to equal 10% (*i.e.*, a 95% certainty of being in the most toxic 10%) the determination of toxicity (edge of the reference envelope) would have been at 63% survival. Obviously, a choice of p=10% would broaden the range of samples which would be classified as "toxic". It must be recognized the 48% level used in this study was chosen as a conservative guideline to identify only the most toxic stations for setting priorities for future work. The 48% survival cutoff used in this study should be recognized as a statistical determination which may or may not reflect the certainty desired by SWRCB and RWQCB staff for sediment quality management purposes.

There is a necessary caution to the ecological applicability of data collected from studies such as reported here. Although measures of toxicity and chemical concentration are used extensively in this study, they can only be used as indicators of possible adverse effects to indigenous communities. Benthic community assessment is the only tool used in this study which can demonstrate actual effects to resident biological communities. In combination, these three measures provide a strong weight of evidence for the conditions found at a particular sampling location. However, it is recommended these lines of evidence be supported with an ecological risk assessment during subsequent investigations of stations of concern.

CONCLUSIONS

The major conclusions of this study were:

1. Two sets of sediment quality guidelines were useful in demonstrating chemical pollution: The ERL/ERM thresholds developed by NOAA (Long and Morgan, 1990; Long *et al.*, 1995) and the TEL/PEL thresholds used in Florida (MacDonald, 1993; MacDonald, 1994). Copper, mercury, zinc, total chlordane, total PCBs, and PAHs were most often found to exceed critical ERM or PEL values. These were considered the major chemicals or chemical groups of concern in the San Diego Bay Region. ERM and PEL summary quotients were developed as chemical indices for evaluating pollution of sediments with multiple chemicals. An ERM summary quotient >0.85 or a PEL summary quotient >1.29 was indicative of sites where multiple chemicals were significantly elevated. Stations with any chemical concentration >4 times its respective ERM or >5.9 times its respective PEL were considered to exhibit elevated chemistry.

2. The identification of degraded and undegraded habitat was determined by macrobenthic community structure, using a cumulative, weight-of-evidence approach. Analyses of the 75 stations sampled for benthic community structure identified 23 undegraded stations, 43 degraded and 9 transitional stations. All sampled stations with an ERM quotient>0.85 were found to have degraded communities. All sampled stations with P450 responses above 60 μg/g BaPEq. were found to have degraded benthic communities.

3. Exceedances of toxicity thresholds were determined using two approaches: the reference envelope approach and laboratory control comparison approach. The reference envelope approach was the more conservative of the two, indicating toxicity for the *Rhepoxynius* (amphipod) sediment test was significant when survival was less than 48%, in samples tested. No reference envelope was determined for the *Strongylocentrotus* (urchin) fertilization or development tests. High variability in pore water data from reference stations produced a lower confidence boundary for the reference envelope below 0% survival. This indicates no significant distinction in toxicity could be made between reference stations and other stations for these pore water tests.

4. Using the EMAP definition of toxicity, 56% of the total area sampled in the San Diego Bay Region was toxic to *Rhepoxynius*. For *Strongylocentrotus* development test, percent of total area toxic was 29%, 54%, and 72% respectively for 25%, 50%, and undiluted pore water concentrations. Samples representing 36%, 27%, or 14% of the study area were toxic to both *Rhepoxynius* in solid phase sediment and to *Strongylocentrotus* larvae in 100%, 50%, or 25% pore water, respectively. Spatial extent of toxicity was not determined using the reference envelope definition of toxicity.

5. Linear regression analyses failed to reveal strong correlations between amphipod survival and chemical concentration. It is suspected instead of a linear response to chemical pollutants, most organisms are tolerant of pollutants until a threshold is exceeded. Comparisons to established sediment quality guideline thresholds demonstrate an increased incidence of toxicity for San Diego Bay Region samples with chemical concentrations exceeding the ERM or PEL values. It is further suspected toxicity in urban bays is caused by exposure to complex mixtures of chemicals. Comparisons to ERM summary quotients (multiple chemical indicators) demonstrate that the highest incidence of toxicity (>78%) is found in samples with elevated ERM summary quotients (>0.85).

Statistical analyses of the P450 Reporter Gene System responses versus the PAHs in sediment extracts demonstrated that this biological response indicator was significantly correlated (r^2 = 0.86) with sediment PAH (total and high molecular weight) concentrations.

6. Stations requiring further investigation were prioritized based on combined evidence from toxicity, chemical and benthic community data. Prioritizations were developed to help direct future investigations by State and Regional Water Board staff at these stations. Each station receiving a high, moderate, or low priority ranking meets one or more of the criteria under evaluation for determining hot spot status in the Bay Protection and Toxic Cleanup Program. Those meeting all criteria were given the highest priority for further action.

Seven stations (representing four sites) were given a high priority ranking, 43 stations were given a moderate priority ranking, and 57 stations were given a low priority ranking. The seven stations receiving the high priority ranking were in the Seventh Street channel area, two naval shipyard areas near the Coronado Bridge, and the Downtown Anchorage area west of the airport. The majority of stations given moderate rankings were associated with commercial areas and naval shipyard areas in the vicinity of the Coronado Bridge. Low priority stations were interspersed throughout the San Diego Bay Region.

7. A review of historical data supports the conclusions of the current research. Possible sources for pollution at prioritized stations are given. Recommendations are made for complementary investigations which could provide additional evidence for further characterizing stations of concern.

RECOMMENDATIONS

Given the supporting evidence of previous studies, the patterns of chemical pollution and bioeffects observed during this assessment of the San Diego Bay Region are convincing. There are additional avenues of investigation though which would complement the results of this study. The results also should be confirmed with further studies before any adverse ecological impacts can be conclusively demonstrated.

Due to the large number of elevated chemicals at the majority of the prioritized sampling stations, toxic biological responses can only be associated with overall chemical pollution, rather than a particular chemical. However, stations on the priority list, where the number of ERM or PEL exceedances is low and the exceedance for a particular chemical is high, are excellent candidates for toxicity identification evaluations (TIE). The ability to distinguish between causative factors of toxicity is enhanced when multiple chemicals are not involved. Stations Naval Base O7(x1), 12 Swartz (Downtown Anchorage), and the San Diego River, where high chlordane concentrations are found, are well suited for TIE manipulations which would attempt to test this organic pesticide as the causative toxicity agent. The Naval Base/Shipyard O10(x6) station, which only demonstrates ERM or PEL exceedances for trace metals, is well suited for manipulations which could remove metal toxicity (*e.g.*, EDTA additions).

Several chemicals of concern identified in the San Diego Bay region have been shown to bioconcentrate and biomagnify in the tissues of marine species. A tissue contamination study for lipophilic compounds such as PCBs, chlordane, and possibly methylmercury is recommended to address human health concerns due to consumption of impacted resident species. This line of investigation seems necessary considering tissue contamination is the only BPTCP criterion not investigated during this study.

Although specific stations are identified as having a high probability of causing adverse effects, no attempt can be made to define the boundaries of the impacted area. Sampling specifically designed to quantify areal extent of an impacted area must be addressed during intensive site characterizations.

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APPENDIX A

DATA BASE DESCRIPTION

for the

SWRCB/NOAA COOPERATIVE PROJECT
SAN DIEGO BAY

A Report prepared for the

California State Water Resources Control Board
Bays and Estuaries Unit
Bay Protection and Toxic Cleanup Program

by the

California Department of Fish and Game
Marine Pollution Studies Laboratories
7711 Sandholdt Road
Moss Landing, CA 95039

September, 1996

I. OVERVIEW OF THE BAY PROTECTION PROGRAM

The California State Water Resources Control Board (SWRCB) has contracted the California Department of Fish and Game (CDFG) to coordinate the scientific aspects of the Bay Protection and Toxic Cleanup Program (BPTCP), a SWRCB program mandated by the California Legislature. The BPTCP is a comprehensive, long-term effort to regulate toxic pollutants in California's enclosed bays and estuaries. The program consists of both short-term and long-term activities. The short-term activities include the identification and priority ranking of toxic hot spots, development and implementation of regional monitoring programs designed to identify toxic hot spots, development of narrative sediment quality objectives, development and implementation of cleanup plans, revision of waste discharge requirements as needed to alleviate impacts of toxic pollutants, and development of a comprehensive database containing information pertinent to describing and managing toxic hot spots. The long-term activities include development of numeric sediment quality objectives; development and implementation of strategies to prevent the formation of new toxic hot spots and to reduce the severity of effects from existing toxic hot spots; revision of water quality control plans, cleanup plans, and monitoring programs; and maintenance of the comprehensive database.

Actual field and laboratory work is performed under contract by the California Department of Fish and Game (CDFG). The CDFG subcontracts the toxicity testing to Dr. Ron Tjeerdema at the University of California at Santa Cruz (UCSC) and the laboratory testing is performed at the CDFG toxicity testing laboratory at Granite Canyon, south of Carmel. The CDFG contracts the majority of the sample collection activities to Dr. John Oliver of San Jose State University at the Moss Landing Marine Laboratories (MLML) in Moss Landing. Dr. Oliver also is subcontracted to perform the TOC and grain size analyses, as well as to perform the benthic community analyses. CDFG personnel perform the trace metals analyses at the trace metals facility at Moss Landing Marine Laboratories in Moss Landing. The synthetic organic pesticides, PAHs and PCBs are contracted by CDFG to Dr. Ron Tjeerdema at the UCSC trace organics facility at Long Marine Laboratory in Santa Cruz. MLML currently maintains the Bay Protection and Toxic Cleanup Database for the SWRCB. Described below is a description of that database system.

II. DESCRIPTION OF COMPUTER FILES

The sample collection/field information, chemical, and toxicity data are stored on hard copy, computer disks and on a 486DX PC at Moss Landing Marine Laboratories. Access is limited to Russell Fairey. Contact Russell Fairey at (408) 633-6035 for copies of data. The data are stored in a dBase 4 program and can be exported to a variety of formats. There are three backups of this database stored in two different laboratories. The data are entered into 1 of 2 files. REG9CHEM.DBF file contains all the collection and chemical data. REG9TOX.DBF file contains all the collection and toxicity test data. A hardcopy printout of the dBase database structure is attached, showing precise characteristics of each field.

The REG9CHEM.DBF file is the chemistry data file which contains the following fields (the number at the start of each field is the field number):

1. STANUM. This numeric field is 7 characters wide with 1 decimal place and contains the CDFG station numbers that are used statewide. The format is YXXXX.Z where Y is the Regional Water Quality Control Board Region number and XXXX is the number that corresponds to a given location or site and Z is the number of the station within that site. An example is West Basin in San Diego Harbor where the STANUM is 90050.0. The 9 indicates Region 9. The 0050 indicates that it is Site 50 and the .0 is the replicate (if any) at the station within Site 50.

2. STATION. This character field is 30 characters wide and contains the exact name of the station.

3. IDORG. This numeric field is 8 characters wide and contains the unique i.d. organizational number for the sample. For each station collected on a unique date, an idorg sample number is assigned. This should be the field that links the collection, toxicity, chemical, and other data bases.

4. DATE. This date field is 8 characters long and is the date that each sample was collected in the field. It is listed as MM/DD/YY.

5. LEG. This numeric field is 6 characters wide and is the leg number of the project in which the sample was collected.

6. LATITUDE. This character field is 12 characters wide and contains the latitude of the center of the station sampled. The format is a character field as follows: XX,YY,ZZ, where XX is in degrees, YY is in minutes, and ZZ is in seconds or hundreds.

7. LONGITUDE. This character field is 14 characters wide and contains the longitude of the center of the station sampled. The format is a character field as follows: XX,YY,ZZ, where XXX is in degrees, YY is in minutes, and ZZ is in seconds or hundreds.

8. GISLAT. This numeric field is 12 characters wide with 8 decimal places and contains the latitude of the station sampled in Geographical Information System format. The format is a numeric field as follows: XX.YYYYYYYY, where XX is in degrees and YYYYYYYY is a decimal fraction of the preceding degree.

9. GISLONG. This character field is 14 characters wide with 8 decimal places and contains the longitude of the station sampled. The format is a character field as follows: XXXX.YYYYYYYY where XXXX is in degrees and YYYYYYYY is a decimal fraction of the preceding degree.

10. HUND_SECS. This character is 1 character wide and contains the designation "h" if the latitude and longitude are

given in degrees, minutes and hundredths of a minute. The designation "s" is given when latitude and longitude are given in degrees, minutes and seconds.

11. DEPTH. This character field is 4 characters wide and contains the depth at which the sediment sample was collected, in meters to the nearest one half meter.

12. METADATA. This is an index directing the user to tables or files of ancillary data pertinent to associated test. Character field, width 12.

TRACE METALS IN SEDIMENT are presented in fields 13 through 32. All sediment trace metal results are reported on a dry weight basis in parts per million (ppm).

A. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed.
B. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected.

Sediment trace metals are numeric fields of varying character width, and including the following elements, listed by field number, then field name as it appears in the database, then numeric character width and number of decimal places:

13. TMMOIST. 6.2
14. ALUMINUM. 9.2
15. ANTIMONY. 7.3
16. ARSENIC. 6.3
17. CADMIUM. 7.4
18. CHROMIUM. 8.3
19. COPPER. 7.2
20. IRON. 7.1
21. LEAD. 6.3
22. MANGANESE. 7.2
23. MERCURY. 7.4
24. NICKEL. 7.3
25. SILVER. 7.4
26. SELENIUM. 6.3
27. TIN. 8.4
28. ZINC. 9.4
29. ASBATCH. 5.1
30. SEBATCH. 5.1
31. TMBATCH. The Batch number that the sample was digested in, numeric character width 5 and 1 decimal places.
32. TMDATAQC. Data qualifier codes are notations used by data reviewers to briefly describe, or qualify data and the systems producing data, numeric character width 3. Data qualifier codes are as follows:

A. When the sample meets or exceeds the control criteria requirements, the value is reported as "-4".
B. When the sample has minor exceedances of control criteria

but is generally usable for most assessments and reporting purposes, the value is reported as "-5". For samples coded "-5" it is recommended that if assessments are made that are especially sensitive or critical, QA evaluations should be consulted before using the data.

C. When QA samples have major exceedances of control criteria requirements and the data are not usable for most assessments and reporting purposes, the value is reported as "-6".
D. When the sample has minor exceedances of control criteriaand is unlikely to affect assessments, the value is reported as -3.

SYNTHETIC ORGANICS are presented in fields 33 through 147. All synthetic organic results are reported on a dry weight basis in parts per billion (ppb or ng/g).

A. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed.
B. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected.

Synthetic organics are reported on a dry weight basis in parts per billion (ppb or ng/g) and are numeric fields of varying character width, and include the following compounds, listed by field number, then field name as it appears in database (and followed by the compound name if not obvious), and then finally, the numeric character width and number of decimal places is given:

33. SOWEIGHT. This numeric field is 6 characters wide with 2 decimal places and contains the weight of the sample extracted for analysis.
34. SOMOIST. This numeric field is 6 characters wide with 2 decimal places and contains the percent moisture of the sample extracted.
35. ALDRIN. 9.3
36. CCHLOR. cis-Chlordane. 9.3
37. TCHLOR. trans-Chlordane. 9.3
38. ACDEN. alpha-Chlordene. 9.3
39. GCDEN. gamma-Chlordene. 9.3
40. CLPYR. Chlorpyrifos. 8.2
41. DACTH. Dacthal. 9.3
42. OPDDD. o,p'-DDD. 8.2
43. PPDDD. p,p'-DDD. 9.3
44. OPDDE. o,p'-DDE. 8.2
45. PPDDE. p,p'-DDE. 8.2
46. PPDDMS. p,p'-DDMS. 8.2
47. PPDDMU. p,p'-DDMU. 8.2
48. OPDDT. o,p'-DDT. 8.2
49. PPDDT. p,p'-DDT. 8.2
50. DICLB. p,p'-Dichlorobenzophenone. 8.2
51. DIELDRIN. 9.3
52. ENDO_I. Endosulfan I. 9.3
53. ENDO_II. Endosulfan II. 8.2
54. ESO4. Endosulfan sulfate. 8.2

55. ENDRIN. 8.2
56. ETHION. 8.2
57. HCHA. alpha HCH 9.3
58. HCHB. beta HCH 8.2
59. HCHG. gamma HCH (Lindane) 9.3
60. HCHD. delta HCH 9.3
61. HEPTACHLOR. 9.3
62. HE. Heptachlor Epoxide. 9.3
63. HCB. Hexachlorobenzene. 9.3
64. METHOXY. Methoxychlor. 8.2
65. MIREX. 9.3
66. CNONA. cis-Nonachlor. 9.3
67. TNONA. trans-nonachlor. 9.3
68. OXAD. Oxadiazon. 8.2
69. OCDAN. Oxychlordane. 9.3
70. TOXAPH. Toxaphene. 7.2
71. PESBATCH.The batch number that the sample was extracted in, numeric character width 6 and 2 decimal places.
72. TBT. tributyltin. 8.4
73. TBTBATCH.The batch number that the sample was extracted in, numeric character width 5 and 1 decimal place.
74. PCB5. 9.3
75. PCB8. 9.3
76. PCB15. 9.3
77. PCB18. 9.3
78. PCB27. 9.3
79. PCB28. 9.3
80. PCB29. 9.3
81. PCB31. 9.3
82. PCB44. 9.3
83. PCB49. 9.3
84. PCB52. 9.3
85. PCB66. 9.3
86. PCB70. 9.3
87. PCB74. 9.3
88. PCB87. 9.3
89. PCB95. 9.3
90. PCB97. 9.3
91. PCB99. 9.3
92. PCB101. 9.3
93. PCB105. 9.3
94. PCB11O. 9.3
95. PCB118. 9.3
96. PCB128. 9.3
97. PCB132. 9.3
98. PCB137. 9.3
99. PCB138. 9.3
100. PCB149. 9.3
101. PCB151. 9.3
102. PCB153. 9.3
103. PCB156. 9.3
104. PCB157. 9.3
105. PCB158. 9.3
106. PCB170. 9.3
107. PCB174. 9.3

108. PCB177. 9.3
109. PCB180. 9.3
110. PCB183. 9.3
111. PCB187. 9.3
112. PCB189. 9.3
113. PCB194. 9.3
114. PCB195. 9.3
115. PCB201. 9.3
116. PCB203. 9.3
117. PCB206. 9.3
118. PCB209. 9.3
119. PCBBATCH. The batch number that the sample was extracted in, numeric character width 6 and 2 decimal place.
120. ARO5460. 9.3
121. ACY. Acenaphthylene. 8.2
122. ACE. Acenaphthene. 8.2
123. ANT. Anthracene. 8.2
124. BAA. Benz[a]anthracene. 8.2
125. BAP. Benzo[a]pyrene. 8.2
126. BBF. Benzo[b]fluoranthrene. 8.2
127. BKF. Benzo[k]fluoranthrene. 8.2
128. BGP. Benzo[ghi]perylene. 8.2
129. BEP. Benzo[e]pyrene. 8.2
130. BPH. Biphenyl. 8.2
131. CHR. Chrysene. 8.2
132. DBA. Dibenz[a,h]anthracene. 8.2
133. DMN. 2,6-Dimethylnaphthalene. 8.2
134. FLA. Fluoranthrene. 8.2
135. FLU. Fluorene. 8.2
136. IND. Indo[1,2,3-cd]pyrene. 8.2
137. MNP1. 1-Methylnaphthalene. 8.2
138. MNP2. 2-Methylnaphthalene. 8.2
139. MPH1. 1-Methylphenanthrene. 8.2
140. NPH. Naphthalene. 8.2
141. PHN. Phenanthrene. 8.2
142. PER. Perylene. 8.2
143. PYR. Pyrene. 8.2
144. TMN. 2,3,4-Trimethylnaphthalene. 8.2
145. PAHBATCH. The batch number that the sample was extracted in, numeric character width 6 and 2 decimal places.
146. SOBATCH. The batch number that the sample was extracted in, numeric character width 6 and 2 decimal places.
147. SODATAQA. Data qualifier codes are notations used by data reviewers to briefly describe, or qualify data and the systems producing data, numeric character width 3. Data qualifier codes are as follows:

A. When the sample meets or exceeds the control criteria requirements, the value is reported as "-4".

B. When the sample has minor exceedances of control criteria but is generally usable for most assessments and reporting purposes, the value is reported as "-5". For samples coded "-5" it is recommended that if assessments are made that are especially sensitive or critical, the QA evaluations should be consulted before using the data.

C. When QA samples have major exceedances of control criteria requirements and the data are not usable for most assessments and

reporting purposes, the value is reported as "-6".
D. When the sample has minor exceedances of control criteria and is unlikely to affect assessments, the value is reported as -3.

SEDIMENT PARTICULATE SIZE ANALYSES DATA. Field 148, with a field name of "FINES", represents the sediment particulate size ("grain size") analyses data for each station. The grain size results are reported as percent fines.

148. FINES. Sediment grain size (percent fines) for each station. Numeric field, width 5 and 2 decimal places.
A. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed.
B. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected.
149. FINEBATCH. The batch number that the sample was analyzed in, numeric field character width 4.
150. FINEDATAQC. Data qualifier codes are notations used by data reviewers to briefly describe, or qualify data and the systems producing data, numeric character width 3. Data qualifier codes are as follows:
A. When the sample meets or exceeds the control criteria requirements, the value is reported as "-4".
B. When the sample has minor exceedances of control criteria but is generally usable for most assessments and reporting purposes, the value is reported as "-5". For samples coded "-5" it is recommended that if assessments are made that are especially sensitive or critical, QA evaluations should be consulted before using the data.
C. When QA samples have major exceedances of control criteria requirements and the data are not usable for most assessments and reporting purposes, the value is reported as "-6".
D. When the sample has minor exceedances of control criteria and is unlikely to affect assessments, the value is reported as -3.

SEDIMENT TOTAL ORGANIC CARBON (TOC) ANALYSES DATA. Field 151 presents the levels of total organic carbon detected in the sediment samples at each station. All TOC results are reported as percent of dry weight.

151. TOC. Total Organic Carbon (TOC) levels (percent of dry weight) in sediment, for each station. Numeric field, width 6 and 2 decimal places.
A. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed.
B. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected.
152. TOCBATCH. The batch number that the sample was analyzed in, numeric field character width 4.
153. TOCDATAQC. Data qualifier codes are notations used by data reviewers to briefly describe, or qualify data and the systems producing data, numeric character width 3. Data qualifier codes are as follows:
A. When the sample meets or exceeds the control criteria

requirements, the value is reported as "-4".

B. When the sample has minor exceedances of control criteria but is generally usable for most assessments and reporting purposes, the value is reported as "-5". For samples coded "-5" it is recommended that if assessments are made that are especially sensitive or critical, the QA evaluations should be consulted before using the data.

C. When QA samples have major exceedances of control criteria requirements and the data are not usable for most assessments and reporting purposes, the value is reported as "-6".

D. When the sample has minor exceedances of control criteria and is unlikely to affect assessments, the value is reported as -3.

The REG9TOX.DBF file is the toxicity data file which contains the following fields (the number at the start of each field is the field number:

1. STANUM. This numeric field is 7 characters wide with 1 decimal place and contains the CDFG station numbers that are used statewide. The format is YXXXX.Z where Y is the Regional Water Quality Control Board Region number and XXXX is the number that corresponds to a given location or site and Z is the number of the station within that site. An example is West Basin in San Diego Harbor where the STANUM is 90050.0. The 9 indicates Region 9. The 0050 indicates that it is Site 50 and the .0 is the replicate (if any) at the station within Site 50.
2. STATION. This character field is 30 characters wide and contains the exact name of the station.
3. IDORG. This numeric field is 8 characters wide with 1 decimal place and contains the unique i.d. organizational number for the sample. For each station collected on a unique date, an idorg sample number is assigned. This should be the field that links the collection, toxicity, chemical, and other data bases.
4. DATE. This date field is 8 characters long and is the date that each sample was collected in the field. It is listed as MM/DD/YY.
5. LEG. This numeric field is 6 characters wide and is the leg number of the project in which the sample was collected.
6. TYPE. This character field is 7 characters wide and describes whether the sample was a field sample, replicate or control.
7. METADATA. This is an index directing the user to tables or files of ancillary data pertinent to associated test. Character field, width 12.
8. CTRL. This character field is 5 characters wide and describes the type of control being used.
9. LATITUDE. This character field is 12 characters wide and contains the latitude of the center of the station sampled. The format is a character field as follows: XX,YY,ZZ, where XX is in degrees, YY is in minutes, and ZZ is in seconds or hundreds.
10. LONGITUDE. This character field is 14 characters wide and contains the longitude of the center of the station sampled. The format is a character field as follows: XX,YY,ZZ, where XXX is in degrees, YY is in minutes, and ZZ is in seconds or hundreds.
11. GISLAT. This numeric field is 12 characters wide with 8 decimal places and contains the latitude of the station sampled

in Geographical Information System format. The format is a numeric field as follows: XX.YYYYYYYY, where XX is in degrees and YYYYYYYY is a decimal fraction of the preceding degree.

12. GISLONG. This character field is 14 characters wide with 8 decimal places and contains the longitude of the station sampled. The format is a character field as follows: XXXX.YYYYYYYY where XXXX is in degrees and YYYYYYYY is a decimal fraction of the preceding degree.

AMPHIPOD SURVIVAL TOXICITY TEST DATA. The following are descriptions of the field headings for the amphipod (Rhepoxynius abronius (RA), presented in fields 13 through 24.

13. RA_MN. Station mean percent survival. Numeric field, width 6 and 2 decimal places.
14. RA_SD. Station standard deviation of percent survival. Numeric field, width 6 and 2 decimal places.
15. RA_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
16. RASITE_MN. Station mean percent survival for replicate of three, when appropriate. Numeric field, width 6 and 2 decimal places.
17. RASITE_SD. Station standard deviation of percent survival for replicate of three, when appropriate. Numeric field, width 6 and 2 decimal places.
18. RASITE_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
19. RA_OTNH3. Total ammonia concentration (mg/L in water) in overlying water (water above bedded sediment used for amphipod tests) for each station analyzed using amphipod toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 7 and 3 decimal places.
20. RA_OUNH3. Unionized ammonia concentration (mg/L in water) in overlying water (water above bedded sediment used for amphipod tests) for each station analyzed using amphipod toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 7 and 3 decimal places.
21. RA_OH2S. Hydrogen sulfide concentration (mg/L in water) in overlying water (water above bedded sediment used for amphipod tests) for each station analyzed using amphipod toxicity tests. When the value is

missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 7 and 4 decimal places.

22. RA_ITNH3. Total ammonia concentration (mg/L in water) in interstitial water (water above bedded sediment used for amphipod tests) for each station analyzed using amphipod toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 10 and 3 decimal places.

23. RA_IUNH3. Unionized ammonia concentration (mg/L in water) interstitial water (water within bedded sediment used for amphipod tests) for each station analyzed using amphipod toxicity tests. When the value is missing or not analyzed, the value is reported as "9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 10 and 3 decimal places.

24. RA_IH2S. Hydrogen sulfide concentration (mg/L in water) in interstitial water (water within bedded sediment used for amphipod tests) for each station analyzed using amphipod toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 10 and 4 decimal places.

25. RABATCH. The batch number that the sample were run in, numeric character width 10.

26. RADATAQC. Data qualifier codes are notations used by data reviewers to briefly describe, or qualify data and the systems producing data, numeric character width 4. Data qualifier codes are as follows:

A. When the sample meets or exceeds the control criteria requirements, the value is reported as "-4".

B. When the sample has minor exceedances of control criteria but is generally usable for most assessments and reporting purposes, the value is reported as "-5". For samples coded "-5" it is recommended that if assessments are made that are especially sensitive or critical, the QA evaluations should be consulted before using the data.

C. When the QA sample has major exceedances of control criteria requirements and the data is not usable for most assessments and reporting purposes, the value is reported as "-6".

D. When the sample has minor exceedances of control criteria and is unlikely to affect assessments, the value is reported as -3.

ABALONE LARVAL SHELL DEVELOPMENT TOXICITY TEST DATA. The following are descriptions of the field headings for the larval (Haliotis rufescens) shell development toxicity tests, presented in fields 27 through 30. Results are given for undiluted

subsurface water (100%).

27. HRS100_MN. Station mean percent normal development in 100% subsurface water. Numeric field, width 6 and 2 decimal places.
28. HRS100_SD. Station standard deviation of percent normal development in 100% subsurface water. Numeric field, width 6 and 2 decimal places.
29. HRS100_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
30. HRS100_NH3. Unionized ammonia concentration (mg/L in water) in subsurface water for each station analyzed in abalone toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 6 and 3 decimal places.

The following are descriptions of the field headings for the sea urchin (Strongylocentrotus purpuratus) fertilization toxicity tests, presented in fields 31 through 41. Results are given for undiluted pore water (100% pore water), pore water that is diluted with Granite Canyon seawater to a 50% of original concentration (50% pore water), and pore water that is diluted with Granite Canyon seawater to a 25% of original concentration (25% pore water).

31. SPPF100_MN. Station mean percent fertilization in 100% pore water. Numeric field, width 6 and 2 decimal places.
32. SPPF100_SD.Station standard deviation of percent fertilization in 100% pore water. Numeric field, width 6 and 2 decimal places.
33. SPPF100_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
34. SPPF100NH3. Unionized ammonia concentration (mg/L in water) in pore water samples (100%). When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 7 and 3 decimal places.
35. SPPF100H2S. Hydrogen sulfide concentration (mg/L in water) in pore water samples (100%). When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0"= not detected. Numeric field,

width 7 and 4 decimal places.

36. SPPF50_MN. Station mean percent fertilization in 50% pore water. Numeric field, width 6 and 2 decimal places.
37. SPPF50_SD. Station standard deviation of % fertilization in 50% pore water. Numeric field, width 6 and 2 decimal places.
38. SPPF50_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
39. SPPF25_MN. Station mean percent fertilization in 25% pore water. Numeric field, width 6 and 2 decimal places.
40. SPPF25_SD. Station standard deviation of percent fertilization in 25% pore water. Numeric field, width 6 and 2 decimal places.
41. SPPF25_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.

The following are descriptions of the field headings for the sea urchin embryo (Strongylocentrotus purpuratus) development tests, presented in fields 42 through 54. Results are given for undiluted pore water (100% pore water), pore water that is diluted with Granite Canyon seawater to a 50% of original concentration (50% pore water), and porewater that is diluted with Granite Canyon seawater to a 25% of original concentration (25% pore water).

42. SPPD100_MN. Station mean percent normal development in 100% pore water. Numeric field, width 6 and 2 decimal places.
43. SPPD100_SD. Station standard deviation of percent normal development in 100% pore water. Numeric field, width 6 and 2 decimal places.
44. SPPD100_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
45. SPPD100NH3. Unionized ammonia concentration (mg/L in water) in pore water samples (100%). When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 7 and 3 decimal places.
46. SPPD100H2S. Hydrogen sulfide concentration (mg/L in water) in pore water samples (100%). When the value is missing or not analyzed, the value is reported as "-

9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0"= not detected. Numeric field, width 7 and 4 decimal places.

47. SPPD50_MN. Station mean percent normal development in 50% pore water. Numeric field, width 6 and 2 decimal places.
48. SPPD50_SD. Station standard deviation of percent normal development in 50% pore water. Numeric field, width 6 and 2 decimal places.
49. SPPD50_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
50. SPPD25_MN. Station mean percent normal development in 25% pore water. Numeric field, width 6 and 2 decimal places.
51. SPPD25_SD. Station standard deviation of percent normal development in 25% pore water. Numeric field, width 6 and 2 decimal places.
52. SPPD25_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
53. SPPDBATCH. The batch number that the samples were analyzed in, numeric character width 10.
54. SPPDQC. Data qualifier codes are notations used by data reviewers to briefly describe, or qualify data and the systems producing data, numeric character width 3. Data qualifier codes are as follows:
    A. When the sample meets or exceeds the control criteria requirements, the value is reported as "-4".
    B. When the sample has minor exceedances of control criteria but is generally usable for most assessments and reporting purposes, the value is reported as "-5". For samples coded "-5" it is recommended that if assessments are made that are especially sensitive or critical, the QA evaluations should be consulted before using the data.
    C. When the QA sample has major exceedances of control criteria requirements and the data is not usable for most assessments and reporting purposes, the value is reported as "-6".
    D. When the sample has minor exceedances of control criteria and is unlikely to affect assessments, the value is reported as -3.

The following are descriptions of the field headings for the sea urchin embryo (Strongylocentrotus purpuratus) cytogenetic tests, presented in fields 55 through 59. Results are given for undiluted pore water (100% pore water).

55. SPPC100_MN. Station mean percent normal mitosis in

100% pore water. Numeric field, width 6 and 2 decimal places.

56. SPPC100_SD. Station standard deviation of percent normal mitosis in 100% pore water. Numeric field, width 6 and 2 decimal places.
57. SPPC100_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 6.
58. SPPC100NH3. Unionized ammonia concentration (mg/L in water) in pore water samples (100%). When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 6 and 3 decimal places.
59. SPPC100H2S. Hydrogen sulfide concentration (mg/L in water) in pore water samples (100%). When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0"= not detected. Numeric field, width 7 and 4 decimal places.

MUSSEL LARVAL SHELL DEVELOPMENT TOXICITY TEST DATA. The following are descriptions of the field headings for the larval (Mytilus edulis) shell development toxicity tests, presented in fields 60 through 63. Results are given for undiluted subsurface water (100%).

60. MES100_MN. Station mean percent normal development in 100% subsurface water. Numeric field, width 6 and 2 decimal places.
61. MES100_SD. Station standard deviation of percent normal development in 100% subsurface water. Numeric field, width 6 and 2 decimal places.
62. MES100_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
63. MES100_NH3. Unionized ammonia concentration (mg/L in water) in subsurface water. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 6 and 3 decimal places.

The following are descriptions of the field headings for the larval (Mytilus edulis) shell development toxicity tests, presented in fields 64 through 68. Results are given for undiluted pore water (100% pore water).

64. MEP100_MN. Station mean percent normal development in 100% pore water. Numeric field, width 6 and 2 decimal places.
65. MEP100_SD. Station standard deviation of percent normal development in 100% pore water. Numeric field, width 6 and 2 decimal places.
66. MEP100_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.
67. MEP100_NH3. Unionized ammonia concentration (mg/L in water) in pore water samples (100%). When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 6 and 3 decimal places.
68. MEP100_H2S. Hydrogen sulfide concentration (mg/L in water) in pore water samples (100%). When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0"= not detected. Numeric field, width 7 and 4 decimal places.

POLYCHAETE SURVIVAL TOXICITY TEST DATA. The following are descriptions of the field headings for the polychaete worm (Neanthes arenaceodentata) survival toxicity tests, presented in fields 69 through 71.

69. NASURV_MN. Station mean percent survival. Numeric field, width 6 and 2 decimal places.
70. NASURV_SD. Station standard deviation of % survival. Numeric field, width 6 and 2 decimal places.
71. NASURV_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not statistically significant. Character field, width 5.

POLYCHAETE WEIGHT TOXICITY TEST DATA. The following are descriptions of the field headings for the polychaete worm (Neanthes arenaceodentata) weight toxicity tests, presented in fields 72 through 80.

72. NAWT_MN. Station mean weight (gm). Numeric field, width 6 and 2 decimal places.
73. NAWT_SD. Station standard deviation of weight (gm). Numeric field, width 6 and 2 decimal places.
74. NAWT_SG. Station statistical significance, representing the significance of the statistical test between the home sediment and the sample. A single * represents significance at the .05 level, and double ** represents significance at the .01 level. ns = not

statistically significant. Character field, width 5.

75. NA_OTNH3. Total ammonia concentration (mg/L in water) in overlying water (water above bedded sediment used for polychaete tests) for each station analyzed using polychaete toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 7 and 3 decimal places.
76. NA_OUNH3. Unionized ammonia concentration (mg/L in water) in overlying water (water above bedded sediment used for polychaete tests) for each station analyzed using polychaete toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 7 and 3 decimal places.
77. NA_OH2S. Hydrogen sulfide concentration (mg/L in water) in overlying water (water above bedded sediment used for polychaete tests) for each station analyzed using polychaete toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 9 and 4 decimal places.
78. NA_ITNH3. Total ammonia concentration (mg/L in water) in interstitial water (water above bedded sediment used for polychaete tests) for each station analyzed using polychaete toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 9 and 3 decimal places.
79. NA_IUNH3. Unionized ammonia concentration (mg/L in water) in interstitial water (water within bedded sediment used for polychaete tests) for each station analyzed using polychaete toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 9 and 3 decimal places.
80. NA_IH2S. Hydrogen sulfide concentration (mg/L in water) in interstitial water (water within bedded sediment used for amphipod tests) for each station analyzed using amphipod toxicity tests. When the value is missing or not analyzed, the value is reported as "-9.0" = not analyzed. When the value is less than the detection limit of the analytical test, the value is reported as "-8.0" = not detected. Numeric field, width 9 and 4 decimal places.

CHEMICAL SUMMATIONS AND QUOTIENTS

In the following section, chemical summations (total chlordane, total DDT, total PCBs, LMW PAHs, HMW PAHs, total PAHs) and quotients (ERM and PEL) are presented. Beginning with samples collected during Leg 20 (June, 1993), additional analytes were added to the standard BPTCP synthetic organic analyte list. These additions were made to enable the data set to be more comparable with other monitoring programs. This included addition of analytes used for some of the chemical summations of the PAHs and total chlordane. Resulting summations may be conservative for the PAH and chlordane data for samples taken before Leg 20, because some of the constituents could not be included.

For purposes of these summations, samples which were found to have chemical concentrations less than the method detection limit (-8 in Appendix A) were adjusted to a value of one-half of the method detection limits given in the methods description. The summations were calculated as follows:

Total chlordane

Leg<15 (TTL_CHLR) = $\sum$ ([cis-Chlordane] [trans-Nonachlor])

Leg=15 (TTL_CHLR) = $\sum$ ([cis-Chlordane] [trans-Chlordane])

Leg>15 (TTL_CHLR) = $\sum$ ([cis-Chlordane] [trans-Chlordane] [cis-Nonachlor] [trans-Nonachlor] [Oxychlordane])

Total DDT

All Legs (TTL_DDT) = $\sum$ ([o',p' DDD] [p',p' DDD] [o',p' DDE] [p',p' DDE] [o',p' DDT] [p',p' DDT])

Total PCB

All Legs (TTL_PCB) = $\sum$ ([PCB8] [PCB18] [PCB28] [PCB44] [PCB52] [PCB66] [PCB101] [PCB105] [PCB118] [PCB128] [PCB138] [PCB153] [PCB170] [PCB180] [PCB187] [PCB195] [PCB206] [PCB209])

Low Molecular Weight PAHs

Leg<16 (LMW_PAH) = $\sum$ ([ACE] [ANT] [BPH] [DMN] [FLU] [MNP1] [MPH1] [PHN])

Leg$\geq$16 (LMW_PAH) = $\sum$ ([ACE] [ACY] [ANT] [BPH] [DMN] [FLU] [MNP1] [MNP2] [MPH1] [NPH] [PHN] [TMN])

High Molecular Weight PAHs

Leg<16 (HMW_PAH) = $\sum$ ([BAA] [BAP] [BEP] [CHR] [DBA] [FLA] [PER] [PYR])

Leg$\geq$16 (HMW_PAH) = $\sum$ ([BAA] [BAP] [BBF] [BKF] [BGP] [BEP] [CHR] [DBA] [FLA] [IND] [PER] [PYR])

Total PAHs

All legs (TTL_PAH) = $\sum$ ([LMW_PAH] [HMW_PAH])

ERM Quotients and PEL Quotients were calculated using summations of the individual chemicals for which ERMs and PELs have been

derived (Table 5). Chemical concentrations are divided by their respective ERM or PEL values to obtain a specific individual chemical quotient (example 1). A value greater than one indicates the chemical concentration in that sample exceeded its respective ERM or PEL. A value of five would indicate the chemical was five times higher than the ERM or PEL in that sample.

example - sample IDORG #199 Copper concentration= 170 mg/g
PEL for copper= 108.2

CopperQ= (170 mg/g) / (108.2 mg/g) = 1.57

Summations and averaging of the individual chemical quotients were calculated to give summary ERM Quotients (ERMQ) and PEL Quotients (PELQ). Each quotient summation is divided by the number of analytes used in the summation (Table 5) to yield an average summary quotient.

Summary ERM Quotient

ERMQ = ((ANTIMONYQ + ARSENICQ + CADMIUMQ + CHROMIUMQ + COPPERQ + LEADQ + MERCURYQ + SILVERQ + ZINCQ + TTL_DDTQ + TTL_CHLRQ + DIELDRINQ + ENDRINQ + TTL_PCBQ + LMW_PAHQ + HMW_PAHQ) / 16)

Summary PEL Quotient

PELQ = ((ARSENICQ + CADMIUMQ + CHROMIUMQ + COPPERQ + LEADQ + MERCURYQ + SILVERQ + ZINCQ + TTL_DDTQ + TTL_CHLRQ + DIELDRINQ + LINDANEQ + TTL_PCBQ + LMW_PAHQ + HMW_PAHQ) / 15)

Description of calculations for cumulative frequency distributions of percent area toxic.

The following identifies and describes each of the spreadsheet columns used to generate cumulative frequency functions for estimates of percent area toxic.

Idorg : lists all samples tested for each toxicity test protocol/pore water dilution.
Block#: lists assigned letter/number code for each area (block) based on EMAP block designations. See Figure 2.
 # samples/block: lists total number of samples collected in given block.
toxic: "1" indicates sample toxicity based on EMAP definition (both significant difference from laboratory control and toxicity value <80% of control value). Blank cell indicates no significant toxicity.
mn as % of control : lists sample toxicity means normalized to percentage of the control value.
Area/block : Area in km2 for block associated with each sample
Area/sample : Area in km2 represented by each sample, calculated as: Block area/number of samples collected in given block.
Area/sample as % of total : Area represented by each sample as a percent of the total area sampled.
Cum area/sample as % of total : Cumulative area per sample as a percent of the total area sampled.
% total area toxic/sample : Area represented by each toxic sample as a percent of the total area.
SUMS : Numbers in this row show column totals. Sum of Area/sample gives total area sampled for a given toxicity test protocol. Sum of % of total area toxic/sample gives the total area defined as toxic for given test protocol /pore water dilution.