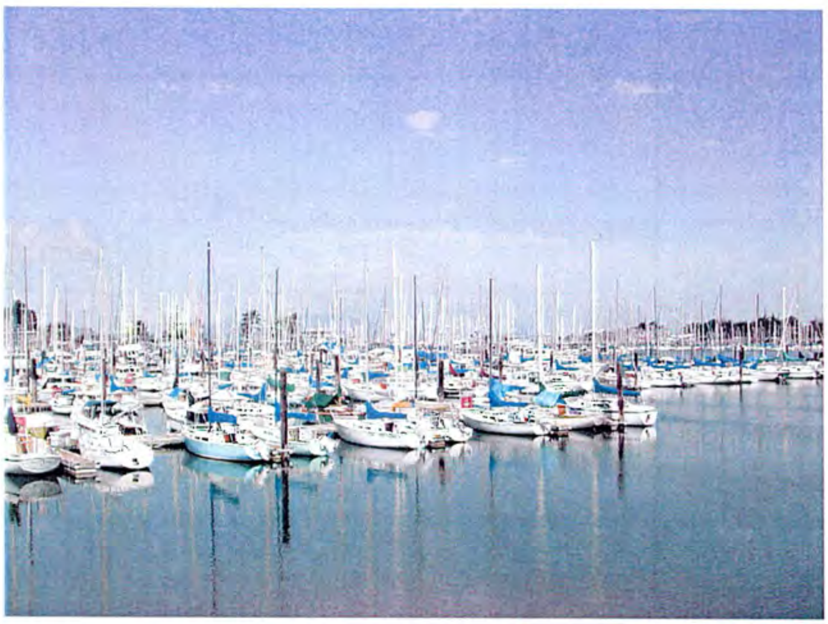
SAN FRANCISCO BAY MARINA WATER QUALITY PROJECT



August 6, 2004

SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION

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INTRODUCTION

There are over sixty recreational marinas[1] within the San Francisco Bay Conservation and Development Commission's (BCDC) jurisdiction. The San Francisco Bay Conservation and Development Commission has jurisdiction over San Francisco Bay,[2] salt ponds,[3] managed wetlands,[4] and certain waterways tributary to the Bay.[5] BCDC also has jurisdiction over a shoreline band of land extending 100 feet inland and parallel to the Bay shoreline.[6] Any person or government agency that wishes to place fill, extract materials, or make substantial changes in use of any land, water, or structure within the Commission's jurisdiction must obtain a permit from the Commission.[7]

The *San Francisco Bay Plan* guides BCDC permitting decisions. Its recreation policies encourage new and expanding recreational marinas in the Bay provided: they do not preempt land or water area needed for other priority uses, are feasible from an engineering viewpoint, would not destroy valuable marshes or mudflats, harm valuable fish and wildlife resources, and would not have significant adverse effects on water quality and circulation, and would not result in inadequate flushing.[8] Since the *San Francisco Bay Plan* marina recreation policies were updated in 1982, new scientific understanding and control methods regarding nonpoint source pollution associated with marinas and recreational boating as well as other categories of nonpoint source pollution, such as urban runoff have emerged on a national scale. Nationwide, marinas and recreational boating are considered a category of nonpoint source pollution,[9] and California has adopted this same view in its *2000 Plan for California's Nonpoint Source Pollution Control Program*.[10] However, while some marina water quality studies have been conducted

[1] This report deals mainly with recreational marinas and recreational boating. For the purposes of this report, a recreational marina is defined as any facility with ten slips or more, ten or more moorings, or piers where ten or more boats can tie up, whose main purpose is to serve recreational boating.

[2] Bay jurisdiction being all areas that are subject to tidal action from the south end of the Bay to the Golden Gate and to the Sacramento River line, including all sloughs, and specifically, the marshlands lying between mean high tide and five feet above mean sea level; tidelands (land lying between mean high tide and mean low tide); and submerged lands (land lying below mean low tide). (See The McAteer-Petris Act, California Government Code Section 66610(a))

[3] Salt pond jurisdiction includes only those used during the three years immediately preceding November 11, 1969 for solar evaporation of Bay water in the course of salt production (California Government Code Section 66610(c)).

[4] Manage wetlands jurisdiction consists of all areas diked off from the Bay and maintained during the three years immediately preceding November 11, 1969 as a duck hunting preserve, game refuge, or for agriculture (California Government Code Section 66610(d)).

[5] Certain waterways tributary to the Bay include Plummer Creek in Alameda County, Coyote Creek in Alameda & Santa Clara Counties (to the easternmost point of Newby Island), Redwood Creek in San Mateo County (to the confluence of Smith Slough), Tolay Creek in Sonoma County (to the northerly line of Sears Point Rd. [State Highway 37]), Petaluma R. in Marin and Sonoma Counties (to its confluence with Adobe Creek and San Antonio Cr. to the easterly line of the Northwestern Pacific right-of-way), Napa R. (to its northernmost point of bull Island), Sonoma Cr. (to its confluence with Second Napa Slough), Corte Madera Cr. in Marin County (to the downstream end of the concrete channel on Corte Madera Creek which is located at the U.S. Army Corps of Engineers Station No. 31850 on the Corte Madera Creek flood control projects) (California Government Code Section 66610 (e)).

[6] For descriptions of BCDC's jurisdiction, see California Government Code Section 66610(b).

[7] See California Government Code Section 66632(a)

[8] BCDC. 2003. San Francisco Bay Plan. San Francisco Bay Conservation and Development Commission (BCDC). San Francisco. Reprinted March 2003, p. 48.

[9] USEPA 2001

[10] SWRCB & CCC 2000. *Plan for California's Nonpoint Source Pollution Control Program.* California State Water Resources Control Board, Sacramento, CA and California Coastal Commission, San Francisco, CA.

worldwide and in Southern California, there is little information on the water and sediment quality conditions at San Francisco Bay marinas. BCDC has begun to fill this gap with its San Francisco Bay Marina Water Quality Project. This project involved an extensive literature review and a Pilot Study, "Condition of Sediments in Selected Marinas in San Francisco Bay," conducted by BCDC's National Oceanic and Atmospheric Administration (NOAA) Coastal Management Fellow in collaboration with Moss Landing Marine Laboratories, Marine Pollution Studies Lab.

The literature review examined marina and recreational boating water quality studies from around the world and examined the status of water and/or sediment quality monitoring at San Francisco Bay marinas. This research identified what are assumed to be typical marina and recreational boating-related contaminants on a national scale, identified existing San Francisco Bay marina water quality data, and established the need for additional monitoring in San Francisco Bay marinas to understand whether these contaminants are present in Bay marinas. This literature review is documented in Chapter Two. Literature on management practices for controlling marina and recreational boating-related pollution was also reviewed, although evaluating management practices were not the major focus of the project. Select examples of management practices are included in Appendix E.

The literature review found few existing water or sediment quality studies at San Francisco Bay marinas. BCDC has taken an important step by conducting the Pilot Study, "Condition of Sediments in Selected Marinas of San Francisco Bay," to help address this data gap. The study aimed to answer five study questions:

1. "What is the sediment chemistry concentration in four recreational marinas in San Francisco Bay in regards to the following pollutants associated with marina and recreational boating operations: trace metals (copper, zinc, chromium, lead, arsenic, cadmium), and polycyclic aromatic hydrocarbons (PAHs)?"
2. "Do sediment chemical concentration levels meet or exceed sediment guidelines currently used (or being developed) for California (e.g. Effects Range Low [ERL] and Effects Range Median [ERM])?"
3. "How do sediment concentration levels compare to ambient sediment concentrations calculated for the Bay, and Regional Monitoring Program (RMP) reference stations at Paradise Cove?"
4. "What general water quality conditions exist in the four marinas in regards to dissolved oxygen, temperature, turbidity, pH, and salinity?"
5. "Is there a noticeable difference in contaminant levels found between those four marinas sampled and can we make plausible inferences as to why those differences exist?"

The Pilot Study characterized overall sediment quality conditions and contaminant levels in four San Francisco Bay marinas. As part of the marina selection process for sediment sampling, BCDC staff conducted an extensive phone survey of over forty marinas and developed a marina matrix containing over twenty fields of information on each marina, including marina size, facilities, surrounding land-uses, the existence of municipal storm drain outfalls, and sedimentation rates. Due to funding limitations, the sampling and laboratory analysis did not examine all the potential contaminants identified in the literature review, but did examine heavy metals and petroleum hydrocarbons; both considered to be San Francisco Bay pollutants. Also due to funding limitations, the study was designed to examine if pollutants are present in marina sediments, but did not thoroughly examine the sources of contaminants found in sediments (e.g. whether sediment contamination comes from specific marina and recreational boating-related activities such as boat maintenance activities, or stormwater runoff). But by careful selection of the pilot marina sites to isolate as much as possible different sources of pollution (e.g., by selecting marinas that do not contain municipal stormwater outfalls), inferences could be made on the likely sources of contaminants found in the marinas. While these inferences are not definitive, they provide a reasonable basis for recommended management actions and future monitoring (See Page 8). The Pilot Study also establishes a good model for characterizing water and sediment quality conditions at San Francisco Bay marinas that can be utilized by marina operators, BCDC or other partner agencies in the San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force,[11] and it lays the groundwork for future "source identification" studies at marinas, and possible future reviews of the marina water quality policies in the recreation section of the *San Francisco Bay Plan*.

This report documents the San Francisco Bay Marina Water Quality Project in detail, and provides recommendations for addressing marina and recreational boating nonpoint source pollution issues in San Francisco Bay. Chapter One provides background for the project, explaining why and how the project evolved, including the policy context, collaborative process, and funding sources. Chapter Two provides a detailed literature review of marina and recreational boating-related pollutants, the possible sources of those pollutants in marinas, and their monitoring status in San Francisco Bay. Appendix A details the Pilot Study, "Condition of Sediments in Selected Marinas in San Francisco Bay," including the marina selection process and marina matrix, the sampling and laboratory methodology, and laboratory results and discussion. The overall conclusions and recommendations for the San Francisco Bay Marina Water Quality Project are presented on the following pages preceding Chapter One.

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[11] A group comprised of marina and boating operators and associations, environmental organizations, and local, state and federal government organizations (Appendix B lists the major active organizations on the Task Force).

Conclusions. The following conclusions are based on the major findings of the San Francisco Bay Marina Water Quality Project, including the literature review on marina and recreational boating pollutants and impacts (Chapter Two), the Pilot Study (See Appendix A), and the literature review on marina management practices to control pollutant discharges from marina and recreational boating operations (See Appendix E).

1. **Literature Review Conclusions on Marina and Recreational Boating-Related Pollutants**
   a. Marina and recreational boating operations are not considered a major sources of nonpoint pollution when compared to other categories of nonpoint source pollution (such as urban and agricultural runoff). However, marina and recreational boating operations can inadvertently lead to locally degraded water quality conditions, impacting aquatic organisms and ecosystems. Studies conducted in California and around the world have identified the following marina and recreational boating-related contaminants: heavy metals (copper, zinc, lead, arsenic, cadmium, chromium, tributyltin, and others); petroleum hydrocarbons (including polycyclic aromatic hydrocarbons [PAHs]); sewage/bacterial contamination; and nutrients (nitrogen and phosphorus) (which can lead to lowered dissolved oxygen levels). These contaminants can also originate from non-marina sources.
   b. Studies conducted in California and around the world have found toxic levels of some heavy metals in some marinas. If heavy metals build up to toxic levels (levels of contaminants that cause adverse effects) in the aquatic environment, a wide range of health effects to marine organisms can occur. These can include tumor formation and genetic derangement, tissue inflammation and degeneration, physiological and developmental changes, reproductive abnormalities, changes in feeding behavior, digestive efficiency, and respiratory metabolism, and growth abnormalities and inhibition. All of these effects combined in individual organisms can have detrimental effects on the biological community structure and overall abundance of resident species.
   c. Studies conducted in California and around the world have found toxic levels of some heavy metals in some marinas. If petroleum hydrocarbons, including polycyclic aromatic hydrocarbons (PAHs) build up to toxic levels in the aquatic environment, a wide range of health effects to marine organisms can occur. These include: arrested development, death from oil smothering, cancer, mutations, interference with embryonic development and reproductive failure. All of these effects combined in individual organisms can have detrimental effects on the biological community structure and overall abundance of resident species.

d. Organic matter contained in sewage, and nutrient enrichment from nitrogen and phosphorus, all of which can be discharged from boats in marinas, can result in eutrophication, or algal blooms, causing low dissolved oxygen in waters, fish kills, and the depletion of desirable flora and fauna.

e. Poor flushing and water circulation within a marina basin can contribute to poor water quality conditions, by causing water stagnation, lowered dissolved oxygen levels, and an environment where pollutants can concentrate in water or sediments.

2. **Pilot Study Conclusions on San Francisco Bay Marina Pollution**

a. Sediment quality benchmarks were useful in the detection of contaminants of concern in marina sediments. Published sediment quality guidelines, including "effects range low" (ERL) and "effects range median" (ERM),[12] "threshold effects level" (TEL) and "probable effects level" (PEL),[13] and "PAH consensus guideline values"[14] were useful in determining whether levels of metals and polycyclic aromatic hydrocarbons (PAHs) found in the samples of four pilot marinas could be harmful to aquatic life. Ambient sediment concentrations calculated for San Francisco Bay,[15] were also useful benchmarks in evaluating sediment metals and PAH data. By comparing sediment metals and PAH concentrations within the marinas to Ambient concentrations, one can tell whether levels in the marinas are above what has been calculated to be current conditions for Bay sediments. If several samples within a marina exceeded both "effects range low" (ERL) guidelines and Ambient concentrations, then they were considered "contaminants of concern" in marinas because chemicals at these concentrations have an increased probability of being harmful to aquatic life and are elevated above current conditions for the Bay. Additionally, comparison of marina sediment concentrations to reference samples taken at Paradise Cove, an area considered to be unimpacted by marina or other development activities, provided additional help to confirm or refute these conclusions, by showing whether marina sediment contaminant concentrations were elevated above a non-marina area.

b. In answering study questions 1-3 (See Page 2), the following conclusion was drawn: Study results found copper, zinc and chromium to be contaminants of concern (with copper and chromium being the greatest of concern) in the pilot marinas because their levels could be harmful to aquatic life (exceeded ERLs), and were higher than what has been calculated as current conditions for Bay sediments (calculated

[12] Long and Morgan 1990; Long et al 1995
[13] MacDonald 1992 & 1994; MacDonald et al 1996
[14] Swartz 1999
[15] SWRCB 1998

Ambient values[16]). Arsenic was also found to be of concern because its levels could be harmful to aquatic life (exceeded ERLs), but of less concern because it did not exceed what is considered to be its ambient levels in Bay sediments. All of the contaminant levels found in the marina sediments are not considered extreme, or highly risky to aquatic life (they did not exceed "effects range median" [ERM] guidelines). However, to prevent these contaminants from accumulating at marinas, and potentially increasing to risky levels, marinas and boaters should implement management practices to prevent and minimize discharges of contaminants at marinas (see conclusion #13). Conclusions on the individual contaminants, including their potential marina and recreational boating-related sources are summarized below.

(1) **Copper.** Copper was identified as a contaminant of concern in marinas because sediment concentrations were found to exceed the copper "effects range low" (ERL) guideline (34 mg/kg) in all of the marina samples (40/40), and one sample exceeded the "probable effects level" (PEL) guideline (108.2 mg/kg). This indicates an increased probability that adverse effects to aquatic life could result from copper toxicity in sampled marinas. Additionally, sediment concentrations exceeded the Ambient value for copper (68.1 mg/kg) in more than half of the marina samples (25/40), and exceeded the average reference station value (48.7 mg/kg) in most of the marina samples (35/40). Data from three out of the four marinas demonstrated increasing levels of copper from samples taken at the mouth of the marinas (lower copper levels) to their innermost harbors (higher copper levels). This indicates a possible localized marina-related copper source. The literature review indicates that potential marina and recreational boating-related sources of copper include anti-fouling paints applied to boats and wood preservatives in docks and pilings. Stormwater runoff from marina maintenance areas, leaching of paints from boats stored in the water, as well as pilings and docks containing copper-based wood preservative treatments are potential marina and recreational boating-related pathways of copper to marina waters.

(2) **Chromium.** Chromium (III) is also considered a contaminant of concern in marinas because sediment concentrations were found to exceed the ERL guideline (81 mg/kg) in all of the marina samples (40/40), and several samples approached, and one sample exceeded, the "probable effects level" (PEL)

[16] SWRCB 1998

guideline (160.4). This indicates an increased probability that adverse biological impacts to aquatic life could result from chromium toxicity in marinas. Additionally, the Ambient chromium value (112 mg/kg) was exceeded in most of the marina samples (38/40), and half of the marina samples (21/40) exceeded the average reference station concentration for chromium (135.3 mg/kg). Data from two out of the four marinas demonstrated increasing levels of chromium from the mouth of the marina (lower chromium levels) to the back, innermost harbor samples (higher chromium levels), indicating a possible localized marina chromium source. The literature review indicates that chromium has been used in various capacities in marinas and by boaters and can wash from parking lots, service roads, and launch ramps into surface waters with rainfall.[17] Chromium compounds are used for chrome plating of boat parts, in dyes, and inorganic paint pigments, and as fungicides and wood preservatives in docks and pilings. Chromium can also oxidize and be leached from stainless steel into a water-soluble form. Chromium is also found in the Bay sediments due because of the geology of soils and rocks in the Bay Area.

(3) **Zinc.** Zinc is considered a contaminant of concern in marinas because sediment concentrations were found to exceed the ERL guideline (150 mg/kg) in a third of the marina samples (14/40) indicating a low to moderate probability that adverse affects to aquatic life could result from zinc toxicity. Additionally, zinc concentrations exceeded the Ambient value for zinc (158 mg/kg) in a quarter of the marina samples (11/40), and the average reference station concentration (99.2 mg/kg) in most of the marina samples (32/40). Two out of the four marinas exhibited increasing levels of zinc from the mouth of the marinas (lower zinc levels) to their back innermost harbors (higher zinc levels), indicating a possible localized marina-related zinc source. The literature review indicates that potential marina and recreational boating-related sources of zinc include anti-corrodants for metal hulls, engine parts, and boat propeller shafts, anti-fouling paints, motor oil, tires, and wood preservatives in docks and pilings. Runoff from marina parking lots, launch ramps, and maintenance areas, and leaching from boats stored in the water as well as pilings and docks are potential marina-related pathways of zinc to marina waters.

[17] U.S. EPA 2001

(4) **Arsenic.** Arsenic is considered a contaminant of concern in marinas because sediment concentrations were found to exceed the ERL guideline (8.2 mg/kg) in a majority of the marina samples (36/40) indicating a low to moderate probability that adverse affects could occur to aquatic life. Few samples (1/40) exceeded the Ambient value (15.3 mg/kg) or average reference station concentrations (12.4 mg/kg) (5/40 samples) for arsenic, so arsenic isn't as much of a concern in marinas as copper, chromium, or zinc. The literature review indicates that potential marina and recreational boating-related sources of arsenic include paint pigments, wood treatments, and pesticides applied to landscaping. While marine paint and coating compounds made with arsenic are no longer used because of their toxicity, arsenic may still be present on older boats. Runoff from maintenance areas, landscaping areas, and leaching from boats stored in the water and docks and pilings are potential marina–related pathways of arsenic to marina waters.

c. Measured concentrations of cadmium, lead and polycyclic aromatic hydrocarbons (PAHs) were generally low in the pilot marinas and are not considered contaminants of concern in the pilot marinas.

d. In answering study question four (water quality measurements), it was found that dissolved oxygen (DO) in two of the pilot marinas was low in bottom waters at several locations and may present a risk of hypoxia (low available oxygen) to aquatic life (DO range: 2.4 mg/L-9.3 mg/L). However, these measurements represent only a snapshot in time. Dissolved oxygen levels naturally fluctuate throughout the day. In order to get accurate assessments of dissolved oxygen trends, it is necessary to take multiple samples at different times of day, and during different tidal regimes. Therefore, it is not possible to draw definitive conclusions about dissolved oxygen levels in the marinas sampled. Additional monitoring of oxygen levels is recommended to improve our understanding of oxygen saturation conditions in marinas.

e. Study question five was not completely answered by this Pilot Study. Ascertaining the specific source of pollutants in the marinas and understanding why differences exist between the marinas was beyond the scope and budget of the Pilot Study. Some preliminary conclusions were drawn, which should be tested with further research: Statistical analysis comparing contaminant levels between the four marinas sampled showed significant differences in metals levels between the marinas. The smallest marina had significantly lower metal concentrations than the other three marinas. Copper, cadmium, and zinc levels were often positively correlated suggesting possible common sources, such as bottom paints. Arsenic did not correlate or was negatively correlated with the other metals indicating a possible separate source in the marinas. Additional research is suggested to increase understanding of specific sources of pollution found in marinas.

f. Additional monitoring and analysis is needed to strengthen our understanding of water and/or sediment quality conditions at marinas in the Bay, to increase our understanding of specific sources of pollution found in marinas, and the impact of contaminant levels on aquatic life (see recommendation 5a-d).

g. Results from the marina selection process and development of a marina matrix for the Bay found that many marinas in San Francisco Bay contain municipal storm drain outfalls, which may discharge stormwater and dry weather flows into the marinas. Marinas with municipal storm drains were not selected for the Pilot Study in order to isolate marina and recreational boating-related pollution from pollution coming from municipal storm drain outfalls. More research is needed, however, to understand the impacts of stormwater and dry weather flows on water and sediment quality conditions at other marinas in the Bay.

3. **Literature Review Conclusions on Management Measures**

   a. Although there are few contaminant-specific management practices, there are general low-cost management practices that can address multiple contaminants, such as maintenance area, parking lot, and landscaping runoff treatment and prevention strategies, and clean boating educational programs for marina tenants and other boaters.

   b. Boaters can help to prevent copper contamination in Bay waters by implementing alternative, non-toxic anti-fouling strategies instead of applying copper-based anti-fouling paints to boat hulls.

4. **Other Conclusions**

   a. Collaboration with regulatory agencies such as the San Francisco Bay Regional Water Quality Control Board, research institutions such as San Francisco Estuary Institute, representatives from the marina and recreational boating community, and environmental non-government organizations is essential to furthering our understanding of, and addressing marina and recreational boating nonpoint source pollution issues in the Bay.

Recommendations. An adaptive management approach should be followed to address marina and recreational boating nonpoint source pollution issues in San Francisco Bay. This approach involves immediate management actions that reflect our current understanding of marina and recreational boating-related nonpoint source pollution in the Bay, continued studies that address our incomplete understanding of marina and recreational boating-related nonpoint source pollution, and in the future adjusting management actions, as appropriate, to reflect changes in our scientific understanding of marina and recreational boating impacts and effectiveness of management practices.

1. **Management Actions**

   a. **Management Practices.** Consistent with Bay Plan water quality policies, the Commission should require that all permitted projects, including new and expanding marinas, and marinas undergoing substantial renovations should, to the best extent practicable, implement management practices, such as controlling runoff from marina parking lots, other paved areas, and maintenance areas, designed to prevent contaminants from entering the Bay.

   b. **Education.** The Commission should continue to collaborate with and support educational programs that promote environmentally friendly boating practices, such as the Boating Clean and Green Campaign (conducted by the California Coastal Commission in conjunction with the California Department of Boating and Waterways and Contra Costa County) and the California Clean Boating Network. Additionally, the Commission should encourage the development of educational programs that educate boaters on management practices to prevent contaminants of concern, such as copper and zinc, from entering Bay waters. Education programs should include non-toxic anti–fouling strategies for boats to help prevent copper contamination in marina and Bay waters.

   c. **Flushing.** The Commission should require permit applicants for new marina projects to submit a hydrological report assessing how the proposed marina design will affect the flushing capabilities of the marina basin.

   d. **Self Monitoring.** To better understand water and sediment quality at marinas, and to evaluate the effectiveness of management practices in preventing contaminants from entering marina waters, marina operators and boating organizations should establish volunteer self-monitoring programs.

2. **Further Studies**

   a. The Commission should consider partnering with or encouraging other relevant agencies (such as the San Francisco Regional Water Quality Control Board and the San Francisco Estuary Institute's Regional Monitoring Program) to pursue special funding to:

      (1) Conduct source identification studies in the four pilot marina sites for copper, chromium, zinc, and arsenic to gain further understanding of the sources of these contaminants in marinas.

      (2) Analyze archived benthic community samples from the four marina pilot sites, to gain further understanding of potential impacts of contaminants to aquatic life.

      (3) Conduct sediment and water characterization studies at additional marinas in the Bay. These studies should include analyses for the major contaminants of concern identified in the Pilot Study, as well as other potential marina and recreational boating-related contaminants and conventional water quality parameters.

      (4) Explore the impacts of urban stormwater runoff and dry weather flows on marina water and sediment quality in the Bay, and support studies that examine the relative contribution of pollutants from urban stormwater and dry water flows and marina and recreational boating-related activities in marinas in San Francisco Bay.

   b. The Commission should consider pursuing special funding to conduct a program that comprehensively analyzes the physical, chemical, and biological testing data already required by the Dredged Material Management Office (DMMO) of applicants for a marina dredging permit, as a cost effective way to increase understanding of contaminants of concern in San Francisco Bay marinas.

3. **Collaboration**

   a. Provided funding is available:

      (1) The Commission should continue to collaborate with existing sewage/bacteria monitoring programs in San Francisco Bay marinas, such as the WaterKeepers Northern California's monitoring program, and consider using their data and reports as appropriate in future possible marina water quality policy updates.

      (2) The Commission should continue to work collaboratively with marina operators, recreational boaters, federal, state, and local government agencies, nonprofits, and others to address marina and recreational boating nonpoint source pollution in the Bay, by providing a forum as needed to address these issues.

(3) The Commission staff should continue to participate on state-wide inter-agency working groups charged with addressing marina and recreational boating-related nonpoint source pollution, such as copper working groups that examine the impacts of copper anti-fouling paints on water quality in marinas.

(4) The Commission should continue to forge strong relationships with monitoring organizations, such as the San Francisco Estuary Institute, the San Francisco Bay Regional Water Quality Control Board, and WaterKeepers Northern California, and encourage water and sediment quality monitoring in San Francisco Bay marinas, and the provision of those data to the Commission.

CHAPTER 1

BACKGROUND OF THE SAN FRANCISCO BAY MARINA WATER QUALITY PROJECT

Pollutants reach the Bay from many different sources and pathways.[1] Pollution from distinct, identifiable sources, such as treated municipal waste and industrial discharges are referred to as "point source" discharges. "Nonpoint source" pollution (NPS) does not come from a distinct source or pathway. It can include, among others, metals, petroleum hydrocarbons, sediments, nutrients and bacteria from stormwater runoff from streets and parking lots, fuel and oil spills and maintenance activities at marinas, and remobilization of bed sediments from "hot spots."[2] All of these pollutants can be transported directly into the Bay. Nonpoint source pollution is one of the top threats to ecological health and human health in San Francisco Bay. The State Water Resources Control Board (State Board) has designated areas of the Bay as impaired waterbodies for metals and other contaminants that can be associated with marinas and recreational boating as well as other sources such as urban runoff and historical industrial pollution. These include, but are not limited to, copper, lead and TBT in Oakland Inner Harbor sediments, lead and zinc in San Leandro Bay sediments, and Polycyclic Aromatic Hydrocarbons (PAHs) in sediments of Castro Cove, Richmond, the San Francisco Bay Central Basin, Islais Creek, Oakland Inner Harbor, and San Leandro Bay. (See Chapter Two for more information on Bay pollution).[3]

BCDC's Nonpoint Source Work Program and Marinas. States are required to control or prevent NPS pollution pursuant to the 1987 amendments to the federal Clean Water Act and the 1990 Coastal Zone Management Act reauthorization amendments. The Plan for California's Nonpoint Source Pollution Control Program (California Plan) identifies 61 specific management measures, which are implemented through management practices, for the control of nonpoint source pollution from agriculture, forestry, urban areas, marinas and recreational boating, hydromodification, and wetlands, riparian areas, and vegetated treatment systems. The California Plan identifies the San Francisco Bay Conservation and Development Commission (BCDC) as an implementing agency with authority and jurisdiction over the following categories of NPS pollution in the Bay: (1) urban; (2) marinas and recreational boating; (3) hydromodification (channel modification); and (4) wetlands, riparian areas and vegetated treatment systems.

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[1] Pollutants can enter estuaries such as San Francisco Bay through multiple point and nonpoint *sources* (activities leading to the release of contaminants contained in boat hull paints, automobile combustion byproducts, and pesticides) and numerous *pathways* (routes through which contaminants are transported such as direct water contact with the product [boat hull paints], urban and agricultural runoff).
[2] "Hot Spots" are areas in the Bay, determined by the San Francisco Regional Water Quality Control Board, that have high levels of historical contaminants (or legacy contaminants) in the sediments.
[3] 2002 CWA Section 303 (d) List of Water Quality Limited Segments. San Francisco Bay Regional Water Quality Control Board. Approved by U.S. EPA July 2003.

In February 2000, the California Resources Agency directed BCDC to develop a five-year nonpoint source pollution control plan. In response to the Resources Agency's directive, BCDC developed and adopted a *Nonpoint Source Pollution Report and Proposed Work Program* (Work Program) consistent with the California Plan that addresses BCDC's role in controlling nonpoint source pollution from urban runoff, hydromodification (alteration of waterways), alteration of wetlands and riparian areas, and marinas and recreational boating in the Bay.

BCDC has little control over the vast majority of polluted runoff coming into San Francisco Bay because the watershed for the Bay drains approximately 40 percent of the State, including a portion of the State of Oregon-areas far beyond the Commission's jurisdiction. Generally, the Commission's jurisdiction covers San Francisco Bay and extends only 100 feet landward of the mean high tide line. Therefore, the Commission has focused its nonpoint source pollution Work Program on marinas and recreational boating because it has specific jurisdiction and authority over these uses.

San Francisco Bay is a popular place for recreational boating. The Bay has over sixty recreational marinas with combined boat storage capacity of over 22,000, including wet slips and dry storage.[4]

Need for Data on San Francisco Bay Marina Water Quality Conditions. In November 2001 BCDC held a public workshop to discuss marina and recreational boating-related nonpoint source pollution issues in San Francisco Bay. Several representatives from marina and recreational boating organizations, individual harbormasters and boaters, environmental organizations, and representatives from local, state, and federal government agencies were in attendance. Out of these discussions, it became clear that there was a need for "additional information" and "concrete data" on water quality conditions at San Francisco Bay marinas, and that increased marina and boater involvement in the process was needed.

Although the U.S. Environmental Protection Agency (U.S. EPA), the State Board, and the California Coastal Commission consider NPS from marinas and recreational boating a primary concern for California,[5,6] few marina monitoring programs are in place in San Francisco Bay to determine whether, and to what extent, marina and recreational boating-related pollution is a problem. Because many of the marinas in San Francisco Bay do not have point source discharges and are not involved in equipment cleaning and maintenance activities, they are not

[4] California Department of Boating and Waterways (DBW), California Coastal Commission, and personal communication with marinas in the Bay (2003-2004).
[5] U.S. EPA 2000. A Summary of the National Water Quality Inventory: 1998 Report to Congress. EPA Office of Water. EPA 841-5-00-001.
[6] SWRCB & CCC 2000. *Plan for California's Nonpoint Source Pollution Control Program.* State Water Resources Control Board, Sacramento, CA and the California Coastal Commission, San Francisco, CA

actively regulated under the Statewide Industrial Stormwater General Permit,[7] but may still generate or discharge many pollutants. Further scientific study is needed to determine the water quality impacts of marinas in San Francisco Bay.

BCDC Obtains Grant and NOAA Coastal Management Fellow to Conduct Marina Study. In October 2001 BCDC staff submitted a proposal to the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center (CSC) to receive a NOAA Coastal Management Fellow ("fellow"). Working with BCDC staff, the fellow would set up a scientifically based volunteer water quality monitoring program for San Francisco Bay marinas, and conduct pilot monitoring projects at selected marinas. NOAA awarded BCDC a fellow to implement the project for 2002-2004, and in August of 2002, she began the San Francisco Bay Marina Water Quality Project.

In July 2002 and 2003, BCDC received funding from the NOAA nonpoint source pollution implementation fund for equipment and consultant services, to be used for the Pilot Study: "Condition of Sediments in Selected Marinas in San Francisco Bay" ("Pilot Study").

San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force is Formed. In September 2002, BCDC staff met with interested parties, such as marina and operators and associations, recreational boaters, environmental organizations, and local, state and federal government organizations, to formally establish the San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force ("Task Force"). Participation was open to all interested parties (Appendix C lists the major active organizations on the Task Force). At this meeting the Task Force expressed its desire to be an advisory committee for the project, and BCDC and the Task Force collectively developed overall objectives for the project. These objectives were refined and added to over the next year, as the project became more defined.

San Francisco Bay Marina Water Quality Project Objectives

1. Establish baseline information, through literature review, data compilation and field sampling, on the condition of selected marinas in San Francisco Bay regarding selected pollutants, to provide a better understanding of existing water and sediment quality conditions at marinas in San Francisco Bay.
2. Use field sampling and laboratory analysis to better identify pollutants of concern, to measure the degree of contamination and identify where pollution does and does not occur.
3. Use field sampling, laboratory analysis, and literature review to gain a better understanding of possible sources of pollution in marinas in San Francisco Bay.

[7] Issued by the San Francisco Regional Water Quality Control Board under the National Pollution Discharge Elimination System (NPDES) program. Currently only marinas with boatyards are actively regulated under this permit program, although all marinas that have fuel docks, outdoor chemical storage, or boat washing areas should possess conditional industrial stormwater permits.

4. Use field sampling, laboratory analysis, and literature review to guide BCDC and other relevant state agencies as to whether additional controls, educational programs, and/or expanded marina monitoring programs are warranted to control marina and recreational boating-related nonpoint source pollution.

Literature Review. Once objectives were developed, BCDC staff conducted an extensive literature review of other monitoring programs and marina water quality studies worldwide, and searched for San Francisco Bay specific data on water quality at marinas. This review included studies on water, sediments, and marine organisms (such as mussels), all three of which are mediums for studying water quality. Information and knowledge gained from the literature review helped in developing a conceptual design for the Pilot Study. BCDC staff presented San Francisco Bay specific information to the Task Force in January 2003. Chapter Two summarizes this literature review by giving an overview of marina and recreational boating-related pollution, and referencing California-specific data. Appendix B provides additional information on worldwide marina studies.

Pilot Study Technical Advisory Committee. Due to the technical nature of the Pilot Study, BCDC staff formed a Technical Advisory Committee (TAC) in December 2002 to supplement the Task Force. This committee was comprised of scientists from the San Francisco Regional Water Quality Control Board (San Francisco Regional Board), California State Water Resources Control Board (State Board), San Francisco Estuary Institute (SFEI), NOAA Coastal Services Center, California Coastal Commission (CCC), Moss Landing Marine Labs (MLML), and representatives from Recreational Boaters of California (RBOC) and the California Association of Harbor Masters and Port Captains. This committee convened in April 2003, July 2003, and May 2004. In April 2003 the group reviewed the conceptual study design for the Pilot Study, and in July 2003 the group selected four marinas for the study, based on criteria developed by BCDC staff in consultation with the TAC, Task Force and MLML. Budgetary constraints restricted the study to four marinas. Appendix A describes this marina selection process in detail.

BCDC Inter-Agency Agreement with Moss Landing Marine Labs. In June 2003, BCDC entered into an inter-agency agreement with Moss Landing Marine Laboratories (MLML), San Jose State University Foundation, to conduct sampling, analysis and reporting for the Pilot Study.

In August 2003, BCDC staff, in conjunction with MLML, began implementation of the Pilot Study, and sampled sediments at the four marinas. Appendix A contains the Pilot Study report.

CHAPTER 2

LITERATURE REVIEW:

OVERVIEW OF MARINA AND RECREATIONAL BOATING-RELATED POLLUTION

Marina and recreational boating operations can inadvertently lead to locally degraded water quality conditions, though they are not considered a major source of nonpoint source pollution to our nation's waterways when compared with other categories of nonpoint pollution (such as urban and agricultural runoff).[1] "Marinas and Recreational Boating" is included as a category in *California's Nonpoint Source Plan.*[2] Marina and recreational boating operations can contribute pollutants such as heavy metals from boat hull paints and plating accessories, engine components, engine oils, and wood treatments in pilings and docks; petroleum hydrocarbons from fueling, oil spills, and fuel combustion from outboard motors; bacterial contamination from boat sewage discharges; nutrients, such as nitrogen and phosphorus, from gray water discharges, landscaping fertilizers, and detergents; and others. Poor flushing and water circulation within a marina basin can contribute to poor water quality conditions, by causing water stagnation, lowered dissolved oxygen levels, and an environment where pollutants can concentrate in water or sediments.

Although some marina studies have been conducted in Southern California and worldwide, few specific marina studies exist in San Francisco Bay. While there are several water and sediment quality monitoring programs for San Francisco Bay as a whole, few examine conditions at marinas. Much of the existing data (e.g. bacteria) is sporadic and disconnected, and studies that have marina stations are do not focus on specific marina-related questions. These gaps were the major impetus for BCDC's Pilot Study: "Condition of Sediments in Selected Marinas in San Francisco Bay," which analyzed metals and hydrocarbons in sediment of four San Francisco Bay marinas (see Appendix A). This effort is a crucial first step towards understanding water and sediment quality conditions in San Francisco Bay marinas, and helps to direct future programs toward identified problems.

Structure of Chapter. This chapter presents a literature review of potential pollutants and sources[3] associated with marinas and recreational boating.[4] It is important, however, to recognize that these pollutants can also come from other sources and pathways of nonpoint pollution, such as urban and agricultural runoff.[5] The sections below focus on the following pollutants:

- Heavy metals
- Petroleum hydrocarbons
- Sewage
- Nutrients

Each of the pollutant sections is organized into the following subsections:

- Summary. This subsection provides a summary conclusion about the pollutant's presence in the Bay and the status of its monitoring in San Francisco Bay marinas.
- Description of Pollutant. This subsection provides a technical description of the pollutant, and its general behavior in the marine environment.
- Effects of Pollutant on Marine Life. This subsection describes potential adverse effects of the pollutant on marine organisms and communities, and human health impacts, if relevant.
- Pollutant in San Francisco Bay. This subsection discusses the status of the pollutant in San Francisco Bay as a whole, which provides context and justification for examining this pollutant at the smaller-scale marina level.
- Potential Sources and Pathways of Pollutant in Marinas. This subsection discusses marina and recreational boating-related sources of the pollutant, other sources of the pollutant, and how these pollutants can enter marina waters.
- Pollutant in California marinas. This subsection describes existing data and studies on the pollutant in California marinas.
- Pollutant in San Francisco Bay Marinas. This subsection describes existing data and studies on the pollutant in San Francisco Bay marinas. It provides context and justification for inclusion or non-inclusion of this pollutant in BCDC's Pilot Study.

Although BCDC's Pilot Study (See Appendix A) does not sample and analyze all of the pollutants described in this chapter, this chapter provides background information on most of the known possible pollutants. This gives a more complete picture of marina and recreational boating-related pollutants nationwide, and provides context for the Pilot Study.

Information for this literature review was obtained from library and internet searches, interviews with water quality professionals in the Bay Area (federal, state, and local government agencies), and with the assistance of the San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force. Additionally, BCDC staff faxed a survey to sixteen well-known marinas in the Bay, to ask if the marina, or anyone else, had ever conducted water quality monitoring in their marinas. Marina harbormasters completed and returned fourteen of these questionnaires.

Heavy Metals

1. **Summary.** Heavy metals contaminate waters and sediments throughout San Francisco Bay. Marina and recreational boating-related activities can introduce heavy metals to Bay waters, specifically within marina basins. While studies have been conducted in Southern California and worldwide (See Appendix B for studies outside of California), there are few specific studies on heavy metals contamination in marinas of San Francisco

Bay. BCDC's Pilot Study has begun to fill this gap by sampling and analyzing sediment chemical concentrations in four San Francisco Bay marinas (see Appendix A). The following sections provide a description of heavy metals, effects on marine life, potential sources and pathways in marinas, and conclude by documenting existing studies on metals in California and San Francisco Bay marinas.

2. **Description of Heavy Metals.** In literature about metals in aquatic systems the term "heavy metals" is often used interchangeably with "trace metals," "toxic metals," "trace elements," and "trace constituents." Heavy metals have generally been associated with contamination in aquatic environments and toxicity to plants and wildlife. They include mercury, copper, cadmium, arsenic (a metalloid), lead, selenium, tin, chromium, zinc, and others. There are also organometals (e.g. Tributyltin [TBT], alkylated lead, and methylmercury), which are extremely toxic to marine organisms, as well as to humans. Heavy metals generally accumulate in sea-bottom sediments because their particle-reactive properties allow them to sorb easily to suspended sediments and other particulate matter.6 Heavy metals can also remain in the water column in dissolved form, or by attaching to small suspended particles.7 The major metals of concern found in some marinas worldwide include copper, tributyltin (TBT), lead, zinc, arsenic, chromium, and cadmium (see below and Appendix B for studies documenting these metals in marinas).

3. **Effects of Metals on Marine Life.** If heavy metals build up to toxic levels (levels of contaminants that cause adverse effects) within a marine organism's system, a wide range of health effects can occur (See Table 1). Pathological responses to metals in organisms include: neoplasm (tumor) formation and genetic derangement, tissue inflammation and degeneration, physiological and developmental changes, changes in feeding behavior, digestive efficiency, and respiratory metabolism, and growth abnormalities and inhibition. Organometals (like TBT) can damage reproductive and central nervous systems. All of these effects combined in individual organisms can have detrimental effects on the biotic community as a whole.8

   It is important to note that the actual toxicity of a metal to a marine organism depends on an organism's ability to take up, store, remove or detoxify the metal. Before an organism can take up a metal, the metal must be "bioavailable," or accessible to the organism. Bioavailability is strongly influenced by whether the metal is in a dissolved or solid state (sorbed on particles, as colloids, etc.).[9] Metals in sediments can become bioavailable to aquatic organisms in the water column by dredging and bioturbation (organism activity that stir up sediments), or released from sediments through remineralization[10] or changes in water pH.[11] When metals are contained in sediments, benthic organisms can become exposed to them. These contaminants can then bioaccumulate in animal tissues and move up the food chain.[12]

4. **Metals in San Francisco Bay.** The San Francisco Estuary Institute's (SFEI) Regional Monitoring Program (RMP) has been tracking the status and trends of contaminants in San Francisco Bay since 1993. It is important to note that sample stations are located primarily in the middle of the Bay, and not the margins where the marinas are located (recent study design changes include more near-shore area sampling sites). In sediment samples taken in the North Bay, copper, chromium, and nickel have exceeded sediment guidelines.[13,14] In the Carquinez Strait, sediment samples containing copper and chromium have exceeded sediment quality guidelines. In the Central Bay, sediment samples have exceeded guidelines for chromium, copper, and nickel. In the South Bay, chromium, copper, mercury, and nickel have exceeded sediment guidelines.[15] Currently the entire San Francisco Bay is listed as an impaired water body for mercury on the State's 2002 303 (d) list. Mission Creek sediments are listed for copper, lead, zinc, and chromium. Oakland Inner Harbor sediments are listed for copper, lead and TBT. San Leandro Bay sediments are listed for lead and zinc.[16] Copper is on the 2002 303 (d) monitoring list for the entire Bay.[17]
5. **Potential Sources and Pathways of Metals in Marinas.** Regarding marina and recreational boating activities, metals are contained in marine paints, anti-corrodants, and other marine products and materials (See Table 1). According to a report on Puget Sound boatyards in Washington State, copper, lead, and zinc are typical constituents of boatyard and shipyard pressure-washing wastewater, with copper and lead labeled as "contaminants of concern" (consistently exceeded the sanitary sewer limits).18 In recent years, California boatyards have taken steps to decrease contamination of stormwater runoff and have installed special equipment to contain wastewater, due to National Pollutant Discharge Elimination System (NPDES) permit conditions,19 however discharges can still occur from maintenance areas not covered under the NPDES program, in-water maintenance work, and/or passive leaching of hull paints and engine components from boats in the water.20 Metals are also contained in wood preservatives used in pilings and docks and can enter the marine environment through passive leaching. Metals are also present in boat engine oils and bilge water, both of which can inadvertently be discharged into marine waters.21 (See below and Appendix B for studies documenting metals in marinas). Metals contained in bottom sediments can be reintroduced to the water column through dredging, boat propeller action, construction

activities, or other activities that stir up the bottom sediments. Metals can also enter marinas through urban runoff and remobilization of sediments from other contaminated areas.

a. **Copper.** Copper-based paints are the most popular anti-fouling paints for boat hulls. The goal of these paints and the biocides contained within (such as cuprous oxide) is to retard the growth of encrusting organisms, such as barnacles. These antifouling coatings slowly release copper in their most toxic form to retard this growth and maintain a smooth surface on the hull.[22] In San Diego Bay, the majority of dissolved copper loading comes from antifouling paints from recreational boats and navy ships, rather than from urban runoff and direct atmospheric deposition.[23] Copper can be released from the boat hull through land-based maintenance and sanding activities, underwater hull cleaning, and through passive leaching as described above. Laboratory experiments conducted by the Southern California Coastal Water Research Program (SCCWRP) found that on a mass basis, ninety-five percent of the copper loading from recreational hull coatings occurs via passive leaching, as opposed to underwater hull cleaning.[24]

   Copper-based products are often used as wood preservatives, such as chromated copper arsenate (CCA) and ammoniacal copper zinc arsenate (ACZA), used in marina docks and pilings. Scientific studies suggest that arsenic, copper, and chromium, and zinc can leach from CCA and ACZA treated wood over time.[25] Currently the San Francisco Regional Water Quality Control Board (San Francisco Regional Board) encourages the use of cement, steel and plastic piles instead of CCA and ACZA in marine waters, but there are no formal regulations or policies regarding their use.[26] BCDC is considering not allowing the new use of CCA or AZCA treated wood in the Bay unless it is wrapped in a manner acceptable to the Regional Board and maintained continually.

   In addition to the above marina-related sources, urban runoff can also contain copper and can enter marina waters through municipal storm drains, creeks, and over-land drainage.

b. **Tributyltin.** Before being banned for most marine uses because of its high toxicity to the marine environment, tributyltin (TBT) was used as the toxic agent in anti-fouling paints, outboard motors, and lower drive units.[27] Acute toxic effects to aquatic organisms, such as clam larvae, have been documented at levels as low as 6 parts per trillion (ppt).[28] In 1989 the U.S. EPA limited the use of TBT. It is still permitted on aluminum boats, vessels over 82 feet, and aluminum outdrives, if they are painted by licensed applicators. [29] In 1988 the State Board conducted an in depth review of TBT, which included review of water and sediment studies. Researchers found that TBT was one of the most toxic chemicals to marine aquatic life, with adverse effects occurring at levels lower than 20 parts per trillion (PPT). As a result, water quality objectives were established for California's Ocean Plan, and Bays and Estuaries plans. The report also documents the widespread occurrence of the contaminant over marine and freshwater habitats across the state. In San Francisco Bay, all sixteen marinas sampled by a joint UC/State Board effort had detectable concentrations of butyltins. Ninety percent of samples taken in California as a whole exceeded State Board criteria (sixty-one percent of non-marina samples also exceeded the criteria). Significant amounts were found in water, sediments, and mollusks. The threat of TBT to human health was also documented in the report. It is assumed to be toxic to humans, because it is toxic to mammalian immune systems. TBT has been found to bio-accumulate in food organisms in California, including fish and shellfish.[30]

c. **Zinc.** Zinc anodes are commonly used as anti-corrodants for metal hulls, engine parts, and boat propeller shafts.[31] Zinc is also contained in boat anti-fouling paints,[32] motor oil, and tires, and is a common constituent of runoff from marina parking lots,[33] and zinc is a component of the wood preservative ACZA, which is used in marine pilings, docks and piers (see Copper section for more information on ACZA). In addition to these marina-related sources, zinc can also enter marina waters through municipal storm drains, creeks, and over-land drainage.

d. **Lead.** Lead compounds are contained in some sailboat keels, marine paints, and lead acid batteries. It can be discharged into the marina environment from leaching of sailboat keels,[34] and corrosion of fittings and lead acid batteries.[35] For example, if batteries are not properly disposed of or stored on the dock or near a waterway, they can leach into the water. Additionally, stormwater runoff from marina parking lots and municipal stormdrains, creeks and overland drainage can act as a conduit for lead contamination in a marina.

e. **Arsenic.** Arsenic is often contained in paint pigments, wood treatments, and pesticides.[36] While marine paint and coating compounds made with arsenic are no longer used because of their toxicity, arsenic is still used in CCA (chromated copper arsenate) treated wood[37] (see Copper section for more information on CCA), and may still be present on older boats. Urban runoff can also contain arsenic and enter marina waters through municipal storm drains, creeks and overland drainage.

f. **Chromium.** Chromium has been found in dredged materials and waters of some marinas.[38] The U.S. EPA indicates that chromium has been used in various capacities in marinas and by boaters and can wash from parking lots, service roads, and launch ramps into surface waters with rainfall.[39] Chromium compounds are used for chrome plating, as dyes, as inorganic paint pigments, and as fungicides and wood preservatives in docks and pilings. Chromium is a component of chromated-copper-arsenate (CCA) treated wood (see Copper and Arsenic sections for further information on CCA). In addition to these marina-related sources, urban runoff can also contain chromium and it can enter marina waters through municipal storm drains, creeks, and over-land drainage.

g. **Cadmium.** Cadmium compounds are used in the metal plating and battery industry, and as stabilizing agents in many polyvinyl chloride (PVC) products, and many of these products are used on boats. Additionally, cadmium is a component of gasoline, diesel fuel, and lubricating oils. In addition to these marina and recreational boating-related sources, cadmium can enter marina waters through municipal storm drains, creeks, and over-land drainage.

6. **Metals in California Marinas.** California studies have found elevated levels of metals in sediments of marinas and harbors. The Southern California Bight '98 regional monitoring survey found that the highest sediment concentrations for metals and other target analytes were found in bays and harbors, with marinas accounting for a large portion. Copper, zinc, lead, and polycyclic aromatic hydrocarbons (PAHs) were among the most elevated contaminants in this strata (in addition to mercury, chlordanes, and PCBs).40 In the California Bight's toxicity survey, within harbors, marina samples had the highest frequency of toxicity (thirty-eight percent). Twenty-seven percent of the area classified as 'high concern' for toxicity occurred in marinas (more than ports/industrial harbors, rivers, and publicly owned treatment works [POTW] discharge areas).41 Shelter Island Yacht Basin (Shelter Island) in San Diego Bay has been extensively studied for copper. To illustrate, Johnston (1990) documented increasing concentrations of dissolved copper (and organotins) in water samples along a gradient from the mouth of the yacht basin to the innermost moored vessels.[42] A decrease in species diversity of marine fouling communities, paralleling an increase in dissolved copper (and organotin) levels was observed, demonstrating their toxic effects on some marine organisms.[43] Most recently, the San Diego Regional Water Quality Control Board (San Diego Regional Board) conducted a survey for dissolved copper concentrations in Shelter Island water samples and found continued high dissolved copper concentrations (as high as

$8\mu g/L$).[44,45] Adverse effects on aquatic biota were also found. In a 2000 toxicity survey conducted by the San Diego Regional Board in Shelter Island, developmental toxicity was observed in the mussel, *Mytilus edulis*, at stations with the high concentrations of dissolved copper, while no toxicity was observed in low concentration stations.[46]

7. **Metals in San Francisco Bay Marinas.** There is very little known about the extent of metals contamination in San Francisco Bay marinas, besides the extensive tributyltin study that was conducted by the State Board in 1988 (See Tributyltin section, p. 21), and sediment testing from maintenance dredging activities. Because of this lack of data, metals were sampled and analyzed as part of BCDC's Pilot Study (See Appendix A). The following paragraphs describe three monitoring efforts that included sampling for metals in San Francisco Bay marinas.

    a. **NOAA National Status & Trends Bioassessment Program.** In 2000 and 2001, researchers from the National Oceanic and Atmospheric Administration (NOAA) sampled sediment at five marina stations in San Francisco Bay, as part of its regional Status and Trends program. They also sampled in other harbors, open water, and tributaries of the Bay. These samples are in the process of being analyzed for chemistry concentrations (PAHs, other organic chemicals, and metals), toxicity, and benthic community structure.[47] Although the Status and Trends program is not focused on answering specific questions about marinas, the marina samples will add to the body of knowledge about marinas in the Bay.

    b. **Bay Protection and Toxic Cleanup Program (BPTCP) (California State Water Resources Control Board [State Board] and San Francisco Regional Water Quality Control Board [San Francisco Regional Board]).** The objective of the toxic hot spot program was to identify toxic hotspots in the Bay. The first stage of this was a toxic hotspot study, which focused on the most polluted areas in the Bay, which were assumed to be those areas located downstream from historical or present pollution sources. This limited researchers' ability to investigate each site in detail. First, toxicity-screening tests were conducted on samples from various stations throughout the Bay's near shore areas.[48] Five marinas sites were included.[49] Researchers then returned to those sites found to be significantly toxic and investigated further with chemical analysis (metals, PAHs and other organic chemicals), and benthic community analysis. Out of the marina areas sampled, three had measurable biological (toxic) impacts, but contaminant levels were low or not measured. In the other two marinas contaminant levels, toxicity levels, and benthic degradation were either low (below thresholds) or were not measured.[50] In Gashouse Cove marina in San Francisco and Richmond

Harbor, nickel values were elevated. However, nickel is known to occur naturally throughout the Bay, so marina-related activities are most likely unrelated. At the conclusion of this study, the five marinas studied were not found to be toxic hotspots in the Bay. Because this program does not focus on answering questions about marinas, and the small amount of testing in marinas was not investigated further, no conclusions about marina quality conditions can be made.

c. **Sediment Testing for Maintenance Dredging.** Metals data exist for marinas that have conducted sediment testing for maintenance dredging and disposal, but these data have not been compiled or sufficiently analyzed for marina impacts. Chemical, physical, and bioassay testing of sediment samples are conducted to determine suitability of the dredged material for in-bay disposal. This is required by several agencies in the Bay Area and the Dredged Materials Management Office (DMMO), including BCDC, the San Francisco Regional Board, and the U.S. Army Corps of Engineers. Samples are taken at depths equal to dredging depths rather than the top few centimeters of sediment. This introduces uncertainty as to whether contamination is marina-related or historical.

Petroleum Hydrocarbons

1. **Summary.** Petroleum hydrocarbons contaminate waters and sediments throughout San Francisco Bay, and research is underway to determine the extent of these and other contaminants' effects on the ecosystem. Marina and recreational boating-related activities have potential to introduce petroleum hydrocarbons to Bay waters, specifically within marina basins. While studies have been conducted in Southern California and worldwide (See Appendix B for studies outside of California), there are few studies on petroleum hydrocarbons in marinas of San Francisco Bay. Studies identified by this literature review suggested that petroleum hydrocarbons are a potential problem that deserved further investigation in San Francisco Bay marinas. BCDC's Pilot Study has begun to fill this gap by sampling and analyzing sediments in four San Francisco Bay marinas (See Appendix A). The following sections provide a description of petroleum hydrocarbons, effects on marine life, potential sources and pathways in marinas, and conclude by documenting existing studies on petroleum hydrocarbons in California and San Francisco Bay marinas.

2. **Description of Petroleum Hydrocarbons.** Petroleum hydrocarbons are a group of organic molecules that can be subdivided into straight-chain alkenes, branched alkanes, cycloalkanes, and aromatics. Heavier, non-water soluble petroleum hydrocarbons sorb readily to particulate matter and suspended sediments, and accumulate in bottom sediments,51 often near points of entry of the sediments.52 These include the high-

and persist in the environment (alkanes and cycloalkanes break down rapidly). They can be re-suspended in the water column through activities such as dredging, boat propellers, or benthic organism activity. Lower-molecular weight aromatics, such as toluene and xylene, are more likely to be found in the water column, but are often lost to evaporation and dissolution after spills.53

3. **Effects of Petroleum Hydrocarbons on Marine Life.** When estuaries and shallow coastal marine environments are exposed to oil pollution, benthic communities can experience dramatic changes. Fine grained sediments in these habitats sorb hydrocarbons and other components of oil, and can re-release the contaminants over years (from disturbance of the bottom due to storms, dredging, or boat propellers, for example). This can arrest the development of benthic communities. Biota can experience lethal and sublethal effects from oil contamination. Lethal effects result from organisms being smothered, trapped or suffocated by a spill. Sublethal effects can result from doses to juveniles and eggs, which in turn affect the community's reproduction, growth, distribution, and behavior, which in turn affect species composition, abundance, and diversity (See Table 1). Effects of Polycyclic Aromatic Hydrocarbons (PAHs) (see "Description of Petroleum Hydrocarbons" above), on marine organisms and biotic communities vary widely in nature, depending on bioavailability of contaminants and the capacity of organisms to metabolize them. In general, dissolved hydrocarbons in the water column are the most bioavailable to organisms, followed by those in the tissues of marine organisms (if they are eaten by other organisms), followed by PAHs in sediments.[54] Since PAHs do not dissolve well in water, benthic organisms are particularly susceptible to PAHs in the sediment. However, compounds can be re-suspended in the water column by bottom currents, bioturbation, etc. Some marine organisms, such as bivalve mollusks and echinoderms, do not metabolize PAHs efficiently, causing PAHs to accumulate to high levels in their tissues. Unmetabolized PAHs can be acutely toxic to marine organisms,[55] causing mollusks to develop neoplasia (tumors), for example. Other marine organisms, such as fish, tend to rapidly metabolize PAHs, and accumulate the contaminants only when exposed to heavily polluted environments. It has also been shown, however, that metabolized PAHs (e.g. epoxides and dihydrodiols) can be damaging, because the reactive metabolites of the PAHs have the ability to bind to cellular proteins and DNA, causing biochemical disruptions and cell damage that lead to mutations, developmental

malformations, tumors, and cancer. For example, the development of hepatic neoplasms in bottom-dwelling fish has been linked to PAH concentrations in sediments. Fish exposed to PAHs have also developed lesions. [56] Recent laboratory studies on zebra fish (*Danio rerio*) show that arrhythmia and loss of cardiovascular function are major effects from PAH exposure (See Table 1).[57]

Other types of petroleum hydrocarbons include benzene, toluene, and xylene, which are water soluble compounds. They can kill organisms in the water column, such as meroplankton,[58] and ichthyoplankton.[59] However, much of the lower-molecular weight aromatics, such as toluene and xylene, are often lost to evaporation and dissolution, making them less of a threat.[60]

4. **Petroleum Hydrocarbons in San Francisco Bay.** The RMP has been tracking the status and trends of contaminants in San Francisco Bay since 1993. It is important to note that sample stations are located primarily in the middle of the Bay, and not the margins where the marinas are located (recent study design changes include more near-shore area sampling sites). In water samples collected from 1997-2001 PAHs frequently exceeded water quality objectives in South Bay sampling stations. PAHs, along with mercury and PCBs, accounted for most of the violations of water quality guidelines in the Bay.61,62 Castro Cove, Richmond, the Central Basin, Islais Creek, Oakland Inner Harbor, and San Leandro Bay, are listed on the State's 2002 303 (d) list for PAHs in sediment.63 In San Francisco Bay as a whole, PAHs are listed on the State's 2002 303 (d) monitoring list.64

   PAHs tend to accumulate in bottom sediments, sorb to suspended sediments, and accumulate in organisms at the base of the food web in the San Francisco Estuary. These PAHs pose acute hazards to invertebrates living in the sediments, and these invertebrates are important food sources for various fish species.[65]

5. **Potential Sources and Pathways of Petroleum Hydrocarbons in Marinas.** According to calculated averages from the National Resource Council's 2002 Oil in the Sea Report for 1990-1999, recreational marine vessels with older carbureted 2-stroke engines are the third largest source (approximately 2.1%, 5.6 thousand tons per year) of petroleum hydrocarbons released in North American waters per year, out of a total of 260,000 tons. Land-based sources (river and runoff) contribute the most (twenty-one percent), and atmospheric deposition accounts for the second largest source (eight percent). Recreational vessels with carbureted two-stroke engines release slightly more than large tanker oil spills, which release 5.3 thousand tons per year.66 These older engines are

currently being phased out for cleaner direct injected two-stroke engines, and many boaters in San Francisco Bay utilize cleaner burning four cycle engines.

Petroleum hydrocarbons comprise more than seventy-five percent by weight of most crude and refined oils.[67] They are also contained in gasoline and other products such as grease, lubricants, finishes, and cleansers. Likely marina-related sources include fueling stations, boat engine maintenance areas, engine operation, and storm water runoff from adjacent parking lots, rooftops and upland areas.[68] For example, maintenance work conducted in marina parking lots and improper disposal of oil and other hazardous materials can increase contaminated runoff.[69] Additionally, gasoline can be spilled into the water during fueling, or through accidental/inadvertent leaks. Two-stroke engines release unburned fuel and exhaust gases into waters because they are designed to accomplish fuel intake and exhaust in the same cycle. They also have lubricant oil mixed in with fuel, which can be released along with the unburned fuel.[70] Older carbureted two-stroke engines are responsible for approximately two percent of petroleum hydrocarbons in North American waters each year,[71] although these numbers may be decreasing as these engines are phased out for cleaner direct injected two-stroke engines.

Petroleum hydrocarbons contained in bottom sediments can be reintroduced to the water column through dredging, boat propeller action, construction activities, or other activities that stir up the bottom sediments (See Table 1).

Water in a boat's bilge can become contaminated with oil or fuel from maintenance related spills or leaks in hoses, seals, and/or gaskets. Contaminated bilge water can then enter marina waters through inadvertent automatic bilge pump discharges or boaters pumping oily bilge water overboard. This practice is illegal, but enforcement by the U.S. Coast Guard is minimal due to limited resources. Sunken and flooded vessels also leak oil and fuel into marina waters (See Table 1).[72]

Particularly toxic forms of petroleum hydrocarbons, PAHs, are contained in both crude and refined petroleum. They are also contained in creosote treated wood, which is often used in submerged pilings and boat docks, and may be a source of PAH contamination.[73] A study conducted by the U.S. Navy, in a naval base in San Diego, found PAHs in the water, which were attributed to weathered creosote from old pier pilings. These levels had decreased due to the removal and replacement of the pilings (See Appendix B for more studies documenting petroleum hydrocarbons in marinas) (See Table 1).[74] BCDC is considering the prohibition of creosote treated wood in the Bay unless it is wrapped in a manner acceptable to the Regional Board and maintained continually.

Additionally, petroleum hydrocarbons may occur in wastewaters, atmospheric discharges from the burning of fossil fuels, urban runoff, agricultural runoff, asphalt production, waste incineration, forest and brush fires and volcanic eruptions.[75]

6. **Petroleum Hydrocarbons in California Marinas.** Southern California studies have documented the presence of petroleum hydrocarbons in marinas. The Southern California Bight '98 Regional Monitoring Survey found that the highest sediment concentrations for PAHs and other target analytes (metals, chlordanes, and PCBs) were in bays and harbors, with marinas accounting for a significant portion. PAHs in marinas were not found to be as high as PAHs in port and industrial harbors, however.76

7. **Petroleum Hydrocarbons in San Francisco Bay Marinas.** At the time of this literature review, little was known about the extent of petroleum hydrocarbon contamination in San Francisco Bay marinas. The following paragraphs briefly describe three monitoring efforts that included sampling for petroleum hydrocarbons in San Francisco Bay marinas.77

    a. **MTBE Impacts on Marine Water Quality.** Bay et al (2000) examined the fate and effects of Methyl-*tert*-butyl ether (MTBE), a fuel additive used to reduce exhaust emissions, in the marine environment. Researchers sampled receiving waters of assumed MTBE inputs: publicly owned treatment works (POTWs) (waste water treatment plants) and oil refineries. Three marinas in San Francisco Bay were sampled, including one in Redwood Creek, in Martinez and in Oakland. MTBE was detected at a frequency of seventy-five to one hundred percent, with a range of 0.9-1.6μg/L. No MTBE was detected in the receiving waters of POTWs and oil refineries.[78] While concentrations in marinas were not high enough to cause toxic effects (the threshold for toxic effects in most sensitive species [amphipod] was 37,000 μg/L), this study points out that fuel spills are a potential issue at marinas. Similar patterns were found throughout California. MTBE contamination was most extensive in San Diego and Mission Bays, with most occurring at marinas (these Bays have no POTWs or refineries). Watercraft with carbureted two–stroke engines were cited as the likely source of the MTBE contamination throughout the California sites studied.[79]

    b. **NOAA National Status & Trends Bioassessment Program.** In 2000 and 2001, researchers for NOAA sampled sediment at five marina stations in San Francisco Bay, as part of their regional Status and Trends program (see Metals in SF Bay

Marinas sections for more information on this study). Preliminary results have found PAHs in marinas as well as other areas sampled.[80] This information provided further indication that PAHs should be investigated in SF Bay marinas. The data helped to inform BCDC's Pilot Study.

c. **Bay Protection and Toxic Cleanup Program (BPTCP).** The "Metals in San Francisco Bay Marinas" section (Page 23) provides a full description of this program. Gashouse Cove Marina in San Francisco was listed as a 'site of concern' for PAHs for the BPTCP.[81] Because of the historical activity at this site, however, it is difficult to isolate the marina as a source.

Sewage/Bacterial Contamination

1. **Summary.** Current bacteriological monitoring efforts in San Francisco Bay do not focus exclusively on marinas, or contributions from marinas and recreational boating. Since existing monitoring efforts are done mainly on a monthly basis, clear trends in contamination are not known. Additionally, biological monitoring results are inherently variable, and it is difficult to ascertain clear trends or sources of contamination in the absence of taking large amounts of daily samples. Some marina studies in other parts of the country (e.g. Fisher et al, see Appendix B) focus on intensive studies over peak use periods, such as holiday weekends. The following sections provide a description of sewage/bacterial contamination, effects on marine life, potential sources and pathways in marinas, and conclude by documenting existing studies on sewage/bacterial contamination in California and San Francisco Bay marinas.

2. **Description of Sewage/Bacterial Contamination.** Sewage discharges can be in the form of raw sewage or treated sewage. Raw sewage is 99 percent water, with the remainder consisting of solid waste (e.g. sediment, floatables, plastics), suspended and dissolved organic matter, oil and grease, nutrients, and pathogens (bacteria, viruses, protozoa, and helminthes [parasitic worms]). When measuring possible sewage contamination, scientists generally look for the presence of bacterial indicators by counting colonies of total coliform, fecal coliform, Escherichia coli, or enteroccocus. These indicator species signal the presence of other fecal matter, which may signal the presence of pathogens (disease-carrying micro-organisms).82

3. **Effects of Sewage/Bacterial Contamination on Marine Life and Human Health.** Sewage discharges can cause eutrophication, or algal blooms (which can also be caused by nitrogen and phosphorus - see "Nutrients" section) in marine waters. Organic matter contained in sewage can exacerbate anoxic and hypoxic conditions by increasing biochemical oxygen demand, which is oxygen consumed during the microbial

decomposition of the waste. Elevated bacterial levels from sewage can lower dissolved oxygen levels (affecting aquatic organism survival) from increased biological oxygen demand. One North Carolina study of marinas found that marinas had significantly lower dissolved oxygen levels than adjacent water bodies, due to poor flushing within the marina basins, and high biological demand, attributed to boat sewage discharges (See Table 1).83

Pathogens contained in sewage pose potential health risks to humans. Those exposed to sewage-contaminated water can get hepatitis, dysentery, gastroenteritis, parasitic infections and even typhoid. Consuming raw or improperly cooked oysters, mussels or clams also presents a risk (See Table 1).[84]

4. **Sewage/Bacterial Contamination in San Francisco Bay.** San Francisco Bay is listed as an impaired water body on the State's 2002 303 (d) list for pathogens in the Napa and Petaluma Rivers (potential sources: agricultural, urban runoff, stormwater and construction/land development [Petaluma River]). Marina Lagoon in San Mateo (potential sources are urban runoff/storm sewers, and nonpoint sources) and Richardson Bay (source identified as substandard sewage systems in houseboat areas, urban runoff/storm sewers, septage disposal, boat discharges, vessel wastes) are listed for high coliform counts.85 Richardson Bay is a federally designated no discharge zone (NDZ). An NDZ is an area of a water body or an entire water body into which the discharge of sewage (whether treated or untreated) from all vessels is completely prohibited.86 Additionally, counties monitor beaches, and some marinas that are located next to swimming areas in the Bay, for indicator bacteria (see below: "Sewage/Bacterial Contamination in San Francisco Bay Marinas"). Warnings are posted in these recreational areas when high coliform counts are detected, to avoid health risks to swimmers. In 2000 San Francisco County had thirteen incidences of beach warnings attributed to rain events (combined sewer overflows can be a major cause of high coliform counts), but no beach closures.87 Monitoring dissolved oxygen in the Bay provides a good indicator of organic enrichment (from nutrients or poorly treated sewage, for example). The USGS has been doing this since the early 1970s. See "Nutrients in San Francisco Bay" (Page 33) for a description of this data.
5. **Potential Sources of Sewage/Bacterial Contamination in Marinas.** Understanding the sources of bacterial contamination in marine waters is a major task for scientists and policy makers.[88] The main marina and recreational boating–related source of bacterial contamination is sewage discharges from marine toilets or marine sanitation devices (MSDs) (See Table 1). Whether boats are a significant source of bacterial contamination

in marinas is a subject of great debate. Fecal bacteria can also come from birds, marine mammals, pet feces, municipal sewer outfall overflows, and leaking septic tanks.[89] Additionally, marine waters contain bacteria and viruses from natural sources.[90] It is against federal law to discharge untreated sewage within three miles of the coast. Some boaters may still discharge waste because of lack of education, or a perception that discharges are not pollution, exacerbated by the lack of convenient, accessible, easy to use pumpout facilities.[91] Some boaters treat their waste with type I and type II marina sanitation devices (MSDs). Although legal, it is still potentially harmful to discharge treated waste in marine waters because of the chemicals used and system malfunctions, and it is illegal to do so in federally designated no discharge zones (NDZs), such as Richardson Bay. A type III marine sanitation device, a holding tank, is the preferred method because it ensures that no sewage, partially treated or not, enters the water.

6. **Sewage/Bacterial Contamination in California Marinas.** This literature review found very few monitoring efforts documenting bacterial contamination in California marinas. One effort worth noting is a current vessel waste study for implementation of a fecal coliform total maximum daily load (TMDL) in Newport Bay by the Santa Ana Regional Water Quality Control Board.92 This study examined one tidally flushed marina and one sheltered marina during periods of high and low use by vessels. Samples were taken inside the marinas and in the outside channels, with approximately 20-30 sampling sites per marina. Although study reports have not been released, results will help to increase the body of knowledge on bacterial contamination at California marinas.

7. **Sewage/Bacterial Contamination in San Francisco Bay Marinas.** Because of the diffuse sources of coliform bacteria in the marine environment, and the lack of Baywide studies or continuous monitoring, the extent of marina and recreational boating-related bacterial contamination problem is still unknown and difficult to quantify in San Francisco Bay. Most current bacteriological monitoring efforts in San Francisco Bay are not focused on isolating marina and recreational boating sources. Various local environmental health departments, such as San Francisco City and County Environmental Health, San Mateo County Environmental Health, and Berkeley Environmental Health, sample monthly at some marinas, but they are mainly focused on public beaches and storm water and sewer outfalls. This is done to make sure the health of swimmers and recreationists are safeguarded, and that public health standards are not violated. The following sections summarize past, present, and future marina bacteriological monitoring efforts.

a. **1981 Vessel Waste Discharge Survey (San Francisco Regional Board).** In 1981 the San Francisco Regional Board conducted a vessel waste discharge survey in sixteen marina areas in San Francisco Bay, to see if they violated the bacteriological water quality objectives for water contact recreation and shellfish harvesting. Recommendations included the proper sewering of houseboats and liveaboards, which represented sites of continuous violations, and the increased installation and use of sewage pumpout facilities.[93] Many marinas have now installed sewage pumpout facilities and/or contracted with mobile pumpout services. BCDC requires all new and expanding marinas in San Francisco Bay to install sewage pumpout facilities, and to have adequate restroom facilities on shore (to discourage people from using their boat toilets). Several clean marina educational programs distribute maps to boaters depicting the location of sewage pumpout facilities (see the California Department of Boating and Waterways, the Boating Clean and Green Campaign, and the San Francisco Estuary Project).

b. **Richardson Bay Regional Authority (RBRA).** For over ten years, the Richardson Bay Regional Authority (RBRA) and the San Francisco Regional Water Quality Control Board have undertaken a bacteriological monitoring program, with monitoring sites at marinas, to see whether Richardson Bay, a federally designated no-discharge zone, is in compliance with the state's water quality objectives. While certain areas have demonstrated random spikes in bacteria levels, it is difficult to track down the source of the problems. Therefore, in addition to monitoring activities, other proactive efforts in Richardson Bay are being undertaken, such as providing a mobile pumpout service, encouraging replacement of old sewage lines for permitted houseboats, and working with un-permitted houseboats, liveaboards and recreational boats to manage waste.[94]

c. **Water Keepers Northern California/San Francisco BayKeeper.** San Francisco BayKeeper, under a State Coastal Nonpoint Source Prop 13 grant, is gearing up for a three-year bacteria study of four marinas in San Francisco Bay. It will characterize indicator bacteria levels during dry and wet season months, and analyze the relative contributions of indicator bacteria from boating activities and storm water inputs. Not only will this give a better picture of problems at marinas, but it will also help to ascertain potential sources if problems are identified.

BCDC is collaborating with both of these sampling efforts, so that future data and reports can inform its marina and water quality programs. Both representatives from Water Keepers and RBRA sit on the SF Bay Marinas and Recreational Boating Nonpoint Source Task Force.

Nutrient Enrichment: Nitrogen and Phosphorus

1. **Summary.** Excessive nutrients can pose dangers to the health of estuarine ecosystems, including San Francisco Bay. While marinas and boating activities can introduce nutrients into the Bay, there are no existing monitoring efforts to date examining this potential issue. Due to funding limitations, BCDC did not include nutrients as part of its Pilot Study. If future funding becomes available, BCDC or other agencies, such as the Regional Water Quality Control Board, should consider monitoring for nutrients in SF Bay marinas. The following sections provide a description of nutrient enrichment, effects on marine life, potential sources and pathways in marinas, and conclude by documenting existing studies on nutrient enrichment in California and San Francisco Bay marinas.
2. **Description of Nutrients.** At least half of the nation's waters do not adequately support aquatic life because of excess nutrients, specifically nitrogen and phosphorus. While both elements are essential for life, excessive nutrient enrichment can cause eutrophication in waters, affecting the natural functioning of ecosystems. Nitrogen is the primary nutrient responsible for eutrophication in temperate estuaries, while phosphorus is a critical element in tropical estuarine and coastal systems.[95]
3. **Effects of Nutrients on Marine Life.** Coastal areas tend to trap much of the nutrients originating from land-based sources (e.g. agricultural fertilizers, sewage treatment plants). Nutrient-enrichment of waters can result in eutrophication and algal blooms, causing low dissolved oxygen of bottom waters, fish kills, and the depletion of desirable flora and fauna.96 Toxic phytoplankton blooms are called "red tides", and these can cause mass mortality of invertebrates and fish.97 (See Table 1)
4. **Nutrients in San Francisco Bay.** According to the United States Geological Service (USGS), San Francisco Bay receives more than 800 million gallons of municipal wastewater containing 60 tons of nitrogen daily.98 Monitoring dissolved oxygen in the Bay provides a good indicator of organic enrichment (from nutrients or poorly treated sewage, for example). The USGS has been doing this since the early 1970s. Since 1993, dissolved oxygen data have shown that Bay waters have sufficient oxygen to sustain the most sensitive marine species. This is a marked improvement from the 1950s and 60s, before the Clean Water Act began regulating wastewater inputs. Summer oxygen

depletions below 5mg/L, especially in the South Bay (nutrient inputs from cannery waste and ammonia, which contains nitrogen) were common through the 1970s. Advanced wastewater processes have vastly improved the oxygen levels in the Bay by reducing the inputs of oxygen-consuming wastes.99 For example, the implementation of advanced wastewater treatment in 1979 immediately reduced the input of ammonia-nitrogen to South San Francisco Bay.100 The Napa and Petaluma Rivers (including their tidal portions), are listed on the State's 2002 303 (d) list for nutrients. The potential source in the Napa River is agriculture. Potential sources in the Petaluma River include agriculture, construction/land development, and urban runoff/storm sewers.101 Other smaller localized areas, such as marinas, may suffer from low dissolved oxygen, however (see below).

5. **Potential Sources of Nutrients in the Marina Environment.** Many detergents used in vessel cleaning, and in on-board kitchens and bathrooms contain nutrients such as nitrogen and phosphorus. Grey water containing these detergents is sometimes discharged at marinas, and inadvertent spills can occur during topside cleaning activities. Sewage also contains nutrients. Additionally, runoff from landscaped areas at the marinas can contain nutrients from fertilizers. Stormwater runoff from upland sources (e.g. agricultural fertilizers) can also contain nutrients.102,103 (See Table 1)
6. **Nutrients in California Marinas.** This literature review found very few monitoring efforts that document nutrient levels in marinas, although dissolved oxygen monitoring efforts might exist. In California, the Lake Tahoe Regional Water Quality Control Board monitors nutrients in marinas in Lake Tahoe. Nitrogen and Phosphorus levels are consistently above water quality standards (0.15 mg/L and 0.008 mg/L respectively), especially in those closed basin marinas that have limited water flushing capabilities. These water quality conditions could be due to grey water discharges, detergents from boat washing, landscaping fertilizers combined with over-watering, waterfowl feces, domestic animal wastes, and urban runoff from streets that are sanded (contains phosphorus).104
7. **Nutrients in San Francisco Bay Marinas.** This literature review found no monitoring efforts examining nutrients or dissolved oxygen levels in San Francisco Bay marinas. Due to funding limitations and limited staff time, BCDC did not include nutrients (e.g. nitrogen and phosphorus) as part of its Pilot Study. Basic water quality parameters, including dissolved oxygen measurements, were taken during sediment sampling at the four marinas selected for the study (see Appendix A). However, these water measurements represent only a snapshot in time. Dissolved oxygen levels naturally

fluctuate throughout the day. In order to get accurate assessments of dissolved oxygen trends, it is necessary to take multiple measurements at different times of day, and during different tidal regimes. Additional monitoring of oxygen levels is recommended to improve our understanding of oxygen saturation conditions in marinas. San Francisco BayKeeper will be taking readings of basic water quality parameters (temperature, dissolved oxygen, pH, and salinity) as part of its bacteria sampling program.

Table 1. Marina Related Pollutants, Sources, Pathways, and Impacts

Pollutant	Potential Marina & Recreational Boating-related Sources	Potential Marina & Recreational Boating-related Pathways	Potential Impacts to Marine Life and/or human health
Heavy Metals (Copper, zinc, lead, arsenic, chromium, cadmium, tributyltin)	Marine/ boat hull paints, engine components, wood preservatives for pilings and docks, engine oils, boat plating accessories	Runoff from maintenance areas, boatyards, and parking lots. In – water leaching of boat hulls, pilings, and docks. Under-water hull cleaning. Boat bilge discharges.	Marine Life: Bioaccumulation in marine food chain; risk to reproductive & central nervous systems; pathological responses (e.g. developmental changes & growth abnormalities); effects on biotic communities.
Petroleum Hydrocarbons (oil, fuel, PAHs)	Fuel, oil, grease, lubricants, finishes, cleansers, 2-stroke engines; creosote treated wood.	Fuel and oil spills from fueling areas, inadvertent leaks, 2-stroke engines. Oil & fuel contaminated bilge water discharges, runoff from boat engine maintenance areas, sunken vessels leaking fuel and oil; leaching of creosote treated pilings and docks. Boat bilge discharges.	Marine Life: Oil-arrested development benthic communities, lethal effects from smothering, sublethal effects to juveniles & eggs. PAHs-very toxic. Carcinogenic, mutagenic, teratogenic; reproductive failure, reduced growth & fecundity.
Bacterial Contamination	Human wastes from recreational boaters.	Direct discharges and overboard discharges from marine toilets, marine sanitation devices, and on-shore facilities	Marine Life: Eutrophication, anoxic, and hypoxic conditions of marine waters-> lowers dissolved oxygen levels-> affects survival of aquatic organisms. Org. loading from sewage also affects macrobenthic communities. Human risks from pathogens: dysentery, hepatitis, typhoid, gastroenteritis, and parasitic infections
Nutrients (Nitrogen, Phosphorus)	Detergents; fertilizers	Grey water discharges, vessel cleaning and maintenance activities, illegal use of detergents on oil spills and in bilge; runoff from fertilized landscaped areas.	Eutrophication; algal blooms; toxic red tides->lower dissolved oxygen levels, reduced light penetration in water->impacts survival of aquatic life. Affects macrobenthic communities

Chapter 2 Endnotes

[1] U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating.* Nonpoint Source Control Branch, Office of Wetlands, Oceans and Watersheds, Office of Water, U.S. Environmental Protection Agency. November 2001.
[2] SWRCB & CCC 2000. *Plan for California's Nonpoint Source Pollution Control Program.* California State Water Resources Control Board, Sacramento, CA and California Coastal Commission, San Francisco, CA.
[3] It is important to note that the Pilot Study (see Appendix A) focuses on determining if pollutants are present in marinas, and is not a detailed source study. However, by careful selection of marinas for the pilot study to isolate out as much as possible different sources, and by looking to the literature, one can start to make inferences as to possible sources of contamination in those marinas sampled.
[4] See BCDC 2003. *Water Quality Protection and Nonpoint Source Pollution Control in San Francisco Bay.* San Francisco Bay Conservation and Development Commission. San Francisco, CA for overview and policies on other categories of nonpoint source pollution in BCDC's jurisdiction.
[5] Pollutants can enter estuaries such as San Francisco Bay through multiple point and nonpoint *sources* (activities leading to the release of contaminants contained in boat hull paints, automobile combustion byproducts, and pesticides) and numerous *pathways* (routes through which contaminants are transported such as direct water contact with the product [boat hull paints], urban and agricultural runoff). For purposes of this chapter, the term 'sources' encompass both sources and pathways.
[6] Kennish, Michael J. 1998. *Pollution Impacts on Marine Biotic Communities.* CRC Press. Boca Raton & New York.
[7] U.S. EPA 2001
[8] Kennish 1998
[9] Kennish 1998.
[10] Remineralization in sediments is the release of organically bound contaminants (metals and organics) to pore water during the bacterial breakdown of sediment organic matter. This process is most active in the shallow oxic layers of the sediment surface. See Jahnke, RA, Reimers, CE and Craven, DB. 1990. Intensification of recycling of organic matter at the sea floor near ocean margins. Nature, 348, 50-54
[11] Hinkey, Lynne Marie 2001. "A Baseline Assessment of Environmental Conditions and the potential for Polycyclic Aromatic Hydrocarbons (PAHs) Biodegradation in Marina Waters and Sediments." A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Marine Sciences (Chemical Oceanography) University of Puerto Rico. Mayaguez Campus.
[12] SDRWQCB. 2003. DRAFT Basin Plan Amendment and Technical Report for Dissolved Copper in the Shelter Island Yacht Basin. California Regional Water Quality Control Board, San Diego Region. January 31, 2003
[13] Nickel and chromium are naturally high in San Francisco Bay because of the types of soils and rocks within the watershed. They do not appear to be causing harm in the estuary (see SFEI 2000 for more information).
[14] California does not currently have regulatory sediment quality objectives like it does with water quality objectives in its "Basin Plans." Guidelines referred to here are based on Long, E.R., D.L. MacDonald, S.L. Smith and F.D. Calder. 1995. *Incidence of Adverse Biological Effects Within Ranges of Chemical Concentration in Marine and Estuarine Sediments.* Environmental Management. 19 (1): 81-97. "Effects Range Low" (ERL) guidelines (in mg/kg dry weight): copper (34), chromium (81), nickel (20.9), mercury (0.15), lead (46.7), zinc (150). Based on
[15] SFEI. 2003. *Pulse of the Estuary: Monitoring and Managing Contamination in the San Francisco Estuary.* SFEI contribution 74. San Francisco Estuary Institute (SFEI), Oakland, CA.
[16] 2002 CWA Section 303 (d) List of Water Quality Limited Segments. San Francisco Bay Regional Water Quality Control Board. Approved by U.S. EPA July 2003.
[17] CWA Section 303 (d) Monitoring List 2002. July 2003.
[18] METRO. 1992. *Maritime industrial waste project: Reduction of toxicant pollution from the maritime industry in Puget Sound.* Municipality of Metropolitan Seattle Water Pollution Control Department, Industrial Waste Section, Seattle, Washington.
[19] MBNMS 1996. Action Plan III: Marinas and Boating. Water Quality Protection Program for Monterey Bay National Marine Sanctuary.
[20] See Schiff, Kenneth C., Dario Diehl, and Aldis Valkirs. 2003. *Copper Emissions from Antifouling Paint on Recreational Vessels.* Technical Report 405. Southern California Coastal Water Research Project. June 2003; and SDRWQCB. 2003. DRAFT Basin Plan Amendment and Technical Report for Dissolved Copper in the Shelter Island Yacht Basin. California Regional Water Quality Control Board, San Diego Region. January 31, 2003
[21] Metals also occur naturally in the environment, from weathering and erosion of rocks, leaching of soils, eruption of volcanoes, and emissions of deep-sea hydrothermal vents. Anthropogenic sources are much greater in coastal waters near urban centers, however (Source: Kennish, Michael J. 1998. *Pollution Impacts on Marine Biotic Communities.* CRC Press. Boca Raton & New York).
[22] Schiff et al 2003
[23] SDRWQCB 2003
[24] Schiff 2003
[25] USDA 2000. *Environmental Impact of Preservative-Treated Wood in a Wetland Boardwalk.* USDA Forest Service, Forest Products Lab, Madison, WI
[26] Personal communication with Dale Hopkins, San Francisco Regional Board, 10/2003
[27] Santa Monica Bay Restoration Commission, Marina Del Rey Clean Marina Program
[28] U.S. EPA. 1994. *Aquatic Toxic Information Retrieval Database.* U.S. Environmental Protection Agency, Environmental Research Laboratory. Electronic Bulletin Board.
[29] MBNMS 1996
[30] SWRCB. 1988. *Tributyltin: A California Water Quality Assessment.* California State Water Resources Control Board, Division of Water Quality. Report #88-12
[31] U.S. EPA 2001
[32] Hinkey 2001
[33] U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating.* Nonpoint Source Control Branch, Office of Wetlands, Oceans and Watersheds, Office of Water, U.S. Environmental Protection Agency. November 2001.

[34] Hinkey, Lynne Marie 2001. "A Baseline Assessment of Environmental Conditions and the potential for Polycyclic Aromatic Hydrocarbons (PAHs) Biodegradation in Marina Waters and Sediments." A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Marine Sciences (Chemical Oceanography) University of Puerto Rico. Mayaguez Campus.

[35] Washington State Department of Ecology (a). 2001. Concentrations of Selected Chemicals in Sediments from Harbors in the San Juan Islands. Publication No. 01-03-007.

[36] U.S. EPA 2001

[37] Texas Water Commission (TWC). *Marina Impacts in Clear Lake and Galveston Bay.* Report No. D7-001. Houston, TX.

[38] Hinkey 2001; EPA 2001

[39] U.S. EPA 2001

[40] Noblet, James A., Eddy Y. Zeng, Rodger Baird, Richard W. Gossett, Robert J. Ozretich, and Charles R. Phillips. 2003. *Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry.* Southern California Coastal Water Research Project (SCCWRP). Westminster, CA.

[41] Bay, Steven M., David Lapota, Jack Anderson, Jeff Armstrong, Tim Mikel, Andrew W. Jirik, Stanford Asato. *S. CA Bight 1998 Regional Monitoring Program: Vol. IV. Sediment Toxicity.* Southern California Coastal Water Research Project (SCCWRP).

[42] Johnston, R.K. 1990. The Use of Marine Fouling Communities to Evaluate The Ecological Effects of Pollution. Technical Report 1349. Space and Naval Systems Center. Systems Center (SPAWAR). San Diego, CA.

[43] Johnston, R.K. 1990. The Use of Marine Fouling Communities to Evaluate The Ecological Effects of Pollution. Technical Report 1349. Space and Naval Systems Center. Systems Center (SPAWAR). San Diego, CA.

[44]California Toxics Rule for dissolved copper is 3.1 mg Cu/L for continuous or chronic exposures (not to be exceeded over a four-day average), and 4.8 mg Cu/L for brief or acute exposures (not to be exceeded over a one-hour average).

[45]SDRWQCB. 2003. DRAFT Basin Plan Amendment and Technical Report for Dissolved Copper in the Shelter Island Yacht Basin. California Regional Water Quality Control Board, San Diego Region. January 31, 2003

[46] SDRWQCB 2003

[47] Personal communication with Ian Hartwell, National Oceanic and Atmospheric Administration (NOAA) 1/03

[48] Personal communication with Karen Taberski, San Francisco Bay Regional Water Quality Control Board, 1/03

[49] Personal communication with Russell Fairey, Moss Landing Marine Labs, Marine Pollution Studies Lab, 1/03

[50] Hunt, J.W., B.S. Anderson, B.M. Phillips, J. Newman, R.S. Tjeerdema, K. Taberski, C.J. Wilson, M. Stephenson, H.M. Puckett, R. Fairey, and J. Oakden. 1998. *Sediment Quality and Biological Effects in San Francisco Bay.* California State Water Resources Control Board. Sacramento, CA. 188 pp.

[51] Kennish, Michael J. 1998. *Pollution Impacts on Marine Biotic Communities.* CRC Press. Boca Raton & New York.

[52] NCDEM 1991

[53] Kennish 1998

[54] NRC. 2002. *Oil in the Sea III: Inputs, Fates, and Effects.* National Research Council (NRC), Committee on Oil in the Sea: Inputs, Fates, and Effects. Ocean Studies Board and Marine Board. Divisions of Earth and Life Studies and Transportation Research Board. National Academy Press. Washington, D.C.

[55] Kennish, Michael J. 1998. *Pollution Impacts on Marine Biotic Communities.* CRC Press. Boca Raton & New York.

[56] Kennish 1998

[57] Tracy Collier, NOAA Seattle, State of the Estuary conference presentation, October 2003

[58] Any of various organisms that spend part of their life cycle, usually the larval or egg stages, as plankton

[59] Fish eggs and larvae

[60] Kennish 1998

[61] In RMP samples collected from 1997-2001, 61% of water samples had contaminant concentrations exceeding water quality objectives for at least one contaminant.

[62] SFEI 2003. *Pulse of the Estuary: Monitoring and Managing Contamination in the San Francisco Estuary.* San Francisco Estuary Institute (SFEI), Oakland, CA.

[63] 2002 CWA Section 303 (d) List of Water Quality Limited Segments. San Francisco Bay Regional Water Quality Control Board. Approved by U.S. EPA July 2003.

[64] CWA Section 303 (d) Monitoring List 2002. July 2003.

[65] SFEI. 2000. *Pulse of the Estuary: Monitoring and Managing Contamination in the San Francisco Estuary.* San Francisco Estuary Institute, Oakland, CA.

[66]NRC 2002

[67] Kennish 1998

[68] U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating.* Nonpoint Source

[69] MBNMS 1996. Action Plan III: Marinas and Boating. Water Quality Protection Program for Monterey Bay National Marine Sanctuary.

[70] Texas Water Commission (TWC). *Marina Impacts in Clear Lake and Galveston Bay.* Report No. D7-001. Houston, TX.

[71] NRC 2002

[72] MBNMS 1996

[73] Washington State Department of Ecology (a). 2001. Concentrations of Selected Chemicals in Sediments from Harbors in the San Juan Islands. Publication No. 01-03-007.

[74] Katz, C.N. 1998. Seawater Polynuclear Aromatic Hydrocarbons and Copper in San Diego Bay. Technical Report 1768. Space and Naval Systems Center. Systems Center (SPAWAR). San Diego, CA.

[75] Kennish 1998

[76] Noblet, James A., Eddy Y. Zeng, Rodger Baird, Richard W. Gossett, Robert J. Ozretich, and Charles R. Phillips. 2003. *Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry.* Southern California Coastal Water Research Project (SCCWRP). Westminster, CA

[77] BCDC's Pilot Study: Condition of Sediments in Selected Marinas in San Francisco Bay (Appendix A) examines PAH concentrations in sediments of four San Francisco Bay marinas.

[78] MTBE is now banned in California

[79] Bay, Steven M. Brown, Jeffrey S. 2000. *Assessment of MTBE Discharge Impacts on California Marine Water Quality Final report for*

SWRCB. Southern California Coastal Water Research Project, Westminster, CA.
[80] Personal communication with Ian Hartwell, NOAA, 1/03
[81] San Francisco Regional Board. 1997. Proposed Regional Toxic Hotspot Plan
[82] Largier, John. 2002. *Beach Water Pollution: Learning What We Need to Know.* California Coast and Ocean. Winter 2002-2003.
[83] NCDEM. 1990. *North Carolina Coastal Marinas: Water Quality Assessment.* North Carolina Department of Environment, Health, and Natural Resources. Division of Environmental Management. Report #90-01.
[84] Kennish 1998
[85] 2002 CWA Section 303 (d) List of Water Quality Limited Segments. San Francisco Bay Regional Water Quality Control Board. Approved by U.S. EPA July 2003.
[86] see http://www.epa.gov/owow/oceans/regulatory/vessel_sewage/
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[99] SFEI 2003
[100] U.S. Department of Interior, United States Geological Survey (USGS), Fact Sheet FS-053-95
[101] 2002 303 (d) list
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[103] Other significant sources of nutrients include municipal and industrial wastewaters, agricultural and urban runoff, dredging and dredged-spoil disposal operations (Kennish 1998)
[104] Personal communication with Mary Fiore-Wagner, Tahoe Regional Water Quality Control Board, 10/03

APPENDIX A

CONDITION OF SEDIMENTS IN SELECTED MARINAS IN SAN FRANCISCO BAY: A PILOT STUDY

Final Report

August 2004

Marine Pollution Studies Laboratory at
Moss Landing Marine Laboratories

Prepared for:
San Francisco Bay Conservation and Development Commission

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SUMMARY

The San Francisco Bay Conservation and Development Commission (BCDC) and Moss Landing Marine Labs (MLML) designed a pilot study to investigate and evaluate the chemical state of water and sediment within San Francisco Bay marinas. The following report describes and evaluates environmental data collected from four recreational marinas: Berkeley Marina, Loch Lomond Marina, Ballena Isle Marina, and Corinthian Yacht Club, as well as a reference site at Paradise Cove. The intent of this work was to describe the chemical and physical conditions of the marinas so that the probability of ecological impacts resulting from marina activities could be assessed. Chemical analyses were performed using aliquots of homogenized sediment samples while water measurements were taken with water quality meters in the field and from grab samples collected at discrete water depths. A total of forty-three stations were sampled during the field survey, in August 2003. Chemical analyses were conducted through the fall of 2003 and the spring of 2004.

Summary of Results:

1. Sediment quality guidelines were useful in evaluating chemical pollution within the sediments of four San Francisco Bay marinas. Arsenic, chromium, copper, and zinc were most often found to exceed established Effects Range Low (ERL), Threshold Effects Levels (TEL) and Ambient guideline values. Use of these guidelines indicates that these chemicals pose a low, to occasionally moderate, probability of having associated acute toxic effects to aquatic life. Of these four metals, copper and chromium are is of greatest concern. Long-term status and trend monitoring of these four trace metals in marinas is recommended.
2. Dissolved oxygen concentrations in Ballena Isle and Berkeley Marinas were low (<4 mg/l) in bottom waters at several locations and may present a risk of hypoxia to aquatic life. Additional monitoring of oxygen levels is recommended to improve both spatial and temporal resolution of oxygen saturation conditions.
3. Measured concentrations of cadmium, lead and polycyclic aromatic hydrocarbons (PAHs) were generally low and pose a low probability of having associated acute toxic effects to aquatic life.
4. Statistical analyses indicate Corinthian Yacht Club tended to have significantly lower metal concentrations than all other marinas, and was similar to the reference site at Paradise Cove. There was no clear pattern of statistical differences in metal or PAH concentrations among Berkeley, and Ballena Isle Marinas. Loch Lomond tended to have significantly lower PAH concentrations than most other marinas, though zinc was significantly greater there. Zinc was the metal most often seen to have significant differences between harbors and thus may be the metal most influenced by local uses. TOC and grain size showed no significant differences among the harbors.
5. PAHs were generally not correlated or were negatively correlated with metals, so their use or sources do not seem strongly linked. Copper, cadmium and zinc were often positively correlated suggesting common uses might be the source of these metals to the marinas. Arsenic did not correlate or was negatively correlated with the other metals indicating a separate use or source as compared to other trace metals.

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LIST OF ABBREVIATIONS

BPTCP	Bay Protection and Toxic Cleanup Program
CDFG	California Department of Fish and Game
COC	Chain of Custody
COR	Chain of Records
EMAP	Environmental Monitoring and Assessment Program
ERL	Effects Range Low
ERM	Effects Range Median
GC/ECD	Gas Chromatograph Electron Capture Detection
HCL	Hydrochloric Acid
HDPE	High-density Polyethylene
HMW PAH	High Molecular Weight Polycyclic Aromatic Hydrocarbons
LMW PAH	Low Molecular Weight Polycyclic Aromatic Hydrocarbons
MDL	Method Detection Limit
MLML	Moss Landing Marine Laboratories
MPSL	Marine Pollution Studies Laboratory
NOAA	National Oceanic and Atmospheric Administration
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
PEL	Probable Effects Level
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RWQCB	Regional Water Quality Control Board
SQC	Sediment Quality Criteria
SFBCDC	San Francisco Bay Conservation and Development Commission
TAC	Technical Advisory Committee
TEL	Threshold Effects Level
TOC	Total Organic Carbon
SWAMP	Surface Water Ambient Monitoring Program
USEPA	U.S. Environmental Protection Agency

Units

milliliter = 1 ml
microliter = 1 μl
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

Ensuring that pollution is prevented and water and sediment quality is maintained is of concern to the San Francisco Bay Conservation and Development Commission (BCDC) in making permitting decisions on projects in and on the shoreline of San Francisco Bay. Marinas and recreational boating have been identified as a category of nonpoint source pollution in California by the State Water Resources Control Board (State Board) and the California Coastal Commission (CCC), and nationally, by the U.S. Environmental Protection Agency (U.S. EPA) and the National Oceanic and Atmospheric Administration (NOAA). However, few scientific studies have been conducted to determine whether, and to what extent, marina-related pollution is a problem in San Francisco Bay. BCDC has taken on this task as part of its nonpoint source pollution program, and this pilot study.

Marina and boating operations can be the source of pollutants such as heavy metals from boat hull paints, anti-corrodants, wood preservatives on docks and pilings, from various boat accessories such as chrome plating and stainless steel, and batteries; petroleum hydrocarbons (including PAHs) from fueling, oil spills, and fuel combustion from outboard motors and from creosote wood treatments in pilings and docks; and other pollutants discussed in Chapter Two, but not analyzed as part of this Pilot Study.

Many of the above pollutants can also originate from other non-marina sources such as municipal storm water discharges and discharges from industrial activities. This Pilot Study: Condition of Sediments in Selected Marinas in San Francisco Bay characterizes sediment quality conditions at four marinas, and isolates as much as possible marina-related pollution from other sources. Sediments samples were collected and analyzed as "surrogates" for water quality because of their ability to act as sinks for heavy metals and PAHs, and act as "long term integrators," allowing for a single sampling event in each marina while representing conditions over a longer time period. Single event measurements of conventional water quality parameters in the water column (dissolved oxygen, temperature, salinity, pH and turbidity) were also taken to get a "snapshot" of general water quality conditions at the time of sampling. Benthic community samples were also taken and archived for future analysis (pending future funding).

Study Questions

BCDC staff and Moss Landing Marine Labs (MLML) developed the following study questions, with input from the marina study's Technical Advisory Committee (TAC)[1] and the San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force (Task Force).[2]

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[1] A group comprised of scientists from the San Francisco Regional Water Quality Control Board (San Francisco Regional Board), California State Water Resources Control Board (State Board), San Francisco Estuary Institute (SFEI), NOAA CSC, California Coastal Commission (CCC), Moss Landing Marine Labs (MLML), and representatives from Recreational Boaters of California (RBOC) and the California Association of Harbor Masters and Port Captains.

[2] A group comprised of marina and boating operators and associations, environmental organizations, and local, state and federal government organizations (Appendix B lists the major active organizations on the Task Force).

1. "What is the sediment chemistry concentration in four recreational marinas in San Francisco Bay in regards to the following pollutants associated with marina and recreational boating operations: trace metals (copper, zinc, chromium, lead, arsenic, cadmium), polycyclic aromatic hydrocarbons (PAHs)?"
2. "Do sediment chemical concentration levels meet or exceed sediment guidelines (e.g. Effects Range Low [ERL], Effects Range Median [ERM], Threshold Effects Level [TEL], and Probable Effects Level [PEL]?"
3. How do sediment concentration levels compare to Ambient sediment concentrations calculated for the Bay, and Regional Monitoring Program (RMP) reference stations at Paradise Cove?"
4. "What general water quality conditions exist in the four marinas in regards to dissolved oxygen, temperature, turbidity, pH, and salinity?"
5. "Is there a noticeable difference in contaminant levels found between the four marinas sampled and can we make plausible inferences as to why those differences exist?"

Study Area

Marina Selection Procedure. BCDC staff developed marina selection criteria for the pilot study in conjunction with the Task Force and the TAC. Because the pilot study involved only four marinas due to budget constraints, selecting these marinas carefully was crucial to best answer the research questions, and to the maximum extent practicable, to be representative of the wide variety of marinas in San Francisco Bay. It is difficult to define a typical marina in San Francisco Bay, because of their wide variety of physical, geographical, environmental, and demographical characteristics. BCDC staff developed a marina matrix for forty-three marinas, which aided in this process. The matrix included the following data for each marina (see Appendix C for the condensed marina selection matrix used by the TAC):

1. Marina size (number of berths)
2. Boat types
3. Marina age
4. Activity level (vessel traffic)
5. Surrounding land-use
6. Historical land-use
7. Current and flushing patterns
8. Marina layout (e.g. open or enclosed)
9. Water depth
10. Sediment depositional rates
11. Sediment depositional patterns
12. Dredging frequency
13. Storm water influence (e.g. municipal storm drain or no municipal storm drain)
14. Marina facilities
15. Environmental services/policies

BCDC staff obtained this data from a variety of sources, including a telephone survey of marina harbormasters, the California Department of Boating and Waterways (DBW) databases, the California Coastal Commission Boating Clean and Green Campaign's databases, task force members, and marina site visits.

The data collected revealed that several marinas in San Francisco Bay contain municipal stormdrain outfalls that may discharge municipal stormwater and dry weather flows into the marina basins. These marinas were automatically disqualified from the Pilot Study in order isolate the pilot sites from non-marina and recreational boating-related sources of nonpoint pollution.

In order to represent the different types of marinas in San Francisco Bay, the remaining marinas were categorized on a scale of 1-4, based on their available facilities and services. Marinas near the top of the scale (#4) were those marinas with a variety of services such as a fuel dock, maintenance areas, haul-out facilities, dry storage, launch ramps, and shore side car parking lots. Marinas on the bottom of the scale (#1) were those marinas with few of those services. After categorization, the following criteria were used to select the most appropriate marinas for the study. Since it is difficult to find four marinas that fit all the criteria perfectly, the criteria were prioritized according to what would affect the results the most.

1. To the best extent practicable, all four marinas will be located beyond the influence of municipal storm drains to minimize the intervening variables associated with nonpoint source pollution from municipal stormwater.
2. To the best extent practicable, the surrounding land-use of all four selected marinas will have low industrial activity to minimize intervening variables associated with nonpoint source pollution from these activities.
3. To the best extent practicable, all four marinas will have similar sediment depositional rates.
4. To the best extent practicable, all four marinas will have roughly the same proportion of 'types' of boats, including sailboats, powerboats, and liveaboards.
5. To the best extent practicable, all four marinas will have roughly the same level of vessel traffic, preferably busier marinas, rather than marinas with boats sitting in slips most of the time.
6. To the best extent practicable, all four marinas will be roughly the same age.
7. To the best extent practicable, all four marinas will be roughly the same depth at Mean Lower Low Water (MLLW).

The selection process resulted in the identification of four suitable marinas and one reference location (Figure 1): Ballena Isle Marina (Alameda), Berkeley Marina, Corinthian Yacht Club (Tiburon), and Loch Lomond Marina (near Richmond/San Rafael). A reference location was selected at Paradise Cove (reference) for comparison to previous surveys and ambient conditions. This survey was intended to give a broad assessment of chemical conditions throughout the four San Francisco Bay marinas by providing multiple analyses from the water column and from sediment samples.

Table 1. Selected Marinas[3]

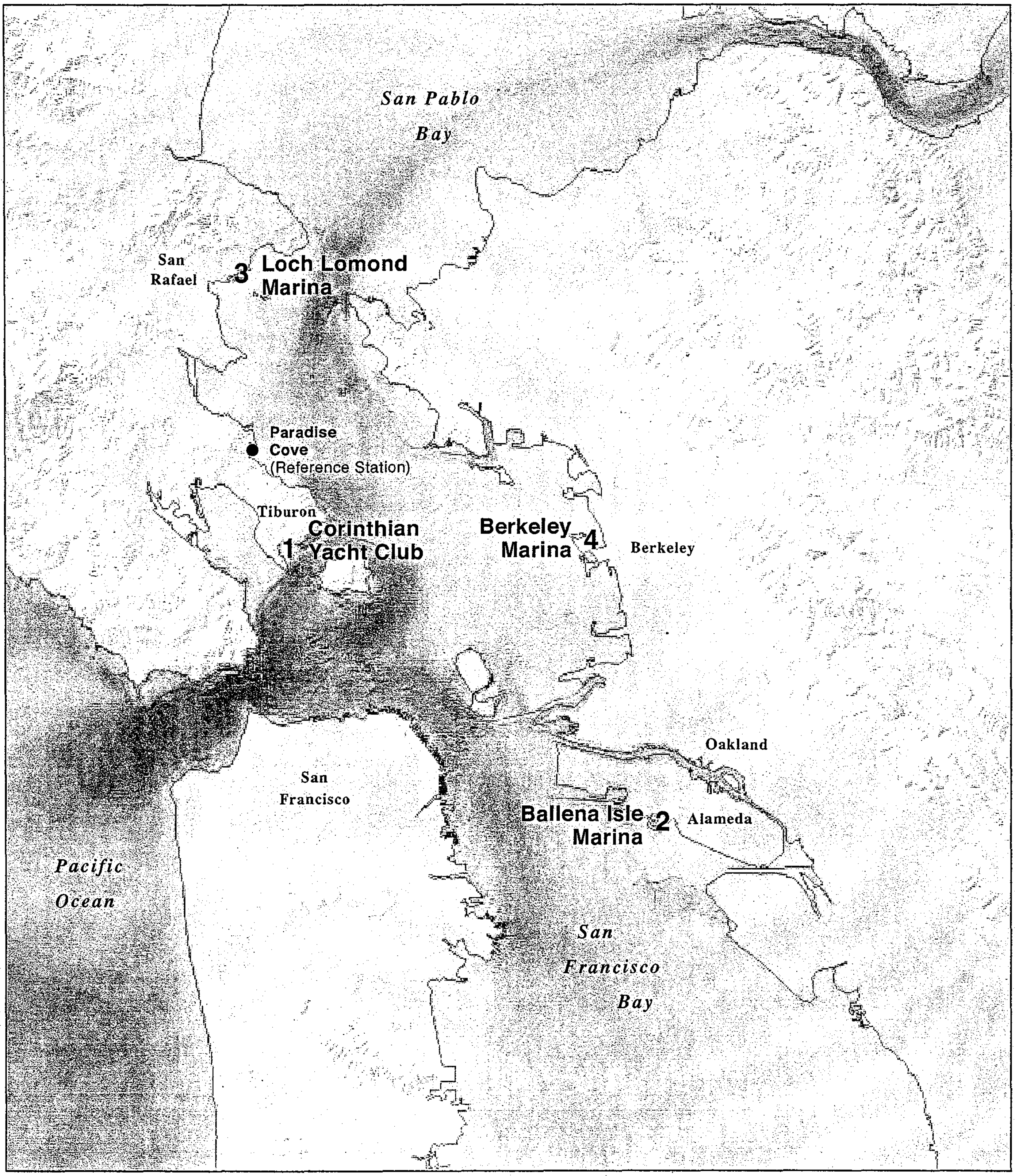
Marina	Location	Size	Facilities	Category
Berkeley Marina	City of Berkeley, Alameda County	1100 wet berths 77 dry storage	fuel dock, full service boat yard, boat launch, dry storage, parking lot	4
Loch Lomond Marina	San Rafael, Marin County	517 wet berths 250 dry storage	fuel dock, mechanic shop, boat launch, parking lot	3
Ballena Isle Marina	City of Alameda, Alameda County	504 wet berths 45 dry storage	fuel dock, hoist, parking lot	2
Corinthian Yacht Club	Tiburon, Marin County	85 wet berths 25 dry storage (+40 dinghy racks)	hoist, small maintenance area, parking lot	1

[3] See Appendix D for additional information on the selection criteria for each marina

NORTH

Figure 1
Marina Pilot Study Sites

SOURCE: San Francisco Bay Conservation and Development Commission;
Relief base map, USGS



San Francisco Bay Conservation and Development Commission

BERKELEY MARINA

Berkeley marina is located on a man-made peninsula on the Western edge of the City of Berkeley, Alameda County, in central east San Francisco Bay, four miles north of the San Francisco Bay Bridge (see Figure 1).

Category. On BCDC's marina scale, Berkeley is categorized as a level four marina. The largest marina in Northern California, Berkeley marina has 1100 berths and can accommodate vessels up to 135 feet long. Available facilities include a fuel dock, a boat yard with haul-out capacity and scraping and sanding services (also a marine canvas business), a public boat launch, a seventy-seven boat capacity dry storage area, a public fishing pier (on open water outside the marina basin), charter fishing boats, and public parking lots. Other marina-related businesses on the marina premises include several restrooms and showers, a yacht club, hotel, restaurants, and a day cruise business (Hornblower), playgrounds, and a marina sports center.

Layout and Structures. The general layout of the marina is an enclosed basin, with an entrance opening flanked by an entrance breakwater, which helps to eliminate surge and rough water. Boat docks are supported with wood pilings and to a lesser extent, concrete pilings. Wood pilings are mostly treated with copper based wood preservatives, while some are treated with creosote (see Chapter Three for a description of these preservatives).

Surrounding Land Use. Berkeley's surrounding land and water-uses include several acres of public parks (including Cesar Chavez Park and Shorebird Park), an adventure playground, a nature center, and the South Sailing Basin with a beach and rocky shore, and a small boat dock and hoist. Just off the marina peninsula along the Bay shoreline is Interstate Highway 80, and City of Berkeley public beaches.

Boat Types and Activity. The marina hosts a wide diversity of vessels, consisting of 80 percent sailing and 20 percent power boats. A few houseboats occupy docks on the East shore. Slips vary in size, with the shortest being eighteen feet, and the longest at eighty-five feet. Approximately 10 percent of recreational boats are marina authorized liveaboards.[4] In addition to recreational vessels, the marina also hosts public fishing charter boats, and large 'Hornblower' dinner cruise boats. A research and marine educational vessel also docks at the marina. The harbormaster describes the marina as fairly busy, especially on weekends when 75 percent of boaters are there, and there is foot traffic from sailing and yacht club clients.

History. The marina was first constructed in 1936, and expanded several times in the 1960s, '70s, and '90s. During World War II the marina was used as a landing barge training base operated by the Navy. For several years, the marina co-existed with a city landfill just to the Northeast, which is now covered by Cesar Chavez Park. The landfill began receiving waste in

[4] Live-aboard boats are designed and used for active navigation but are distinguished from other navigable boats in that they are also used as a primary place of residence. See BCDC. 2003. San Francisco Bay Plan. San Francisco Bay Conservation and Development Commission (BCDC). San Francisco. Reprinted March 2003, p. 49. See also California Code of Regulations Title 14. § 10128. "A 'live-aboard' boat is a boat that is not a transient boat, that is capable of being used for active self-propelled navigation, and that is occupied as a residence as that term is defined in California Government Code Section 244."

1961 and concluded operations in 1983, after which it underwent formal closure, and is currently conducting post-closure operations and maintenance (SCS Engineers 2003). An operational methane burner still exists on site, and the site's groundwater and storm water is monitored periodically by the City of Berkeley.

Sediment Deposition. Berkeley Marina has an average water depth of twelve feet at mean lower low water (MLLW), and an entrance depth of eight feet (MLLW). It has not been dredged since 1989. The North entrance is currently in need of dredging. According to information from Emery Cove Yacht Harbor next door, sediment deposition rates are about 2.4 inches per year.

Environmental Services and Policies. The marina has a variety of environmental services, and conducts some environmental management practices. Services include a sewage pump out station, used oil collection, and absorbent pad distribution and collection facilities. Additionally, the marina has several ordinances in its tenant lease that apply to environmental issues, which are summarized below. Dilapidated, unseaworthy boats are prohibited in the harbor. Dock boxes are prohibited to contain flammable liquids or hazardous materials. All discharges of any material are prohibited in the harbor, including oil, spirits, flammable liquids, contaminated bilge water, treated or untreated sewage, grey water, and solid and hazardous waste. Garbage must be deposited in receptacles provided by the marina. Additionally, docks must be kept free and clear of hazardous or flammable materials. While repairs and maintenance of vessels are allowed in berths, no debris or fluids from this activity are allowed to accumulate on the docks or enter marina waters. Welding equipment, burning torches, spray paint and sand blasting equipment is prohibited except in specifically designated areas. The use of boat sanitary facilities is prohibited while docked in the marina, except in vessels that are equipped with an approved operating device for the containment of sewage and gray water. Fish cleaning is prohibited in the marina except in designated areas. The boatyard, which is a separately owned business, conducts wet sanding and has a waste water filtration system (this is regulated under a National Pollution Discharge Elimination System [NPDES] permit, administered through the San Francisco Regional Board).

Non-BCDC Water Quality Data. Some water quality monitoring has been conducted in Berkeley Marina. The City of Berkeley (Environmental Health Department) monitors for bacteria (fecal coliform and *E. coli*) in the marina and its adjacent shorelines, in a proactive effort to safeguard public health in this large public recreation area. While some problems have occurred on the North and South Shorelines (outside the marina basin) and within the sailing basin, it is difficult to ascertain clear trends or problems using monthly data. While BCDC did not sample for bacteria in its pilot study, WaterKeepers Northern California/San Francisco BayKeeper will include this marina as part of its bacteria monitoring program, and the information obtained will help inform BCDC's marina program.

SCS Engineers, a consultant for the City of Berkeley Public Works Engineering Department periodically monitors the groundwater and surface stormwater of Cesar Chavez Park, the former landfill located adjacent to and Northeast of Berkeley Marina. Although these measurements were not taken within the marina basin and were not factored into the sediment analysis, the data are presented here for the reader's reference. In August 1994 samples taken from levee seepage wells, leachate wells, and groundwater monitoring wells were analyzed for total dissolved solids (TDS), chemical oxygen demand (COD), chloride, chromium, lead, and volatile organic compounds (VOC), and volatile aromatic hydrocarbons (using EPA Method 8240). Five shallow ground water monitoring wells were sampled. TDS concentration for ground water samples ranged from 3,200 to 23,000 mg/l. Chloride concentrations ranged from 3,600 to 14,000 mg/l. Lead was not detected in any of the samples. Chromium was detected in samples from three of the wells at concentrations ranging from 0.031 to 0.064 mg/l. Chromium concentration was above the drinking water MCL of 0.050 mg/l in samples from two of the wells. VOCs were not detected in any of the five ground water wells sampled. In leachate wells, TDS concentrations ranged from 2,000 to 7,800 mg/l. Chloride concentrations ranged from 500 to 1,700 mg/l. Lead was not detected in any of the leachate wells. Chromium was detected in two of the wells, one of which had a concentration slightly above the MCL of 0.05 MG/L (L-7, 0.059 mg/l). Low concentrations of volatile aromatic hydrocarbons were detected in samples from two wells (L-6 and L-7). Benzene was detected in well L-6 at a concentration of 1.4 μ/l. In levee seepage wells, TDS concentrations ranged from 1,300 mg/l to greater than 5,300 mg/l. Chloride concentrations ranged from 54 to 5,300 mg/l. Lead was not detected in any of the samples. Chromium was detected in samples from three of the wells at concentrations ranging from 0.013 to 0.023 mg/l which are all below the MCL of 0.050 mg/l. Volatile aromatic hydrocarbons were detected in one of the wells (G-5). Benzene was detected at a concentration of 2.7 μ/l which is slightly higher than its MCL of 1.0 μ/l (SCS Engineers, 1994). Selected chemical analysis results were reviewed for general correlation to observed measures in the current marina Pilot Study.

LOCH LOMOND MARINA

Loch Lomond Marina is located in Central San Rafael, Marin County, in San Pablo Bay just northwest of San Rafael Canal (Figure 1).

Category. On the marina scale Loch Lomond is categorized as a level three marina. It has 517 wet berths and a 250 boat capacity dry storage area (one half of which is slated for condo conversion), and parking lots. Other facilities include a fuel dock, a maintenance area for boat engine work, public boat launch ramp, some covered slips, and a bait shop located on the fuel dock. Additional supporting facilities include restrooms, showers, a restaurant, and a yacht club.

Layout and Structures. The general marina layout is a rectangular shaped enclosed basin, flanked by a manmade breakwater of vegetated rip rap on the East and South sides, which also serves as a pedestrian pathway. The marina was constructed by filling in mudflats and then dredging out the basin. A recent upgrade of the marina was conducted in 1995 replacing several docks. Currently marina structures are wood docks supported by creosote treated wood pilings (see Chapter Three for a description of this wood preservative).

Surrounding Land Use and History. Loch Lomond's surrounding land-use is mainly residential, especially in the surrounding hills. The marina property contains a commercial strip mall with a dry cleaning and laundry facility. Before the marina was constructed in 1958, the marina basin site was characterized by mud flats.

Boat Types and Activity. According to its harbormaster, Loch Lomond is a very busy marina, especially on weekends. Approximately sixty percent of Loch Lomond's boats are power boats, and the remaining forty percent are sailboats. Slips accommodate boats as small as twenty-four feet and as long as sixty-two and a half feet. Ten percent of all boats are marina authorized liveaboards.

Sediment Deposition. The marina basin has an average water depth of seven feet and eight feet at the entrance. Sediment depositional rates are fairly rapid with 0.5 – 1 feet filling in per year, requiring frequent maintenance dredging episodes. Depositional patterns are uneven however, with the west basin filling in faster than the east basin, according to the harbormaster. Before the last dredging episode in April 2003 depths in the channel ranged from –3.5 to –6.0 feet MLLW, and depths around the berths ranged from –3.0 to –8.0 MLLW (ABT 2001). Prior to this episode, it hadn't been dredged for at least five years. The east basin was last dredged five years ago.[5]

Environmental Services and Policies. Environmental services at the marina include a sewage pumpout station located on the fuel dock, used oil recycling, and an absorbent pad exchange program. The marina also has some rules and regulations for its tenants that apply to environmental issues. No fueling is allowed at any place other than the fuel dock. Petroleum, paint products, and batteries are prohibited from being stored in dock areas. Fish cleaning and preparation of bait are also prohibited in the dock areas. Repairing or servicing of automobiles is prohibited at the marina, and oils and oil filters from vessels are prohibited from being dumped in garbage bins. These items are required to be disposed of in recycling areas. Unseaworthy, dilapidated, badly deteriorated, or inoperable vessels are not permitted to be stored in the harbor.[6] The marina office also provides free clean boating literature.

Non-BCDC Water Quality Data. There is no active water quality monitoring program at Loch Lomond marina. However, in 2001 the marina conducted tier three testing of bottom sediments in preparation for maintenance dredging. This information provided background data to help inform BCDC's pilot study. This testing was conducted in accordance with requirements from the Dredged Materials Management Office (DMMO), a collaboration of regulatory agencies for dredging (U.S. Army Corps of Engineers, U.S. EPA, SF Regional Water Quality Control Board, and BCDC). Analytical chemistry, bioassay testing (water column and benthic), and grain size analysis were conducted on sediments from Loch Lomond. Samples were collected and composited in February 2001 at seven sites around the entrance channel and berth areas. Sample cores were taken at depths of the anticipated dredge (-10 feet MLLW). Selected chemical analysis results were reviewed for general correlation to observed measures in the current marina Pilot Study.

[5] Personal communication with Pat Lopez, Loch Lomond harbormaster, 6/03

[6] Loch Lomond Marina Berth Rental Agreement and Rules and Regulations

Ballena Isle Marina

Ballena Isle Marina is located in Central San Francisco Bay in an enclosed basin on the south side of Alameda Island. While most Alameda marinas are located on the north side, in the Oakland Estuary, Ballena Isle is located in San Francisco Bay, and is isolated from the other marinas (Figure 1).

Category. Ballena Isle is categorized as a level two marina on BCDC's marina scale. It has 504 berths, and a forty-five boat capacity dry storage area. Available facilities include a fuel dock, a hoist for hauling out boats, and parking lots. Additional supporting facilities include restrooms and showers, a yacht club, restaurant, a convenience store, and laundry.

Layout and Structures. Ballena Isle is a horseshoe shaped enclosed-basin marina built between land and a man made peninsula, made from dredged material. There is a small breakwater made from rip rap at the Southeast end. Docks are supported by wood pilings treated with creosote and copper based wood preservatives (see Chapter Three for a description of these wood preservatives).

Surrounding Land Use and History. The marina's surrounding land-use is mostly residential and open space. One unique aspect of Ballena Isle is that it is located next to several waterfront condos with private boat slips (located in Ballena Bay channel). Historically, the marina's surrounding area was owned by the federal government, and was kept as open space.

Boat Types. Sixty-five percent of the boats docked in the marina are sailboats, and thirty-five percent are power. Slips accommodate boats from twenty-four to seventy feet. The marina allows 10 percent of its tenants to be liveaboards.

Sediment Deposition. The average depth of the marina basin and the entrance is eight feet at MLLW and the entrance is eight feet at MLLW. Based on a 2001 bathymetric survey, the marina receives approximately six inches per year of sediment deposition. The marina was last dredged in April 2002, when approximately 27,000 cubic yards of sediment were removed from the main fairway and the rest of the marina area.[7] The marina needs to be dredged approximately every seven years, although the harbormaster predicts it will need to be dredged in two years time, sooner than usually predicted. This could be due to strong currents, and the fact that new sand was added to the nearby Crab Cove Beach.

Environmental Services and Policies. Environmental services at the marina include a sewage pumpout, absorbent pad distribution and collection, and waste oil collection. The marina also has some terms of mooring and rules and regulations that apply to environmental issues. Any unnecessary operation of engines is not permitted. Tenants must agree not to do major boat repairs, such as motor overhauls, hull painting and structural changes, to their boats while in the marina. Dock areas must be kept free of non-marina approved materials. Boaters are prohibited from introducing hazardous wastes into marina waters or adjoining property. Boats are prohibited

[7] BCDC permit no. 12-84, amendment #4, dredge quantity computations by Sea Surveyor, Inc. maximum amount authorized in permit 50,000 cubic yards until 2006

from being fueled anywhere except at the fuel dock. Waste oils, paint solvents, paints and other chemicals must be disposed of in receptacles specifically provided by the marina. Fishing and swimming are not permitted within the marina. Open fires or barbecues are not permitted on docks, but gas fired barbecues are permitted on boats only. Pets must be leashed at all times, and pet owners are responsible for cleaning up pet feces. Lastly, marine sanitation devices must be emptied at the designated discharge facility (pumpout).

Non-BCDC Water Quality Data. There is no active water quality monitoring program at Ballena Isle Marina. However, bottom sediments were sampled and analyzed in preparation for maintenance dredging and disposal in August 1998. This information provides background data to inform BCDC's pilot study. Advanced Biological Testing, Inc. (ABT) conducted chemical, physical, and bioassay testing of sediments at Ballena Isle by under guidelines established in PN 93-2 (ACOE et al 1992) as well as guidelines provided in the Testing Manual for the Evaluation of Dredged Material Proposed for Ocean Disposal (U.S. EPA/ACOE, 1991). The marina was divided into three dredging sections, and one composite sample comprised of five sediment cores was tested per site, for a total of three composite samples. Each core sample was taken to a maintained depth of –10 feet MLLW. Selected chemical analysis results were reviewed for general correlation to observed measures in the current marina Pilot Study.

CORINTHIAN YACHT CLUB

Corinthian Yacht Club is a private 'members-only' marina in Tiburon, Marin County. The marina is located on the north-western side of Raccoon Straits between Corinthian and Belvedere Islands in the west, and the Tiburon / San Francisco - and Angel Island - Ferry docks to the east (Figure 1).

Category. On BCDC's marina scale, Corinthian is categorized as a category one marina. It has approximately eighty-five boats in wet slips, and a 25-boat capacity dry storage area, where members also conduct maintenance work adjacent to the water's edge. Additionally, the club has forty dinghy racks under the clubhouse for Zodiacs and small dinghies. The only other available facilities are a launch hoist and parking lot.

Layout and Structures. A manmade breakwater on the southeast side gives the marina a fish hook shape and encloses Corinthian's basin. Its docks are supported by plastic coated steel pipe pilings, and twenty-five pilings are made of creosote treated wood (See Chapter Three for a description of this wood preservative).

Surrounding Land Use. The surrounding land uses at Corinthian are commercial and residential, with several shops and restaurants flanking Tiburon's main street and the Bay's shoreline just northeast of the marina basin.

Boat Types and Activity. Sixty-six percent of Corinthian's boats are sailboats, with the remaining thirty-four percent power. While weekday boat traffic is low in the marina, the weekends are quite busy, with thirty-five of its boats in use, as well as guest boaters going to nearby cafés and restaurants.

History. Corinthian is a relatively old marina. Anchorage and moorings were created in 1887, and the marina has slowly expanded since then. The historical use near the site included a terminal and railhead for the Pacific Northern Railroad Ferry, connecting to San Francisco's docks and the Pacific Northwest.

Sediment Deposition. Corinthian's water depth varies, ranging from 4.7 feet in section G (in the center of the basin) to 9.7 feet near the breakwater (east to southeast end of the basin). The channel entrance depth is 12.5 feet. Sediment deposits at an approximate rate of five to six inches per year, in an uneven pattern. The northwest end of the basin has experienced more silting than other areas. Corinthian was last dredged in 1998, and approximately 31,000 cubic yards of sediment was removed.[8] The marina is on a six-year dredging cycle and currently in need of dredging. Marina officials are proposing to dredge approximately 48,800 cubic yards over the next ten years.[9]

Environmental Services. This small marina does not have any extensive environmental services, such as sewage pumpouts or used oil collection and recycling. The harbor has several binding rules and regulations that apply to environmental issues, however. No discharge of marine toilets or contaminated bilge water is permitted in the marina basin. Boats in berths are prohibited from continuously running their engines. Liveaboards are prohibited. Solid and hazardous wastes must be disposed of in specific containers provided by the club, or permanently removed from the premises. Storage of flammable materials are not permitted in lock boxes, and major repair, rebuilding or remodeling work is not permitted in the harbor. Minor repair in the harbor is permitted, but rules state that it must be performed in an environmentally sound way (no specific practices are listed in the rules and regulations document). Finally, unseaworthy boats are not permitted to be berthed in the harbor.[10]

Non-BCDC Water Quality Data. Like most marinas in San Francisco Bay Corinthian does not regularly test marina waters or sediments. Corinthian conducted sediment sampling in preparation for maintenance dredging and disposal activities in 2003, however. Chemical and physical analyses of sediments were conducted, as well as biological testing (bioassays). Sediment core samples were collected from eight stations within the harbor. Four sample stations were assigned to each of the two designated sample areas within the harbor. Individual core samples were composited in the laboratory to form one representative sample per area. Test results were evaluated to assess the suitability of the harbor's dredged material for the in-Bay sediment disposal site located at the Alcatraz Environs (SF-11). Analytical methods followed procedures specified in: *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual* (ITM; USEPA/ACE 1998) and *Guidelines for Implementing the Inland Testing Manual in the San Francisco Bay Region* (PN 01-01; USACE 2001). Selected chemical analysis results were reviewed for general correlation to observed measures in the current marina Pilot Study.

[8] Ingo Schreiber, per. com., 11/03

[9] BCDC permit application M81-67 amendment #1

[10] Corinthian Yacht Club Harbor Rules and Regulations. As amended December 2002.

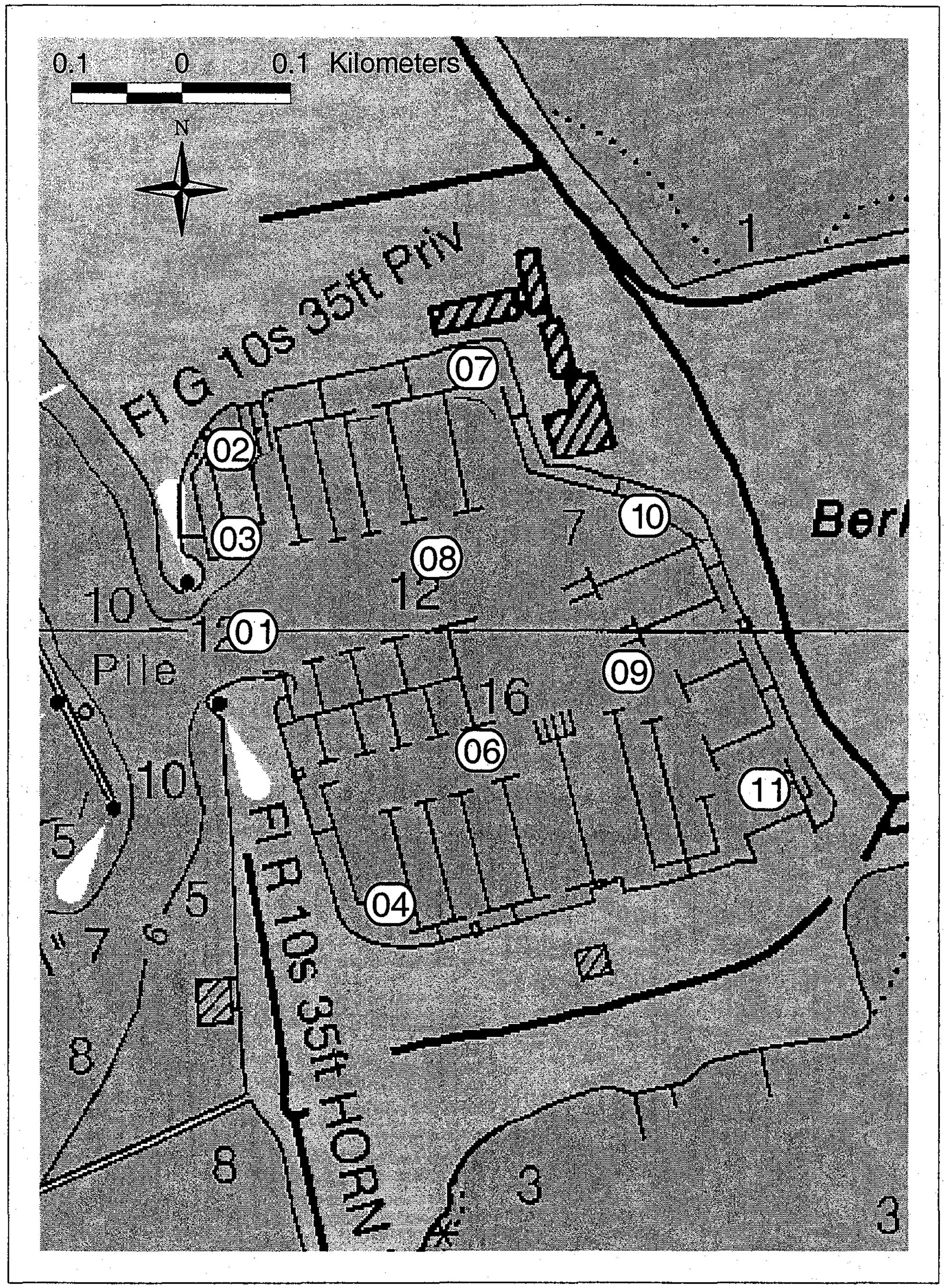


Figure 2a. San Francisco Bay Marina Sampling Locations-Berkeley Marina

*Sample #5 is not shown because it is a blind field duplicate taken at station #8

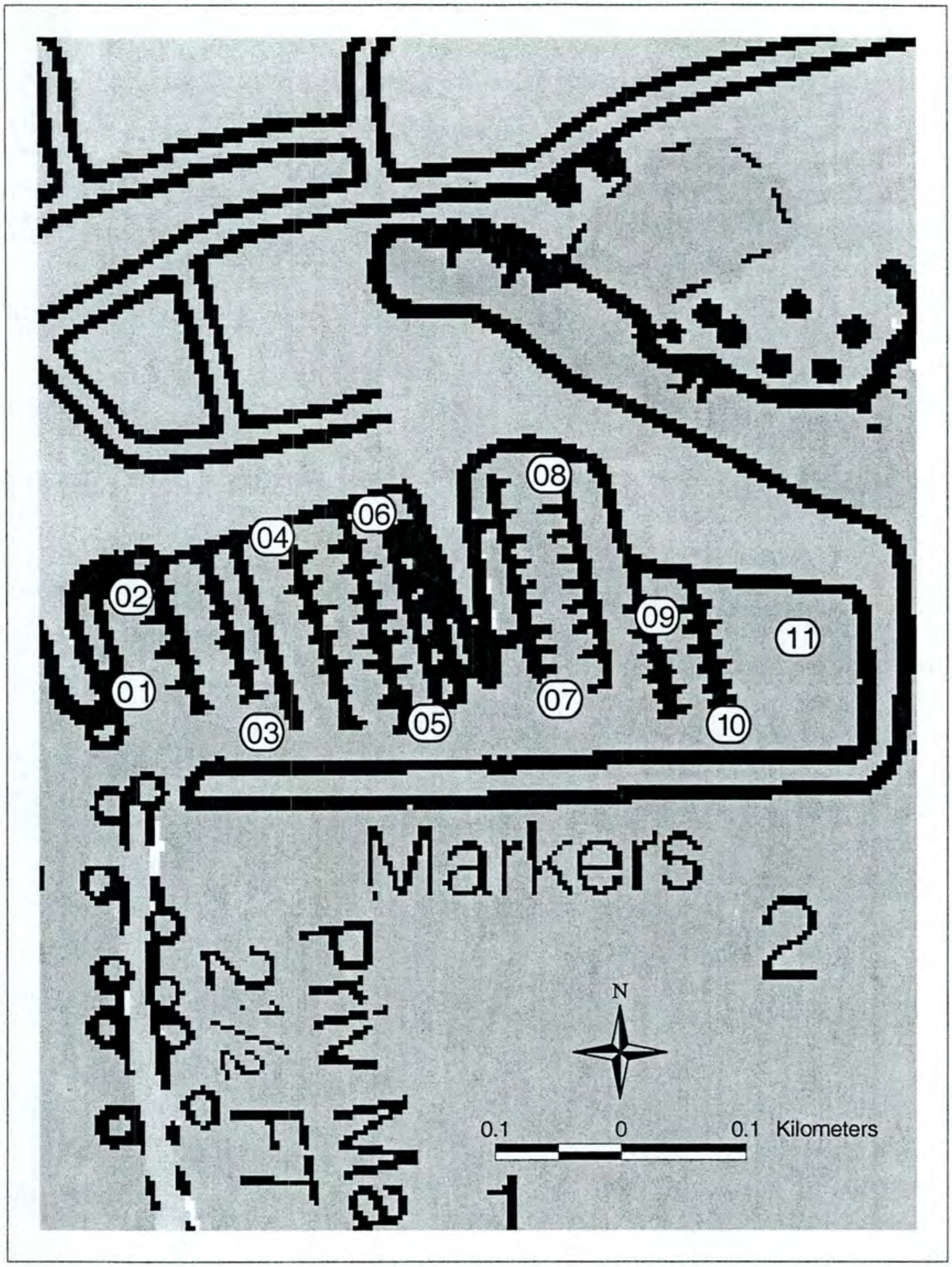


Figure 2b. San Francisco Bay Marina Sampling Locations-Loch Lomond Marina

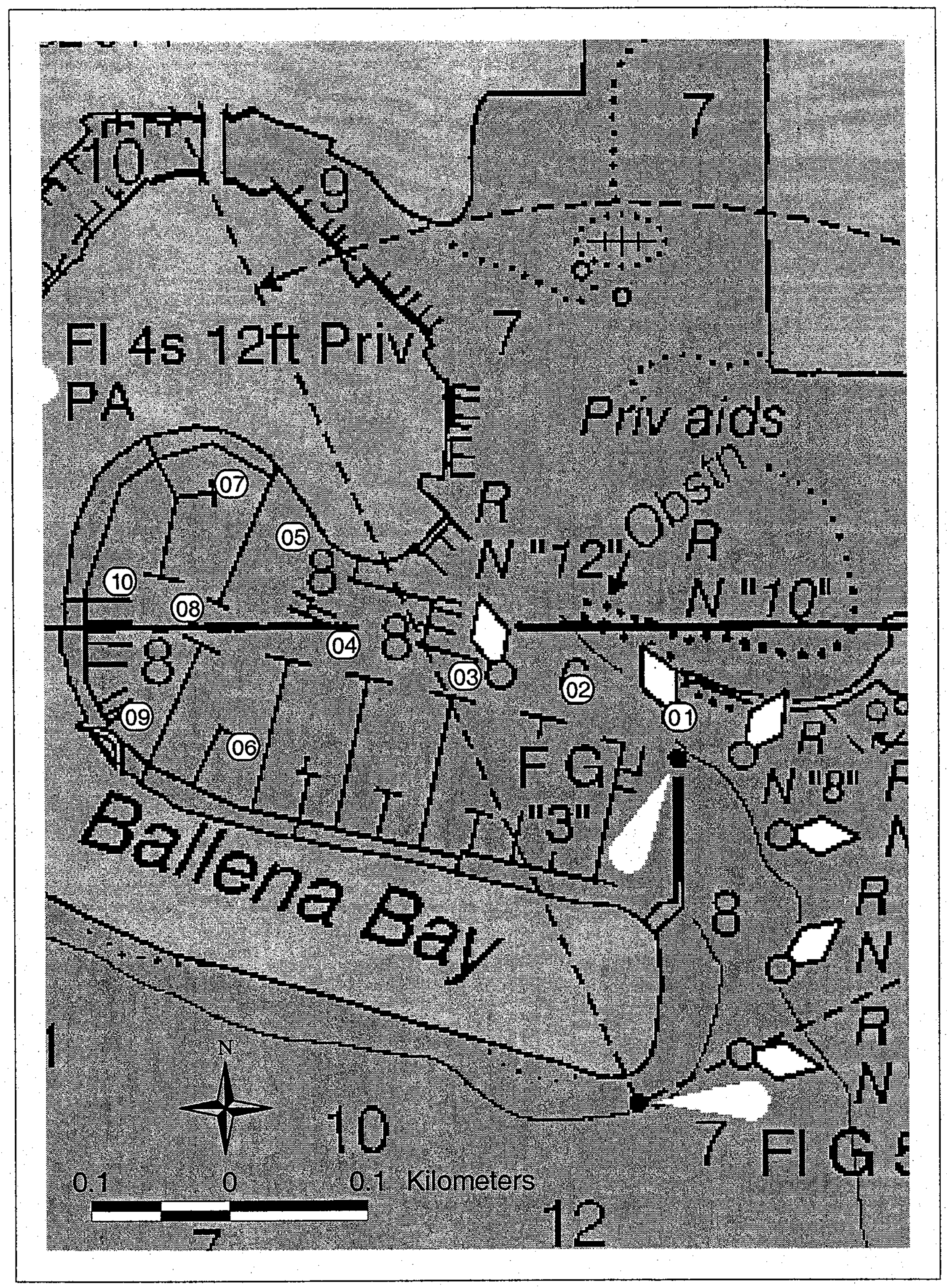


Figure 2c. San Francisco Bay Marina Sampling Locations-Ballena Isle Marina

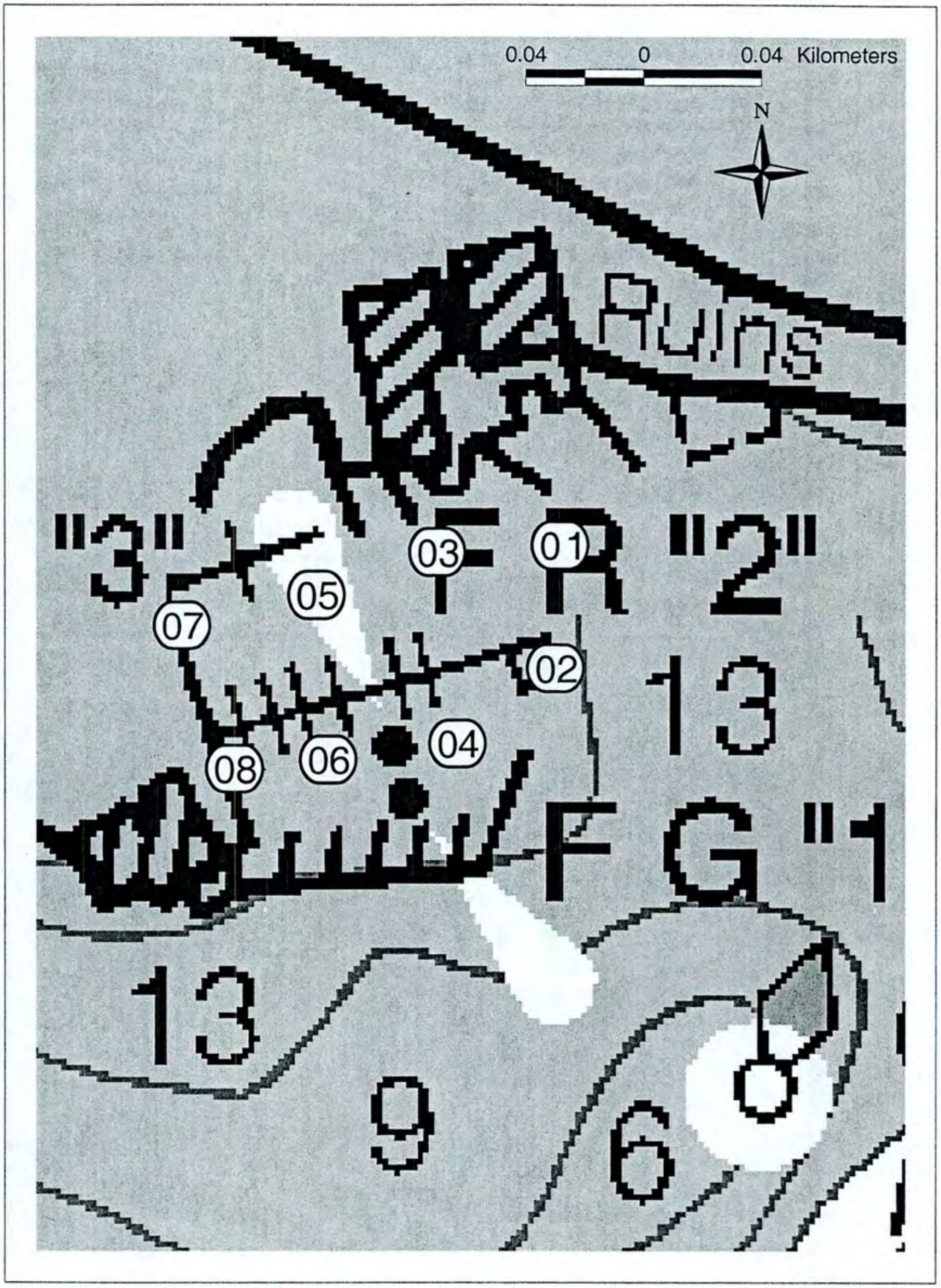


Figure 2d. San Francisco Bay Marina Sampling Locations-Corinthian Yacht Club

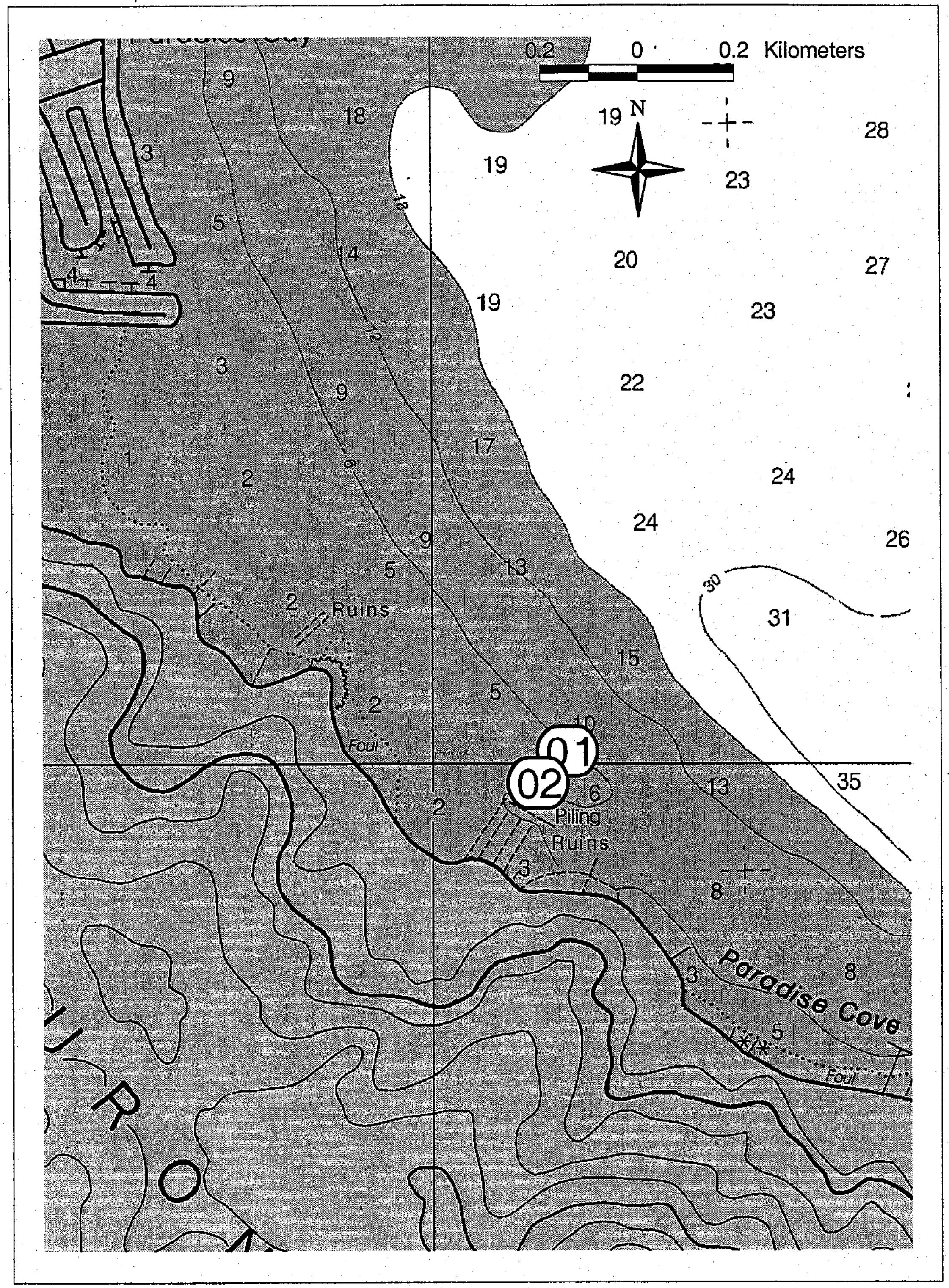


Figure 2e. San Francisco Bay Reference Sampling Locations-Paradise Cove
*Sample #3 not shown because it's a blind field duplicate taken at station #1

METHODS

Sampling Design

A directed point sampling design was required to address the need to identify potential areas of concern within marinas. Station locations (latitude & longitude) were predetermined by agreement with Moss Landing Marine Labs (MLML) and BCDC staff, as well as the Technical Advisory Committee (TAC). The intent of the survey and sample locations was to give a broad assessment of chemical conditions throughout the four San Francisco Bay marinas by providing multiple chemical analyses from sediment samples and single event measurements of conventional water quality parameters. A total of forty-one stations and two field duplicate stations within the four harbors and the Paradise Cove reference site were sampled August 26-27, 2003 (Figures 2 a-e). Sample locations were chosen along a gradient from the front entrance to the back of each marina, with several samples along the channels and fairways of each marina (See figures 2a-e). Water column profiles were conducted at each station to provide discrete measures of salinity, temperature, pH, turbidity, and dissolved oxygen at three depths. Sediment samples were collected and analyzed for grain size, total organic carbon, trace metals, and trace organics.

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 BPTCP, EMAP, and SWAMP, which 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 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 followed by a sea-water 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.

Sample Collection

All sampling locations (latitude & longitude), whether altered in the field or predetermined, were verified using a Garmin Global Positioning System, and recorded in the field logbook. The primary method of sediment collection was with a 0.1m² Young-modified Van Veen grab aboard a sampling vessel. Modifications include a non-contaminating Tefzel® 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 5 cm of surficial sediment was sub-sampled from the grab. Subsamples were taken using a precleaned flat bottom HDPE 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 5 cm was removed from the grab and placed in a pre-labeled polycarbonate container. Between subsequent grabs, the container was covered with a lid and kept cool. When a sufficient amount of sediment was collected, the sample was sealed and placed on wet ice for transport to the laboratory.

Benthic infaunal samples (n=12) were opportunistically collected at a subset of sampling locations. Sediment cores were sieved through a 0.5 mm screen and residues (e.g., organisms and remaining sediments) were rinsed into containers and preserved with a 10% formaldehyde solution. After 3 to 4 days, samples were rinsed and transferred into 70% isopropyl alcohol. These samples were archived for possible sorting and taxonomic identification at a later date.

Discrete Water Measurements/Water Quality Profiles

Water quality was measured at three depths (surface, mid-depth, near bottom) using a Hydrolab DataSonde. Temperature, pH, oxygen concentration (dissolved oxygen and oxygen saturation), depth and salinity were recorded at each depth. In addition, discrete water samples were collected at the same depths using a 1-liter Kemmerer water sampler for turbidity analysis in the field using a LaMotte2020 Turbidimeter.

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 transported back to the laboratory following the sampling cruise.

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 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 grain size, TOC, trace metal analysis, and organic analysis. Samples were placed in boxes sorted by analysis type. Sample containers for sediment chemistry (metals, organics) were stored in a freezer (-20°C) until distributed to the appropriate analytical laboratory.

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. Station numbers and station names, date and time 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.

Trace Metals Analysis of Sediments

Summary of Methods

Trace metal analyses were conducted at the California Department of Fish and Game's (CDFG) Marine Pollution Studies Laboratory at Moss Landing, CA. Table 1 indicates the trace metals analyzed and lists method detection limits for sediments. Inductively coupled plasma-atomic emission spectrometry (ICP-AES) was used to determine trace metal concentrations in sediments. A full description of the performance based methods and procedures can be found in the U.S. EPA publication Method 200.7, Trace Elements in Water, Solids, and Biosolids by Inductively Coupled Plasma-Atomic Emission Spectrometry, Revision 5.0, August 1998 (USEPA 1998).

Analytes and Detection Limits

Table 2. Trace reporting limits in sediments (μg/g, dry weight)

Element	Reporting Limit (μg/g, dry weight)
Arsenic	0.1
Cadmium	0.002
Chromium	0.03
Copper	0.003
Lead	0.002
Silver	0.008
Zinc	0.02

Sediment Digestion Procedures

One half gram aliquot of sediment was placed in a pre-weighed Teflon vessel, and 5 ml of concentrated double distilled nitric acid and 3 ml of hydrofluoric acid mixture was added. The vessel was capped and digested in a CEM Microwave Accelerate Reaction System 5 using the following steps: 15 minute ramp to 195°C and 250psi (controlled by temperature), 20 minute hold at temperature and pressure, 20 minute cool down cycle. Once cool, 20 ml of 2.5% Boric Acid are added to each vessel. The samples are returned to the microwave to undergo the following: 5 minute ramp to 195°C and 250psi (controlled by temperature), 15 minute hold at temperature and pressure, 20 minute cool down. The vessels are allowed to cool completely and vented. Then the final weight is recorded before the digestates are transferred into pre-cleaned polyethylene bottles.

ICP_AES Methods

Samples were analyzed by ICP-AES on a Perkin-Elmer Elan 6000 ICPMS. Samples, blanks, 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. Continuing calibration check standards (CLC) were analyzed with each sample batch, and a calibration standard was run after every 10 samples. Blanks and standard reference materials, MESS1 or PACS were analyzed with each set of samples for sediments.

Trace Organic Analysis of Sediments (Polycyclic Aromatic Hydrocarbons (PAHs))

Table 3: Subset of PAHs analyzed and their reporting limits in sediment (ng/g dry weight)

PAH	Reporting Limit (ng/g dry weight)
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

Sets of 12-16 homogenized sediment samples are scheduled for extraction by the project lead chemist. Extraction methods employed were developed and validated by the Water Pollution Control Laboratory. Extract cleanup and partitioning methods are modifications of the multi-residue methods for solids described in EPA Method 3500B-3545 from EPA Test Methods for Evaluating Solid Waste Vol. 1B.

Homogenized sediment samples are removed from the freezer and allowed to thaw. A separate extraction bench sheet is initiated for each project, sample matrix type, and analysis type.

A 1-5 g (sediment homogenate) sample is weighed into a pre-weighed aluminum planchet and placed in a 70°C oven for 48 hours to determine moisture content. A 10 g sample is mixed using a clean glass stirring rod with approximately 7 g of pre-extracted (twice) Hydromatrix (Varian Part NO: 0019-8003) in a 250 mL Trace Clean Wide Mouth Jar until the mixture is free flowing. The mixture is then poured into a 33 ml stainless steel Dionex Accelerated Solvent Extractor (ASE 200) extractor cell and packed by tamping the mixture. A solution containing PAH surrogate compounds is added to the cell and the cap is screwed onto the cell. The extractor cells (maximum of 24) are placed on the ASE 200 autosampler rack and the samples are extracted twice with a 50/50 mixture of acetone/dichloromethane (DCM) using heat and pressure. The extracts are automatically collected in 60 ml VOA vials. The extracts are combined and dried using sodium sulfate, evaporated to approximately 0.5 ml using Kuderna-Danish (K-D) glassware equipped with 3-ball Snyder columns and micro-Snyder apparatus and diluted to 10 mL using DCM. The extracts are then filtered through a 0.45 µm syringe filter into J2 Scientific AccuPrep 170 (GPC) autosampler tubes equipped with teflon septum lined caps.

The GPC autosampler tubes are then placed on the GPC autosampler for initial sample cleanup. All samples are cleaned up using the large GPC column. The cleaned-up extracts are evaporated using K-D apparatus and solvent exchanged into pentane. The extracts are then fractionated using a standard 10 mm x 300 mm small column packed with 1 ml sodium sulfate (drying agent), 2 ml alumina, 4 ml silica and another 1 ml sodium sulfate. The alumina/silica columns are eluted with 1:1 dichloromethane:pentane. The fractions are concentrated to an appropriate volume using K-D/micro K-D apparatus prior to analysis by gas chromatography/mass spectroscopy.

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 l 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 l 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 l 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 (approximately 48 hrs). Visual inspection of the dried sample before homogenization was used to ensure complete removal of carbonate containing materials (e.g., 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 manufacturers 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 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 the 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 0.01 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 1 l 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 pre-weighed 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.

Quality Assurance/Quality Control
Summary of Methods
Detailed descriptions of quality assurance and quality control procedures are described under separate cover in the Surface Waters Ambient Monitoring Program (SWAMP) Quality Assurance Project Plan (QAPP). This document describes procedures within the program that ensure data quality and integrity and can be viewed or downloaded from the SWAMP website at http://www.swrcb.ca.gov/swamp/qapp.html. Quality assurance procedures for this project were followed in accordance to SWAMP guidelines. 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 MLML-MPSL for further review.

Chemical Specific Sediment Quality Guidelines
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 chemical pollutants from field collected sediments are associated with effects observed in toxicity tests. Reported guidance values are based on individual chemical pollutants within sediments so 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 that were not measured. They do however provide empirical sediment quality guidelines (SQGs)that can be used as screening tools to help predict when chemical conditions have an increased probability of toxicity and/or biological community impairment. In this study the chemical results for individual trace metals and PAHs (also PAH groupings) were compared to their respective SQGs.

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 that 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 (Table 3). 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.,* 1996). 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 SQG. 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 that should help explain the relationships between observed chemical concentrations and the probability that a biological effect would be associated with that particular sediment chemical.

Because this study focused on polycyclic aromatic hydrocarbons (PAHs), an additional sediment quality guideline that focuses specifically on PAH mixtures was considered. PAHs virtually always occur in field collected sediments as a complex mixture of covarying compounds so Swartz (1999) proposed a consensus based guideline value based on a mixture of 13 PAH compounds that the USEPA identified as priority pollutants. This consensus guideline value (Table 3) is particularly useful because it allows estimates of ecological risk due to the cumulative effects of multiple PAHs. It also relies on a normalization approach with organic carbon that helps address the bioavailablity of PAHs in organic rich sediments where binding of organic chemicals is enhanced.

In addition to these national guidelines, there has been an extensive regional effort at determining ambient chemical concentrations in the sediments of San Francisco Bay. Regional Board Resolution 92-145 was published to establish screening criteria for the beneficial reuse of dredged sediments in San Francisco Bay (SWRCB, 1992). As part of that effort and the work of other organizations, the basis of ambient chemical concentrations in San Francisco Bay was developed (SWRCB, 1998). Although the ambient concentrations (Table 3) are not meant to be used as screening values, by comparing sediment chemical concentrations within the marinas to ambient conditions, it is possible to gain the context for predicting whether marina sediments fall within the range of what is expected as ambient or whether they are potentially elevated. In this report, comparisons are made to both sediment quality guidelines and to ambient concentrations for as many chemicals as possible.

For comparative purposes, two other sets of sediment quality guidelines are presented in Table 4. The first was established for the State of Washington and are called Apparent Effect Thresholds (AET; PTI, 1991). AET values are concentration above which biological effects are always expected to occur. The second set were sediment criteria developed by the USEPA (1993) using an equilibrium partitioning (EqP) approach for several individual PAHs.

Table 4. Sediment quality guidelines and San Francisco Bay ambient chemical concentrations

Chemical Name	ERL	ERM	TEL	PEL	Other SQGs	Ambient
Arsenic	8.2 *ug/g*	70 *ug/g*	7.24 *ug/g*	41.6 *ug/g*	700 *ug/g* [1]	15.3 *ug/g*
Cadmium	1.2 ug/g	9.6 ug/g	0.68 *ug/g*	4.21 *ug/g*	n/a	0.33 ug/g
Chromium	81 *ug/g*	370 *ug/g*	52.3 *ug/g*	160.4 *ug/g*	270 *ug/g* [1}	112 *ug/g*
Copper	34 *ug/g*	270 *ug/g*	18.7 *ug/g*	108.2 *ug/g*	1300 *ug/g* [1]	68.1 *ug/g*
Lead	46.7 *ug/g*	218 *ug/g*	30.2 *ug/g*	112.18 *ug/g*	660 *ug/g* [1]	43.2 *ug/g*
Nickel	20.9 *ug/g*	51.6 *ug/g*	15.9 *ug/g*	42.8 *ug/g*	n/a	112 *ug/g*
Mercury	0.15 *ug/g*	0.71 *ug/g*	0.13 *ug/g*	0.7 *ug/g*	n/a	0.43 *ug/g*
Silver	1.0 *ug/g*	3.7 *ug/g*	0.73 *ug/g*	1.77 *ug/g*	6.1 *ug/g* [1]	0.58 *ug/g*
Zinc	150 *ug/g*	410 *ug/g*	124 *ug/g*	271 *ug/g*	1600 *ug/g* [1]	158 *ug/g*
Acenapthene	16 *ng/g*	500 *ng/g*	6.71 *ng/g*	88.9 *ng/g*	230 *ug/g* OC [2]	26 *ng/g*
Acenaphthylene	44 *ng/g*	640 *ng/g*	5.87 *ng/g*	127.89 *ng/g*	n/a	88 *ng/g*
Anthracene	85.3 *ng/g*	1100 *ng/g*	46.9 *ng/g*	245 *ng/g*	n/a	88 *ng/g*
Fluorene	19 *ng/g*	540 *ng/g*	21.2 *ng/g*	144.35 *ng/g*	n/a	19 *ng/g*
2-methylnapthalene	70 *ng/g*	670 *ng/g*	20.2 *ng/g*	201.28 *ng/g*	n/a	19.4 *ng/g*
Naphthalene	160 *ng/g*	2100 *ng/g*	34.6 *ng/g*	390.64 *ng/g*	n/a	55.8 *ng/g*
Phenanthrene	240 *ng/g*	1500 *ng/g*	86.7 *ng/g*	543.53 *ng/g*	240 *ug/g* OC [2]	237 *ng/g*
Low m.w. PAHs	552 *ng/g*	3160 *ng/g*	312 *ng/g*	1442 *ng/g*	24000 *ng/g* [1]	434 *ng/g*
Benz[a]anthracene	261 *ng/g*	1600 *ng/g*	74.8 *ng/g*	692.53 *ng/g*	n/a	412 *ng/g*
Benzo[a]pyrene	430 *ng/g*	1600 *ng/g*	88.8 *ng/g*	763.22 *ng/g*	n/a	371 *ng/g*
Chrysene	384 *ng/g*	2800 *ng/g*	108 *ng/g*	845.98 *ng/g*	n/a	289 *ng/g*
Dibenz[a,h]anthracene	63.4 *ng/g*	260 *ng/g*	6.22 *ng/g*	134.61 *ng/g*	n/a	32.7 *ng/g*
Fluoranthene	600 *ng/g*	5100 *ng/g*	113 *ng/g*	1493.54 *ng/g*	300 *ug/g* OC [2]	514 *ng/g*
Pyrene	665 *ng/g*	2600 *ng/g*	153 *ng/g*	1397.6 *ng/g*	n/a	665 *ng/g*
High m.w. PAHs	1700 *ng/g*	9600 *ng/g*	655 *ng/g*	6676.14 *ng/g*	69000 *ng/g* [1]	3060 *ng/g*
Total PAHs	4022 *ng/g*	44792 *ng/g*	*1684* ng/g	16770.54 *ng/g*	1800 *ug/g* OC [3]	3390 *ng/g*

ERL and ERM values were taken from Long *et al.*, 1995; TEL and PEL values were taken from MacDonald *et al.*, 1996

Other SQGs were taken from [1] PTI Environmental Services (AETs); [2] USEPA, 1993 (EqP) and [3] Swartz, 1999 (Consensus); Ambient values were taken from SWRCB, 1998

Statistical Analyses

A One Way Analysis of Variance (ANOVA) was used to determine if there was a difference in analyte concentration among harbors. If a particular analyte met the assumptions of an ANOVA (e.g., normality), a parametric One Way ANOVA was run grouped by marinas (four marinas and Paradise Cove). If there was a significant difference due to the marinas, then each pairwise comparison was tested with a Tukey test to determine where significant differences existed among the marinas. The Tukey test was chosen because it is a conservative test and a Type I error (i.e., reject a true null hypothesis) would less likely occur. If the data was not normally distributed, a non-parametric Kruskal-Wallis One Way ANOVA, which is based on ranks, was run. Pairwise comparisons were made with the Dunn's method without adjustment for ties.

To determine the strength of association between various analytes (e.g., between arsenic and cadmium), a Pearson Product Moment Correlation was used. The correlation coefficient (r) ranges between -1 and 1 in which a value near 1 indicates a positive relationship with both variables increasing together. A value near -1 suggests a negative relationship with one variable always increasing as the other decreases. A value near 0 indicates no association. All statistical analyses were performed with SigmaStat and a p value less than or equal to 0.05 was used to determine a significant difference.

RESULTS AND DISCUSSION

Data Management and Quality

Tabulated data for all field information and chemical analyses are stored in a MS Access database. The database structure used for reporting the current data is the same used by the SWAMP program for reporting environmental monitoring data. This format was selected so that the marina survey data could be uploaded to the SWAMP database and shared via the web to future data users. The SWAMP Information Management (IM) plan describes the business rules for data capture and storage, the organizational table structures, data formats and data flow for the SWAMP program. The IM plan can be downloaded from *http://www.swrcb.ca.gov/swamp/qapp.html#appendixi* in Appendix J where updated versions are presented on the State Water Resources Control Board's SWAMP website. Data were exported from the SWAMP database in MS EXCEL and SYSTAT for manipulation and analysis. Data is to be made available in EXCEL format (SFMarina_2003.xls) but can be delivered in ACCESS format on request. The summary data presented in the following results sections were used to demonstrate significant findings from the analysis of the full data set in the database.

Analytical results were required to meet data quality objectives (DQOs) specified in the SWAMP QAPP. Review of the analytical quality assurance information demonstrated some minor exceedances of the DQO's for the trace metals cadmium and lead. The lab duplicate vessel broke during one of the digestion (2003Dig24), therefore duplicate information was not available for one of the batches. In addition, the matrix spike % recovery was slightly elevated for cadmium and lead that pushes these samples outside required SWAMP DQOs. We believe this was a data entry error where the final matrix solution weight on the original digestion data sheet was incorrectly entered, however, we are unable to verify this supposition. All other QA objectives for the trace metal analyses were met and duplicates at stations in Berkeley (Stations 5 and 8 were blind field duplicates) and Paradise Cove (Stations 1 and 3 were blind field duplicates) demonstrated acceptable precision. It is recommended that all trace metal data be considered acceptable and valid in spite of the above noted minor DQO exceedances for cadmium and lead.

Review of the data quality for the PAH analyses revealed minor exceedances of some SWAMP DQOs. The matrix spike % recovery was slightly low for naphthalene in one sample. The surrogate corrected values for the standard reference material (SRM) were systematically high for the higher molecular weight PAHs so those values are not surrogate corrected. The C1,C2,C2 substituted results are considered screening values because the concentrations were calculated from the other standards (e.g. they didn't have standards for "C1 naphthalenes" so 1-methyl naphthalene was used to calculate it). Post extraction holding times were exceeded by 10 days due to instrumentation problems but should have no effect on data quality. Each of the above QA flags in the data are considered minor and do not diminish the quality of the data. All other QA objectives for the PAHs were met and duplicates at stations in Berkeley (Stations 5 and 8 were blind field duplicates) and Paradise Cove (Stations 1 and 3 were blind field duplicates) demonstrated acceptable precision. It is recommended that the sediment PAH results be considered acceptable and valid in spite of the above noted minor DQO exceedances.

Conventional Water Quality Parameters

Water quality measures were collected at the time of sampling to give a general sense of the range of physical conditions observed in the different marinas during the two days of sampling. Because the water quality measures are highly dependent on the time of sampling due to tidal cycle, light conditions, wind conditions, time of year, etc., the measures reported here should only be viewed as a snapshot in time and not necessarily representative of average or extreme conditions in each of the marinas. The measures are however useful in assessing relative differences among harbors at the time of sampling.

Temperature ranged from 15.9^0 C to 24.3^0 C (Figure 3) with the lowest temperatures measured in Corinthian Yacht Club and greatest temperatures measured in Loch Lomond Marina. Temperatures were stratified, with colder waters near bottom, within the confined marinas when compared to the well-mixed open waters at the reference stations in Paradise Cove.

Dissolved oxygen concentrations ranged from 2.4 mg/L to 9.3 mg/L (Figure 4) and also exhibited a pattern of depth stratification with measured oxygen concentrations lowest in near bottom waters. Ballena Isle Marina exhibited the lowest oxygen concentrations and demonstrated a concentration gradient where oxygen values decreased, moving from the front to the back of the marina. Bottom waters near the back of the marina had oxygen concentrations less than 4 mg/l suggesting hypoxic conditions that could impact biological activity. Similarly, three stations in the southeastern quarter of Berkeley marina exhibited bottom waters with low oxygen concentrations.

Salinity values ranged from 28.82 ppt to 35.01 ppt (Figure 5). Salinity values were consistent with depth within Berkeley, Ballena Isle and Loch Lomond marinas, but varied with depth at Corinthian Yacht Club and Paradise Cove. A strong flood tide occurred the morning of sampling and salinity stratification most likely reflects a lens of less saline waters from San Pablo Bay on top of marine waters brought in by tidal flow. Corinthian Yacht Club demonstrated the highest average salinities and the lowest average temperatures at the time of sampling, indicating a strong tidal influence of offshore marine waters from flowing into the marina. This pattern is expected, except the very high salinity value of 35.01 in the back bottom waters of Corinthian Yacht Club, that coincidentally also had the lowest temperature values and the greatest turbidity values. It is unclear if this high salinity value was real or an instrumental artifact, though instrument calibrations were all within acceptable ranges.

Turbidity measures ranged from 3.02 NTU to 37.9 NTU (Figure 6). Turbidity measures were stratified at all marina stations where near bottom waters were consistently more turbid than mid-depth or surface waters. Bottom waters in the back areas of Corinthian Yacht Club demonstrated the greatest turbidity.

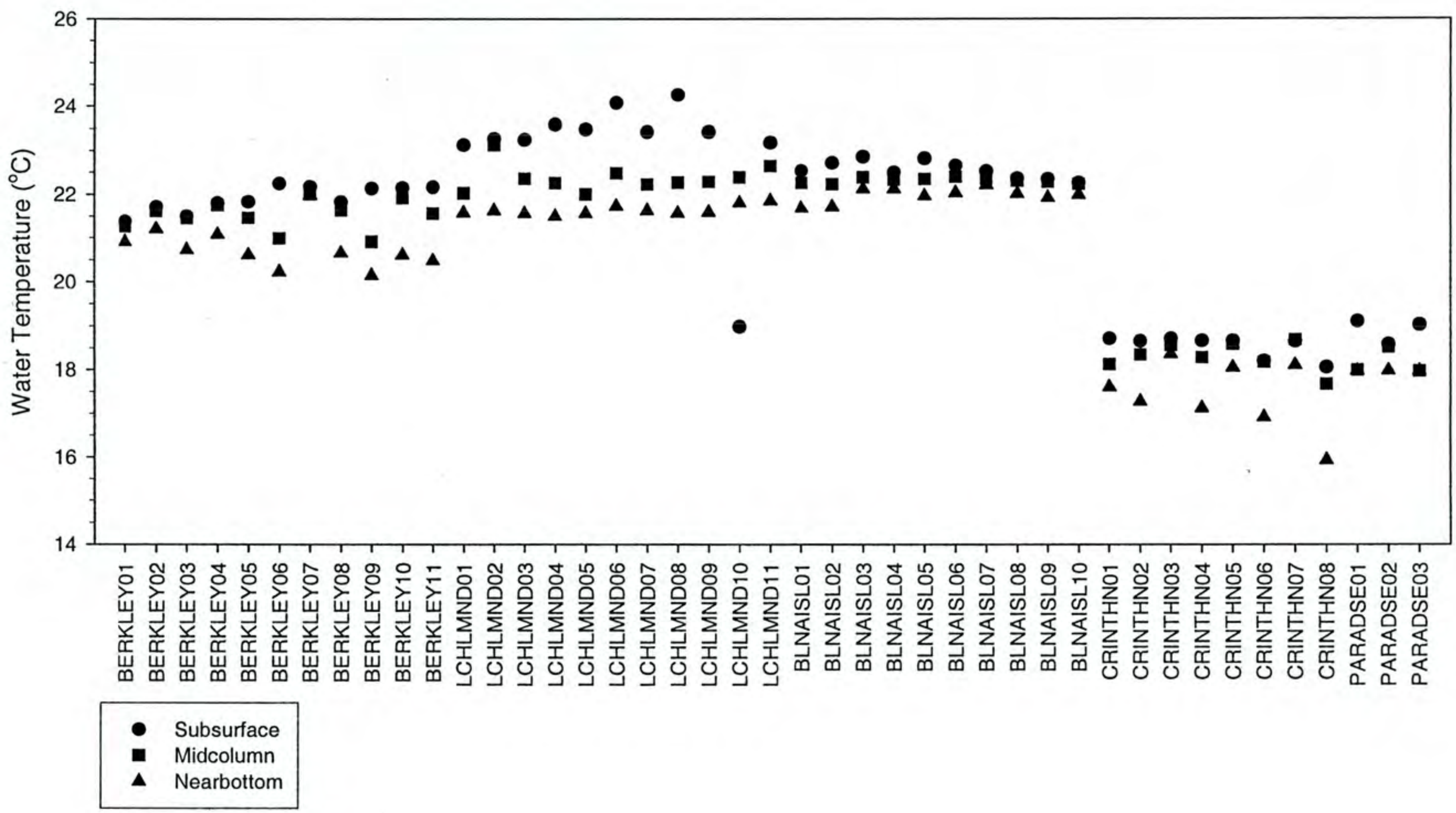


Figure 3. Histogram of water temperature in the marinas and reference site.

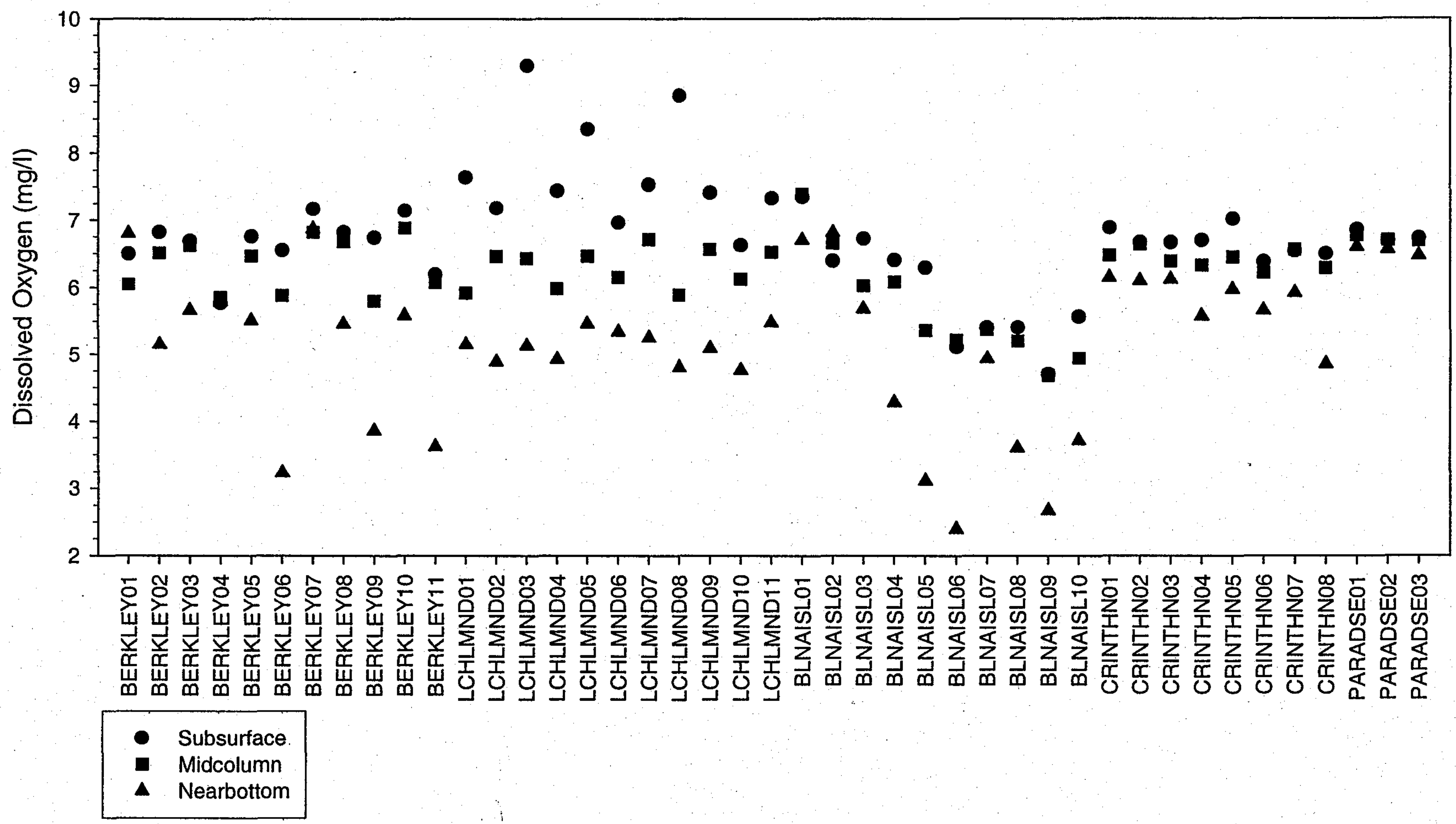


Figure 4. Histogram of dissolved oxygen in the marinas and reference site.

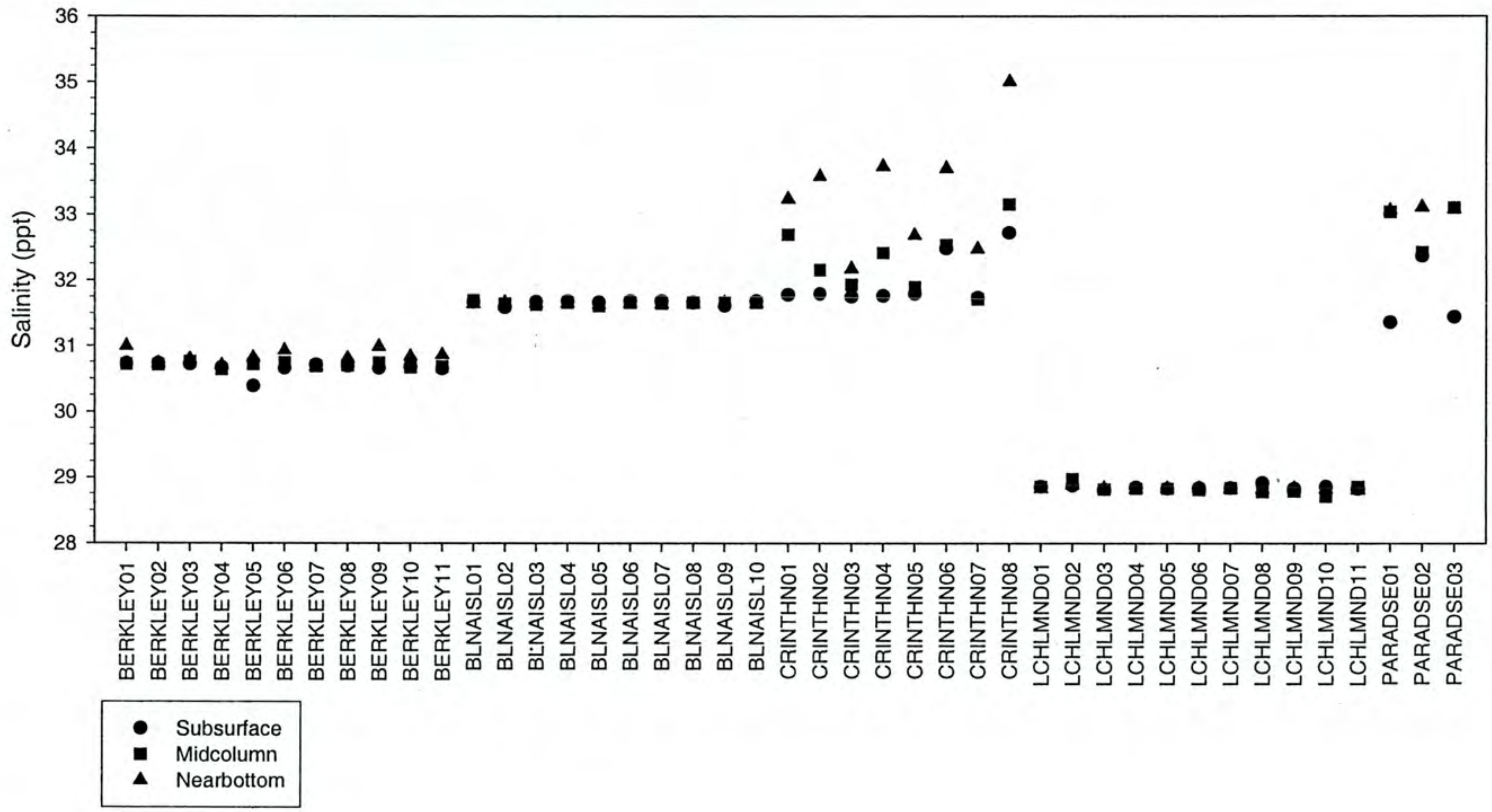


Figure 5. Histogram of salinity (ppt) in the marinas and reference site.

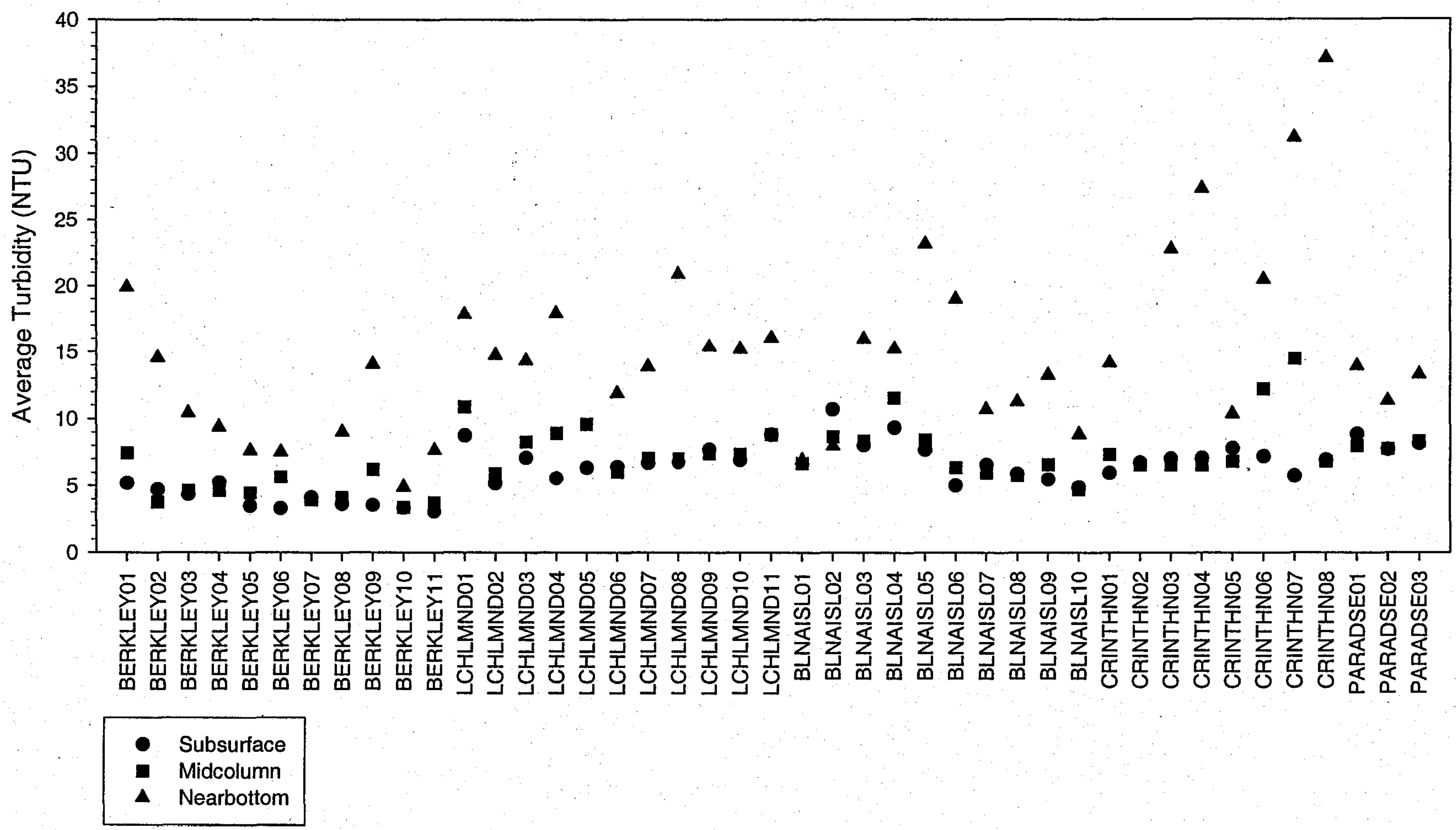


Figure 6. Histogram of average turbidity in the marinas and reference site.

Sediment Grain Size and Total Organic Carbon

Sediment grain size measures were taken to assess general physical characteristics of marina sediments and to compare relative differences in sediment characteristics among marinas. Sediment grain size measures ranged from 73.7% silt/clays to 99.9% silt/clays though most stations were well above 95% (Figure 7). The only obvious pattern was seen at Corinthian Marina where relatively more coarse grained sediments were found at the more exposed mouth of the marina and more fine sediments were found in the flow restricted back areas of the marina. Coarse grained sediments were measured at several locations in Berkeley and Loch Lomond marinas, but these locations had shell debris in the sample that were mixed with the silts and clays. Other than these shell debris locations, the marinas and reference site all had similar grain size characteristics, primarily fine mud dominated by silt and clay fractions. No obvious sediment type differences related to boating or dredging activities could be discerned.

Organic carbon is a major factor in controlling the bioavailability of nonionic organic compounds in sediments. This is based on equilibrium portioning theory (EqP) in which the partitioning of organic chemicals is controlled by the equilibrium between sediment organic carbon and interstitial waters. Sediments that are organically rich tend to bind organic compounds and lower pore water concentrations thus reducing the major exposure route and subsequently bioavailability. To account for the freely dissolved concentration of organic chemicals in pore water, Total organic carbon (TOC) is often used to normalize compounds for comparison to published sediment quality guidelines (PTI, 1991; Swartz, 1999). TOC was measured at all locations in the current survey and concentrations ranged from 0.73% to 1.77% organic carbon. Ballena Isles Marina and Berkeley Marina demonstrated a concentration gradient where sediment TOC increased at stations moving from the front to the back of the marinas. TOC values are used later in this report to help predict the probability of toxicity from exposure to PAHs.

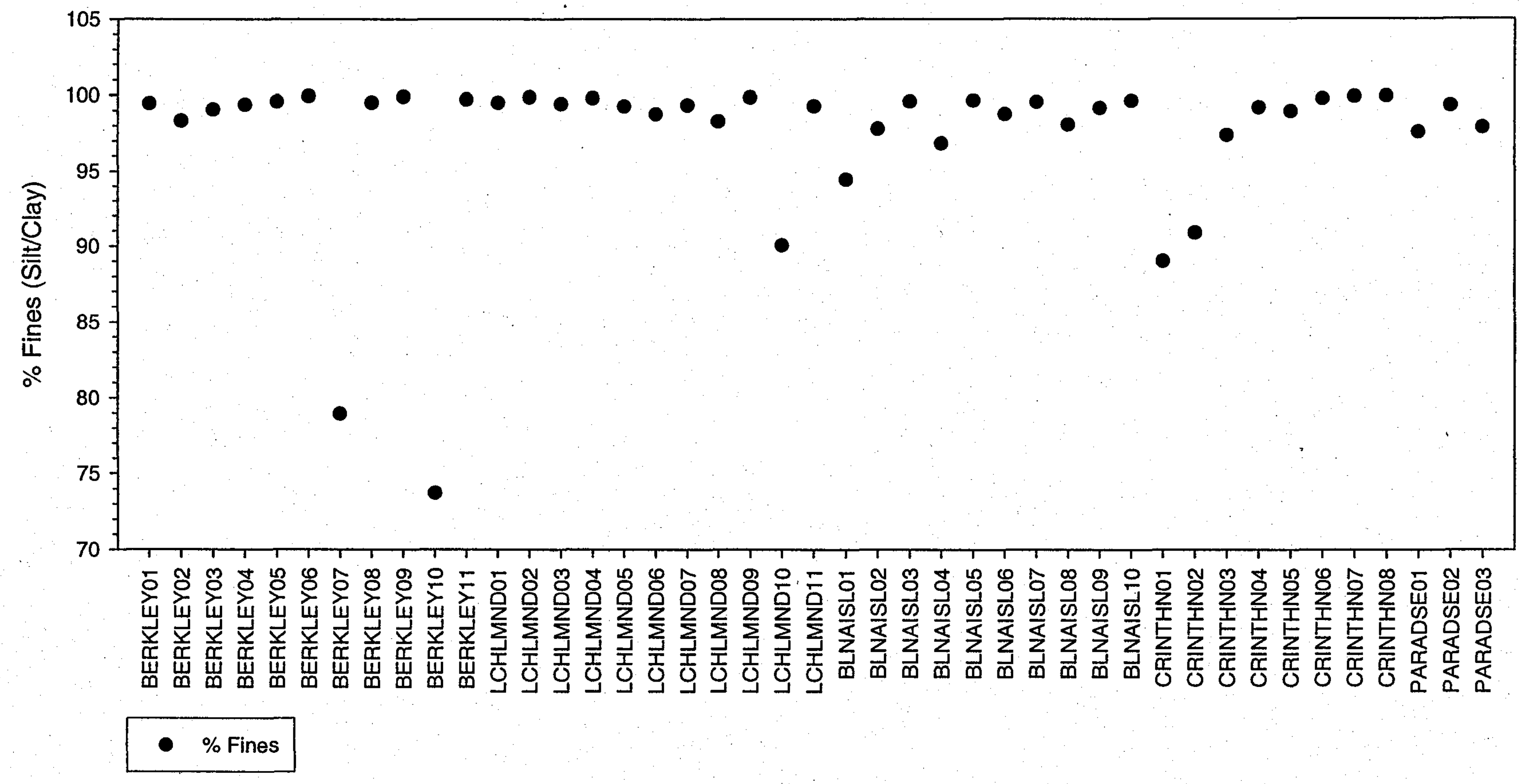


Figure 7. Histogram of grain size (% Fines) in the marinas and reference site

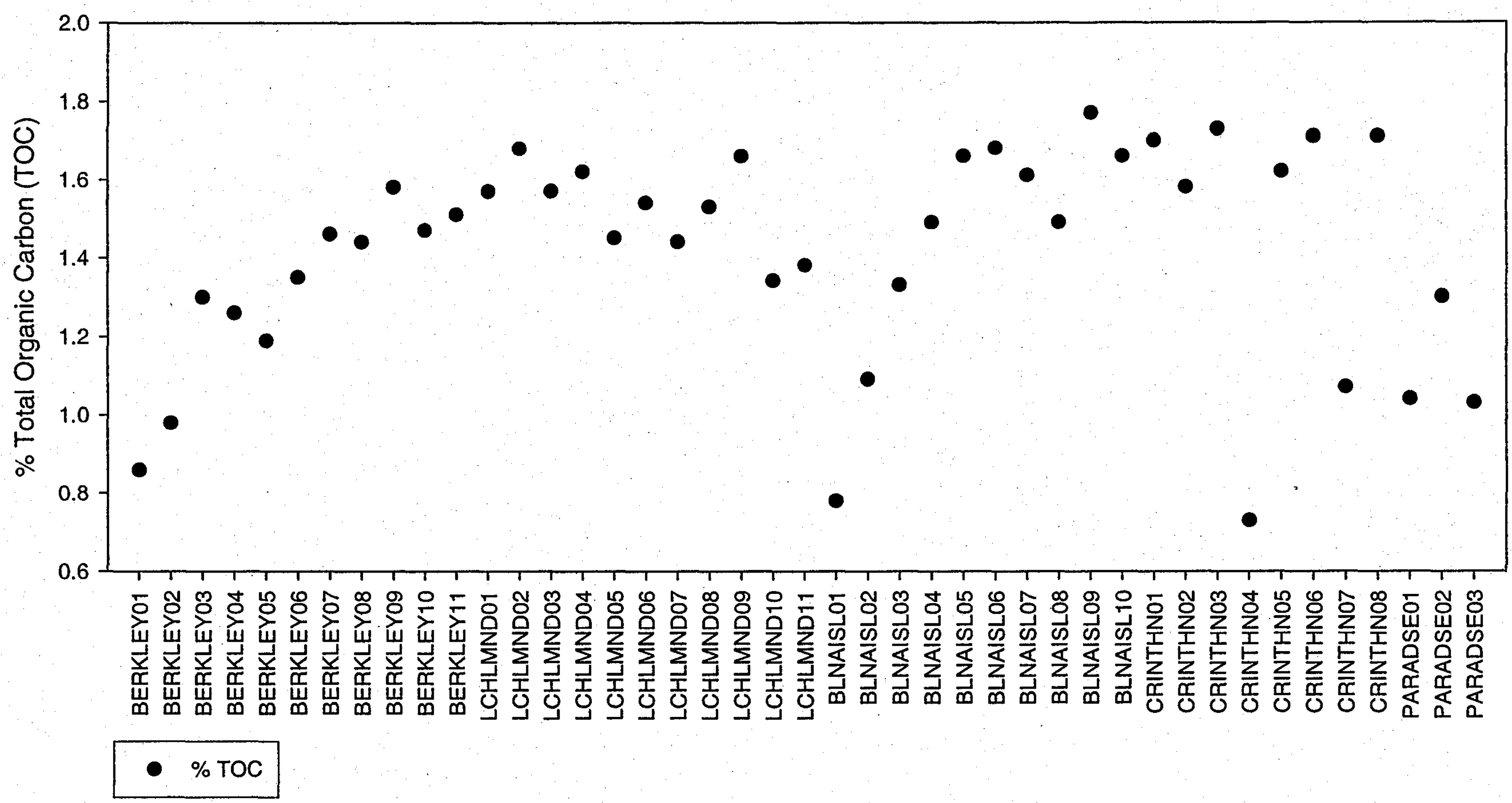


Figure 8. Histogram of total organic carbon (% TOC) in the marinas and reference site

Sediment Trace Metals

Arsenic. Arsenic, a metalloid, is often contained in paint pigments, wood treatments, and pesticides (U.S. EPA 2001). While marine paint and coating compounds made with arsenic are no longer used because of their toxicity, it is still used in CCA (chromated copper arsenate) treated wood in docks and pilings and may still be present on older boats. The toxicity of arsenic is highly dependent upon the nature of the arsenic compound (organic or inorganic) and the valence state of the arsenic atom. However, it is however total arsenic that is usually included in monitoring programs and is most often used as an indicator of arsenic contamination. Screening values for sediments are based on total arsenic so comparisons in this survey are made with total arsenic. Arsenic concentrations in the current survey ranged from 7.15 – 16.5 mg/kg (Figure 9), most of which exceeded the ERL of 8.2 mg/kg. Only one sample within Berkeley marina slightly exceeded Ambient concentrations for San Francisco Bay (16.5 vs 15.3 mg/kg), however the field duplicate sample was collected at the same location had measured arsenic concentrations slightly below Ambient. The relative percent difference between the duplicates (13%) is very reasonable considering field heterogeneity, so the one sample slightly above Ambient does not deserve undue attention. Considering the median/probable effects concentrations for arsenic (70 mg/kg - ERMand 41.6 mg/kg -PEL) are far from being exceeded, it is unlikely that any acute biological impacts would be associated with the observed arsenic concentrations. The study results indicate that total arsenic concentrations in the marinas are similar to ambient conditions throughout San Francisco Bay and currently present a low risk of toxicity in the marinas.

Copper. 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). Marina related sources of copper include anti-fouling paints and wood preservatives in docks and pilings. Copper (II) acetate is the common form used in fungicides, insecticides, mildew preventatives, corrosion inhibitors, fuel additives and anti-fouling paints. Sediment total copper concentrations in the current survey ranged from 38.2 – 151 mg/kg (Figure 10). Copper concentrations above the ERL (>34 mg/kg) were found at all locations throughout the San Francisco Bay marinas and approximately half the samples were elevated above Ambient concentrations for San Francisco Bay (68.1mg/kg; Figure 11). Four samples in Ballena Isle Marina and one in Berkeley were at or above the probable effects levels (108.2 mg/kg –PEL) though all samples were below ERM concentrations (270mg/kg –ERM). Values well above the ERL and expected Ambient values are notable because they represent an increased probability that adverse biological impacts could result from copper toxicity in the marinas. Copper should therefore be considered one of the major chemicals of concern in marinas. It should be noted however that the observed sediment copper concentrations are not indicative of high ecological risk. These represent a moderate probability of being associated with acute effects to aquatic life, and therefore worthy of management actions and future monitoring.

Pre-dredge testing of sediments in the front half of the marina (ABT, 1998) indicated copper concentrations that are very comparable to those measured in the current study. The current study sampled a larger area and found that copper concentrations are noticeably greater toward the back end of the marina. It is clear that a strong copper gradient exist in Ballena Isles Marina but it is unclear if the lower copper concentrations toward the front of the marina are a result of recent dredging activities. It is plausible that maintenance dredging has removed accumulated sediment associated copper, while in place sediments toward the rear of the harbor reflect historical concentrations and/or more recent accumulations.

All marinas except Berkeley demonstrated a similar copper concentration gradient that increased geographically from the entrance to the inner areas of the marinas. Berkeley exhibited the same general trend however the fringes of the marina tended to have both low and high concentrations. The greatest concentration of copper observed in this study (151 mg/kg) was found near the boatyard and haul out area in the northwest corner of Berkeley marina. The Berkeley Marine Center, the marina's boatyard, tests the effluent of its water filtration system regularly and also samples storm water every fall, after the first rain. The source of copper within the sediments near the boatyard is still undetermined, however, untreated stormwater collected from the boatyard collection sump after November and December, 2003 rainfall events (Sequoia Analytical, 2003) demonstrated elevated concentrations of total copper (2100ug/l and 3400ug/l). This stormwater subsequently receives treatment for removal of contaminants and is not discharged into the marina, but it does point to the boatyard area as a potential copper source through stormwater runoff if activities are not carefully controlled. Although elevated copper in the marina sediments nearest the boatyard suggest a significant local source of copper loading to the marina, additional testing would be required to confirm and quantify this and other copper sources contributing to the sediment reservoir.

Cadmium. Cadmium compounds are used in the metal plating and battery industry, and as stabilizing agents in many polyvinyl chloride (PVC) products. Cadmium is a component of petrol, diesel fuel and lubricating oils. Cadmium is highly persistent in the environment and will concentrate or bioaccumulate in aquatic animals. Sediment total cadmium concentrations in the current survey ranged from 0.225 – 0.671 mg/kg (Figure 12). The greatest concentration of cadmium was observed in the back area of Ballena Isle marina (station 7) with a noticeable decreasing gradient at stations extending away from that area. The area around station 7 may be a source of cadmium to the rest of the marina and may warrant future investigation to better identify the extent of the contaminant and its likely source. In general, cadmium concentrations in the marinas were all near the expected San Francisco Bay Ambient concentrations and well below the ERL thresholds so have a low probability of posing a significant risk of acute effects to aquatic life.

Chromium. Chromium is chiefly found in its trivalent form in natural environments, except in seawater where chromium in its hexavalent state is prevailing, but at extremely low concentrations. Another oxidation state of practical importance is chromium (VI), but though there are some natural sources for chromium (VI), the majority originates from industrial activities. Compared to chromium (III), chromium (VI) is assumed to be about 100 to 1000 times more toxic. Chromium compounds are used for chrome plating (e.g. protective coatings for equipment accessories), as dyes, as inorganic paint pigments, and as fungicides and wood preservatives in docks and pilings. Chromium may be oxidized and leached from stainless steel into a water-soluble form. The U.S. EPA indicates that chromium has been used in various capacities in marinas and by boaters and can wash from parking lots, service roads, and launch ramps into surface waters with rainfall (U.S. EPA 2001). Sediment total chromium (III) concentrations in the current survey ranged from 107 – 161 mg/kg (Figure 13). The greatest chromium concentration was observed in Ballena Isle Marina (BLNAIS08), interestingly very near the location where the greatest cadmium concentration was observed (BLNAIS07). It is possible that the cadmium and chromium sources in Ballena Isle Marina are in some way linked. Chromium concentrations increased along a gradient moving toward the back of the marinas in both Corinthian Yacht Club and Loch Lomond Marina. Chromium concentrations in the marinas and at the reference station were well all above the ERL and all but one were above San Francisco Bay Ambient concentrations. Chromium concentrations at several locations in Berkeley, Ballena Isle and Loch Lomond marinas approached or exceeded the probable effects level (PEL = 160.4mg/kg) and present an increased probability of biological impairment. Chromium should therefore be considered one of the major chemicals of concern in marinas and should be considered a moderate risk, worthy of management actions and future monitoring.

Lead. Marina and boating-related sources of lead compounds can include sailboat keels, marine paints, and lead acid batteries. Lead can be discharged into the marina environment from leaching of sailboat keels (Hinkey 2001), and corrosion of fittings and lead acid batteries (Washington State Department of Ecology 2001(a)). Lead is poisonous in all forms, is cumulative and the toxic effects are many and severe. Sediment total lead concentrations in the current survey ranged from 17.3 – 40.9 mg/kg (Figure 14). The greatest concentration (40.9 mg/kg) was observed near the boatyard in Berkeley Marina where other elevated metals have been observed. The next greatest lead concentration was observed in Ballena Isle Marina (BLNAIS08) at the same location where the greatest chromium concentration was observed. Lead concentrations in the marinas and at the reference station were all below the ERL thresholds and the San Francisco Bay Ambient concentrations, so appear to present a low probability of toxicity.

Zinc. Zinc anodes are commonly used as anti-corrodants for metal hulls, engine parts, and boat propeller shafts (U.S. EPA 2001). Zinc is also contained in boat anti-fouling paints (Hinkey 2001), motor oil, and tires, and is a common constituent of runoff from marina parking lots (U.S. EPA 2001), and zinc is a component of the wood preservative ACZA, which is used in marine pilings, docks and piers. Generally, zinc and its salts have high acute and chronic toxicity (particularly zinc chromate) to aquatic life and zinc chromate is listed as a potential carcinogen. Sediment total zinc concentrations in the current survey ranged from 82.7 – 219 mg/kg (Figure 15). The lowest mean values were measured in Corinthian Yacht Club and were in the same range as the reference station at Paradise Cove. The greatest mean values were measured in the back end of the Loch Lomond Marina. A zinc concentration gradient that increased geographically from the front to the back of the marinas was observed in both Ballena Isle and Loch Lomond marinas (Figure 16). The ERL and Ambient values for zinc are 150 and 158 mg/kg, respectively with about a third of the samples exhibiting concentrations above these guideline values. None of the samples exceeded ERM or PEL guidelines where acute effects would be more probable, however the large number of stations exceeding the lower guidelines may warrant some attention and future monitoring efforts to examine this pattern for any change.

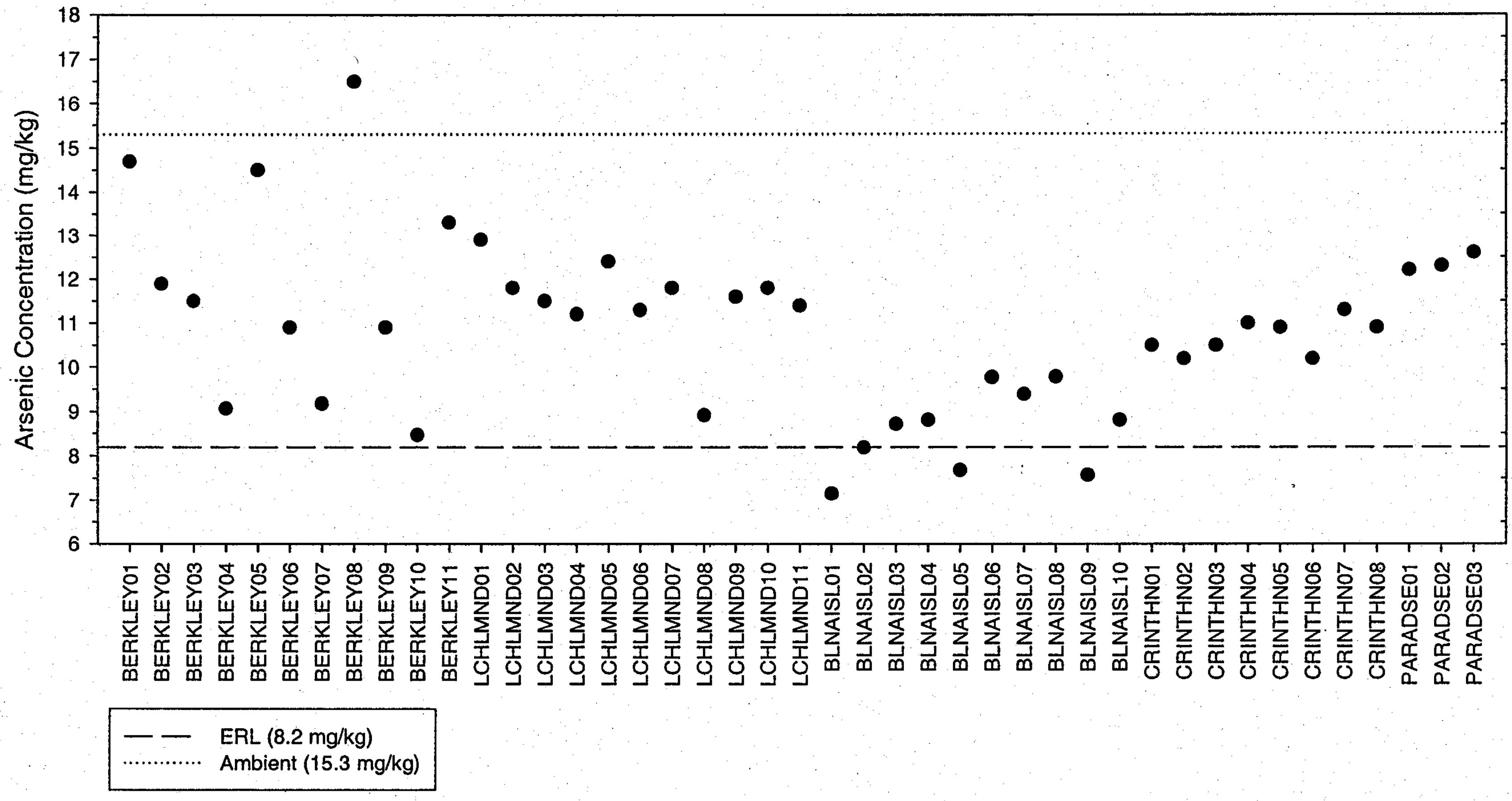


Figure 9. Sediment arsenic concentrations in the marinas and reference site.

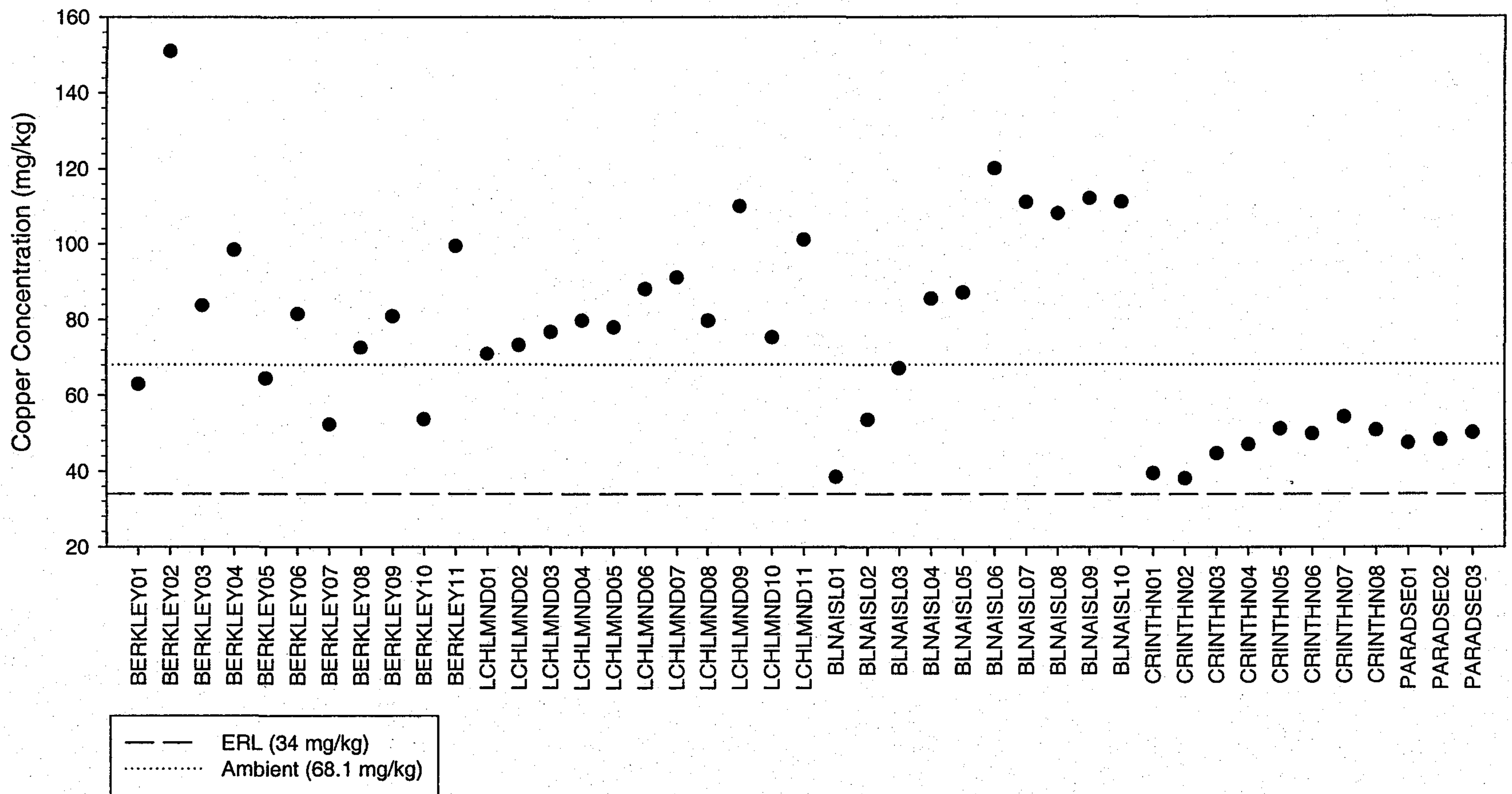


Figure 10. Sediment copper concentrations in the marinas and reference site.

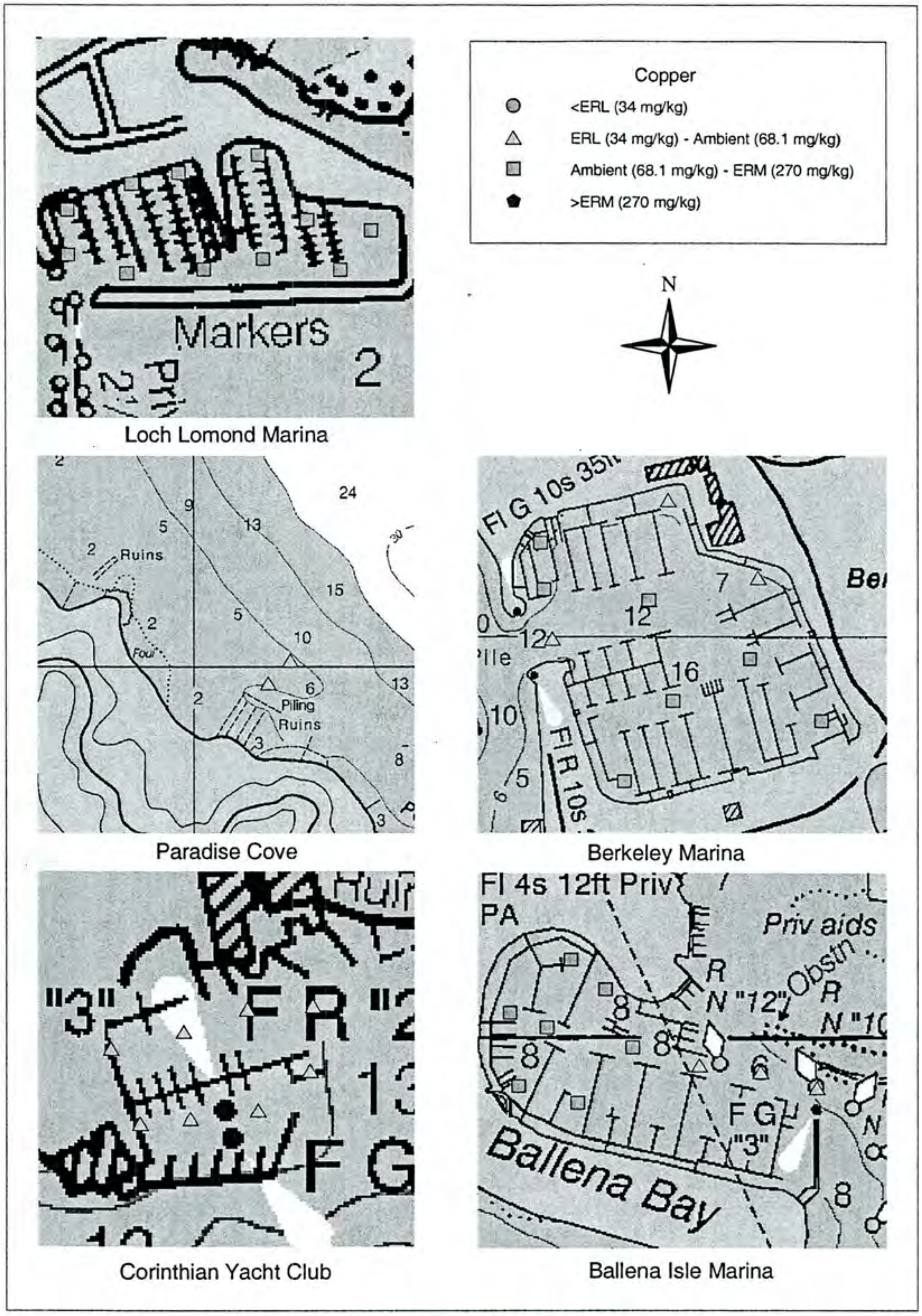


Figure 11. Map displaying distribution of copper concentrations relative to sediment quality guideline thresholds.

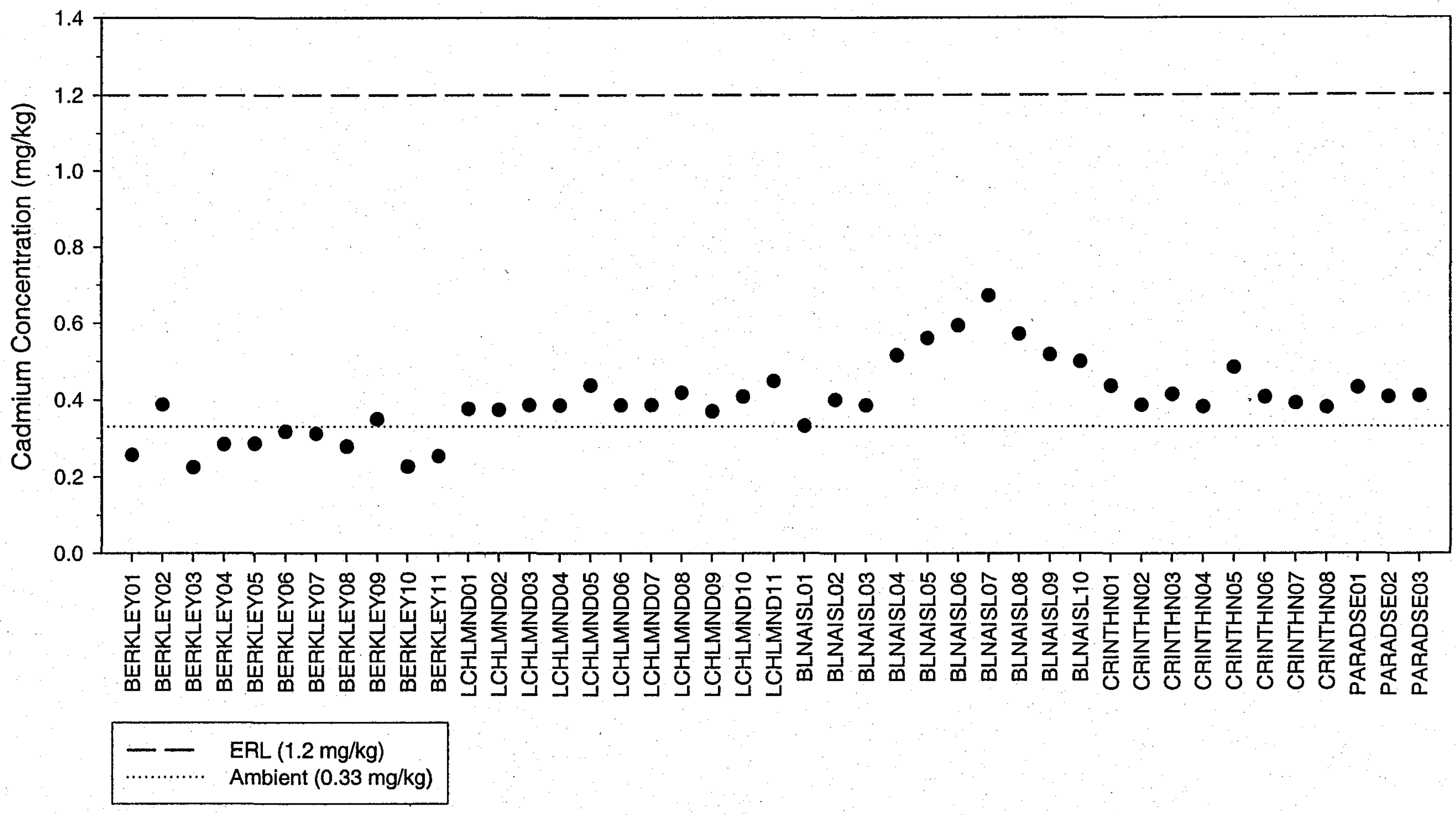


Figure 12. Sediment cadmium concentrations at the marinas and reference site.

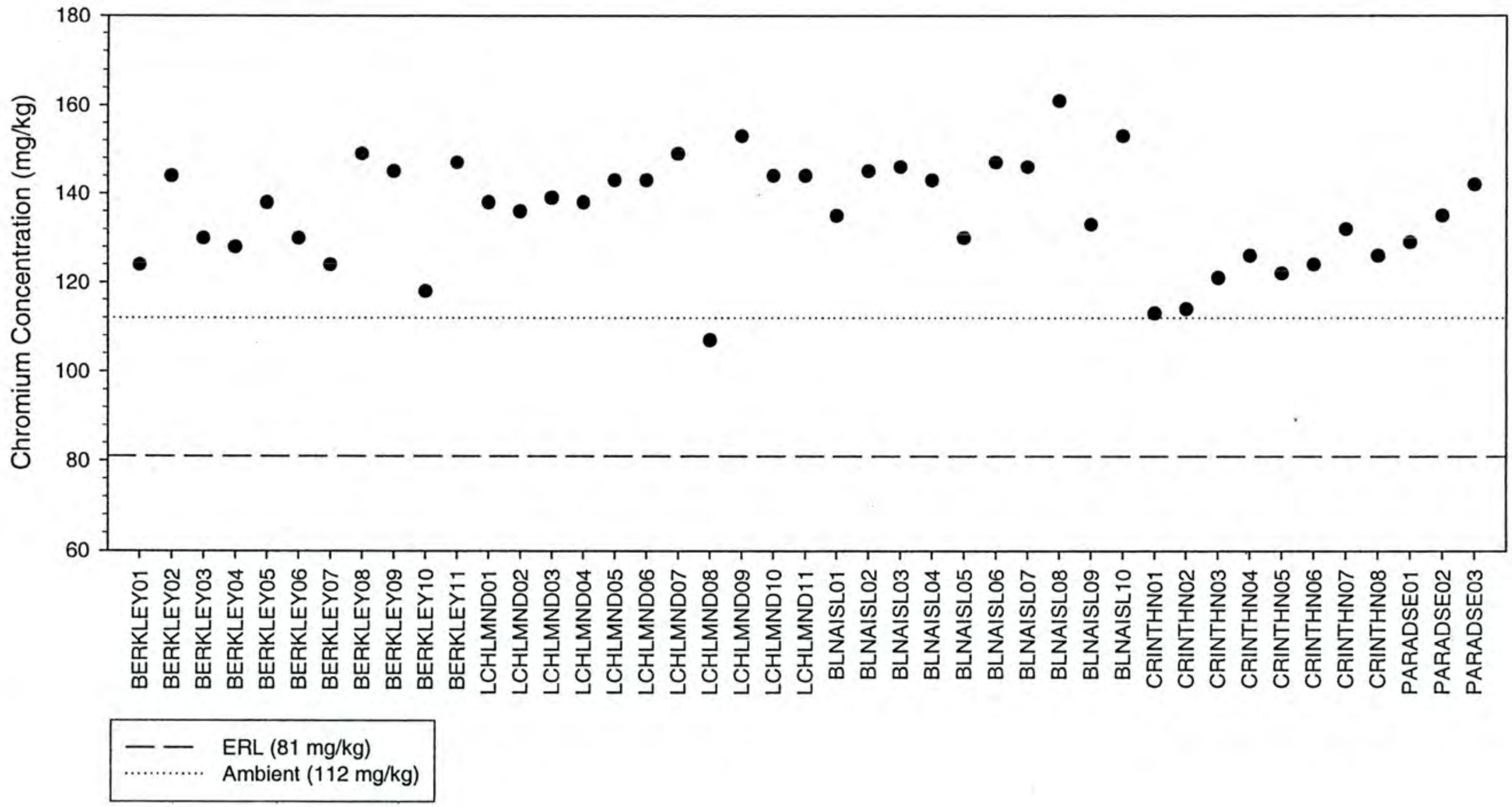


Figure 13. Sediment chromium concentrations at the marinas and reference site.

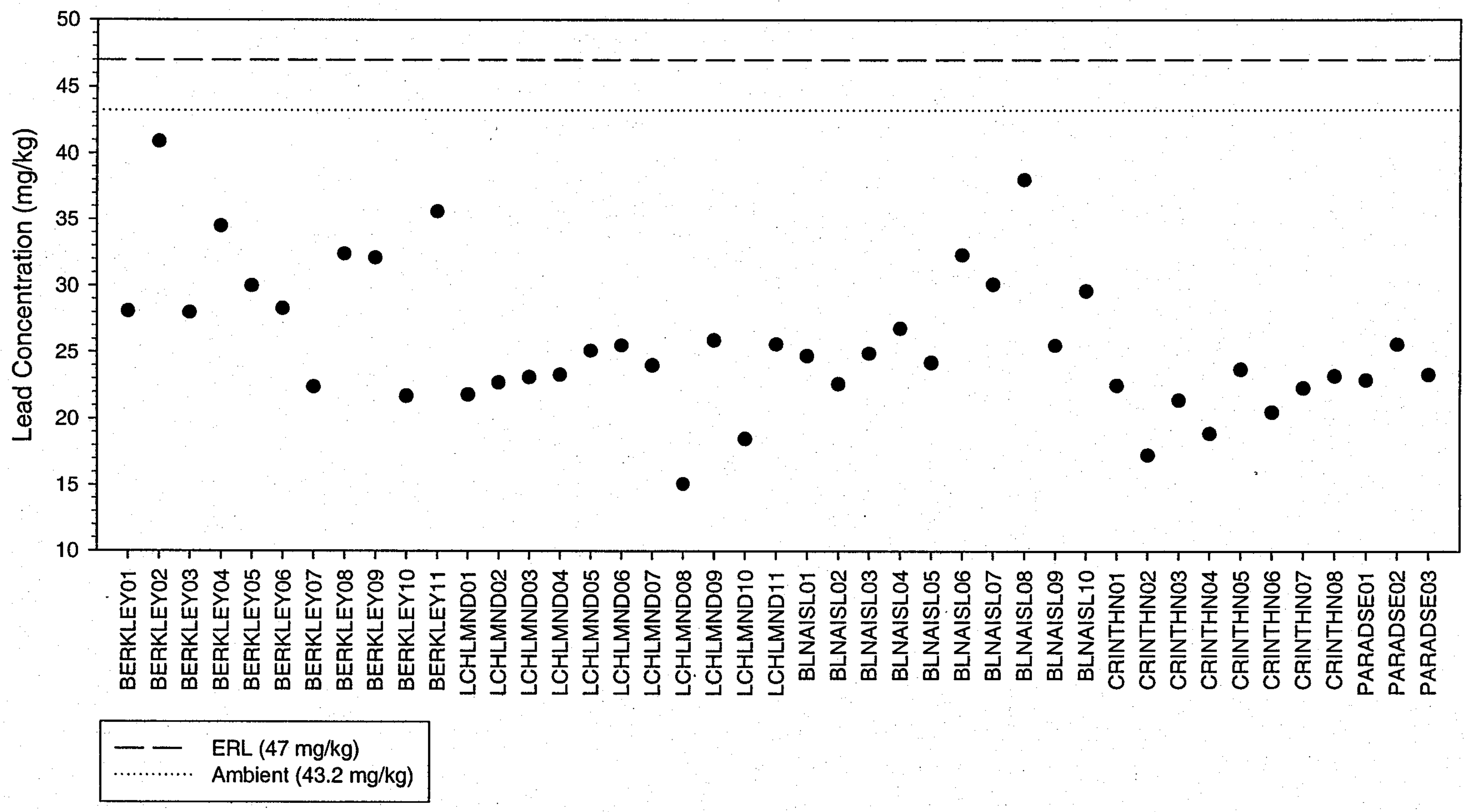


Figure 14. Sediment lead concentrations at the marinas and reference site.

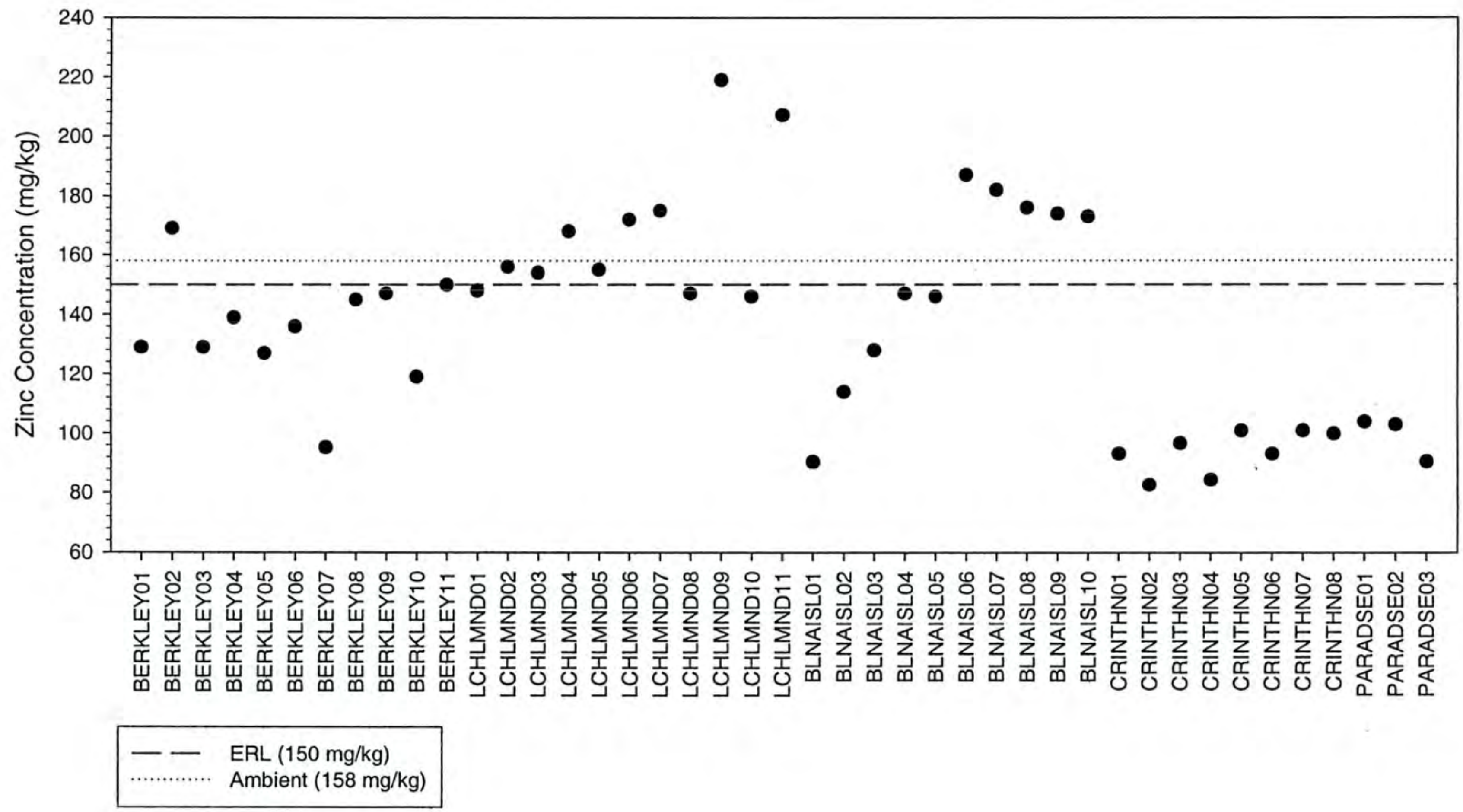


Figure 15. Sediment zinc concentrations at the marinas and reference site.

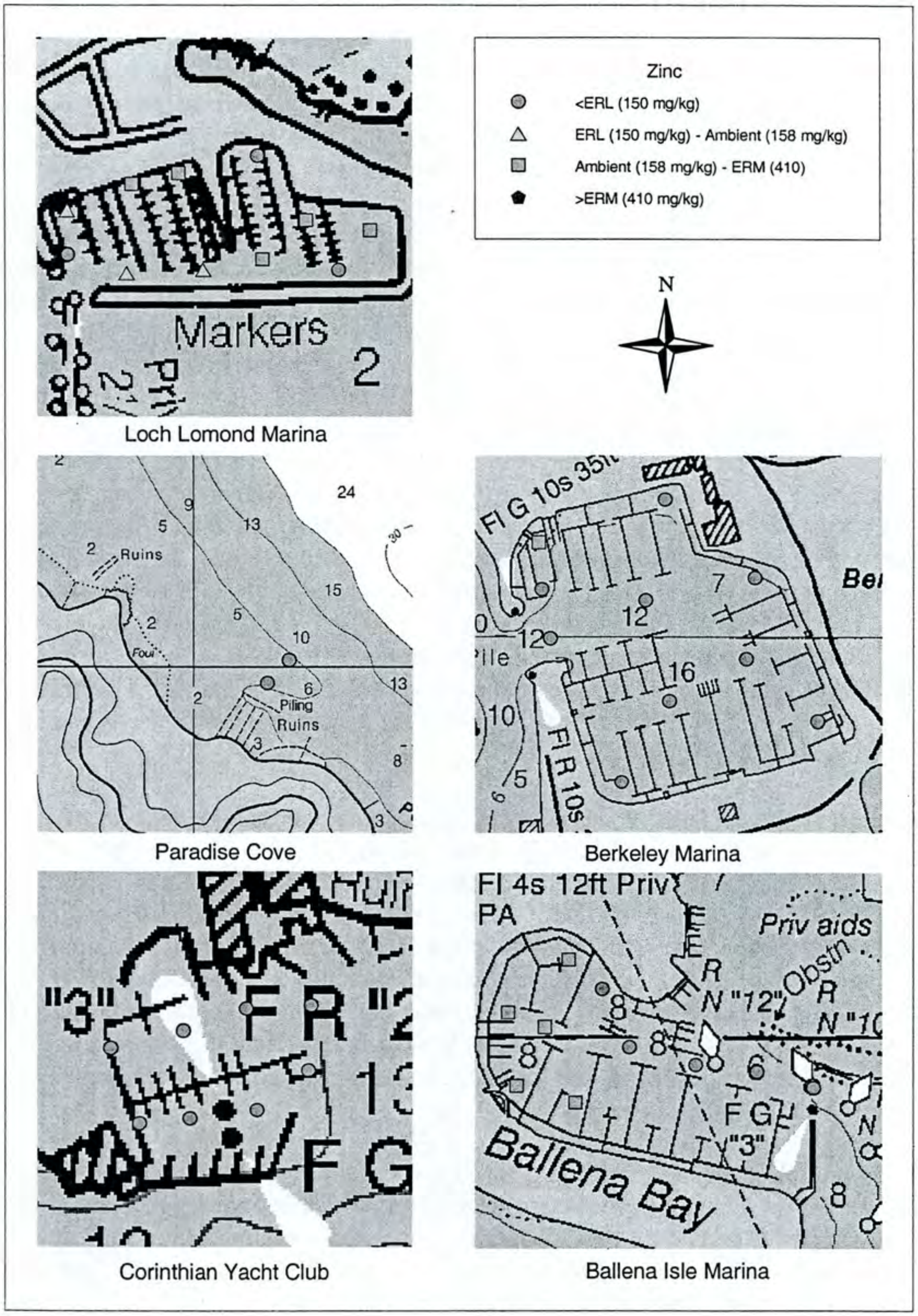


Figure 16. Sampling location maps displaying distribution of zinc concentrations relative to sediment quality guideline thresholds.

Trace Organics (PAHs)

Polycyclic (polynuclear) aromatic hydrocarbons (PAHs) are base/neutral organic compounds with a fused ring structure of two or more benzene rings. Polycyclic aromatic hydrocarbons are formed by the incomplete combustion of coal, oil, petrol, wood, tobacco, charbroiled meats, garbage, or other organic materials. Potential marina and boating related sources of PAHs include fuel and oil spills from fueling and maintenance activities, oily bilge discharges, and releases from older carbureted two-stroke engines (unburned fuel and exhaust). 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 molecular weight PAHs (LMW_PAH) are acenapthene, acenaphthylene, anthracene, fluorene, naphthalene and phenanthrene. Individual PAHs used for the summations of high molecular weight PAHs (HMW_PAH) are benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, fluoranthene and pyrene. Total PAHs (TTL_PAH) are based on the summation of low and high molecular weight PAHs. Total PAHs were normalized to organic carbon (TOC) to allow comparison to consensus sediment quality guidelines that are based on EqP theory and therefore dependent on OC normalized PAH concentrations from the marina samples. Each of these summations is based on the recommendations of Swartz (1999). Sediment LMW_PAH in the current survey ranged from 111.7 – 1213.3 ng/kg (Figure 17). Sediment HMW_PAH in the current survey ranged from 612.9 – 4081 ng/kg (Figure 18). Sediment TTL_PAH in the current survey ranged from 774.3 – 5294.3 ng/kg (Figure 19). Organic carbon normalized TTT_PAH in the current survey ranged from 57.8 – 326.8 ug/g OC (Figure 20).

Low molecular weight and total PAHs rarely exceeded either the ERL guidelines or Ambient concentrations for San Francisco Bay. Only two stations in Corinthian Yacht Club and one in Ballena Isle Marina demonstrated concentrations above these guideline values. High molecular weight PAHs were slightly more elevated with approximately half exceeding ERL guidelines. Two stations in Berkeley, one in Ballena Isle and two in Corinthian exceeded both the ERL guidelines and the ambient values. Loch Lomond marina exhibited significantly lower PAH concentrations than the other marinas. A single station in Corinthian Yacht Club (CRINTHN05) consistently demonstrated the greatest values for low, high, total and OC normalized PAHs. It is unclear why this one location stands out for PAH contamination, so additional attention may be needed at this location in future surveys.

None of the multiple chemical summations (high, low or total PAHs) exceeded ERM or PEL guidelines for any grouping of PAHs where acute effects would be more probable. Similarly, none of the samples exceeded the organic carbon normalized guideline value (1800ug/g OC) for PAHS (Figure 20), where biological effects would be expected. It is unlikely that the PAH levels in the marina pose a significant risk of acute effects to aquatic life.

PAH distributions are effective interpretive tools in hydrocarbon fingerprinting and can be used to distinguish general sources of hydrocarbons as either pyrogenic or petrogenic. By examining the relative distribution of the C_1, C_2, C_3, and C_4 alkyl homologues of a PAH class (Sauer *et al.*, 1993) and the relative concentrations of the low molecular weight PAHs (e.g.- naphthalene, fluorene, dibenzothiophene) to the higher molecular weight PAHs (e.g.-fluoranthene, chrysene, benzo(a)pyrene) general sources can be determined (Boehm *et al.*, 1981) Examination of the relative higher abundance of high molecular parent PAHS indicates that PAHs in the marina samples PAHs have a pyrogenic signature, most likely from the combustion of fuel. Further review of the C_1 - C_4 homologues for naphthalene, chrysene, and phenanthrene/anthracene further support a pyrogenic source, but also show some indications of a petrogenic signal, which is likely uncombusted fuel. This pattern is consistent throughout the marinas so it seems plausible to infer that PAHs in marina sediments are primarily from combusted fuel, but do show some further indications of unburned fuel. Minor fuel or oils spills or bilge pumping may be possible suspects for the source of unburned fuel though additional fingerprinting research would be required to fully investigate sources.

In summary, PAH compounds are currently detectable in the marinas though not at concentrations that present a high probability of acute toxicity. The PAHs present are primarily from burned fuel with some minor indications of spilled fuel also being present.

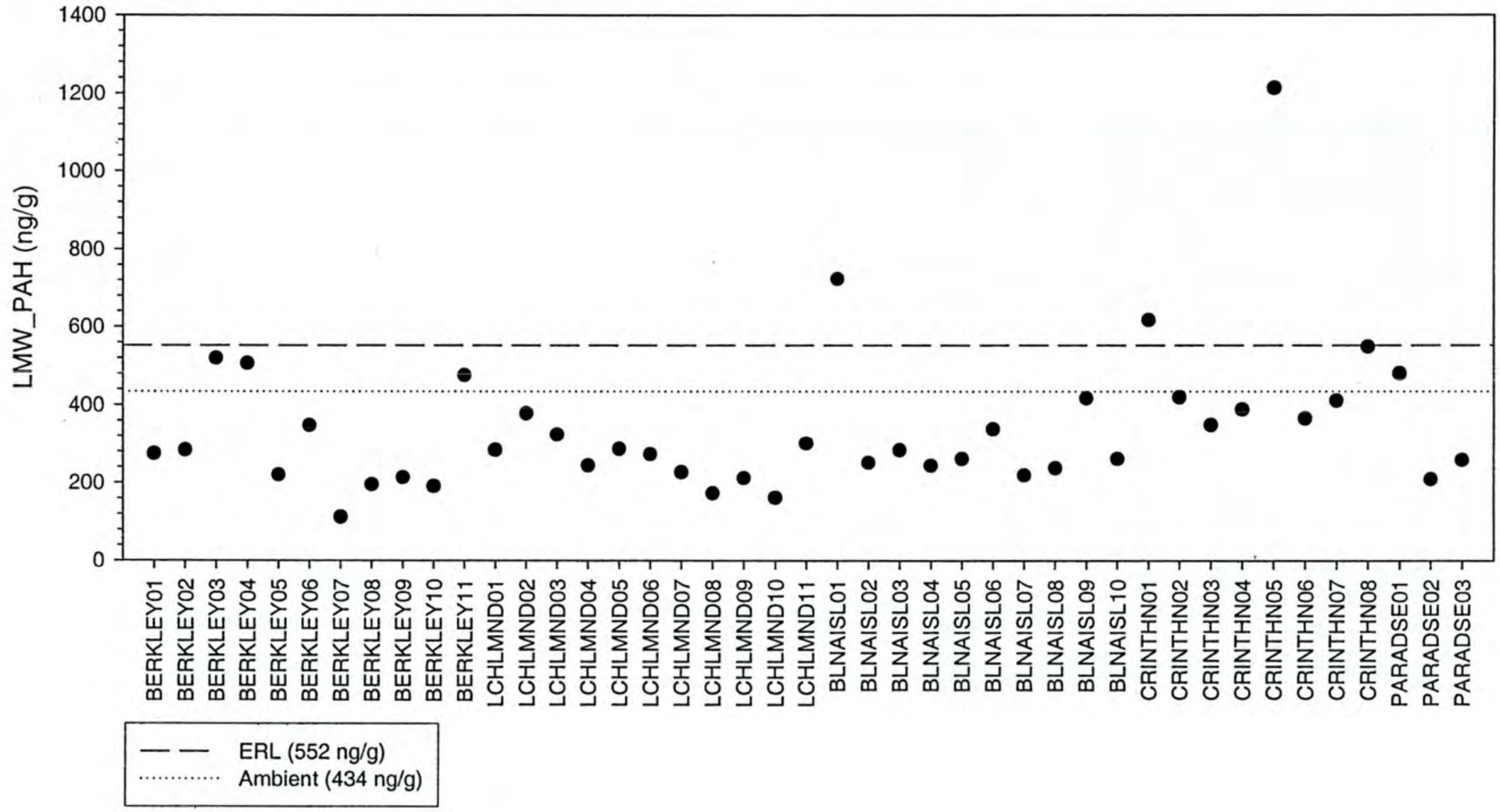


Figure 17. Histogram of Low Molecular Weight PAHs (LMW_PAH) in the marinas and reference site.

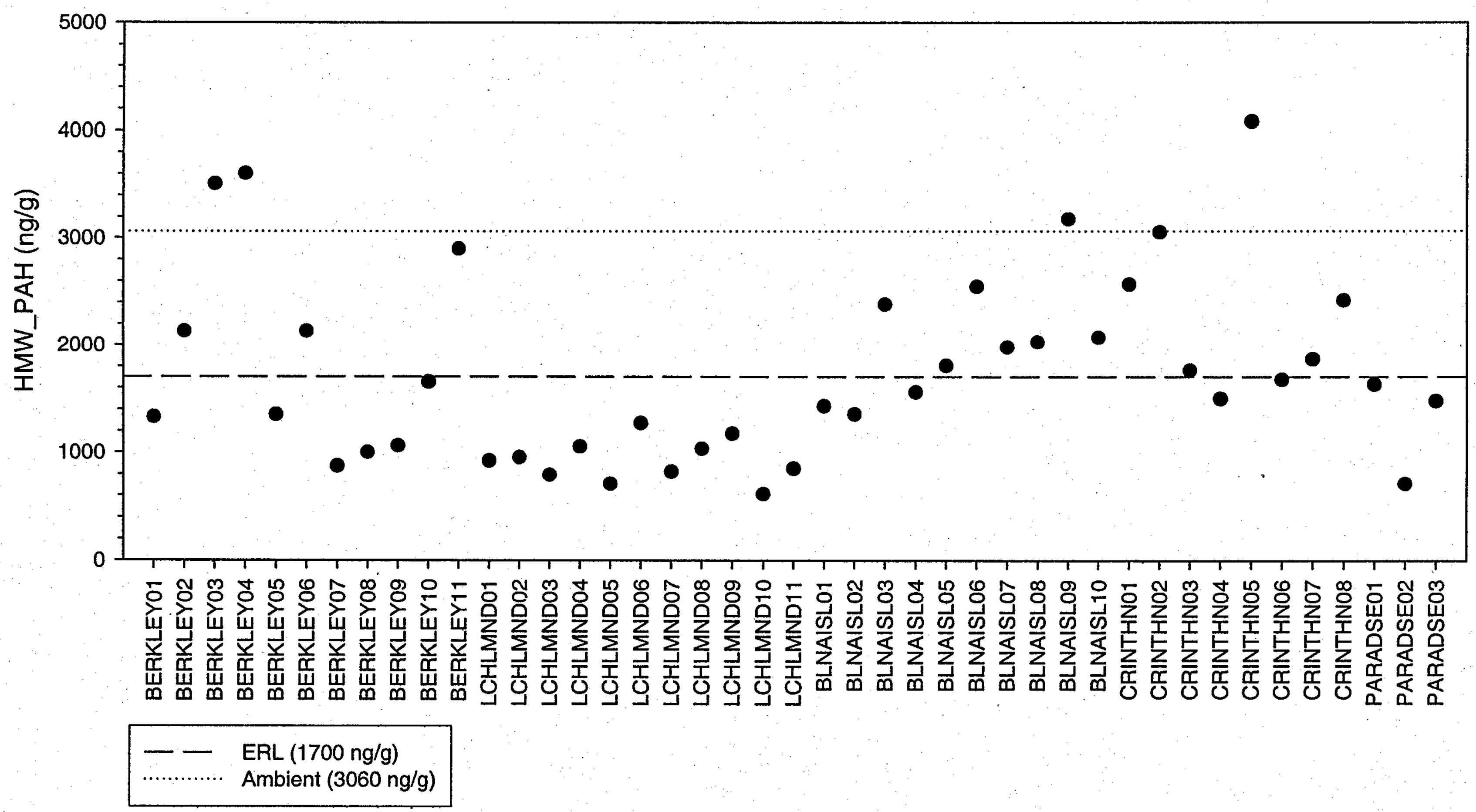


Figure 18. Histogram of High Molecular Weight PAHs (HMW_PAH) in the marinas and reference site.

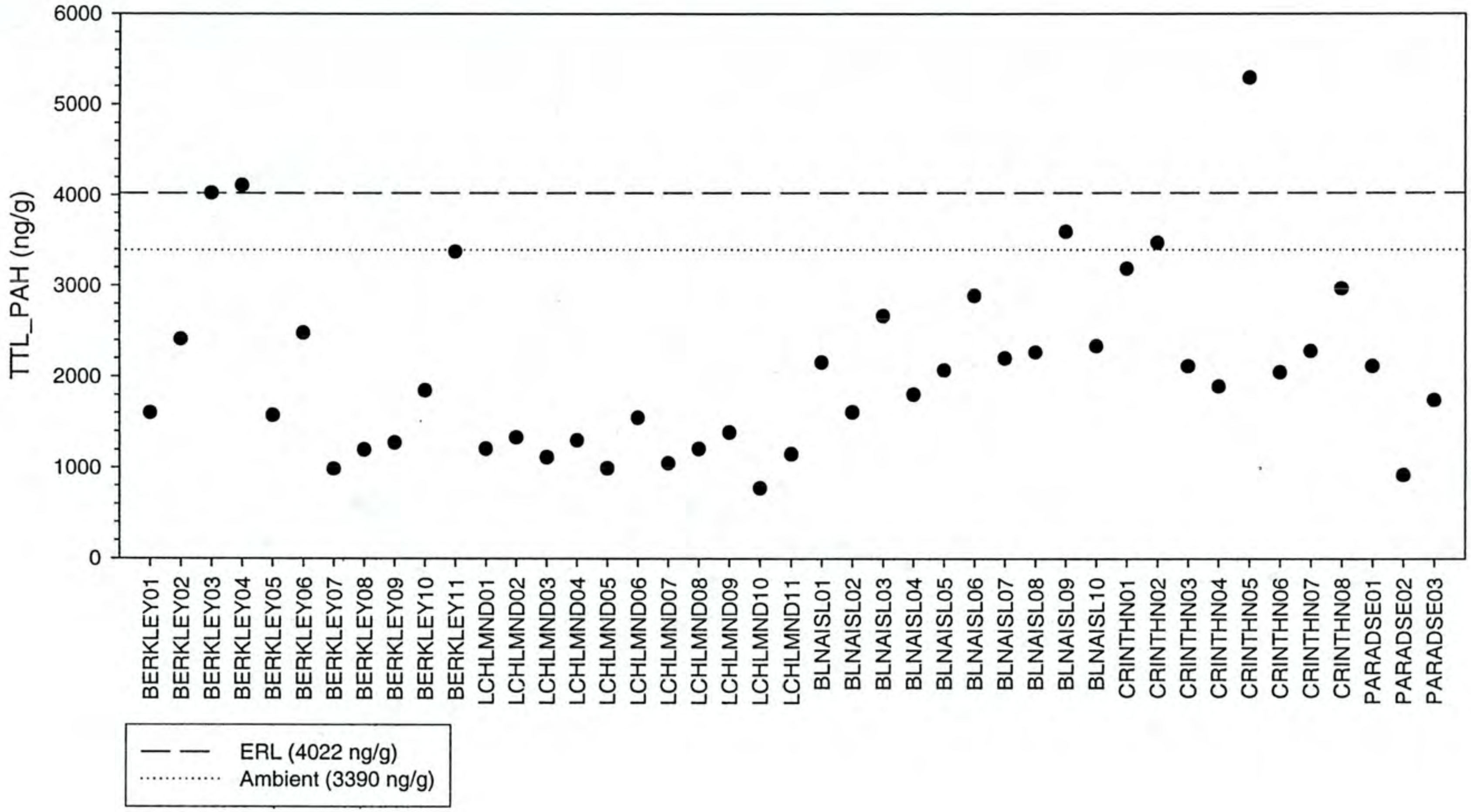


Figure 19. Histogram of Total PAHs (TTL_PAH) in the marinas and reference site.

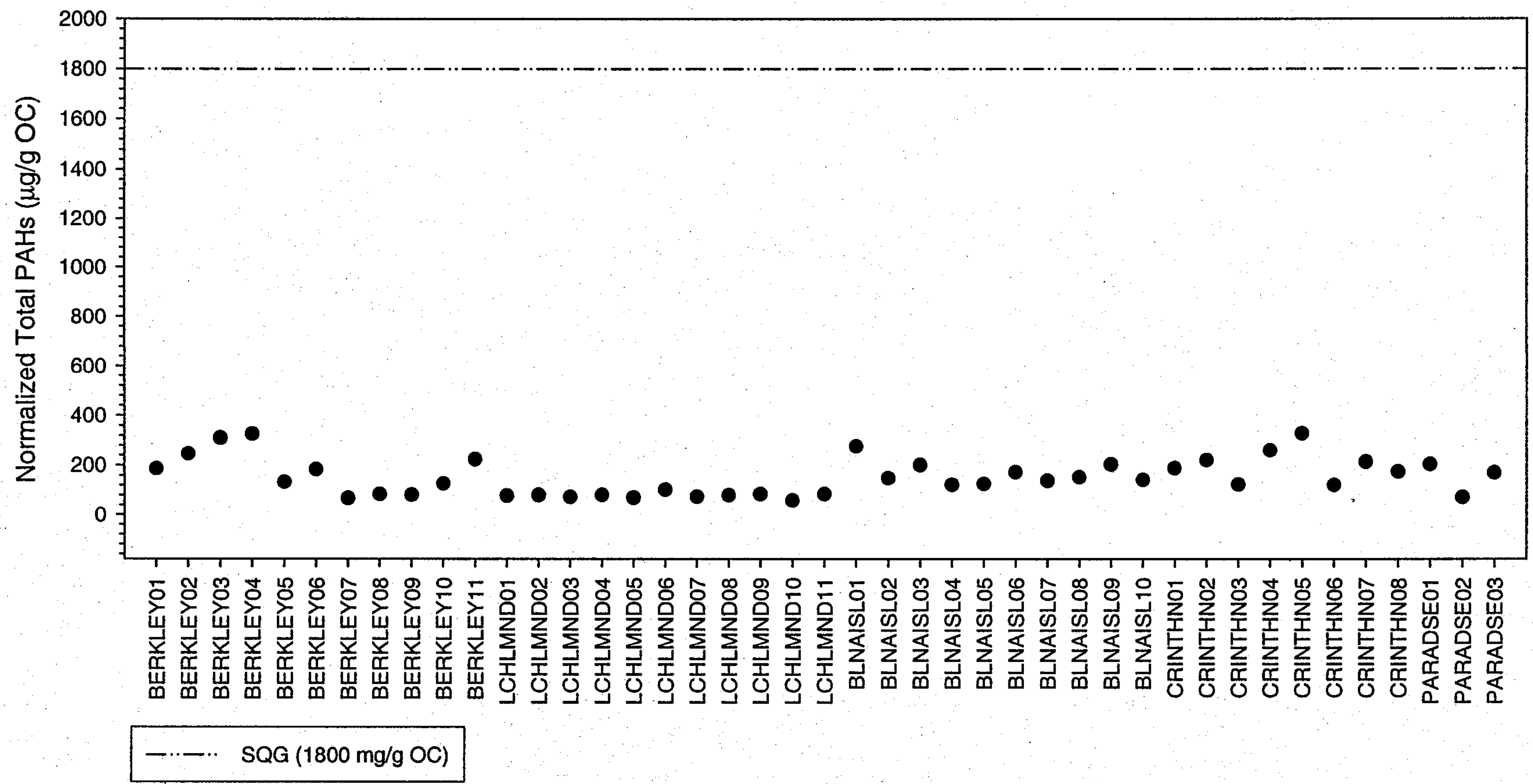


Figure 20. Histogram of Total PAHs normalized to Total Organic Carbon (TOC) in the marinas and reference site.

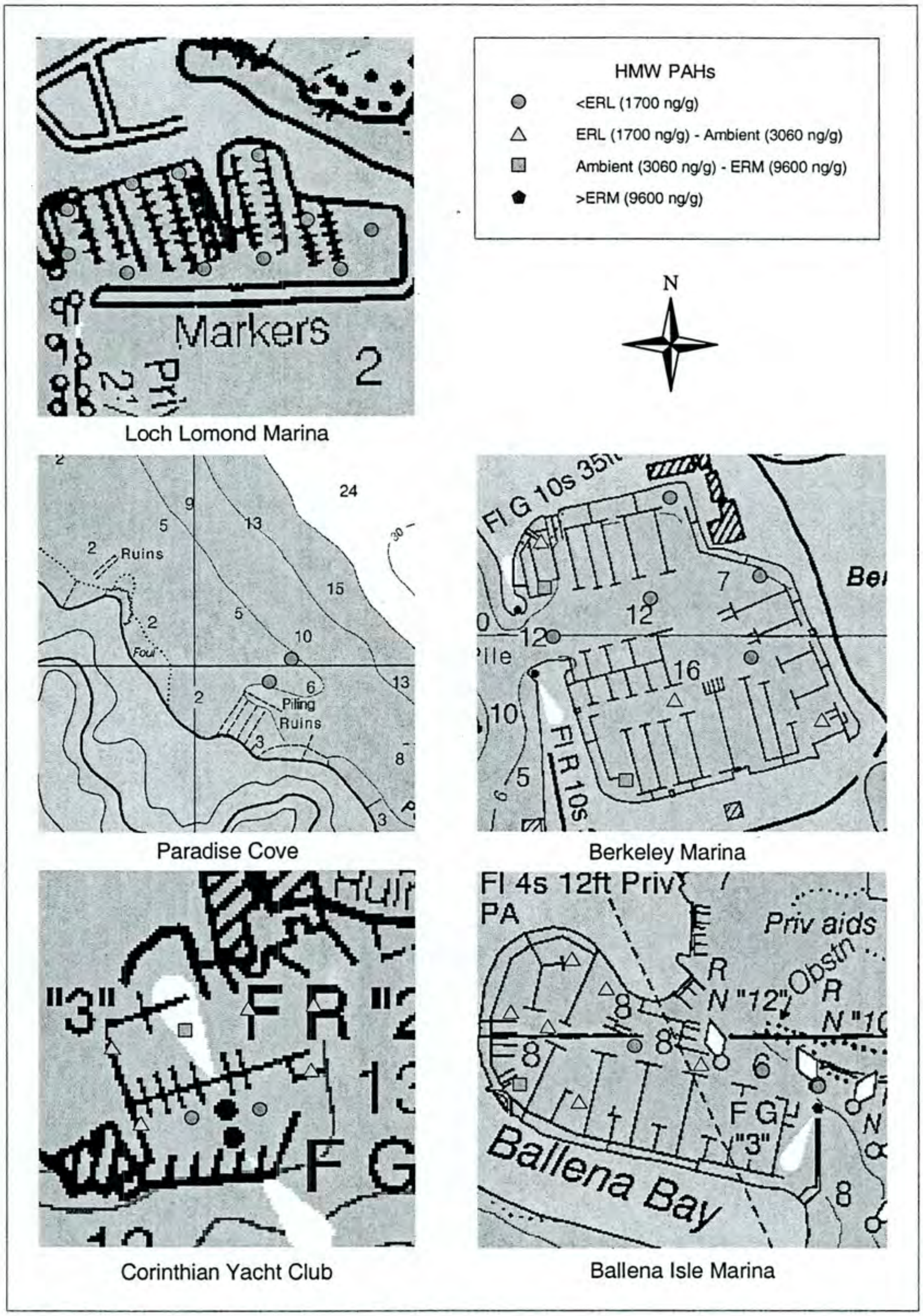


Figure 21. Map displaying distribution of HMW PAH concentrations relative to sediment quality guideline thresholds.

Statistical Analyses

Sediment concentration significantly differed for each metal across all marinas (Table 4). Pairwise comparisons indicate Berkeley and Corinthian Yacht Club were not significantly different than Paradise Cove reference station for each metal (Table 4). Furthermore, Loch Lomond only had one significant difference (zinc) with Paradise Cove. These results could be an artifact of location in that Corinthian Yacht Club, Paradise Cove, and Loch Lomond are on the same side of the Bay. However, it is interesting to note that Loch Lomond and Corinthian Yacht Club had the most significant differences (n=7). A clear pattern did not exist between Berkeley, Loch Lomond, and Ballena Isle. In terms of each metal, zinc had the highest number of significant correlations with other metals (cadmium, chromium, copper, and lead), PAHs (LMW and normalized total), % fines, and % TOC (Table 5). Chromium also appears to have a high number of positive associations with other analytes (copper, % fines, lead, zinc, and LMW PAHs). While most of the metals had a positive association (i.e., both tending to increase in concentration), arsenic and cadmium had a negative correlation in which cadmium concentration decreased as arsenic concentration increased.

Sediment concentration of LMW, HMW, total, and normalized total PAHs significantly differed across all marinas (Table 4). Loch Lomond marina had significantly lower sediment concentrations of HMW, total, and normalized total PAHs compared to Berkeley, Ballena Isle, and Corinthian Yacht Club, where LMW PAHs also significantly differed, but showed no significant differences with Paradise Cove reference station (Table 4). Other pairwise comparisons between the marinas showed no significant differences. All of the PAHs (i.e., LMW, HMW, total, and normalized total) were correlated and showed a positive relationship (Table 5).

Anova comparisons of chemicals indicated numerous significant chemical specific differences between the various harbors (Table 4). In some cases a particular marina exhibited significantly lower concentrations of one chemical while also exhibited significantly greater concentrations of another. One example is that arsenic concentrations were significantly lower in Ballena Isle marina than other marinas, yet copper concentrations were significantly greater there than seen at Corinthian and at the Paradise Cove reference stations. Another example is that zinc was significantly higher in Loch Lomond than all marinas except Ballena Isle. Although differences are evident, overall there was no clear pattern of differences in metal concentrations between Berkeley, and Ballena Isle Marinas. Specific differences of note are: 1) Corinthian Yacht Club tended to have significantly lower metal concentrations than all other marinas, which is further supported by the observation that no statistical differences could be discerned between Corinthian Yacht Club and the nearby reference site at Paradise Cove; 2) Loch Lomond tended to have significantly lower PAH concentrations than most other marinas, though zinc was significantly greater there; 3) TOC and grain size showed no significant differences among the harbors, 4) Zinc was the metal most often seen to have differences between harbors.

Specific chemical correlations were performed to investigate whether any common patterns in use or sources could be discerned (Table 5). As expected, all the PAHs tended to be correlated with each other and suggest a common source. Earlier discussion of PAHs indicated that burned fuel is the most likely explanation. PAHs were generally not correlated or were negatively correlated with metals, so their use or sources do not seem to strongly linked. Copper, cadmium and zinc were often positively correlated suggesting common uses (such as bottom paints) might be the source of these metals to the marinas. Arsenic however did not correlate or was negatively correlated with the other metals indicating a separate use or source (such as wood preservatives). Zinc was positively correlated with all the metals, except arsenic, and also positively correlated with TOC and grain size. Interestingly, zinc was the only chemical positively correlated with lead. These relationships, in concert with the strong differences in zinc concentrations between harbors provide a complex picture for use and sources of zinc that cannot easily be discerned from this study. Zinc in the marina sediments may result from multiple uses or sources.

Table 5. Results for the statistical comparison of analyte concentrations across all marinas and among marinas. A 'Yes' value indicates a significant difference according to either a parametric One Way Analysis of Variance (ANOVA) or a non-parametric Kruskal-Wallis One Way ANOVA. If a significant difference was present, the test statistic, test value, degrees of freedom (df), and p value are listed.

Comparison	Arsenic	Cadmium	Chromium	Copper	Lead	Zinc	% Fines	% TOC	LMW_PAH	HMW_PAH	TTL_PAH	nTTL_PAH
All Harbors	**Yes** (KW, H=23.35, df=4, p<0.01)	**Yes** KW, H=25.10, df=4, p<0.01	**Yes** (AN, F=5.87, df=4, p<0.01)	**Yes** (AN, F=6.75, df=4, p<0.01)	**Yes** (AN, F=7.88, df=4, p<0.01)	**Yes** (AN, F=15.40, df=4, p<0.01)	No	No	**Yes** (KW, H=11.72, df=4, p=0.02)	**Yes** (AN, F=6.29, df=4, p<0.01)	**Yes** (AN, F=5.94, df=4, p<0.01)	**Yes** (KW, H=19.13, df=4, p<0.01)
Berkeley & Loch Lomond	No	No	No	No	**Yes** (T, q=6.02, p<0.01)	**Yes** (T, q=4.80, p=0.01)			No	**Yes** (T, q=4.87, p=0.01)	**Yes** (T, q=4.33, p=0.03)	**Yes** (D, Q=3.26, p<0.05)
Berkeley & Ballena Isle	**Yes** (D, Q=3.62, p<0.05)	**Yes** (D, Q=4.77, p<0.05)	No	No	No	No			No	No	No	No
Berkeley & Corinthian Yacht Club	No	No	No	**Yes** (T, q=5.08, p=0.01)	**Yes** (T, q=6.66, p<0.01)	**Yes** (T, q=5.49, p<0.01)			No	No	No	No
Berkeley & Paradise Cove	No	No	No	No	No	No			No	No	No	No
Loch Lomond & Ballena Isle	**Yes** (D, Q=3.96, p<0.05)	No	No	No	No	No			No	**Yes** (T, q=5.09, p=0.01)	**Yes** (T, q=4.60, p=0.02)	**Yes** (D, Q=3.27, p<0.05)
Loch Lomond & Corinthian Yacht Club	No	No	**Yes** (T, q=5.29, p=0.01)	**Yes** (T, q=5.38, p<0.01)	No	**Yes** (T, q=9.90, p<0.01)			**Yes** (D, Q=3.18, p<0.05)	**Yes** (T, q=6.23, p<0.01)	**Yes** (T, q=6.36, p<0.01)	**Yes** (D, Q=3.85, p<0.05)
Loch Lomond & Paradise Cove	No	No	No	No	No	**Yes** (T, q=6.57, p<0.01)			No	No	No	No
Ballena Isle & Corinthian Yacht Club	No	No	**Yes** (T, q=6.53, p<0.01)	**Yes** (T, q=6.04, p=0.01)	**Yes** (T, q=4.75, p=0.02)	**Yes** (T, q=7.57, p<0.01)			No	No	No	No
Ballena Isle & Paradise Cove	**Yes** (D, Q=3.55, p<0.05)	No	No	**Yes** (T, q=4.18, p=0.04)	No	**Yes** (T, q=4.97, p=0.01)			No	No	No	No
Corinthian Yacht Club & Paradise Cove	No	No	No	No	No	No			No	No	No	No

AN = One Way Analysis of Variance (ANOVA), D = Dunn's Pairwise Multiple Comparison, KW = Kruskal-Wallis One Way ANOVA on ranks, T = Tukey Pairwise Multiple Comparison

Table 6. Results for the analyte comparisons with the Pearson Product Moment Correlation (r). A positive r value indicates a direct relationship while a negative value indicates an inverse relationship. Sample size is 43 for each comparison.

	Arsenic	Cadmium	Chromium	Copper	% Fines	Lead	% TOC	Zinc	LMW_PAH	HMW_PAH	TTL_PAH	nTTL_PAH
Arsenic	*	**Yes** (r=-0.41, p=0.01)	No	No	No	No	No	No	No	No	No	No
Cadmium		*	No	**Yes** (r=0.32, p=0.04)	No	No	**Yes** (r=0.36, p=0.02)	**Yes** (r=0.31, p=0.04)	No	No	No	No
Chromium			*	**Yes** (r=0.59, p<0.01)	**Yes** (r=0.38, p=0.01)	**Yes** (r=0.58, p<0.01)	No	**Yes** (r=0.65, p<0.01)	**Yes** (r=-0.34, p=0.02)	No	No	No
Copper				*	**Yes** (r=0.33, p=0.03)	**Yes** (r=0.67, p<0.01)	No	**Yes** (r=0.87, p<0.01)	No	No	No	No
% Fines					*	No	No	**Yes** (r=0.32, p=0.04)	No	No	No	No
Lead						*	No	**Yes** (r=0.45, p<0.01)	No	No	No	No
% TOC							*	**Yes** (r=0.35, p=0.02)	No	No	No	**Yes** (r=-0.40, p=0.01)
Zinc								*	**Yes** (r=-0.37, p=0.01)	No	No	**Yes** (r=-0.37, p=0.02)
LMW PAHs									*	**Yes** (r=0.67, p<0.01)	**Yes** (r=0.77, p<0.01)	**Yes** (r=0.72, p<0.01)
HMW PAHs										*	**Yes** (r=0.99, p<0.01)	**Yes** (r=0.83, p<0.01)
TTL PAHs											*	**Yes** (r=0.86, p<0.01)
nTTL PAHs												*

LIMITATIONS

It is important to note that the current study was not a comprehensive monitoring effort designed for targeting a wide range of anthropogenic contaminants. Due to funding constraints, the specific pollutants targeted (five metals and PAHs) were identified as those most likely related to boating activities within the marina. There are a substantial number of other pollutants, related to other activities, which may be present in the marinas that this survey has not considered. Examples are industrial and agricultural compounds such as PCBs, pthlates, nutrients, pesticides, fungicides and estrogenic compounds that may enter the marinas through runoff, leaching, stormwater drains or other sources. Effects from unmeasured pollutants should not be implied here, but neither should the potential impacts of other chemicals be overlooked based on the findings of the survey. The marinas that were studied for this survey were selected based on criteria that minimized inputs from many of the outside sources, relative to other San Francisco Bay marinas. From that bias it should become clear that other unmeasured pollutants may pose an even greater probability of biological risk within the other marinas.

It should also be made clear that extrapolation of the results presented here to the numerous other marinas of San Francisco Bay must be made with caution. Although selection criteria were carefully considered in choosing the four marinas surveyed, not all marinas fit the selection criteria in the same ways with respect to size, use and potential sources of contamination. Each likely present its own unique chemical signature based on the conditions and activities that are found there. For example, different water flushing rates and patterns may contribute to differences in contaminant levels found in each marina. For these reasons, the reader is cautioned from drawing definitive conclusions on the differences between the marinas surveyed and whether one marina "worse" or "better" than another in terms of controlling pollution. The four marinas surveyed here do however encompass a broad range of conditions and activities commonly found in most marinas, so have been good representatives for this pilot study to help establish chemical ranges and probabilities of biological impacts.

The sediment quality guidelines used in this report for chemical comparisons were primarily developed based on short term (10 day) acute exposures of amphipods to field collected sediments. Chronic toxicity test, bioaccumulation or community indices that better integrate more sensitive species and long term exposure have not been well incorporated into the guideline development. The purpose of the incidental collection of benthic community samples was to allow some biological assessment of chronic exposure to marina contaminants. Until funding is secured to analyze those communities few informed statements can be made about community health. It is therefore prudent to caution that the sediments in the marinas have not been appropriately investigated for effects resulting from chronic exposure to pollutants.

SUMMARY OF RESULTS

1. Sediment quality guidelines were useful in evaluating chemical pollution within the sediments of four San Francisco Bay marinas. Arsenic, chromium, copper, and zinc were most often found to exceed established Effects Range Low (ERL), Threshold Effects Levels (TEL) and Ambient guideline values. Use of these guidelines indicates that these chemicals pose a low, to occasionally moderate, probability of having associated acute toxic effects to aquatic life. Of these four metals, copper and chromium are of greatest concern. Long-term status and trend monitoring of these four trace metals in marinas is recommended.
2. Dissolved oxygen concentrations in Ballena Isle and Berkeley Marinas were low (<4 mg/l) in bottom waters at several locations and may present a risk of hypoxia to aquatic life. Additional monitoring of oxygen levels is recommended to improve both spatial and temporal resolution of oxygen saturation conditions.
3. Measured concentrations of cadmium, lead and polycyclic aromatic hydrocarbons (PAHs) were generally low and pose a low probability of having associated acute toxic effects to aquatic life.
4. Statistical analyses indicate Corinthian Yacht Club tended to have significantly lower metal concentrations than all other marinas, and was similar to the reference site at Paradise Cove. There was no clear pattern of statistical differences in metal or PAH concentrations among Berkeley, and Ballena Isle Marinas. Loch Lomond tended to have significantly lower PAH concentrations than most other marinas, though zinc was significantly greater there. Zinc was the metal most often seen to have differences between harbors while TOC and grain size showed no significant differences among the harbors.
5. PAHs were generally not correlated or were negatively correlated with metals, so their use or sources do not seem to be strongly linked. Copper, cadmium and zinc were often positively correlated suggesting common uses, such as bottom paints, might be the source of these metals to the marinas. Arsenic did not correlate or was negatively correlated with the other metals indicating a separate use or source, possibly treated wood products.

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APPENDIX B

Selected Marina Water Quality Studies from Around the World

Several studies worldwide document water quality conditions in marinas by analyzing marina sediment, water, and mussel tissue samples. This appendix summaries key marina studies worldwide. It does not summarize studies conducted in California, which are included in Chapter Two. Many of the studies described in this section were conducted in marinas that have different characteristics and conditions than California marinas.

Studies Documenting Metals in Marinas. Several studies worldwide document elevated metals concentrations in marinas. A 1991 study by the North Carolina Department of Environmental Management on North Carolina marinas found that copper and zinc were detected in oyster tissue samples at significantly higher concentrations within the marinas compared with reference stations outside the marinas. In addition, sediment samples showed significantly higher concentrations of copper, zinc, arsenic, cadmium, chromium, lead, mercury, and nickel within marinas compared with reference sites. While these sediment concentrations were elevated, they were not high enough to be considered toxic to marine life.1

In a study of South Carolina marinas, Marcus and Thompson (1986) found detectable concentrations of copper, zinc, cadmium, lead, nickel, and chromium in oyster tissue at the sampled marinas. While these concentrations were similar to South Carolina oysters in other non-marina areas, dynamic zinc and copper concentrations were found to be highly correlated with marina proximity.[2] Another study by Marcus and Swearingen (1988) found copper, zinc, lead, chromium, and nickel at elevated concentrations in sediment at an excavated boat basin in Murrells Inlet, South Carolina. Metals in this basin were significantly higher than other marinas in South Carolina, and this was found to be due to low water circulation.[3]

[1] NCDEM 1991. *Coastal Marinas: Field Survey of Contaminants and Literature Review.* Report #91-03. North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management, Water Quality Section.
[2] Marcus, J.M., and A.M. Thompson. 1986. *Heavy Metals in Oyster Tissue Around Three Coastal Marinas.* Bulletin of Environmental Contamination and Toxicology 36: 587-594
[3] Marcus, J.M. and G.R. Swearingen, A.D. Williams, and D.D. Heizer. 1988. *Polynuclear aromatic Hydrocarbons and Heavy Metals Concentrations in Sediments at Coastal South Carolina Marinas.* Archives of Environmental Contamination and Toxicology 17: 103-113

In Chesapeake Bay, Hall et al (1988) examined dissolved copper concentrations in waters of four recreational marinas. Three of these marinas had high dissolved copper levels, and recreational boats housed in these marinas were considered the likely source.[4]

A study by the Australian Environment Council in 1989 found that copper levels in *Saccostrea commercialis*, oysters transplanted to marinas from a 'clean' area, increased by three orders of magnitude and lead increased by up to thirty-three orders of magnitude. Zinc levels increased by two orders of magnitude, but were half of what was found just outside the marinas, making it difficult to identify whether the contamination was coming from marina activities, or not.[5]

In the Caribbean, sediments of two marinas in St. Thomas were sampled for metals by researchers from the University of Puerto Rico. Total metals concentrations were highest in the Independent Boatyard (IBY), the marina with the highest level of active vessel maintenance activity, with the highest concentrations found adjacent to the dinghy dock and vessel haul-out station (Al 5.28μg/g, As 13.55μg/g, Cd 0.47μg/g, Cu 1535μg/g, Fe 3.42μg/g, Pb 178.50μg/g, Ag 0.14μg/g, Sn 33.4μg/g, Zn 441.5μg/g). Wash down and maintenance activities were cited as a probable source. At the Crown Bay Marina (CBM), the total highest metals concentrations were found nearest to a storm drain (As 9.27μg/g, Cu 70.85μg/g, Ni 11.05μg/g, Zn 92.60μg/g) indicating urban runoff as the likely source of contamination.[6]

Studies Documenting Petroleum Hydrocarbons in Marinas. Several studies have found high concentrations of petroleum hydrocarbons in marinas, particularly those characterized by poor flushing. In a North Carolina study, mononuclear aromatic hydrocarbons were detected at higher frequency in the waters of marinas that had fueling services than at reference sites, although concentrations were low and did not violate the State's standard. These hydrocarbons included benzene, toluene, xylene, and ethyl benzene, which are components of gasoline and used as degreasers, in cleaners, and as fuel additives, solvents and thinners. Additionally, PAHs were detected in sediments at six marinas with fuel docks, and one marina had levels exceeding toxicity thresholds.[7] In South Carolina, Marcus et al (1988) examined petroleum hydrocarbons in sediments of three marinas. They found that samples taken near or in marinas yielded high PAH levels, and PAH levels increased in the larger marinas.[8] Elevated PAHs were also found in

[4] Hall, W., S. Bushong, L. Hall, M. Lenkevich, and A. Pinkney. 1988. *Monitoring Dissolved Copper Concentrations in Chesapeake Bay.* Environmental Monitoring and Assessment 11:33-42.
[5] McMahon, P.J.T. 1989. *The Impact of Marinas on Water Quality.* Water, Science, and Technology. Vol. 21, No. 2, pp 39-43, 1989.
[6] Hinkey, Lynne Marie 2001. "A Baseline Assessment of Environmental Conditions and the potential for Polycyclic Aromatic Hydrocarbons (PAHs) Biodegredation in Marina Waters and Sediments." A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Marine Sciences (Chemical Oceanography) University of Puerto Rico. Mayaguez Campus.
[7] NCDEM 1991
[8] Marcus et al 1988

an excavated boat basin in Murrels Inlet, South Carolina[9], and Wendt et al (1990) found PAHs in sediments in another South Carolina marina over three seasons, while none were found in the control site. The same study found PAHs in oysters collected from the marina during summer months, at levels well above the control site.[10] Yet another South Carolina study examined PAHs in oyster tissue at three coastal marinas. Oyster tissues collected from the two larger marinas in this study, contained a larger variety of PAH compounds than the smallest marina.[11]

A study of Chesapeake Bay marinas, which compared creeks containing marinas to creeks without marinas (and hence, less boating activity), found significantly higher levels of hydrocarbons (both aliphatic and aromatic) in the creeks containing marinas.[12]

In Washington State, the Washington State Department of Ecology studied sediment particulate matter and bottom sediments at two marinas in Thea Foss Waterway in Commencement Bay. PAHs were measured at levels above Commencement Bay sediment quality standards. However, there was no clear evidence isolating marina-related sources from other sources of this contamination. The marinas were not enclosed by breakwaters, allowing sediments and particulates to flow freely in and out.[13] In another study of four marinas in the San Juan Islands of Washington, total PAH concentrations in sediments were elevated, but did not exceed sediment quality standards.[14]

In the Caribbean, water and sediment of two marinas (Crown Bay Marina [CBM] and Independent Boatyard [IBY]) in St. Thomas were sampled for Polycyclic Aromatic Hydrocarbons (PAHs) by researchers from the University of Puerto Rico. This study illustrates the complexities with identifying the sources of contaminants in marinas. Elevated concentrations of PAHs in water and sediment at various stations around the two marinas were found, but researchers suggest that the concentrations within the marinas were similar to PAH inputs from non-marina activities such as urban runoff and wastewater treatment plant discharges. Average sediment PAH concentrations within both marinas was 384.6 ng/g, and the average outside the marinas was 125.5 ng/g. The highest concentrations of PAHs in water were found at the fuel dock of Crown Bay Marina (CBM) (1123.5 ng/L), however, in sediments near the same fuel dock, the lowest PAH concentrations were found (3.9 ng/g). Flushing patterns at CBM indicated, however, that petroleum from the fuel dock could have migrated through the water col-

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[9] Marcus, J.M. and G.R. Swearingen. 1983. A Water Quality Assessment of Selected Coastal Marinas, Beaufort County, South Carolina. South Carolina Department of Health and Environmental Control. Technical Report No. 022-83.

[10] Wendt, P.H., R.F. Van Dolah, M.Y. Bobo and J.J. Manzi. *Effects of Marina Proximity on Certain Aspects of the Biology of Oysters and Other Benthic Macrofauna in a South Carolina Estuary.* South Carolina Marine Resources Center. South Carolina Wildlife and Marine Resources Department. Technical Report #74.

[11] Marcus, James M. and Tina P. Stokes. 1985 *Polynuclear Aromatic Hydrocarbons in Oyster Tissue Around Three coastal Marinas.* Bulletin of Environmental Contamination and Toxicology. 35:835-844

[12] Voudrias, E.A., and C.L. Smith. 1986. *Hydrocarbon Pollution from Marinas in Estuarine Sediments.* Estuarine, Coastal, and Shelf Science 22: 271-284.

[13] Washington State Department of Ecology (b). 2001. Contaminants Associated with Settling Particulate Mater and Bottom Sediments at Two Marinas in Thea Foss Waterway. Publication No. 01-03-023. Olympia, WA.

umn and deposited in sediments at the dinghy dock (which had a PAH concentration of 1102.9 ng/g in sediments) and the sampling station located in the low flushing area of the marina (which had a PAH concentration of 82.1 ng/g in sediments). A similar pattern was observed at Independent Boatyard Marina (IBY), where dinghy dock (408.6 ng/g) and low flushing stations (372.2 ng/g) had high PAHs in sediments, and these were located downwind and down current from a fuel dock in an adjacent marina. Dinghy engine exhaust were sited by researchers as also a likely source of PAHs at the dinghy docks of both marinas. At the Crown Bay Marina (CBM), however, in addition to vessel and fuel dock operations, another likely source was spills from oil tanks located across the road and entering the marina through a storm drain, and road run-off.[15]

Studies Documenting Bacterial Contamination in Marinas. A few studies have looked at the association of bacterial contamination and recreational vessels in marine waters but drawing conclusions is complicated by environmental and climatic conditions, flushing and water circulation patterns, and types of boats and usage at different marinas. Seabloom (1969) studied the water quality of Wallochet and Meydenbauer Bays in Washington State. It was found that vessel discharges adversely affected the bacteriological quality of Wollochet Bay, however, sampling results did not show an adverse affect in Meydenbauer Bay. Coliform levels could have been affected by exposure to sunlight, competition for nutrients, seawater temperature, and the existence of marine predators during the summer months.16 Fisher et al (1987) compared two marinas in North Carolina during a peak use period. They found elevated fecal coliform levels near boats during high periods of usage and occupancy, however, conditions were worse at the enclosed, lower flushing marina, compared to the open water marina. Differences in physical and hydrographic conditions, and difference in boat types and usage patterns were complicating factors in determining the contribution of boats to fecal coliform levels. This study does show that an open water marina, which allows for better water circulation and flushing, can substantially dilute and kill-off microbial contaminants from fecal waste discharges.17

In the Caribbean, researchers from the University of Puerto Rico examined fecal coliform levels in five marinas over three seasons (winter, spring, summer) in one year in Puerto Rico and the U.S. and British Virgin Islands. Approximately four stations (fuel dock, dinghy dock, low flushing area, outside marina) in each marina were sampled for at least two mornings and two afternoons in each season. While the sample size was small and insufficient to provide sta-

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[14]Washington State Department of Ecology (a). 2001. Concentrations of Selected Chemicals in Sediments from Harbors in the San Juan Islands. Publication No. 01-03-007.
[15] Hinkey 2001
[16] Seabloom, Robert W. 1969. *Bacteriological Effects of Small Boat Wastes on Small Harbors.* University of Washington College of Engineering. Seattle, Washington. July 1969.
[17] Fisher, John S., Richard R. Perdue, Margery F. Overton, Mark D. Sobsey and Ben L. Sill. 1987. *A Comparison of Water Quality at Two Recreational Marinas during a Peak Use Period.* UNC Sea Grant College Program. North Carolina State University. UNC Seagrant Publication #UNC-WP-87-1

tistically meaningful comparisons, results provided information on the need for research on the correlations between elevated fecal coliform levels at a fuel dock in summer and the presence of petroleum hydrocarbons (PAHs). Overall, the annual fecal coliform averages in the outside marina stations (57.6 cfu/500ml) were higher than within marina stations (50.1 cfu/500 ml). Both averages were higher than the control annual average of 11.1 cfu/500ml.[18]

Studies Documenting Nutrients in Marinas. In the Caribbean, researchers from the University of Puerto Rico monitored nutrients for one year, including the fall, winter, spring and summer, in five marinas in Puerto Rico and the U.S. and British Virgin Islands. Within the marinas, average nitrate and phosphate concentrations were higher than the average in control stations in every season except winter. Nitrate concentrations ranged from 0.0 μM to 3.5 μM (highest concentration at a station just outside of a marina). Phosphate concentrations ranged from 0.0 μM to 0.4 μM at a fuel dock station. Researchers speculated that fuel dock activities, such as using detergents to clean up boat bilges, as a likely cause.19 See Chapter Two for nutrient monitoring conducted in Lake Tahoe, California.

[18] Hinkey 2001
[19] Hinkey 2001

APPENDIX C

SAN FRANCISCO BAY MARINAS AND RECREATIONAL BOATING NONPOINT SOURCE TASK FORCE REPRESENTATION

Government	Marinas and Boating	Non Government Organizations	Water Quality Research
California Coastal Commission	Ballena Isle Marina	Bay Planning Coalition	San Francisco Estuary Institute
Richardson Bay Regional Authority	Benicia Marina	WaterKeepers Northern California/San Francisco BayKeeper	
Port of Oakland	Berkeley Marina		
Contra Costa County Public Works Department	Brisbane Marina		
San Francisco Bay Regional Water Quality Control Board	California Association of Harbormasters and Port Captains		
City of Pittsburg	Corinthian Yacht Club		
State Water Resources Control Board	Coyote Point Marina		
San Francisco Estuary Project	Loch Lomond Marina		
Port of San Francisco	Northern California Marine Association (NCMA)		
	Oyster Point Marina		
	Pacific Interclub Yacht Association (PICYA)		
	Recreational Boaters of California (RBOC)		
	California Marine Affairs and Navigation		
	San Francisco Marina		

MARINA TECHNICAL ADVISORY COMMITTEE REPRESENTATION

Government	Marinas and Boating	Water Quality Research
Karen Taberski, San Francisco Regional Water Quality Control Board	Ted Warburton, Brisbane Marina	Jon Leatherbarrow, San Francisco Estuary Institute
Revital Katznelson, State Water Resources Control Board	Russ Robinson, Recreational Boaters of California	Russell Fairey, Moss Landing Marine Laboratories, Marine Pollution Studies Lab
Lynne Hinky, National Oceanic and Atmospheric Administration	Neil Ross, Marina Environmental Consultant/Marine Environmental Education Foundation	
Vivian Matuk, California Coastal Commission		

APPENDIX D:
MARINA SELECTION MATRIX

Name	Scale	Facilities*	Municipal Stormdrain?	Land-use	Sediment deposition	Flushing ✣	Boat type*(sail/power)	Activity level✦	Age	Depth
Berkeley Marina	4	BM, DS, FD, FP,HL,HO,LR,PL,R, RR,SH,	No	Park/old landfill, rest., hotel.	2.4"/yr	"Good".	80/20. 10% LB, some houseboats	'pretty busy'. Wknd 75%	1936	12'MLLW
Loch Lomond, San Rafael	3	BM, BS, DS, FD, LR, R, YC	No	Residential, comm., sewer main on rd. Hist: mudflats	6-12"/yr	"pretty good". Strong current	40/60. 10% liveaboards	Very busy on weekends	1958	7'MLLW
Oyster Point, South San Francisco	2	B, DS, FD, FP, L, LR, PL, PN,RR, SH, R	No	Comm.*, rd, old landfill under parking lot	1"/yr	"relatively well." East better west	50/50. 10% LB	'not busy'	1963	7'MLLW
Emery Cove Yacht Harbor, Emeryville✈	2	L, LR, PL, RR, SH,	No	None	2.4"/yr	Good	75/25. 25 LB	Not busy	1984	8.5'MLLW
Emeryville City Yacht Harbor✈	2	FD, FP, L, LR, PL, PN, RR, SH,	No	None	2-4"/yr	" "	50/50. 10 FB, 20 LB.	Busy on weekends	mid 70s	8' MLLW
Ballena Isle Marina, Alameda	2	FD, H, L, LR, PL, RR, SH, YC	No	Residential/open space. Peninsula created from dredged material	6"/yr	"pretty good"	65/45. 51 liveaboards	Light	1965	8'MLW
Richmond Marina Bay Marina, Richmond	1 or 2	DS, L, RR, R, SH, YC	No	Residential, parks, comm. Hist: shipyard	4.8"/yr	"good"	80/20. 10% liveaboards	"sporadic/ weather controlled"	1970s	15'MLLW
San Leandro Marina, San Leandro	2	FD, LR, PN, R, RR, SH, YC,	No	Parks, golf course, commercial. Hist: mudflats	9"/yr	"very good tidal action"	60/40. 10% liveaboards	Moderate weekdays, pretty heavy weekends	1963	7'MLLW
Aeolian Yacht Club, Alameda☆	1 or 2	BM (not in use currently), DS, HO, L, RR, SH	No	Residential, across from Bayfarm island. Hist: open space	6"/yr	"good"	60/40. 5 liveaboards (some old rusty boats, nice yachts)	"50% berthers use boats on daily basis"	1908	11' at high tide, 6' at low tide
Clipper 3 Yacht Harbor, Sausalito	2	BM, HO	No	Residential, commercial,town streets/hist: naval shipyard	3.6"/yr	***	40/60. 10% liveaboards	Seasonal	1950	8'MLLW

Matrix Key:
* B=beach, BM=boat maintenance, BR=boat rinse, BS=bait shop, Comm=Commercial, DS=dry storage, FC=Fish Cleaning, FD=fuel dock, FP=fishing pier, H=hoist, Hist=historical, HL=hotel, HO=Haul Out, LB=liveaboard, LR=launch ramp, L=laundry, PN=picnic area, PL=parking lots, R=restaurant, RR=restroom, SH=showers, YC=yacht club.
**According to harbormaster, runoff from Sausalito streets next ends up in the Bay. There may be outfalls at the end of each street.
***Many harbormasters say Richardson Bay is well flushed, because of the 6 feet tidal amplitude, emptying out the Bay and then filling back up again. But others say that this water is largely recycled.
✣Flushing has not been calculated scientifically for marina basins, and very few portions of the Bay have been calculated. Qualitative flushing characteristics obtained from harbormasters. Harbormasters knew little about flushing, or did not disclose.
✦Subjective accounts from harbormasters
☆Marina seems to be in disrepair. Older, rustier boats. Old dredger on one of the side ties.
✈Emeryville City might be dredging this summer. Could this also affect sampling at adjacent Emery Cove? Coyote Point is dredging in July.

Name	Scale	Facilities*	Municipal Stormdrain?	Land-use	Sediment deposition	Flushing ✣	Boat type*(sail/power)	Activity level✦	Age	Depth
Coyote Point Marina, San Mateo✈	2	FD, LR, YC, RR, SH, PN, B	No	Rec. area, golf course, restrnt, PG&E power substation. Hist: lumberschooners, amuse pk, merch. marine school.	8"/yr	"fairly good"	65/35	'fairly busy' on weekends	1942	8MLLW
Pelican Yacht Harbor, Richardson Bay	1	L, PL, RR, SH	No**	Residential, commercial, town streets. Hist*: naval shipyard	1.8"/yr	"very good"***	80/20, 10% liveaboards	busy	1972	12'MLW
Marina Plaza Harbor, Richardson Bay	1	PL, PN, RR	No**	" "	2"/yr	"OK, not good"	90/10, 10% liveaboards	Relatively quiet	1984	12' MLW
Richmond Yacht Club, Richmond	1	BR, DS, HO, PL, R, RR, SH	No	Residential, oil. Hist: old army fuel depot, brickworks across street, shipyards, metalworks	1.2"/yr	"well flushed"	99/1	Busy times revolve around boat races	1962	8'MLLW
Brickyard Cove Marina, Richmond	1	DS, H, L, PL, R, RR, SH	No	" "	1.5"/yr	"stays surprisingly clean"	95/5. 6% liveaboard	"high side of normal" (norm low)	1978	8'MLLW
South Beach Harbor, San Francisco	**1**	**PL, RR, R, SH, YC**	**No**	**Urban, Pac Bell Park. Hist: shipping/lght. Ind.**	**1.2"/yr**	**"very good"**	**60/40**	**Very busy**	**1987**	**15'MLLW**
Corinthian Yacht Club, Tiburon	**1**	**DS, LR**	**No**	**Residential, commercial. Hist: Ferry term & railhead**	**5-6"/yr**	**"quite well" near raccoon straights**	**66/34**	**Busy on weekends**	**1887**	**8' but varies dramatically around the marina**
Clipper 4 Yacht Harbor, Richardson Bay	1		No	Residential, commercial,town streets/hist: naval shipyard	3.6"/yr	***	40/60	Seasonal	1950	8'MLLW
Clipper 2 Yacht Harbor, Richardson Bay	1	DS, FD adjacent to basin, LR	No	Residential, commercial,town streets/hist: naval shipyard	3.6"/yr	***	40/60	Seasonal	1950	8'MLLW
Brisbane Marina, Brisbane	1	FC, PN, RR, SH	No	Few commercial high rises. Open land. Hist: dump (construction rubble)	4-5"/yr	"not very good" (2-3 days)	50/50	"relatively more active than other marinas"	1983	8'MLLW

Matrix Key:

* B=beach, BM=boat maintenance, BR=boat rinse, BS=bait shop, Comm=Commercial, DS=dry storage, FC=Fish Cleaning, FD=fuel dock, FP=fishing pier, H=hoist, Hist=historical, HL=hotel, HO=Haul Out, LB=liveaboard, LR=launch ramp, L=laundry, PN=picnic area, PL=parking lots, R=restaurant, RR=restroom, SH=showers, YC=yacht club.

**According to harbormaster, runoff from Sausalito streets next ends up in the Bay. There may be outfalls at the end of each street.

***Many harbormasters say Richardson Bay is well flushed, because of the 6 feet tidal amplitude, emptying out the Bay and then filling back up again. But others say that this water is largely recycled.

✣Flushing has not been calculated scientifically for marina basins, and very few portions of the Bay have been calculated. Qualitative flushing characteristics obtained from harbormasters. Harbormasters knew little about flushing, or did not disclose.

✦Subjective accounts from harbormasters

✫Marina seems to be in disrepair. Older, rustier boats. Old dredger on one of the side ties.

✈Emeryville City might be dredging this summer. Could this also affect sampling at adjacent Emery Cove? Coyote Point is dredging in July.

APPENDIX E

EXAMPLES OF MANAGEMENT PRACTICES[1]

Non-Toxic Anti-Fouling Strategies for Boats. Copper-based paints are the most popular anti-fouling paints for boat hulls. These antifouling coatings slowly release copper into the water in their most toxic form to retard this growth and maintain a smooth surface on the hull. Copper can be released from the boat hull through land-based maintenance and sanding activities, underwater hull cleaning, and through passive leaching as described above. Laboratory experiments conducted by the Southern California Coastal Water Research Program (SCCWRP) in San Diego found that on a mass basis, ninety-five percent of the copper loading from recreational hull coatings occurs via passive leaching, as opposed to underwater hull cleaning.2

Boaters can help to address copper contamination in marinas by implementing non-toxic anti-fouling strategies. Marinas and boatyards can help by educating boaters on these alternative strategies. Non-toxic anti-fouling strategies involve combining the use of non-toxic or less toxic bottom coatings with mechanical methods, such as frequent cleaning, and companion strategies.[3]

Currently available non-toxic bottom coatings include:

- Silicon-based
- Epoxy-based
- Water-based
- Polymer-based
- Epoxy and silicon based coatings do not adhere to residual copper-based paints, so existing layers of paint must be stripped first.

[1] These are examples only, and are not an exhaustive list of marina and recreational boating management practices. For more information, see *The California Clean Marina Toolkit: A Resource for Environmentally Sound Marina Management and Operation.* California Coastal Commission Boating Clean and Green Campaign. 2004.
AND
U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating.* Nonpoint Source Control Branch, Office of Wetlands, Oceans and Watersheds, Office of Water, U.S. Environmental Protection Agency. November 2001.

[2] Schiff, Kenneth C., Dario Diehl, and Aldis Valkirs. 2003. *Copper Emissions from Antifouling Paint on Recreational Vessels.* Technical Report 405. Southern California Coastal Water Research Project. June 2003; and SDRWQCB. 2003. DRAFT Basin Plan Amendment and Technical Report for Dissolved Copper in the Shelter Island Yacht Basin. California Regional Water Quality Control Board, San Diego Region. January 31, 2003

[3] Taylor-Johnson, Leigh and Jamie Anne Miller. 2002. *What You Need to Know about Non-Toxic Anti-Fouling Strategies for Boats.* California Sea Grant/UC Cooperative Extension. Report No. T-049. AND
Taylor-Johnson, Leigh and Jamie Anne Miller. 2003. *Making Dollars and Sense of Nontoxic Antifouling Strategies for Boats.* California Sea Grant/UC Cooperative Extension. Report No. T-052.

Companion Strategies include:

- Frequent cleaning of hulls to remove early stages of growth before they harden[1]
- Using the vessel more often
- Using vessels at high speeds
- Storing vessels on land or hoisting them above water in the slips
- Surrounding vessels with plastic liners and adding 10-15% fresh water to reduce salinity
- Using an underwater hull cleaning dive service or a mechanical scrubbing system

Controlling Runoff from Parking Lots and Other Paved Areas[2]

- Place vegetated areas and filter strips to slow the flow of surface water and stabilize the shoreline
- Sweep and vacuum sweep parking lots regularly
- Design parking lots to reduce impervious land coverage and filter runoff before it reaches drainage areas and the Bay. Techniques include: utilizing crushed aggregate, porous asphalt, pervious concrete, or open-celled unit pavers for parking stalls; and creating "parking groves" with a grid of trees and bollards to delineate parking stalls.[3]

Controlling Runoff from Boat Maintenance Activities

- Find out if boat maintenance activities conducted at the marina require an industrial stormwater permit from the San Francisco Bay Regional Water Quality Control Board. Conditions in these permits require specific management practice to control polluted runoff.
- Avoid in-water cleaning of boats. If not feasible, wash boat hulls above the waterline by hand.
- Avoid in-water hull scraping. If not feasible, hire certified underwater hull cleaning dive service.
- Perform boat cleaning, maintenance, and repair work on shore in enclosed areas, either indoors or by using spray booths, or temporary plastic or tarp enclosures.

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[1] Check with local boat maintenance yards for appropriate cleaning schedules for specific coatings. In San Diego, non-toxic coatings may need to be cleaned once every 2-2.5 weeks.

[2] See *The California Clean Marina Toolkit: A Resource for Environmentally Sound Marina Management and Operation*. California Coastal Commission Boating Clean and Green Campaign. 2004.
AND
U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating*. Nonpoint Source Control Branch, Office of Wetlands, Oceans and Watersheds, Office of Water, U.S. Environmental Protection Agency. November 2001.

[3] Bay Area Stormwater Management Agencies Association and Tom Richman & Associates. 1999. *Start at the Source: Design Guidance Manual for Stormwater Quality Protection*. Forbes Custom Publishing. New York.

- Clean maintenance areas immediately after maintenance activities take place, and properly dispose of debris
- Sweep or vacuum around maintenance areas frequently
- Capture pollutants from cleaning and maintenance activities with tarps and filter cloths
- Store chemicals and other hazardous materials in enclosed areas

Controlling Pollution from Landscaped Areas[1]

- Adopt integrated pest management practices (check with state or county agricultural extension office for information on particular pests)
- Use native plants that are disease and pest resistant, and will out-compete weeds (See BCDC's Bay shoreline landscape guide)
- Use pesticides only when all other options are exhausted
- Limit fertilizer use
- Design landscaping strategies that minimize water use (e.g. select drought resistant plants, mulch, build healthy well-drained soils to avoid excess runoff, use efficient water delivery system such as drip irrigation)

Clean Boating Education for Boaters

- Distribute clean-boating educational materials to boaters, through the marina office, newsletters, monthly bills, or other appropriate means
- For educational materials, contact the California Department of Boating and Waterways http://dbw.ca.gov/ 916-263-1331 and the Boating Clean and Green Campaign at http://www.coastal.ca.gov/ccbn/ccbndx.html 415-904-6905

[1] See *The California Clean Marina Toolkit: A Resource for Environmentally Sound Marina Management and Operation*. California Coastal Commission Boating Clean and Green Campaign. 2004.
AND
U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating*. Nonpoint Source Control Branch, Office of Wetlands, Oceans and Watersheds, Office of Water, U.S. Environmental Protection Agency. November 2001.