Assessment of Environmental Contaminants Associated with the National Defense Reserve Fleet in Suisun Bay, California

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Acronyms and Abbreviations

ΣERMq	Mean Effects Range Median Quotient
μg/kg	micrograms per kilogram
ANOVA	analysis of variance
cm	centimeter
COC	contaminant of concern
CO-OPS	Center for Operational Oceanographic Products and Services
ERL	Effects Range–Low
ERM	Effects Range–Median
HPAH	high-molecular-weight PAH
K-W	Kruskal-Wallis
LPAH	low-molecular-weight PAH
m	meter
m^2	square meter
MARAD	U.S. Department of Transportation Maritime Administration
mg/kg	milligrams per kilogram
MLLW	mean lower low water
MLML	Moss Landing Marine Laboratory
mm	millimeter
NDRF	National Defense Reserve Fleet
ng/g	nanograms per gram
NOAA	National Oceanic and Atmospheric Administration
NS&T	National Status and Trends
OC	organic carbon
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
RMEI	R&M Environmental and Infrastructure Engineering, Inc.
RMP	Regional Monitoring Program
RRF	Ready Reserve Force
RWQCB	Regional Water Quality Control Board
SAP	Sampling and Analysis Plan
SBRF	Suisun Bay Reserve Fleet
SFEI	San Francisco Estuary Institute
SQG	sediment quality guideline
TEG	TEG Oceanographic Services
TBT	tributyltin
TOC	total organic carbon
UCL	upper confidence level
USGS	U.S. Geological Survey

1.0 Executive Summary

In response to requests from the U.S. Congress, the National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration (OR&R) investigated environmental conditions related to the National Defense Reserve Fleet in Suisun Bay, California. These vessels are maintained by the U.S. Department of Transportation Maritime Administration and include more than 70 obsolete or decommissioned ships, sometimes referred to as the Reserve Fleet. A multidisciplinary team of scientists from OR&R initiated the study because of concerns regarding potential effects of peeling paint and hazardous materials that may have been released from these ships.

In July 2008, NOAA collected surface and subsurface sediment samples in the vicinity of the fleet, referred to as the Suisun Bay Reserve Fleet (SBRF) study area, and at reference and other locations within Suisun Bay and Carquinez Strait for contaminant analyses. NOAA also deployed mussels from June to September 2008 and collected resident clams to assess the bioavailability of contaminants. During the study, over 200 sediment samples from 72 stations and 42 tissue samples from 15 stations were analyzed for a suite of metals, some of which have been used in paint formulations applied to vessels. Polychlorinated biphenyls (PCBs), which may have been included in some paint formulations, and polycyclic aromatic hydrocarbons (PAHs) were also measured.

When developing the sampling plan, NOAA considered the dynamic nature of the San Francisco Bay system, which drains 40% of California and carries large amounts of sediment depending upon the time of year and water flow rates. In Suisun Bay and Carquinez Strait, locations of high and low water velocities exist, creating zones of sediment erosion or deposition. Major floods export large quantities of sediment and cause net erosion within Suisun Bay.

NOAA focused the sampling primarily within Suisun Bay and to a lesser extent into Carquinez Strait based on a hypothesis that fleet-related contaminants would tend to accumulate in areas of sediment deposition and that attribution to the fleet would be more feasible by examining sites closer to the SBRF rather than farther away. Although water currents and river flows move sediments downstream and away from the SBRF, factors such as dilution, sediment dispersion, and the presence of other contaminant sources were expected to confound interpretation of any contaminant inputs from the SBRF beyond Suisun Bay. Consequently, the sampling plan included more intensive sampling in the SBRF study area and suspected depositional areas near the fleet and less sampling farther away. Sampling locations were identified in part through analysis of available hydrodynamic information that revealed patterns of sediment erosion and deposition. Based on this hypothesis and approach, NOAA did not extend its sampling for this study into other parts of San Francisco Bay beyond Carquinez Strait.

NOAA recognizes that multiple industrial and municipal contaminant sources exist upstream of and in the vicinity of Suisun Bay and the greater San Francisco Bay area that could contribute environmental contaminants similar to those evaluated in this study. Characterization of other potential sources of contamination was not part of this study. However, NOAA did compare sediment contaminant concentrations identified in Suisun Bay to results from earlier studies and ongoing regional monitoring programs to provide a perspective on the magnitude and the distribution of specific contaminants in the greater bay area.

Based on a review of the literature and available data for the area, our discussions with scientists and stakeholder groups within the Suisun Bay and the greater San Francisco Bay areas, and evaluation of the data set generated by this study, NOAA concludes the following:

1. SEDIMENT ANALYSES: According to NOAA's statistical analyses, contaminant concentrations in sediments in the vicinity of the SBRF are not elevated relative to contaminant concentrations at reference locations. There are some instances in which concentrations of arsenic, copper, lead, and chromium observed across the project area are elevated relative to ambient values reported for other parts of San Francisco Bay. Generally, sediment metals concentrations from NOAA's study are within a factor of two of the San Francisco estuary sediment ambient concentrations derived by the San Francisco Bay Regional Water Quality Control Board. NOAA did not find PCBs or PAHs in the project area at concentrations that exceeded sediment quality guidelines or ambient values.

2. PAINT CHIPS IN SEDIMENT: Surface sediment samples from the vicinity of the SBRF were examined for visible metal debris and paint chips as well as various contaminants of potential ecological concern. In the project area, 18% of the surface sediment grab samples contained such debris or paint chips. In general, there did not appear to be elevated sediment contamination associated with those samples in which metal debris or paint chips were found. Finding paint chips in sediments is consistent with observations that paint continues to exfoliate from the vessels; this remains a matter of concern as an ongoing source of contamination to the bay.

3. TISSUE ANALYSES FOR TRANSPLANTED MUSSELS: According to NOAA's statistical analyses, concentrations of contaminants in mussels transplanted to the vicinity of the SBRF were not elevated relative to those at reference locations. However, the tissue concentration values should be considered preliminary and interpreted with caution. The transplanted mussels had low lipid levels, which could indicate stress caused by the low salinity regime encountered during the study. This might affect feeding rates and overall uptake of contaminants by the mussels.

4. TISSUE ANALYSES FOR RESIDENT CLAMS: Concentrations of contaminants in clams collected from the vicinity of the SBRF were similar to concentrations found in resident clams from other parts of Suisun Bay and in other studies, although no statistical analyses were performed due to the limited number of tissue samples.

5. POTENTIAL FOR BIOLOGICAL EFFECTS: Concentrations of contaminants in sediments were compared to literature guidelines to indicate the potential for toxicity to sediment dwelling organisms. Of the 18 metals that were analyzed for this study, nine have published sediment quality guideline concentrations for the effects range low (ERL) and the effects range median (ERM). Concentrations of some paint-related contaminants (for example, copper) in individual sediment samples in the vicinity of the SBRF exceeded the ERL, which is defined as a level below which adverse biological effects are rarely observed. Based on available data from previous studies, exceedances of the ERL are common for sediments throughout Suisun Bay and San Pablo Bay. Exceedances of the ERM values, defined as the concentration above which effects are observed in 50% of studies, occurred for nickel, mercury, and lead. Nickel concentrations throughout San Francisco Bay tend to be elevated and often exceed the ERM. Although all sediment samples in this study exceeded the ERM for nickel, previous studies revealed a poor relationship between observed toxicity and nickel concentrations, reducing the confidence in this ERM value. Nine percent of sediment samples in this study exceeded the guideline for mercury, and one sample exceeded the guideline for lead. Mercury is a known contaminant in San Francisco Bay due to historical use. None of the other metals analyzed exceeded the ERM.

Based on the points above, particularly comparison of the chemistry data collected for this study to sediment quality guidelines, NOAA concludes that sediments from the SBRF study area and the rest of Suisun Bay have a low to moderately low potential for toxicity to benthic invertebrates. The contaminant concentrations observed are largely comparable to values for the same metals and organics measured in other regions of the greater San Francisco Bay. Following this analysis, NOAA does not recommend specific sediment remedial actions in the vicinity of the SBRF at this time.

2.0 Project Objectives

The National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration investigated environmental conditions in and around the Suisun Bay Reserve Fleet (SBRF) in Suisun Bay, California, in the summer of 2008. More than 70 obsolete or decommissioned vessels currently make up the SBRF, which is maintained by the U.S. Department of Transportation Maritime Administration (MARAD).

The State of California and several environmental groups have raised concerns about the potential for contaminants to be released from the fleet vessels into Suisun Bay. In response to these concerns, the U.S. Congress funded NOAA to design and implement an environmental study of contaminants in the vicinity of the SBRF. Although environmental concerns regarding the SBRF include in-water vessel hull cleaning, the potential introduction of invasive species or marine debris, and a broad range of chemical contaminants, the primary focus of this study was to assess the distribution, magnitude, and ecological significance of exfoliating paint and paint-associated chemicals in sediments and biological tissue from this area. A variety of heavy metals and organometals have been used in the paint formulations applied to these vessels, and these compounds were included in the study as contaminants of concern (COC). Because polychlorinated biphenyls (PCBs) may also have been present in paint formulations applied where heat resistance was desirable, such as near engine rooms, they were evaluated as well. Polycyclic aromatic hydrocarbons (PAHs) also were included as COCs because of general concern for petroleum-related contamination in the area.

Based on discussions with State agencies and other stakeholders and on background information, NOAA defined four specific objectives for the study as follows:

1. Improve characterization of chemical concentrations and physical properties of surface and subsurface sediment in areas most likely to be affected by past and ongoing releases of exfoliated paint and other potentially associated contaminants from ships within the SBRF.

2. Compare sediment contamination in the vicinity of the SBRF with sediment quality guidelines and reference locations in Suisun Bay.

3. Examine sediment samples for visual evidence of exfoliated paint from the fleet.

4. Begin to assess the bioavailability of paint-related contaminants through the analysis of bivalve tissue samples collected within and around the SBRF study area and at reference locations.

NOAA developed a site conceptual model to assist in developing the sampling design for the study. The site conceptual model incorporates results of past studies of tides and currents, salinity regimes, suspended sediment, zones of sediment accretion and erosion within the bay, contaminant loadings from sources in and around Suisun Bay, and multiple long-term biological and physical monitoring programs. The sampling design derived from this conceptual model of the area was not intended to represent an exhaustive investigation of all contaminants potentially released from the SBRF, nor was it intended to investigate all locations where released materials may have migrated within and outside of Suisun Bay. The sampling design was intended to answer questions about contamination of sediment in the vicinity of the SBRF with sufficient statistical power to yield quantifiable levels of confidence in the area of evaluation and address the previously stated objectives. For locations outside of the SBRF study area, the sampling design was intended to yield more qualitative information that were used to help interpret results.

3.0 Background

3.1. Suisun Bay Reserve Fleet Site History

MARAD administers the National Defense Reserve Fleet (NDRF), which was established under Section 11 of the Merchant Ship Sales Act of 1946 to serve as a reserve of ships for national defense and other emergencies (NDRF 2009). In 1950, the NDRF held over 2,000 ships at several locations throughout the country. At present, the NDRF consists of fewer than 300 ships, which are berthed at three principal locations: James River, Virginia; Beaumont, Texas; and Suisun Bay, California. Over the years, the size of the NDRF has fluctuated as ships were added, scrapped, and reactivated. NDRF ships are periodically activated for both national and international emergencies, such as the Korean War and 2005's Hurricane Katrina.

When the NDRF was established, its ships were meant to be available for duty within 20 to 120 days. In 1976, a Ready Reserve Force (RRF) component of the NDRF was also established; ships in the RRF are maintained at a heightened state of readiness that requires only four to 20 days to activate. Many of the newer merchant ships added to the NDRF are held for potential upgrade to the RRF, while vessels determined by MARAD to be of insufficient value to merit further preservation for commercial or military operation by the Federal Government are being disposed of over time.

The SBRF, the focus of this study, is located in General Anchorage #26, on the northwest side of Suisun Bay, California (Map 1). The anchorage extends approximately 4½ nautical miles northeast from the Benicia-Martinez Bridge and is approximately ½ nautical miles in width. Water depths range from about 14 meters (45 feet) at mean lower low water (MLLW) at the southwestern end of the anchorage to about 8 meters (26 feet) MLLW at the shallowest berths shoreward, toward the northeastern end of the anchorage.

Ships are moored within the anchorage in nests (i.e., rows). A nest acts as a single unit, with all of its anchors and chains working in unison to hold the ships together in a raft, secure against the wind and current, allowing no more than approximately 15 to 30 meters (50 to 100 feet) of movement in any direction. In the late 1950s to early 1960s, more than 500 ships were moored at the SBRF (MARAD 2008). More recently, ship counts have been 235 (1969), 104 (1980), 84 (1996), and 79 (2006) (MARAD 1996; RMEI 2007). Currently, the SBRF comprises 72 vessels, including:

- Commercial vessels, such as tankers and break-bulk cargo ships;
- U.S. Naval auxiliary vessels, such as landing ships, tenders, repair and replenishment ships, amphibious assault ships, combatants, and a small number of service craft, such as tugs and barges; and
- U.S. Coast Guard icebreakers and buoy tenders.

The anchorage currently consists of seven rows, labeled E, F, G, I, J, K, and L from south to north, and two barge nests (H and K1) (Map 2). The ships range in size from a 270-meter

(887-foot) battleship and 184-meter (603-foot) helicopter carrier to 55-meter (180-foot) buoy tenders and a single NOAA meteorological buoy. Most vessels are 60 to 200 meters (200 to 600 feet) in length. In 2003, the rows ranged in length from 185 meters (about 600 feet) to 420 meters (about 1,375 feet). Excluding barge nests, G-row was the largest at about 78,916 square meters (m^2) (19.5 acres) and I-row was the smallest at about 24,282 m^2 (6 acres).

The location of the SBRF area over time was delineated based on rectified aerial photographs from 2003, 1993, 1980, and 1969; the SBRF has covered a total of about 2.9 million m^2 (720 acres) (Map 2). The SBRF rows have generally been located on the edge of and extending into the Reserve Fleet Channel. The shoreward edge of the rows appears to have been fairly consistent over time, while fluctuations in the size of the SBRF appear to have been accommodated by adding ships to the outer (channel) side of the rows.

Little is known about any contaminant releases from the SBRF since its inception in 1948. Based on information from MARAD, removal of vessels for foreign disposal occurred on a regular basis until the mid-1990s, when PCBs were discovered in some construction materials and exports were abruptly halted. It was during the next decade that weathering of topside painted surfaces began to impact the fleet (MARAD 2009 personal communication). In 2006, MARAD contracted a limited project to analyze metals in paint chips, sediment, and pore water samples (RMEI 2007). For MARAD's study, 130 paint samples were collected from the hulls and surfaces of the exterior superstructures of 40 of the 79 vessels present at the time. The concentrations of 17 metals were measured in the paint samples, 24 bulk sediment samples, and six pore water samples. In addition, acid volatile sulfides/simultaneously extracted metals, which constitute a measure of bioavailability, were determined in the pore water samples. Appendix 10.1 contains the Executive Summary of findings from the MARAD report.

3.2. Physical Environment

The SBRF is situated in the northwest portion of Suisun Bay, which is the farthest inland sub-embayment of northern San Francisco Bay (Map 1; Map 3). Suisun Bay extends from the Sacramento-San Joaquin River Delta west to Carquinez Strait, a narrow and deep channel that connects Suisun Bay with San Pablo Bay and the rest of San Francisco Bay. Upstream and inland from Carquinez Strait, Suisun Bay has a bifurcated channel. The SBRF is located in the northern channel (known as the Reserve Fleet Channel), which continues past Grizzly Bay, a large marsh with extensive shallow areas less than 2 meters (6.5 feet) deep at MLLW, into the Suisun Cutoff Channel**.** The southern channel (known as the Navigation Channel) continues to the Sacramento-San Joaquin River Delta. A shallow bar, partially exposed at low tide, interspersed with several islands, separates the Suisun Cutoff Channel and the Navigation Channel. The Navigation Channel is rejoined by the Suisun Cutoff Channel in Middle Ground and continues past the large and shallow Honker Bay (Map 1). The Navigation Channel ends about 2 kilometers (1.2 miles) downstream from the confluence of the Sacramento and San Joaquin rivers.

3.2.1. Hydrodynamics and Sediment Transport

Suisun Bay is a partially mixed, complex estuary with riverine and tidal forcing. The hydrodynamics of Suisun Bay and the SBRF anchorage are influenced by the presence of sills (steep changes in bathymetry) located near Carquinez Strait and between the Reserve Fleet Channel and the Suisun Cutoff Channel (Map 3). These topographic features place an upstream limit on gravitational circulation and tend to trap particles in the Reserve Fleet Channel (Schoellhamer 2001).

Based on variability analysis of suspended sediment concentration, Schoellhamer (2001) and Schoellhamer *et al*. (2003) concluded that the deposition and erosion cycles in Suisun Bay are more aligned with the twice monthly spring neap cycle than the diurnal tidal cycle. In particular, at Benicia and the Reserve Fleet Channel, salinity stratification and deposition are greatest at neap tide (Schoellhamer 2001).

Tides in Suisun Bay are mixed diurnal and semidiurnal, with the tidal range varying from about 0.6 meter (2 feet) during the weakest neap tides to 1.8 meters (6 feet) during the strongest spring tides (Schoellhamer 2001). Maximum tidal currents vary from 0.78 to 2.0 meters per second (1.5 to 4 knots) (Ganju and Schoellhamer 2006; NOAA CO-OPS 2008).

Local currents within Suisun Bay, and in particular the SBRF study area, vary based on bathymetry, salinity gradients, and other factors, including wind, waves, and freshwater flow, which also vary seasonally. Freshwater flow into Suisun Bay comes primarily from the Sacramento-San Joaquin River Delta and, aside from storm events, is typically controlled by reservoir releases and water operations.

Sediment dynamics in Suisun Bay are complex and highly variable across location and time. Consequently, predictions over short to moderate time scales and geographic areas are difficult to quantify. Examination of seasonal variations in sediment flux patterns indicates that in addition to the significant downstream input of sediment from the Sacramento-San Joaquin River Delta, there is a clear seasonal pattern of sediment exchange between San Pablo Bay and Suisun Bay (Ganju and Schoellhamer 2006). These observations of suspended sediment flux indicate that Suisun Bay exports sediment during the wet season and imports sediment from San Pablo Bay during dry periods. Additionally, major floods export large quantities of sediment and cause net erosion within Suisun Bay (Schoellhamer *et al*. 2007). Over the time period that the SBRF has existed, there have been large storms with significant rainfall and wind, which may also have initiated sediment resuspension and transport (GGWS 2008).

Although sediment dynamics in Suisun Bay are complex and variable, there is a clear pattern of net downstream transport of sediment into and out of Suisun Bay. However, there is also a seasonal, tidally driven exchange of sediment from San Pablo Bay into Suisun Bay.

3.2.2. Bathymetric Change

NOAA used bathymetric data from three sources to inform our understanding of the sediment transport regime in the vicinity of the SBRF, to design the sampling and analysis program, and to interpret contaminant data. The three sources are:

- The U.S. Geological Survey (USGS) 1942-1990 bathymetric change analysis;
- NOAA Navigation Chart 18656; and
- The NOAA/USGS 2002-2007 bathymetric change analysis.

The bathymetric change data have been interpreted over different spatial scales (all of Suisun Bay and only the SBRF) and temporal scales (50 years and 5 years). Note that the

NOAA/USGS 2002-2007 bathymetric change analysis was not available when the sampling and analysis program was designed; therefore, the project team relied on the USGS 1942-1990 bathymetric change analysis to inform selection of subsurface sediment sampling stations. Both bathymetric change analyses are discussed below.

USGS 1942-1990 Bathymetric Change Analysis

Suisun Bay

NOAA used the 1942-1990 USGS analysis of historical bathymetric change in Suisun Bay (Cappiella *et al*. 1999) as a guide to understanding the erosion and deposition that have occurred in Suisun Bay over the period the SBRF has been present (Map 4). The USGS analysis of bathymetric surveys from 1942 and 1990 shows that long-term net erosion occurred in Suisun Bay at an average rate of 1.2 centimeters/year (cm/year) (0.47 inch/year) during the period of the study.

SBRF

NOAA performed an analysis using the USGS bathymetric change data (Jaffe 2008 personal communication) to focus on the changes in sediment erosion and deposition in the vicinity of the historical SBRF anchorage (Map 5). Our analysis calculated an average depth of net accumulated sediment of 84.4 cm (33.2 inches) over the subset of the SBRF area covered by the USGS study (8.9 million m^2, or 2,216 acres)[1]. The average rate of deposition was 1.75 cm/year (0.7 inch/year) for the time period 1942-1990[2]. Our analysis of the bathymetric change grid indicates that between 1942 and 1990, the SBRF area has eroded over time in the area closest to the fleet channel, and sediment has deposited in the areas closer to shore.

NOAA/USGS 2002-2007 Bathymetric Change Analysis

SBRF

To better understand recent erosion and deposition in the Reserve Fleet area, NOAA performed a change analysis between multibeam bathymetric data collected by NOAA's Office of Coast Survey in 2007 for the MARAD fleet and the USGS 2002 bathymetric data. This analysis indicates an average of -0.64 meter (approximately 2 feet) of change (erosion) in elevation between 2002 and 2007 for the SBRF area (Map 6; Appendix 10.2). Although there is an overall trend of erosion, there also appear to be longitudinal areas of shoaling (along the axis of the Reserve Fleet Channel) upstream and downstream of the location of the current vessel rows, as well as shoaling inshore and between J-row and G-row. Accretion in these areas ranges from 0.25 meter (0.8 foot) up to 1.5 meters (4.9 feet) of sediment.

The observed net erosion over the five-year period from 2002 to 2007 in the SBRF area is consistent with the findings of multiple studies indicating that the San Francisco Bay complex is increasingly net erosional and, in particular, Suisun Bay has undergone erosion in shallow areas over the past 60 years (McKee *et al*. 2006; Cappiella *et al*. 1999).

Although efforts have been made to model the flux of sediment through Suisun Bay (Ganju and Schoellhamer 2006; Schoellhamer *et al*. 2007), these efforts do not provide the spatial or temporal detail necessary to adequately track movement of contaminants or paint chips associated with sediments from the SBRF. Furthermore, uncertainties exist

[1] The SBRF area NOAA defined for the present study was not completely sampled in the USGS study.
[2] See Appendix 10.2 for the detailed analysis of accretion/erosion at sediment sampling stations.

regarding the dynamics of bottom sediments (and associated contaminants). These uncertainties include vertical mixing, consolidation, erosion and burial, interaction with the water column, redistribution, and bioturbation, which all vary on tidal, seasonal, and decadal time scales.

3.3. Biological Environment

The San Francisco Bay system is the largest estuary on the West Coast, encompassing roughly 4,140 square kilometers (1,600 square miles) of central California. The estuary's aquatic and wetland habitats range from the brackish water of the lower delta and Suisun Bay to the dilute salt water of San Pablo Bay and the highly saline waters of South San Francisco Bay.

Suisun Bay comprises about 137.6 million m^2 (34,000 acres) of shallow and deep subtidal mud and sand habitat, about 60.7 million m^2 (15,000 acres) of tidal flat and tidal marsh habitat, and approximately 242.8 million m^2 (60,000 acres) of diked agricultural bayland (Goals Project 1999). Suisun Marsh at the northern edge of Suisun Bay is the largest brackish-water wetland complex in the western United States and is an important stop on the Pacific Flyway for migrating waterfowl (Goals Project 1999). The baylands of Suisun Bay have been recommended for increased tidal marsh restoration to benefit waterfowl, shorebirds, and songbirds, as well as aquatic invertebrates and fishes. The waters of Suisun Bay and associated baylands serve as migration, feeding, and nursery habitat for important fish and invertebrates, such as Chinook salmon, steelhead salmon, green and white sturgeon, striped bass, delta smelt, starry flounder, Sacramento splittail, bay shrimp, and Dungeness crab (NOAA 2007; Goals Project 2000).

Suisun Bay, along with the entire San Francisco Bay estuary, is an ecosystem under stress. Over 50 species of plants and wildlife in this region are on the State of California or Federal threatened and endangered species list, primarily because of habitat loss (Goals Project 1999). However, habitat loss is not the only stress factor; invasive species such as the Asian clam and anthropogenic contaminants are also stressing the Suisun Bay ecosystem. Luoma and Nichols (1993) noted that primary production in the bay has been reduced concurrent with the invasion of the Asian clam (*Corbula amurensis*, formerly known as *Potamocorbula amurensis*). Coincidentally, populations of important species have also declined. Anthropogenic contamination of Suisun Bay/delta benthos has affected upper-trophic-level organisms such as birds and fish (Luoma and Nichols 1993).

3.4. Contaminant Sources

Suisun Bay receives contaminant inputs from upstream agricultural, urban, industrial, and current and historical mining sources (SFEI 2007a). Within Suisun Bay, multiple point source dischargers contribute to contaminant loading to the watershed, including municipal treatment plants, power plants, chemical plants, oil refineries, and the Concord Naval Weapons Station (SFEI 2007a). Downstream of Suisun Bay in San Pablo Bay, other contaminant sources include the former Mare Island Naval Shipyard, refineries and chemical plants, inputs from the Petaluma River, and additional municipal treatment plants. All of these sources, plus nonpoint source inputs, may serve to confound the inputs that have occurred from the SBRF. The complexity and variability of Northern San Francisco Bay's hydrodynamics prevent clear understanding of the contaminant loads from each of these sources and their contribution to total contaminant loadings in Suisun Bay.

Numerous studies have assessed general sediment contamination and toxicity in San Francisco Bay, including Suisun Bay. Agencies conducting sampling efforts and assessments include the San Francisco Estuary Institute (SFEI), NOAA's National Status and Trends (NS&T) Program, the San Francisco Bay Regional Water Quality Control Board (RWQCB), and the USGS. Appendix 10.3 describes 106 existing contaminant data studies for San Francisco Bay (including Suisun Bay), which NOAA has compiled into a Query Manager database.

3.5. Conceptual Model

NOAA developed a site conceptual model of Suisun Bay to assist in developing the sampling design for this study. Based on our bathymetric analyses (Section 3.2; Appendix 10.2), NOAA's conceptual model assumes that, although hydrodynamically complex and with localized areas of deposition, Suisun Bay overall has been net erosional over the time period that the SBRF has been present.

The conceptual model (Figure 1) presumes that contaminants originating from paint exfoliating from vessels in the SBRF, in addition to other contaminants potentially released from the SBRF, are likely adsorbed, transported, and deposited with suspended sediment and bedload (Section 3.2). Larger paint chips or flakes could be transported as surficial sediment bedload.

Although we presume that Suisun Bay overall has been net erosional, NOAA's review and analysis of hydrodynamics and sediment transport studies indicate that over the time the SBRF has been present, there are some localized areas of net deposition. The depositional area closest to the SBRF, and therefore most likely to contain contaminants or paint chips that can be attributed to the SBRF, is along the flanks of the Reserve Fleet Channel extending shoreward (Map 5). Based on the hydrophobic nature of the primary COCs and the depositional nature of sediment at the edge and shoreward from the ship rows over the history of the SBRF, NOAA assumes that nearby surface and subsurface sediments would be the best media for quantifying contaminants originating from the SBRF over time. For contaminants dissolved in the water column or associated with suspended sediment, bivalves or other filter feeders are considered reasonable receptors for evaluating both the distribution and bioavailability of contaminants. NOAA used the analyses of hydrodynamics and sediment transport, along with our assumptions of likely contaminant pathways, to design this study.

4.0 Project Design

4.1. Sample Matrices

4.1.1. Surface Sediment

For this study, NOAA chose the top 5 cm (approximately 2 inches) of sediment from Van Veen grab samples to represent surficial sediment. This interval is consistent with the sample depths used in SFEI's Regional Monitoring Program (RMP) and other San Francisco Bay sediment studies, as well as with the sampling depths chosen by the RWQCB for evaluating sediment contamination across California. In addition, surface sediment was represented by the top 5 cm (2 inches) for the 2006 MARAD study (RMEI 2007) as well. This consistency allows comparisons among a larger body of reference data for Suisun and San Francisco bays and adds to the body of data (SFEI 1997; RMEI 2007).

Since its inception, the RMP has used the top 5 cm (2 inches) of sediment as its standard depth for surface sediment sampling. The RMP concluded that there is no uniform biologically active sediment layer or uniform burial depth across the whole of San Francisco Bay that could be targeted for sediment monitoring (RMP 1998).

The selection of this depth also supports the project objective of evaluating recent and ongoing contaminant releases, although actual age of surface sediments is likely highly varied across San Pablo Bay (Appendix 10.2).

4.1.2. Subsurface Sediment

A review of the information from USGS bathymetric analysis (Jaffe 2008 personal communication; Cappiella *et al*. 1999) regarding the accumulation of sediment within the project area indicates that portions of the project area are depositional and accreting sediments, while other areas have been erosional over the time the SBRF has been operational (see Section 3.2). This information was used to select stations for sediment core sampling in depositional areas within the SBRF study area, Suisun Bay, and Carquinez Strait. The results in Hornberger (1999) suggest that a 1.2-meter (4-foot) core should approach or exceed a depth associated with the appearance of Cs-137[3]. This horizon also includes a discontinuity layer representing a depositional hiatus that extends from about 1880 to 1950 as seen by Hornberger (1999) in Grizzly Bay. Given the accumulated sediment depths and the expected variability of depositional rates in Suisun Bay based on the USGS bathymetric change analysis (Section 3.2), core sampling depths of 2.5 meters (8 feet) were deemed to reflect the period of the SBRF operation (1948 to the present), with the top 1.2 meters (4 feet) of the cores being sectioned and analyzed for contaminants.[4] NOAA did not age-date the cores collected in this study.

4.1.3. Bivalve Tissue

The principal reason for analyzing contaminants in biological tissues is to provide a direct measure of the bioavailability of contaminants.

Bivalves, which include both clams and mussels, have become standard biological indicators of exposure because of their ability to concentrate and integrate chemicals from water and sediment into their tissues (Gunther *et al*. 1999). Numerous programs, including NOAA's NS&T Program (Gunther *et al*. 1999), the California State Mussel Watch, and the RMP, have conducted bivalve bioaccumulation monitoring in San Francisco Bay for decades. For this study, bivalve bioaccumulation in tissue was incorporated using two approaches: (1) collection and chemical analysis of resident clams (*Corbula amurensis*), and (2) chemical analysis of transplanted (bagged) mussels from the *Mytilus* complex[5].

[3] A radioisotope commonly used for sediment dating, whose disappearance in sediments roughly corresponds to about 1950 (Hornberger 1999).

[4] A detailed summary of the estimated net erosion for Suisun Bay and the SBRF from both the USGS 1942-1990 study and NOAA's 2002-2007 study is in Appendix 10.2. This summary includes estimated net erosion or deposition at sediment core locations.

[5] *M. trossulus* (native), *M. galloprovincialis* (nonnative), and a hybrid (Suchanek *et al*. 1997)

The most straightforward method of conducting bivalve tissue analysis involves the collection and chemical analysis of a single, benthic resident species at all the sites of concern and the reference sites. The advantages of this approach are that resident organisms have been exposed to site and reference conditions over their entire life spans and represent the bioavailability of contaminants from the sediments in which they reside. However, this approach requires that the selected species be present in sufficient biomass (and at similar age and size distributions) at all locations. In a highly variable environment, such as the euryhaline conditions found in Suisun Bay, this presumption is problematic. To best address these issues, NOAA chose the Asian clam (*Corbula amurensis*) as the target resident species. Although a nonnative species, *Corbula* is established in Suisun Bay, tolerates a wide salinity range, and is important in the modern Suisun Bay ecosystem as a food source for sturgeon, scaups, and scoters (Cohen 2005). Further, the USGS has been working with *Corbula* as a potential biomonitor of metals pollution in the bay since the early 1990s (Brown and Luoma 1995), which offers some comparable data for the bay.

The use of transplanted organisms placed above the sediment surface integrates exposure from sediment and the water column. While the length of exposure to potential contamination is shorter than with resident organisms, this approach has the major advantage that sufficient organisms of the chosen species can be placed at specific locations that can later be resampled. Although bioaccumulation in transplanted organisms may be less than in resident organisms, studies have shown that deployment of two to three months in length is sufficient to approximate peaks in bioaccumulation for many metals (Regoli and Orlando 1994; ASTM 2002). Studies also indicate that transplanted organisms are good surrogates for native individuals (Hull *et al*. 2006). The California State Mussel Watch protocols call for deployment times of one to four months, with three months being preferred (Method #MPSL-102a). Because of project time and funding constraints, NOAA chose a deployment time of 60 days, within the range of California State Mussel Watch protocols.

Several bivalve species were considered for transplanted deployment, including the freshwater clam *Corbicula fluminea*, the oyster *Crassostrea gigas*, and the native oyster *Ostreola conchaphilia* (NOAA 2008b). Based on consultation with regional experts and stakeholders, NOAA chose the *Mytilus* complex for this study. Despite concerns about the potential for low-salinity stress, the *Mytilus* complex was selected because it generally has good survival rate in bag deployments. It also exhibits strong bioaccumulation of metals, PAHs, and PCBs in other San Francisco Bay monitoring programs, making it an attractive choice for achieving comparability with other data sets (Gunther *et al*. 1999).

4.2. Project Area

The project area is roughly defined as Suisun Bay bounded by Carquinez Strait to the west and approximately Middle Ground to the east (Map 1). While contaminants from the SBRF have likely migrated outside of the defined project area, it would be difficult to attribute contamination found outside Suisun Bay to the SBRF, as opposed to other potential sources, if elevated contaminant concentrations were not found in depositional areas closer to the SBRF. The data collected in and near the SBRF should therefore help determine the need for further study of the potential transport and fate of contaminants originating from the SBRF.

For this study, NOAA defined four types of areas to be sampled at varying intensities based on hydrodynamic and sediment transport information and on historical sediment and biota contaminant data; those areas are referred to here as the Suisun Bay Reserve Fleet study area (SBRF study area), near-fleet depositional areas (near fleet), reference areas, and other potential source areas (potential source). Areas that are routinely dredged or are within the charted dredge disposal area were not sampled because of the high variability associated with dredging and because extant sediment core data indicate sand/gravel composition of over 90%.

Sampling locations (both area and station) and the media collected at each location are summarized in Table 1 and on Map 7.

4.2.1. Suisun Bay Reserve Fleet Study Area Stations

NOAA defined the SBRF study area to be the regulated navigation area (General Anchorage #26 on NOAA Chart 18656) and a portion of the Reserve Fleet Channel to the east of the anchorage (Map 7). The overall area is approximately 9.1 million m^2 (2,251 acres), extending from the Benicia-Martinez Bridge to the southwest to the northern extent of the regulated navigation area to the north and bounded by the shoreline to the west and a line 300 meters (1,000 feet) east of the charted, regulated navigation area boundary. By extending the SBRF boundary eastward, the study captures an area of potential migration of sediment into the Reserve Fleet Channel (Schoellhamer 2001) and accounts for historical anchorage of ships (Map 2). Of the areas sampled, the SBRF study area was the focus of the most intensive statistically based gridded sampling effort, including surface and subsurface sediment sampling, placement and retrieval of transplanted mussels, and sampling of resident clams.

Sampling stations within the SBRF study area were selected using a gridded sampling approach to better characterize the area encompassing rafted vessels from the late 1940s to the present (regulated navigation area) and the proximate areas of likely sediment accumulation. As noted above, our conceptual model indicates that sediment (and associated contaminants) in this dynamic and tidally influenced estuarine system is suspended and redistributed in a complex manner based on the diurnal, tidally driven currents, gravitational circulation, freshwater flow (particularly storm events), wind, and waves (Schoellhamer 2001; Schoellhamer *et al*. 2007; Ganju and Schoellhamer. 2006). Because the size and shape of depositional areas were difficult to predict, a triangular grid was chosen to provide the most efficient statistical basis for evaluating contaminant distribution (Gilbert 1987). In addition to the statistically gridded design, a subsurface sediment core (RF51) collected in an area of potentially high deposition and two surface sediment sampling stations (RF52 and RF53) collocated with transplanted mussel stations were added to the sampling regime.

Use of a statistically based triangular grid (Map 8) characterizes the SBRF study area while minimizing the unsampled area. NOAA's sample size of 50 stations following this sampling design provides 95% confidence (β) that a circular area of radius 222 meters (728 feet) would not go unsampled. The distance between samples in the SBRF study area is approximately 427 meters (1,400 feet). A statistical power analysis (one-sided *t*-test) using the 24 surface sediment samples collected for metals chemistry by MARAD in 2006 (RMEI 2007) and performed during planning for this study indicated that the number of surface sediment samples NOAA planned to collect exceeds by an order of magnitude the minimum number of samples needed to characterize the SBRF study area for most metals (excepting mercury and nickel).

The distance between sampling stations and the size of a given unsampled area depend on the number of sampling stations. One of the goals of the sampling design described here was to collect the greatest spatial density of sediment samples (surface and subsurface) possible in the SBRF study area (within the study constraints), thereby minimizing the distance between samples. In 2003, the areal extent of each row of ships was between 25,500 m^2 (6.3 acres) and 79,300 m^2 (19.6 acres).

4.2.2. Near-Fleet Depositional Area (Near Fleet) Stations

The near-fleet depositional area stations were located in Suisun Bay outside the SBRF study area (Map 7), where hydrodynamic analysis and suspended sediment transport studies indicate a potential for contaminant transport and deposition from the SBRF study area (Section 3.2). To the extent possible, these stations were sited away from other known contaminant point sources. Surface and subsurface sediment and transplanted mussels were collected at these stations.

The sampling stations were identified based on information from several sources, including sediment monitoring data from the RMP, the NS&T Program, and USGS suspended sediment and historical contaminants analysis, as well as hydrodynamic studies, bathymetric surveys, and analyses of bathymetric change (Map 7; Table 1). The sampling design incorporated seven surface sediment stations, four sediment cores, and one tissue station. Surface sediment contaminant data from these areas were evaluated qualitatively through summary statistics.

4.2.3. Reference Area Stations

Based on existing surface sediment data, reference stations were selected to capture a range of grain size distribution similar to what is found in the SBRF study area and, based on our review of limited data, were expected to represent areas with hydrodynamic conditions similar to those in the SBRF study area. The sampling design included six judgmentally placed surface and subsurface sediment stations and three tissue stations. Five of the six reference stations were in Suisun Bay and one station (CS01) was approximately 5 kilometers (3 miles) west of the Benicia-Martinez Bridge in Carquinez Strait. These reference stations, while specifically chosen to avoid areas of known sediment contamination, may nevertheless be influenced by other contaminant inputs, such as refineries, Concord Naval Weapons Station, municipal outfalls, storm drains, sediment resuspension and distribution within Suisun Bay, and sediment exchange from San Pablo Bay. Five of the six sediment sampling stations were near RMP sampling stations, providing NOAA with some pre-sampling knowledge of the physical and contaminant characteristics of the area.

Surface sediment samples consisted of three replicate samples at each of the six reference stations to allow for statistical comparisons to SBRF study area samples.

4.2.4. Other Potential Source Area (Potential Source) Stations Within Suisun Bay and Carquinez Strait

In the original planning of this study, three stations located in Suisun Bay and one station in Carquinez Strait were chosen for a qualitative evaluation of other known sources of contamination such as Concord Naval Weapons Station, Tosco Corporation, and Shell Oil Co. Martinez. However, because of safety concerns, NOAA did not collect a surface grab sample or surface core sample at one of the stations (SB05). Instead, sampling occurred at three of the four judgmentally chosen stations. Two additional transplanted mussel stations collocated with surface sediment stations (CS01T and CS03T) were included in the potential sources category. Therefore, this sampling category consisted of five surface grab samples, two subsurface sediment cores collected at two of the five surface sediment sampling stations, and two transplanted mussel stations collocated with two of the five surface sediment sampling stations (Map 7; Table 1).

4.3. Contaminant Analyses

Table 1 provides a summary of contaminants analyzed by media and station.

4.3.1. Metals and Organotins

All surface grab sediment samples, all subsurface sediment sample intervals to 120 cm (approximately 47 inches), and tissue samples were analyzed for metals and organotins in addition to matrix-appropriate conventional parameters: total organic carbon (TOC), grain size, and lipids. The subsurface sample intervals were:

- 0 to 15 cm (0 to approximately 6 inches);
- 15 to 30 cm (approximately 6 to 12 inches);
- 30 to 45 cm (approximately 12 to 18 inches);
- 45 to 60 cm (approximately 18 to 24 inches);
- 60 to 90 cm (approximately 24 to 35 inches); and
- 90 to 120 cm (approximately 35 to 47 inches).

Subsurface samples deeper than 120 cm (approximately 47 inches) were archived for future analysis, if needed.

A subset of samples was also analyzed for PAHs and PCBs, as detailed below.

4.3.2. PAHs and PCBs

Sampling stations selected for PAH and PCB analyses are identified in Table 1; the sampling locations are shown on Maps 9 and 10.

All resident clam (*Corbula*) and transplanted mussel (*Mytilus* complex) tissue samples, their collocated surface sediment samples, and all surface sediment samples from reference areas were analyzed for PAHs and PCBs, representing 22 of the 87 surface sediment samples (including duplicates) collected. Of the remaining 65 surface sediment samples, 33 were analyzed for PAHs and PCBs, for a total of 55 surface sediment samples that were analyzed for the full suite of analytes.

Of those 55 surface sediment samples, 22 (40%) were collected within the SBRF study area, 22 (40%) were collected in the reference areas, five (9%) were collected in potential source areas, and six (11%) were collected in near-fleet depositional areas. The 55 surface sediment samples were judgmentally selected for PCB and PAH analyses based on:

1. Spatial coverage and expected range of grain size within the SBRF study area;
2. Representativeness of depositional areas outside the SBRF study area; and
3. Potential for influences from other sources in Suisun Bay.

Of 143 subsurface sediment core intervals collected, 49 were analyzed for PAHs and PCBs in addition to metals, organotins, grain size, and TOC. These 49 samples were collected from:

1. Eight stations (containing 26 core interval samples) within the SBRF study area;
2. Three stations (containing eight core interval samples) in the reference areas;
3. Two stations (containing six core interval samples) in potential source areas; and
4. Three stations (containing nine core interval samples) in near-fleet depositional areas.

All subsurface stations selected for PCB and PAH analyses also received the expanded analyses for their associated surface sediment grabs and from the following core intervals: 0 to 15 cm (0 to approximately 6 inches), 30 to 45 cm (approximately 12 to 18 inches), and 90 to 120 cm (approximately 35 to 47 inches). Samples from other depth intervals and remaining surface sediment samples were archived for future analyses if necessary.

4.3.3. Contaminant Analytical Methods and Detection Limits

Analytical methods used to measure sediment and tissue chemistry for metals, organotins, PAHs, PCBs, and conventional measurements are presented along with their detection limits in Table 2. The analytical methods are consistent with the NS&T Program's quality assurance requirements or, in cases where no NOAA method has been designated, with the RMP.

4.3.4. Archiving

Archived samples (core intervals greater than 120 cm [47 inches] and samples not analyzed for PCBs and PAHs) were frozen and will be held for either one year from sample collection or until NOAA determines whether there is need for further analyses, whichever comes first.

4.4. Data Analysis Approach

4.4.1. General Data Handling

For this project, NOAA used Query Manager for contaminant data management and dissemination. Project data are included in the Query Manager San Francisco Bay Database (NOAA 2008a), which contains all the analytical data generated, including field and laboratory duplicate samples.

Sampling and analysis of sediment from any one station and depth may have involved various combinations of four sample types:

1. Solitary sample—a single sample taken at a particular station and depth;

2. Field duplicate samples—two or more samples taken at the same depth and coordinates while the boat remained anchored;

3. Laboratory duplicates—two or more sample aliquots from the same field sample; and

4. Station replicate samples—multiple samples taken at the same station location but the boat was moved up to 100 meters (about 300 feet) and reanchored between samples. For this study, station replicate samples were collected only at reference stations. Most reference station replicates were collected 40 to 80 meters (approximately 130 to 260 feet) apart from one another.

Field and laboratory duplicates function as checks on the consistency of the data collection and analysis, while station replicates are used to assess variability within a station location for statistical purposes.

In cases where a single value was needed to allow for qualitative comparisons or where detection limits might be a factor (i.e., in making comparisons to sediment quality guidelines), the duplicates and replicates were treated in the following manner:

1. Results for laboratory duplicates were averaged first.

2. Results for any field duplicates were then averaged.

3. When appropriate, results for station replicates were averaged last.

The averaging process was handled as follows:

1. If all analytical results for duplicates/replicates at a given station were above the detection limits, then the results were averaged.

2. If some analytical results for duplicates/replicates at a given station were below the detection limits, then only those values above the detection limits were averaged.

3. If all analytical results for duplicates/replicates at a given station were below the detection limits, the highest detection limit was used in the data analysis.

This averaging method did not impact statistical analyses, as the nonparametric statistics used for this study rely on ranks.

4.4.2. PAH and PCB Summing

For the statistics used in this study, NOAA calculated total PAHs to be consistent with the approach used in the RMP, which determines total PAHs based on the sum of up to

26 PAHs[6], depending on the year. This summing routine is slightly different than the routine used in Query Manager (NOAA 2008a), which generates sums based on the 10 low-molecular-weight PAHs (LPAHs) and eight high-molecular-weight PAHs (HPAHs) most commonly measured by the NS&T Program (18 PAHs in total). For the statistical analyses used in this study, results below detection limits were treated as zeros. Because the statistics used are nonparametric, this has no impact on the results.

Total PCBs were calculated using congener data. For statistical analyses, NOAA used the summing routine (as performed by Query Manager) in which compounds below detection limits are treated as zeros. If all compounds that comprise the total were not detected, then the highest non-detect value was reported with a "U" qualifier. If the detection limit for any one of the compounds below detection limits was greater than the sum of the detected compounds, then the highest non-detect value was reported with a “U” qualifier.

4.4.3. Data Analysis and Hypothesis Testing

NOAA approached data analysis with regard to the four study objectives as follows:

Objective 1: Improve characterization of chemical concentrations and physical properties of surface and subsurface sediment in areas most likely to be affected by past and ongoing releases of exfoliated paint and other potentially associated contaminants from ships within the SBRF.

To address this objective, NOAA performed qualitative comparisons of physical properties and chemical analysis results for sediment samples collected from stations in the SBRF study area against the results for samples taken from near fleet depositional area stations, other potential source area stations, and reference area stations as well as against San Francisco Bay ambient concentrations (SFEI 1997). The San Francisco Bay RWQCB developed San Francisco Bay ambient sediment concentrations based on the 85^{th} percentile of contaminant concentrations from relatively “clean” RMP and RWQCB stations in San Francisco Bay for the objective of assessment and management of contaminated sediments (SFEI 1997). Ambient sediment concentrations were developed for arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc, total PAHs, and total PCBs (SFEI 1997).

Objective 2: Compare sediment contamination in the vicinity of the SBRF with sediment quality guidelines and reference locations in Suisun Bay.

For the latter component of this objective, the following hypotheses addressed comparison of sediment contamination within the SBRF study area to reference locations. These hypotheses were tested using the Kruskal-Wallis (K-W) nonparametric analysis of variance (ANOVA) if data distributions were not appropriate for parametric tests.

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6 Acenaphthene, Acenaphthylene, Anthracene, Benzo(a)anthracene, Dibenzo(a,h)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(e)pyrene, Benzo(g,h,i)perylene, Dibenzo(g,h,i)perylene, Biphenyl, Benzo(k)fluoranthene, Chrysene, Dibenzothiophene, Fluoranthene, Fluorene, Indeno(1,2,3-c,d)pyrene, 1-Methylnaphthalene, 2-Methylnaphthalene, 2,6-Dimethylnaphthalene, 1-Methylphenanthrene, 2,3,5-Trimethylnaphthalene, Naphthalene, Perylene, Phenanthrene, and Pyrene.

1. *H_0: There is no statistical difference between concentrations of individual contaminants in surface sediment of the SBRF study area (n≈52) and concentrations of the six reference stations (n=3 each).*

2. *H_0: There is no statistical difference between concentrations of contaminants in specific subsurface sediment horizons of the SBRF study area (n=10) and concentrations at analogous horizons in cores from the six reference stations (n=6) and all other stations (three groups).*

It should be noted that while the subsurface depth horizons across stations are generally consistent, this does not equate to sediments of comparable age, because deposition is highly variable across Suisun Bay. Additionally, NOAA did not age-date the sediment cores.

For the first component of Objective 2, NOAA compared individual surface and subsurface sample concentrations to published sediment quality guidelines (SQGs). This was a qualitative comparison with no statistical significance attached. This approach is commonly used by ecotoxicologists for initial screening of contaminant data as part of an ecological risk assessment. In Superfund and other waste site programs conducted for the Federal Government and State of California, ecological risk assessments are routinely performed for sites or facilities where there is potential for an adverse effect to the ecological environment from contamination (Cal/EPA 1996).

Numerous SQGs are available for screening the potential toxicity of sediments. NOAA's Effects Range–Low (ERL) and Effects Range–Median (ERM) guidelines (Long *et al*. 1995) are some of the most frequently used. With respect to this study, ERLs and ERMs are available for nine metals, 13 individual PAHs, LPAHs as a class, HPAHs as a class, total PAHs, and total PCBs (Table 3).

ERLs represent chemical concentrations in sediment below which adverse biological effects are rarely observed. ERMs represent chemical concentrations in sediment above which effects are more frequently observed (Long *et al*. 1995). The ERL/ERM SQGs are based on empirical analysis of existing sediment and concurrent effects data; the sediment data used to develop the ERLs/ERMs generally contain mixtures of contaminants. Therefore, the exceedance of an individual ERM may indicate the possibility that a sediment sample is toxic, but any toxicity observed may or may not be due to that particular contaminant. This issue is shared by most commonly used sediment quality guidelines.

In evaluating potential sediment toxicity, the quotient approach can be used to account for contaminant mixtures. In this approach, individual contaminant concentrations are divided by their respective SQGs, and the results for all contaminants are summed and divided by the number of contaminants. For this study, we used the SQGs and quotient categories developed by NOAA (Long and Morgan 1991; Long *et al.* 1995; Long and Macdonald 1998): the ERL, ERM, and Mean Effects Range Median Quotient (ΣERMq).

Because potential sediment toxicity depends on both the magnitude of exceedance of individual ERMs and the combination of chemicals occurring in the sediment, the ΣERMq was developed to take these factors into account. Based on an analysis of more than 1,000 sediment samples with associated amphipod toxicity data, Long and Macdonald (1998) developed a four-category scale of potential sediment toxicity (Table

4) based on the number of individual ERL and ERM exceedances and the ΣERMq, which included both inorganic and organic contaminants. This scale ranks potential for toxicity from very low to very high.

The four-category scale of potential toxicity is based on the summation of both organic and inorganic (metals) contaminants. Therefore, calculation of ΣERMqs that are to be compared to these values is based on both organic and inorganic contaminants. As the number of ERMs used to calculate a ΣERMq increases, the value of the ΣERMq decreases. For each additional contaminant added to the process, the denominator increases by one while the numerator generally increases by less than one. To interpret potential toxicity from a mixture of contaminants using the scale developed by Long and MacDonald (1998), quotients must be adjusted to account for both inorganic and organic contamination.

Objective 3: Examine sediment samples for visual evidence of exfoliated paint from the fleet.

This objective was addressed through a systematic, qualitative assessment of field surface sediment samples for the presence or absence of paint chips and metal debris.

Sampling locations where metal debris or paint chips were observed in surface or core samples were recorded and mapped. The presence of paint chips or metal debris was compared to metals contamination in the analytical samples.

Objective 4: Begin to assess the bioavailability of paint-related contaminants through the analysis of bivalve tissue samples collected within and around the SBRF study area and at reference locations.

NOAA addressed this objective in several ways, both statistically for comparisons of contaminant concentrations in deployed mussels and through qualitative comparisons of contaminant concentrations in deployed mussels and resident clams. First, the following hypothesis was tested:

> *H_0: There is no statistical difference between concentrations of individual contaminants in transplanted mussel tissue from the SBRF study area and concentrations at reference stations and all other stations (three groups).*

This hypothesis was tested using a Kruskal-Wallis nonparametric ANOVA if the data distribution did not support using parametric statistics.

Second, NOAA qualitatively compared deployed mussel contaminant concentrations from this study to past mussel concentrations from monitoring programs in San Francisco Bay. No other mussel data from within Suisun Bay were available for comparison, and interspecies comparisons are problematic due to variations in lipid concentration and species uptake rates.

Last, NOAA qualitatively compared resident clam (*Corbula*) contaminant concentrations to *Corbula* concentrations in 1991 USGS data from Suisun, San Pablo, and San Francisco bays for six metals measured by the USGS. NOAA did not statistically evaluate *Corbula* contaminants because of small sample size.

5.0 Field Sample Collection

Sampling activities were directed and performed by NOAA staff with support from Ridolfi, Inc., of Seattle, Washington, and field contractors retained by NOAA. MARAD provided additional support, including access and transport to ships and use of shore facilities for sample processing. The field crew involved with sampling logistics, collection, and processing included personnel from NOAA, Ridolfi, Inc., and Moss Landing Marine Laboratory (MLML) of Moss Landing, California. TEG Oceanographic Services (TEG) of Santa Cruz, California, provided support for the subsurface sediment sampling.

Field sampling consisted of four sampling events conducted between June and August 2008 and was performed in accordance with the Sampling and Analysis Plan (SAP) (NOAA 2008b). The first event was deployment of transplanted mussels (*Mytilus* complex) on June 26, 2008. The second event occurred in mid-July 2008 and involved both surface and subsurface sediment sampling, screening for paint chips, and collection of resident clams *(Corbula*). In the third event, the field crew recovered the transplanted mussels on August 26, 2008. In addition to these three events, a supplemental round of resident clam sampling occurred on September 23, 2008, in collaboration with a USGS field crew. The details of these sampling events and processing of sampled media are described in the following sections.

5.1. Sampling Vessels

MLML provided an approximately 6-meter (19-foot) Boston Whaler as the primary vessel for surface sediment and tissue field operations. This vessel was used in the deployment and retrieval of transplanted mussels, surface sediment collection, paint chip screening, and collection of resident clams. Subsurface and surface sediment sampling at most subsurface stations was performed aboard an approximately 15-meter (50-foot) steel barge operated by TEG. The supplemental resident clams were collected using an approximately 6.5-meter (21-foot) Boston Whaler, the R/V *Frontier*, supplied by the USGS.

5.2. Sampling Station Occupation

NOAA generated sampling station coordinates in Decimal Degrees, NAD83, which were used with a wide area augmentation system-enabled global positioning system to navigate to planned sampling stations, as outlined in the SAP (NOAA 2008b). If a planned station could not be occupied because of shallow depth or navigational concerns, or if low salinity (i.e., less than 7 parts per thousand [ppt]) prevented mussel deployment, a nearby alternative station was selected if possible. Deviations from planned sampling stations are discussed in the relevant sample media sections below. All field observations were noted on the field sheet or field logbook (see example field sheet in Appendix 10.4).

5.3. Surface Sediment Sampling

From July 7 through July 17, 2008, samples of the top 5 cm (approximately 2 inches) of sediment were taken using a modified Van Veen sampler (Figure 2) at 72 stations; field duplicates were collected at three of those stations. The planned number of surface sediment stations was 68; however, five additional samples were taken to capture sediment chemistry near deployed *Mytilus* stations and one station (SB05) was not sampled due to in-field conditions (discussed in Section 5.7). NOAA collected a total of 84 surface sediment samples, including three replicates collected at each of the six reference area stations. Surface sediment procedures followed the methods outlined in the SAP (NOAA 2008b).

5.3.1. Paint Chip Sampling and Processing

Paint chip samples were taken from half of the first Van Veen grab retrieved at each station. In total, 73 paint chip samples were collected. An approximately 10-cm-wide (4-inch-wide) polycarbonate tube core was inserted to a depth of approximately 10 cm (approximately 4 inches) and emptied into either a Ziploc bag for later sieving on land or a 1-millimeter (mm) (0.04-inch) mesh sieve for immediate sieving while on the boat. The decision to sieve on the boat or on land was made based on the availability of field personnel for work on the boat. If a sample was immediately sieved, the residual sample was photographed, emptied into a Ziploc bag or glass jar, and then put on ice for later examination. If sieved on land, the sample was rinsed out of the Ziploc bag and sieved through a 1mm (0.04 inch) mesh sieve, then immediately examined for paint chips or other debris that could be associated with ships from the SBRF. Samples sieved on land were not always photographed because of processing logistics. However, after examination, all samples with indications of potential paint chips or debris were photographed and archived as described below.

The visual examination of paint chips was initially performed by spooning the sieved sample by aliquots into gridded Petri dishes until the majority of the sample was distributed, although inevitably small fragments were left behind. Each sample was viewed under a dissecting microscope at 10x magnification as it was methodically moved from the top to the bottom of the Petri dish. The presence of biota, plant debris, and other items was noted on the field sheet ("sample description"). When possible, samples in which *Corbula* appeared to be abundant were noted for the information of NOAA personnel responsible for collecting resident clams in the field. If paint chips, metal, or other questionable items were observed, the items were photographed and collected into a small jar labeled with the sample identification and collection date.

After processing approximately 30 samples using this methodology, we determined that the magnification of the dissecting microscope exceeded our needs and that examination of the samples under a magnifying desk lamp would yield the same results. Therefore, the rest of the samples were examined using a small magnifying lamp as samples were sorted methodically from the top to the bottom of a shallow white tray. If paint chips, metal debris, or other questionable items were observed, the samples were photographed, collected into a small jar labeled with the sample identification and collection date, and shipped to Seattle. NOAA conducted a second review of all samples containing paint chips, metal debris, or questionable material at NOAA laboratories in Seattle, Washington. This subset of samples was further inspected under a 5x to 10x magnification microscope with fiber-optic lighting. When a sample was observed to contain paint chips or metal debris, it was photographed to document the sample in better light than was available in the field. Samples of particular note were photographed at 25x magnification using a microscope-mounted camera.

This methodology allowed NOAA to map the qualitative distribution of metal debris and paint fragments found in surface sediments. Paint chip photo documentation is provided in Appendix 10.5.

5.4. Subsurface Sediment Sampling

Subsurface sediment samples were collected at 26 of the 27 planned stations in Suisun Bay and Carquinez Strait by NOAA and TEG staff. Additionally, one field duplicate sample was collected at Station RF29 within the SBRF study area. Surface sediment samples were collected by the subsurface sediment sampling team immediately following core sample retrieval, excepting at reference stations, where MLML collected replicate samples (CS01, GB01, GB02, SB04, SB07, SB08), and at stations RF44 and RF48, where strong current precluded recovery by the subsurface field team. Surface and subsurface sediment samples were not collected from station SB05 (near Seal Islands) because of safety concerns related to the possibility of encountering unexploded ordnance from the Concord Naval Weapons Station. Surface sediment sample retrieval and processing followed the protocols described in the SAP (NOAA 2008b) and are detailed in the following paragraphs.

Core samples were collected using a vibrocorer aboard the approximately 15-meter (50-foot) steel barge R/V *Retriever* from July 14 through July 18, 2008. The vibrocorer and approximately 2.4 meter (8 foot) aluminum tube (extrusion) were cleaned prior to sampling at each station by scrubbing all surfaces with a brush and seawater to remove adhering sediments, scrubbing all sediment contact surfaces with residue-free Micro detergent, and rinsing with seawater. The approximately 10 cm (4 inch) polycarbonate tubes were steam-cleaned, rinsed with residue-free Micro detergent, and then rinsed clean by TEG prior to the start of field work. A new core liner was used at each sampling station.

Upon retrieval and capping of the sediment core, sampling intervals were cut, capped, and labeled. Subsurface sediment samples were divided into 15 cm (approximately 6 inch) intervals for the first 60 cm (approximately 24 inches) of recovered core and then divided at 30 cm (approximately 12 inch) intervals to the length of recovered core (Figure 2). All subsamples were promptly stored on ice in a covered ice chest until they were transported back to the field lab for preparation for analytical testing.

Sediment sample intervals were collected from 26 subsurface stations and one duplicate station. Nineteen samples collected from 120 to 180 cm (approximately 47 to 71 inches) below the surface and two samples collected from 180 to 240 cm (approximately 71 to 94 inches) below the surface were archived for possible further analysis per the sampling plan.

On average, five subsurface samples were collected at each station (Map 11). At stations where full recovery was not achieved, the reason was generally that a sandy, rocky, or clay layer was encountered. In total, 143 samples from 0 to 120 cm (0 to approximately 47 inches) below the sediment surface were analyzed for metals and organotins. Of these, 139 samples were analyzed for grain size and TOC (there was insufficient material for analysis at RF07, RF51, SB01, and SB03). At 17 stations that had sufficient retrieval, intervals from 0 to 15 cm (0 to approximately 6 inches), 30 to 45 cm (approximately 12 to 18 inches), and 90 to 120 cm (approximately 35 to 47 inches) were also analyzed for PCBs and PAHs, for a total of 50 samples. All samples that were not analyzed for the entire suite of contaminants were archived for future analysis if warranted.

5.5. Sediment Sample Handling, Mixing, and Shipping

Both surface and subsurface sediment samples remained in ice chests (on ice, in double-wrapped plastic bags) until the containers were brought back to the onshore field laboratory, where they were homogenized and apportioned into aliquots for chemical analysis. All sediment samples then remained iced in coolers until they were prepared for shipment to analytical laboratories. To prepare the samples for shipment, surface sediment samples were stirred with the scoop that had been used to collect that sample until the sediment appeared homogeneous or for at least five minutes. Subsurface sample cores were placed over pre-cleaned stainless steel mixing bowls and extruded directly into the bowls for homogenization using a trace-clean stainless steel spoon, which was cleaned between samples.

All pre-labeled sediment chemistry jars were filled using a clean scoop or stainless steel spoon, then stored on ice for shipment. Chain-of-custody forms were completed for all sediment samples and accompanied the samples to the laboratories. Information on the field sheets was entered into a database for data management and sample tracking.

5.6. Bivalve Tissue

5.6.1. Mussel Deployment and Collection

Mussels (*Mytilus* complex) were collected and deployed following California Department of Fish and Game Marine Pollution Studies Lab procedures (Method #MPSL-102a). Upon retrieval, mussels were handled and processed in a manner similar to California State Mussel Watch protocols (Method #MPSL-105). Mussels to be deployed in Suisun Bay were collected by MLML staff in Tomales Bay on June 24, 2008, and transported to Moss Landing for bagging on June 25, 2008. These mussel samples consisted of 33 mesh bags (three mesh bag replicates deployed at each of 11 stations, including nine field stations, one duplicate, and a control collected from Tomales Bay at the same time). Each mesh bag contained approximately 50 individuals. The control sample was kept at the laboratory and put into the freezer for dissection and homogenization concurrent with the later preparation of the field-deployed mussels.

Mussels were deployed on June 26, 2008, at nine stations, four within the SBRF study area, two in Carquinez Strait, and three in Suisun Bay toward Grizzly Bay (Map 12). Three replicate bags of mussels were deployed at each station, with a field duplicate at station RF52 (i.e., six bags deployed). Within the SBRF study area, mussel sample bags were deployed on three different rows and on one buoy in the southern part of the anchorage. Station RF13 was deployed on the barge nest, K(1)-row; RF52 was deployed in L-row; RF53 was deployed in F-row; and RF44 was deployed on a large buoy supplied by MARAD.

Mussel deployment was attempted at stations SB07 and SB08 but low salinity measurements (6 and 5 ppt, respectively) indicated a low probability of survival, so alternative stations were chosen. The desired salinity for deployment is greater than 15 ppt. NOAA encountered few stations with salinity at that level that also met the project team's desire to have the broadest spatial coverage. At the time of deployment, station salinities ranged between 7 and 15 ppt, with an average of 12 ppt, although salinity at some stations likely ranged higher due to tidal exchange.

Mussel samples were retrieved and bagged by NOAA and MLML staff on August 26, 2008, and placed in a sample cooler for transit back to the MLML. The mussels appeared alive and generally healthy at all stations except those at Grizzly Bay, where there was high mortality: at GB01T, 100% mortality and at GB02T, 70% to 80% mortality and low body weight (CC&R MPSL 2008). Both of these sample locations are near the marsh edge, have very fine-grained sediments and perhaps had less water flow through the bag, and potentially had lower salinity (≤ 9 ppt) at the time of deployment.

5.6.2. Clam Collection

Sampling of resident clam (*Corbula)* was collocated with surface sediment chemistry stations. Six samples were collected from July 7 to 13, 2008. Sampling locations were opportunistically chosen based on spatial coverage and observed presence of *Corbula* during the course of sediment sampling. For example, if a large number of *Corbula* were noted while the field team was occupying a surface sediment station, a tissue sample was collected from that location. Three of the sampling stations were within the SBRF study area and three were outside of the SBRF study area.

Corbula were collected using a modified Van Veen grab sampler. After retrieval of the Van Veen grab sampler, its entire contents were deposited into a sorting tub. Sampling staff wearing polyethylene gloves sifted the sediment by hand and poured the sediment through a 1 mm (0.04 inch) mesh sieve. The sediment material was quickly rinsed through the sieve using seawater, and the *Corbula* were then transferred from the sieve into a trace-clean glass jar. Most *Corbula* were less than 1 cm (0.4 inch) in width, with many organisms approximately 5 mm (approximately 0.2 inch) in width. Due to the small size of the *Corbula,* clean forceps were used to transfer them to the glass jars. Field crews attempted as many as 20 grabs per station in order to collect enough *Corbula* tissue. Upon returning to the field lab, each *Corbula* sample was rinsed using deionized water from a squirt bottle to remove any remaining sediment or debris. After rinsing, *Corbula s*amples were promptly stored on dry ice and frozen prior to shipment to the laboratory. Upon receipt at the laboratory, samples were thawed by lab personnel, individual clams were shucked, and the clams' soft tissue was collected into a trace-clean jar for homogenization and analysis.

On September 23, 2008, NOAA field staff accompanied a USGS field crew to collect supplemental *Corbula* samples at the same six stations that had been sampled in July (Map 12). The hope was that the *Corbula* would be of larger size in the fall than in the summer and that opportunistic collection would increase NOAA's sample size and sample weight sufficient to allow for analysis of PAHs and PCBs in addition to metals.

The USGS used sampling and processing protocols that varied slightly from NOAA's protocols. Like NOAA, the USGS collected sediment using a 0.10 m^2 Van Veen grab and handled the samples while wearing polyethylene gloves. The differences were that USGS sieved sediment for clams using a 4-mm (0.15-inch) screen, placed the clams in jars of ambient water, and then transported the clams to the laboratory, where they were allowed to depurate for 48 hours. Depuration allows for excretion of sediment in the clams' digestive tracks, often leading to lower overall contaminant levels than in nondepurated clams. Additionally, at the time of processing, which was several days later, the clams were measured to the nearest one-hundredth of a millimeter and the soft tissue was removed and placed into a trace-clean jar for homogenization.

5.7. Deviations from the Sampling and Analysis Plan

The following exceptions to the sampling protocols detailed in the SAP (NOAA 2008b) are noted:

1. During the collection of surface sediment samples for chemistry analysis, a Teflon sheet was not used to cover samples between grabs or before sample processing, because the samples were processed for laboratory analysis within 24 hours of collection.

2. Sampling staff attempted to avoid exhaust from any engine aboard any vessel involved in sample collection. Boat engines were turned off when sampling at all surface sediment stations except CS01 and SB06. At these two stations, strong currents and high winds prevented anchoring; therefore, the boat was positioned to face into the strong headwind and the sample was taken upwind of the boat engine.

3. The SAP called for photographing each paint chip sample, but this was not consistently done. Photographs were taken of samples sieved on the MLML boat. However, in the case of paint chips collected by the coring team, logistics prevented sieving of the samples on the boat. On the coring vessel, paint chip grab samples were not photographed at RF14, RF21, RF25, and RF41. At the field laboratory, all samples were sieved as per the SAP, but only samples with observable paint chips, metal debris, or unidentifiable material (i.e., potential paint chips) were photographed or retained after processing.

4. Due to field lab constraints, not all subsurface sediment samples were photographed at the time of processing.

5. Sediment homogenization was performed using either the trace-clean scoop used during the collection of surface sediment samples or trace-clean stainless steel spoons, not Teflon stir rods as stated in the SAP.

6. A field duplicate sample was collected at CS03 but was not processed due to an error in sample handling in the field.

7. Surface and subsurface sediment samples were not collected at SB05 (a potential source station) because of safety concerns related to the Concord Naval Weapons Station.

8. As noted above and in the SAP, mussel deployment was attempted in the eastern portion of Suisun Bay, but salinity measurements of less than 7 ppt indicated a low probability for survival. Because of this, mussels were not deployed at reference stations SB07 and SB08. Transplanted *Mytilus* samples were deployed within the SBRF study area as planned; outside of the SBRF study area (GB01T, GB02T, CS01T, CS03T, and SB12), the mussel bags were attached to available structures based on field conditions.

9. Due to field logistics and proximate samples, collocated surface sediment was not collected at *Corbula* stations SB09 and RF19T.

6.0 Results

6.1. Sediment Data Summary and Qualitative Comparisons

All contaminant data from this study, as well as from numerous other data sources, are available through NOAA's Query Manager database, which is freely available at http://response.restoration.noaa.gov/querymanager. Data from this study is part of the San Francisco Bay Database and can be explored after downloading both the Query Manager and Marplot applications.

Metals were detected in over 99% of all individual analyses performed on 84 surface grab sediment samples and their duplicates plus, 142 core sediment samples and their duplicates. Of the 18 metals analyzed, only arsenic, selenium, and silver had any non-detect values. Similarly, at least one of the 25 individual PAH compounds summed to represent total PAHs was detected in every surface sediment sample, and there were only three occurrences of an individual PAH non-detect in any surface sediment sample. By contrast, organotins were detected in only two of 84 surface sediment samples and their duplicates and five of 142 core sediment samples and their duplicates. PCB congeners were below the detection limits in nearly 84% of surface sediment samples. Concentrations above detection limits were observed in only 10 samples: four collected from the SBRF study area, three from the Grizzly Bay reference area, and three from the Carquinez Strait area.

Tables 5 and 6 summarize the minimum, maximum, mean, standard deviation, and 95% upper confidence level (UCL) of the mean of contaminant results for surface sediment grabs (Table 5) and surface and subsurface sediment cores (Table 6) by sampling area (i.e., SBRF study area and reference, near fleet, and potential source areas). For comparison, Tables 5 and 6 also provide San Francisco Bay ambient sediment concentrations (SFEI 1997). Statistical analyses for these data are found in Section 6.2.

Individual sediment sample results are graphed by sampling area for selected sediment contaminants on Figures 3 through 10. Contaminants were chosen for graphical display based on their potential association with SBRF contaminants or based on exceedances of San Francisco Bay ambient concentrations. On Figures 3 through 9, arsenic, mercury, chromium, manganese, copper, lead, and iron data from this study, the recent MARAD study (RMEI 2007), and other Suisun Bay/San Pablo Bay data from the Query Manager San Francisco Bay Database (including RMP, NOAA NS&T Program, and other studies listed in Appendix 10.3) are displayed. Figure 10 displays the mercury data from this study by discrete depth intervals. For comparison, these graphs also show San Francisco Bay ambient concentrations and the ERL/ERM concentrations (described in Section 4.4.3 and discussed in more detail in Section 6.3).

Maps 13 to 22 show the geographical distributions of percent fine-grained sediments ("percent fines") and selected analytes (mercury, lead, copper, chromium) in surface sediments from this study and from the larger Query Manager San Francisco Bay Database (NOAA 2008a) compared to the ERL and ERM concentrations (described in Section 4.4.3 and discussed in more detail in Section 6.3).

For surface and subsurface sediment samples, percent fines at the reference stations and the SBRF study area sampling stations are similar (Table 5, Table 6; Map 13, Map 14). In Suisun Bay, sediments generally had higher percent fines shoreward and in Grizzly Bay, with coarser-grained sediments found in the Reserve Fleet Channel.

For surface sediments, mean and 95% UCL concentrations in the SBRF study area and reference area stations were below ambient concentrations for all contaminants except chromium (Table 5). However, there were sporadic, individual station exceedances of San Francisco Bay ambient concentrations for all contaminants (Table 5). For the near fleet and potential source areas, individual stations also exceeded ambient concentrations, but mean and 95% UCL concentrations at these stations did not (Table 5). Results for SBRF study area, near fleet, and potential source stations were generally within the standard deviation of the reference area for all contaminants except lead; for lead, the SBRF study area had a greater mean. These comparisons are qualitative and were not tested for statistical significance.

Subsurface samples from the SBRF study area had higher mean and maximum concentrations for most contaminants than did the surface grab samples. Subsurface mean and 95% UCL concentrations exceeded ambient concentrations for arsenic, cadmium, chromium, copper, and mercury in the SBRF study area. Arsenic and chromium mean and 95% UCL subsurface sediment concentrations in the reference area also exceeded San Francisco Bay ambient concentrations. Cadmium and chromium mean subsurface sediment concentrations exceeded San Francisco Bay ambient values in the potential source areas (Table6). Results for SBRF study area, near fleet, and potential source sampling stations were generally within the standard deviation of the reference area stations for all contaminants except manganese, for which the SBRF study area had a greater mean. These comparisons are qualitative and were not tested for statistical significance.

In the case of contaminants that lack published San Francisco Bay ambient values, a qualitative comparison suggests that mean and 95% UCL contaminant concentrations in both surface and subsurface sediment samples were generally higher at either the SBRF study area or the near-fleet depositional area stations than in the reference area or other potential source area stations (Table 5, Table 6). However, these values were generally within a single standard deviation and comparisons are qualitative.

6.2. Sediment Statistical Analyses

Complete statistical analyses are provided in Appendix 10.6 and are summarized below and in Table7. Statistical analyses were performed using either IGOR Pro 6.04 (www.wavemetrics.com) or SYSTAT 10.2 (www.systat.com).

Experience has shown that environmental contaminant data typically do not meet the assumptions required for testing by parametric statistical procedures, namely normal distributions and homogeneous variance. To verify this presumption, the surface sediment data were tested for normal distribution with Kolmogorov-Smirnov tests and for homogeneity of variances with Bartlett's test (Table 7). For all parameters, data are non-normally distributed and generally skewed, Selenium was the only contaminant for which homogeneous variance is indicated (Table 7). Therefore, nonparametric tests were selected for statistical analyses. Additionally, the general power of statistical tests performed was investigated to qualitatively assess appropriateness of the tests. Conservative estimates of the power for surficial sediment tests on each analyte indicated that the tests were performing acceptably: the probability of wrongly concluding no differences existed (a type II error, or not rejecting the null hypothesis when in fact it is false) was typically estimated to be less than 10% for most analytes.

Because of the variability in general conditions and in the dynamics known to be present within the SBRF study area, six reference stations were chosen to represent the range of these conditions in reference areas. For these six stations, three surface grab samples were collected from discrete stations. Together, these 18 samples from six sites represent an envelope of reference conditions against which results of surface grabs from the SBRF area can be contrasted. For each of these stations, one subsurface core was taken. A single sample per station would not allow for a reference envelope approach for cores as was done for surface samples.

Although this study ultimately identified nine reference stations, three were bivalve stations. These stations locations were selected based on sampling logistics and did not have sediment replicates. The surface grab samples collected from these stations were not used for statistical analyses in this study.

6.2.1. Metals

Analytical results for samples from the SBRF study area were compared using a Kruskal-Wallis nonparametric test with a significance level set at $p= 0.1$. Because nonparametric statistics rely on ranks, not absolute values, the selection of values to represent below-detection results has no impact upon the statistical tests; below-detection results were set to zero for this analysis.

K-W tests look for significant differences among all tested groups (in this case, seven, consisting of six reference stations plus the SBRF study area). Like ANOVA, K-W tests do not indicate where significant differences may occur, but rather simply suggest whether there are differences among all the tested groups. When a difference is detected, a follow-up test is conducted to determine where the difference lies. The six reference stations were selected to represent the range of conditions present across the project area and form a “reference envelope” of values. A specialized type of follow-up test, called a multiple contrast test, was conducted; this test contrasts the collection of reference stations against the SBRF study area. Unlike a multiple comparison test, the multiple contrast test does not indicate differences among the six reference sites, nor does it indicate differences with individual reference sites; rather, the multiple contrast test examines the likelihood of differences between the SBRF study area and the reference envelope.

K-W tests of surface sediment contaminants indicate that significant differences exist among the SBRF study area and the six reference stations for every metal (Table 7). K-W tests were followed up with multiple contrast tests to determine whether the differences were between the SBRF study area and the reference envelope. The multiple contrast tests failed to find any significant differences between any of the metals concentrations in surface sediment at the SBRF study area and the reference envelope. This indicates that metals concentrations in surface sediments are indistinguishable from the envelope of levels from reference stations.

In the case of core samples, K-W tests were conducted for each metal at each depth horizon to look for significant differences among stations within the SBRF study area, stations in the reference areas, and all other stations. For cores, the reference envelope was represented by individual stations from five of the reference locations (no core was retrieved at CS01 due to refusal) without replication at each station. Indications of potential for any significant differences based on the K-W tests were followed up with multiple comparisons (the Dunn-Holland Wolfe test, which supports unequal sample sizes and accounts for tied ranks) to ascertain where significant differences were suggested among the three groups (SBRF study area, reference areas, and all other stations).

Based on the results of all of these statistical tests, there is only one indication of significant difference supported by multiple comparisons: Manganese concentrations at every depth interval within the SBRF study area are significantly greater than those observed within the reference envelope. For other analytes, including antimony, arsenic, chromium, iron, lead, mercury, nickel, and zinc, K-W tests indicate that there are significant differences among station groups, but overall median SBRF study area concentrations are not elevated when compared to reference locations.

6.2.2. Organotins

Organotins were detected in one surface sediment sample and its field duplicate. The sample from station RF26 contained 430 micrograms per kilogram (µg/kg) tributyltin (TBT), which was confirmed in a laboratory duplicate. No statistical analysis was performed for TBT in surface sediment samples because of the small number of detections.

For core samples, TBT was above the detection limit in five sample and duplicate analyses. Neither monobutyltin nor dibutyltin was observed above detection limits. A K-W test was performed for each depth horizon from the SBRF study area stations, reference stations, and all other stations. No significant difference in organotins was found.

6.2.3. PAHs

The list of 25 PAHs commonly summed in the SFEI RMP was used to represent total PAHs, with one substitution—the stereo-isomer 1,6,7-trimethylnaphthalene was substituted for the RMP isomer of 2,3,5-trimethylnaphthalene. In the analysis of 25 individual PAHs in 77 surficial sediment samples or duplicates, only four analytical results were below the detection limits (4/1,927 or 0.2% non-detects).

Similar to metals, K-W tests of surface sediment indicated that significant differences exist among station groups for total PAHs. But again, multiple contrast tests did not indicate any significant differences between the mean level of PAHs in surface sediment in the SBRF study area stations and the reference envelope, on either a raw or TOC-normalized basis.

PAHs were also ubiquitously observed above detection limits in subsurface sediment samples, with only three instances of below-detection results out of 875 (0.3%) individual PAH analyses in 35 samples or duplicates. Data for K-W tests were available for two depth horizons in sediment core samples from the SBRF study area stations, reference area stations, and all other stations: 30 to 45 cm (approximately 12 to 18 inches) and 90 to 120 cm (approximately 35 to 47 inches). Tests were conducted on both raw data and TOC-normalized data. Total PAH was represented by the summation of 25 individual PAH compounds to coincide with summations made for the RMP. These statistical tests yielded no indication of significant differences.

6.2.4. PCBs

The incidence of PCB detection in surface sediments was low (Table 5). For surface sediments, K-W tests and contrast to the reference envelope did not yield any significant differences.

Total PCB data for sediment core samples were available for the 30 to 45 cm (approximately 12 to 18 inch) and 90 to 120 cm (approximately 35 to 47 inch) horizons. Total PCB was detected in seven of the 32 SBRF study area and reference samples (Table 6).

6.2.5. Sediment Physical Properties

The physical properties of surface sediment, as characterized by TOC and percent fines (Table 5), were also examined. These two parameters are often highly influential in the physico-chemical partitioning of contaminants, especially organics, onto sediment particles. As such, they often can be surrogate predictors of contaminant trends or patterns.

In surface sediments, although K-W tests indicated significant differences, subsequent multiple contrast tests indicated no differences between the percent fines and TOC in the SBRF study area and the reference envelope.

In sediment cores, no significant differences were indicated in the percent fines among the 15 to 30 cm (approximately 6 to 12 inch), 30 to 45 cm (approximately 12 to 18 inch), 45 to 60 cm (approximately 18 to 24 inch), 60 to 90 cm (approximately 24 to 35 inch), and 90 to 120 cm (approximately 35 to 47 inch) intervals for the SBRF study area, reference envelope, and all other stations combined. For the 0 to 15 cm (0 to approximately 6 inch) core horizon, a statistically significant difference was indicated among groups, but multiple comparisons did not indicate statistical significance. Likewise, no differences were indicated for TOC in the 0 to 15 cm (0 to 6 inch) or 30 to 45 cm (12 to 18 inch) horizon.

6.3. Comparisons to Sediment Quality Guidelines

A description of sediment quality guidelines (SQGs) and how they were used in this study is provided in Section 4.4.3.

6.3.1. Metals

The following discussion examines metals results on the basis of duplicates and replicates being treated as individual samples, which is the more conservative approach. Immediately following, the same data are discussed on the basis of duplicates and replicates being averaged to yield one concentration per station depth interval. This difference in treatment yields different numbers of samples.

If field and laboratory duplicates and station replicates are counted separately, between 254 and 263 surface and subsurface sediment samples were analyzed for metals. Nickel concentrations in all 255 samples analyzed for nickel exceeded the ERM (51.6 parts per million [ppm]). Other ERM exceedances include mercury and lead. For mercury, 24 of 254 surface and subsurface sediment samples (9%) exceeded the ERM of 0.71 ppm (Figure 4, Figure 10; Map 15, Map 23). For lead, one surface grab sediment sample exceeded the ERM of 218 ppm (Figure 8; Map 17). Copper was a primary contaminant of interest during this study, but there were no exceedances of the ERM (270 ppm) for copper in any sediment sample (Figure 7; Map 19).

The numbers of samples for which metals concentrations exceeded ERLs but not ERMs are:

- Chromium—245 of 256 samples;
- Arsenic—215 of 263 samples;
- Copper—210 of 256 samples;
- Mercury—152 of 254 samples;
- Zinc—62 of 256 samples;
- Lead—17 of 256 samples; and
- Silver—1 of 256 samples.

No published SQGs are available for antimony, barium, iron, manganese, selenium, thallium, total tin, and vanadium.

If field and laboratory duplicates and station replicates are averaged to yield one concentration per station depth interval, 209 samples were analyzed for metals. Nickel concentrations in all samples exceeded the ERM (51.6 ppm). Three surface sediment samples (one grab and two core intervals) and 17 subsurface sediment samples also exceeded the mercury ERM (0.71 ppm), and one surface grab sample exceeded the lead ERM (218 ppm) (Table 8). In surface sediment grab samples, no sample exceeded more than two ERMs (nickel plus either lead or mercury). At least one ERL was exceeded in all samples (including those samples that exceeded ERMs); for metals, the number of ERLs exceeded in any one sample ranged from one to seven. Of 209 samples total, the number of samples that exceeded ERLs for specific metals are nickel, 209; chromium, 201; arsenic, 174; copper, 174; mercury, 147; zinc, 52; lead, 16; and silver, 1.

There are no ERLs or ERMs for organotins; however, Meador *et al*. (2002) derived a concentration for organic carbon (OC)-normalized tributyltin of 6,000 nanograms per gram organic carbon (ng TBT/g OC; parts per billion [ppb]). This value is considered protective of juvenile salmonid prey and was used in this study for comparison because of the lack of other guideline values and because organotins are a primary contaminant of interest. Only one sample (RF26 surface grab) had concentrations of all three organotins (mono-, di-, and tri-) above the detection limits (Map 24). Six core samples from three cores had TBT concentrations above detection limits (Table 9). When adjusted for organic carbon, only the RF26 surface grab sample, with a concentration of 43,000 ng TBT/g OC, exceeded the Meador *et al*. (2002) concentration of 6,000 ng TBT/g OC.

6.3.2. PAHs

No ERMs for individual PAHs were exceeded. One sample (surface grab sample at CS02) had an individual PAH concentration above the ERL (acenaphthene at 16.4 ppb).

To take a very conservative approach, the sums for LPAH, HPAH, and total PAH were calculated using the full detection limits to represent analytical results below the detection limits, although it is more typical to use one-half the detection limit to represent non-detect data. Even under this conservative approach, LPAH, HPAH, and total PAH did not exceed their respective ERLs (Table 5, Table 6).

6.3.3. PCBs

The incidence of PCB detections in this study was very low (Table 5, Table 6). Taking the most conservative approach of calculating total PCBs using the full detection limit for all 40 congeners analyzed, all surface and subsurface samples have total PCBs above the ERL (22.7 ppb), but well below the ERM (180 ppb), with a range of 33.3 to 43.5 ppb. A more common approach is to use one-half the detection limit in calculating total PCBs; in that calculation, only two samples (CS03 surface grab at 24.2 ppb and RF34 surface core at 28.5 ppb) exceeded the ERL (22.7 ppb) for total PCBs. Using Query Manager's summing method, which is summarized in Section 4.4.2, total PCB concentrations did not exceed the ERL in any sample (Table 5, Table 6).

6.3.4. ERM Quotient Analysis

The methodology for calculating the Mean Effects Range Median Quotient (ΣERMq) is presented in Section 4.4.3. After sediment sample duplicates and replicates are averaged (but treating tissue stations separately), there are 87 records (both surface and subsurface) having data for the full suite of metals, PAHs, and PCBs. The mean ΣERMq for those 87 records is 0.15 and is the same regardless of whether non-detect PCBs are represented by the detection limit, half the detection limit, or zero. If only metals are used to calculate the ΣERMq, the mean ΣERMq for the 87 records is 0.39, which is more than two and one-half times higher (Table 10). In order to compare all 209 samples having metals data to the Long *et al*. (2000) scale, we assumed that the organics data for the 87 records are representative of Suisun Bay as a whole. Therefore, the ΣERMq for those records without PAH or PCB data was estimated as follows:

1. For each of the 87 records, the sample ΣERMq for combined organics and inorganics was divided by the sample ΣERMq for metals only.

2. The mean (0.38) and 90th percentile (0.40) of this ratio were then calculated.

3. The 90th percentile was chosen as a conservative estimate of the ratio.

4. The ΣERMq based solely on metals for those records without organics data was multiplied by the 90th percentile value of 0.40 to estimate what the ΣERMq would have been had organics data been available.

Whether evaluating just the 87 records with the full suite of metals, PAH, and PCB data or evaluating all 209 samples using estimates for those without organics data, the ΣERMq for any record did not exceed 0.25. This value falls within the Category 2 (Medium Low) range of Long *et al*. (2000) (Table 4). The number of ERL and ERM exceedances (which ranged from one to seven and zero to two, respectively) also placed all samples in the Medium Low range. This range is typical for the San Francisco Bay estuary, where, according to NOAA's Query Manager database, RMP stations have fallen within the Category 1 (Low) range less than 2% of the time since 1993 (NOAA 2008a).

Table 10 provides summary statistics from this study for the various methods of calculating ΣERMq, including using only metals. Twenty records (approximately 10% of the 209 samples) had an ΣERMq of less than 0.1, which places them in the Category 1 (Low) range for potential toxicity (Table 10). However, 17 of the 20 records had less than 20% fines and 13 had less than 10% fines, which may partially explain the low ΣERMq values. Based on the calculations described here, no records fell within Category 3 or 4 (Table 10; Map 25).

6.4. Paint Chip Analysis

Samples evaluated for the presence of paint chips and metal debris were collected at 73 surface sediment stations. Preliminary visual examination of these samples was performed in the field laboratory, which resulted in 18 samples archived for further evaluation based on the presence of paint chips, metal debris, or unknown material (e.g., rocks, silica, crystalline structures) (Table 11).

Upon further review of these 18 samples, three had naturally occurring crystalline structures and two had no debris of note. Twelve samples were classified as containing metal debris, with five exhibiting paint. One sample was identified as solely a paint chip. Paint chips were found only in samples from within the SBRF study area, while metal debris was found in samples from within the SBRF study area and at CS01 (a reference station) and SB06 (a potential source station). Within the SBRF study area, 22% (11/51) of samples collected contained metal debris or paint; out of all samples collected, metal debris or paint chips were detected in 18% (13/73) of the samples. Map 26 depicts the locations of these stations. Of these surface sediment samples, two also had an exceedance of an ERM or the organotin sediment value published by Meador *et al.* (2002) (Table 11). Photographs of these samples taken during the analysis process are provided in Appendix 10.5.

6.5. Bioavailability

6.5.1. Deployed Mussels

When recovered, the deployed mussels at most stations appeared alive excepting those at the Grizzly Bay stations, where there was high mortality: at GB01T, 100% mortality and at GB02T, 70% to 80% mortality and low body weight (CC&R MPSL 2008).

Table 12 presents the summary statistics (minimum, maximum, mean, standard deviation, 95% UCL) for contaminants analyzed in deployed mussels. Metals were detected in all 24 field-deployed samples and their duplicates. Antimony, thallium, and tin were not detected in any of the field samples; silver and organotins were rarely detected (Table 12). PAHs were detected in a high percentage of mussel samples, but PCBs were detected in only three of the 24 field-deployed mussel samples (Table 12).

Concentrations of 11 of the 18 metals analyzed were slightly higher in mussels deployed at the near-fleet depositional station than at the other locations in the project area, although sample means were within a standard deviation of one another. For three contaminants—manganese, LPAHs, and monobutyltins—concentrations were higher in the control samples (mussels that were collected, immediately frozen, and never deployed) than in mussels from any of the Suisun Bay stations (Table 12). Because of small sample size, statistical testing was not performed to distinguish near fleet samples from other stations.

Statistical testing (the K-W test) was performed on aluminum, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, vanadium, zinc, monobutyltin, and total PAH concentrations to investigate differences among the SBRF study area stations, the reference stations, and all other stations (near fleet and potential source combined). At the p = 0.10 level, no significant differences were detected.

Lipids from deployed mussels were also compared to lipids from controls (a subsample of pre-deployment mussels frozen at the time of field collection). The K-W test showed significance at the p= 0.09 level, with deployed mussels having lower lipid concentrations than did controls.

NOAA also compared mussel contaminant concentrations from this study to concentrations from other mussel studies in San Francisco Bay. Because of our relatively small sample size, we conservatively compared our maximum contaminant concentrations in mussel tissue for all samples, including duplicates, to the mean, minimum, and 10th percentile contaminant concentrations found in mussels from San Francisco Bay, as sampled by NOAA's NS&T Program (1984-1993) and SFEI's RMP (1997-2002; 2004-2005) and reported in the Query Manager database (NOAA 2008a) (Table 13). The maximum concentrations in this study exceeded the minimum concentrations from the database for five metals (no data were available for barium or vanadium and only a single data point each was available for silver, thallium, and tin), seven individual PAHs, and total PAHs (Table 13). Only lead and perylene in this study had maximum concentrations greater than the 10th percentile concentrations for San Francisco Bay, and none exceeded the mean concentrations from San Francisco Bay (Table 13).

Based on significant differences in lipids when compared to controls, mussels in this study may have been stressed, likely from low salinity. The salinity at the stations in Suisun Bay ranged from 7 to 15 ppt when the mussels were deployed. The minimum salinity recommended for mussel deployment is 15 ppt. Further, the maximum percent lipid for this study was 1%; the minimum for other San Francisco Bay studies was 2.8%, with a tenfold difference between the maximum percent lipids for this study versus the mean of all San Francisco Bay mussels (Table 13).

6.5.2. Resident Clam (*Corbula*) Collection

Map 27 shows the distribution of surface grabs collected by NOAA where *Corbula* were noted as being present in field notes.

Table 14 presents the summary statistics (minimum, maximum, mean, standard deviation, 95% UCL) for contaminants analyzed in *Corbula* samples collected in July 2008 and September 2008. A qualitative comparison of analytical results shows generally higher mean concentrations of metals in samples from the SBRF study area than from all other stations for the July sampling event, with the opposite being the case for analytical results from the September sampling event (Table 14). However, these means are within a standard deviation of one another.

Insufficient tissue mass was collected to analyze for PAHs or lipids at any station. Sufficient tissue mass was not available to analyze all stations for PCBs, but for the stations having sufficient mass, mean total PCB concentrations were higher at stations outside the SBRF study area than within the SBRF study area (Table 14). No statistical testing was performed for *Corbula* samples because of the small sample size and lack of representation of samples from reference stations (Table 1).

NOAA also qualitatively compared *Corbula* summary statistics from this study to *Corbula* data for eight metals (cadmium, chromium, copper, lead, nickel, silver, vanadium, and zinc) obtained from the USGS (Table 15). The USGS data were collected during 1991-1992 and were summarized in Brown and Luoma (1995). NOAA converted tissue concentrations from this study to dry weight for comparison to the USGS data set. Although no statistics were run on these data because of low sample size, clam depuration appears to have made a difference in contamination levels found in the July 2008 and September 2008 samples collected for this study. For seven of the eight contaminants measured in the USGS study, concentrations in the July 2008 nondepurated *Corbula* samples were greater than concentrations in depurated *Corbula* samples from September 2008 by roughly a factor of four or more. The exception is cadmium, which was greater in the September 2008 samples than July 2008 samples. Comparing NOAA's September 2008 collection to the USGS 1991-1992 data set, copper, lead, and silver concentrations are higher in USGS *Corbula* samples from San Francisco Bay than in *Corbula* samples collected for this study or in USGS samples from Suisun Bay, although this was not statistically analyzed due to low sample size (Table 15). Chromium, nickel, and vanadium concentrations were greatest in clams from the NOAA September 2008 collection; cadmium and zinc concentrations were greatest in the USGS Suisun Bay and Carquinez Strait samples (Table 15).

7.0 Discussion

7.1. Distribution of Reserve Fleet-related Contaminants

One concern raised by State agencies and environmental groups that gave rise to this study was the potential release of contaminants associated with exfoliated paint to the estuarine environment of Suisun Bay. NOAA's sampling design sought to evaluate areas where our pre-study analysis (Section 3.2.2) indicated the highest likelihood of finding contaminant deposition that could be attributed to the fleet, as well as areas that would likely not be impacted by SBRF-related contaminants. The design assumed that contaminants would be deposited with the sediment bedload (Section 3.5).

In general, our findings reveal that contaminant levels in all media (sediment, *Mytilus*, and *Corbula*) within the project area are below or similar to commonly used SQGs, San Francisco Bay ambient concentrations (SFEI 1997), and contaminant levels found in other San Francisco Bay contaminant monitoring studies (Tables 5, 6, 13, 15; Figures 3 through 10; Maps 16, 18, 20, 22). This pattern held true within the SBRF study area, where NOAA predicted the highest likelihood of finding elevated levels of paint-associated contaminants such as lead, copper, and zinc. Further, no statistically significant differences in contaminant concentrations were found between the SBRF study area and reference stations, with the exception of manganese in sediment core samples. However, a limited number of individual stations within the SBRF study area did indicate elevated concentrations for individual contaminants. For example, station RF26 exhibited the greatest lead concentration (276 ppm) for surface sediments in this study and had the only detection of organotins (total organotins, 900 ppb) within the SBRF study area. This sample also contained metal debris and paint chips (Map 26). However, this is the only sample in which both elevated (although not statistically significant) contaminant concentrations were measured and paint chips were noted. Other samples with paint chips and/or metal debris did not display similarly elevated contaminant concentrations.

The only contaminant that showed a consistent, statistically significant elevated mean concentration in the SBRF study area as compared to the reference areas or other locations is manganese in core sample intervals, including the surface core interval of 0 to 15 cm (0 to approximately 6 inches) (Table 6;Table 7; Figure 6). However, the surface grab samples collected in the SBRF study area were not statistically different from those collected in reference areas (Table 7). Manganese concentrations in surface grabs from the SBRF study area ranged from 490 to 1,370 ppm (mean = 824 ppm). In the reference area surface grabs, manganese ranged from 479 to 1,080 ppm (mean = 740 ppm). For the 0 to 15 cm (0 to 6 inch) horizon, manganese in SBRF study area core samples ranged from 486 to 1,720 ppm (mean = 1,036 ppm), while the reference area ranged from 465 to 942 ppm (mean = 681 ppm) (Table 5, Table 6; Figure 6).

This difference between manganese concentrations in grab and core surface horizons might be explained by (1) nonhomogenous concentrations in the environment; (2) the different depth intervals, reflecting different periods of deposition (surface grabs represent 0 to 5 cm, surface cores are 0 to 15 cm); (3) differences in the ability of the different sampling equipment to represent surface sediment (vibro-core equipment may eliminate the fine, shallowest sediment); and/or (4) the difference between the surface grab sampling design (gridded design with random starting point) and the core sampling design (sample locations judgmentally selected from a subset of the surface sampling stations) in the SBRF study area.

Manganese is a ubiquitous trace element, the 12th most abundant element in the Earth's crust (USEPA 2008). It is commonly used in steel manufacture as an industrial metal alloy. It can also be found in some pigment formulations and oxidizers. NOAA does not have information about specific sources or discharges of manganese in Suisun Bay, but it is possible that manganese could be associated with the presence of the SBRF or other industrial activities in the area. Although there is no RWQCB ambient concentration for manganese, some surface sediment data are available from the NS&T Program and the RMP, as found in Query Manager (NOAA 2008a). The manganese levels found at Suisun Bay appear to be within the range and average found in those studies throughout San Francisco Bay (Map 28).

Other contaminants found at individual stations at levels above San Francisco Bay ambient concentrations include arsenic, chromium, copper, and mercury. None of these contaminants is statistically elevated in the SBRF study area compared to the reference areas, and their concentrations are generally within a factor of two of the San Francisco Bay ambient concentration values (Figures 3 to 5, Figure 7). Chromium is known to be at elevated concentrations in Suisun Bay from upstream and background contamination, and our results support that finding, given there is no elevation of chromium in the SBRF study area over other areas of Suisun Bay or San Pablo Bay (SFEI 2007a) (Figure 5; Map 22). Mercury is also known to be at elevated concentrations in Suisun Bay from historical mining practices, as well as industrial sources, and is one of the main contaminants of concern for the health of San Francisco Bay as a whole (SFEI 2008). NOAA found mercury at concentrations above San Francisco Bay ambient concentrations in surface and subsurface samples from both reference areas and the SBRF study area (Figure 10; Map 15, Map 16, Map 23). These were all within a factor of two of the ambient concentration. Mercury is a well-identified problem, with concentrations above San Francisco Bay ambient concentrations and ERM values found throughout the estuary (Capiella *et al*. 1999; SFEI 2008). Map 16 presents mercury concentrations in surface sediment studies from the Query Manager database compared to the ERL and ERM SQGs for San Pablo Bay and Suisun Bay.

Copper was historically a contaminant of concern in the estuary but is currently of lower concern in the watershed than are other contaminants due to decreased loadings and lower levels of bioavailability (SFEI 2008). NOAA found concentrations in the project area to be consistent with concentrations found in our Query Manager database (Map 20).

There are several possible explanations for the lack of elevated contaminant concentrations (except manganese) within the SBRF study area relative to the rest of the project area of Suisun Bay and Carquinez Strait:

1. No contaminants have been released from the fleet.

2. Sampling within the SBRF study area and the project area in general was insufficient to detect contaminant signals.

3. Contaminants have been released at such a low rate that any signal is masked by contamination from upstream and other sources.

4. Contaminants are periodically transported away.

5. The dynamic hydrology of Suisun Bay has mixed contaminants from the SBRF with other contaminant inputs to the bay.

Explanation 1 is not supported by the results of this study because, at a minimum, it has been determined that paint chips from the fleet have entered Suisun Bay, and antifouling paints used on ships' hulls are designed to release their antifouling component (e.g., copper, TBT) into the environment. While explanation 2 cannot be totally discounted, intensive sampling was performed within the SBRF study area boundaries to examine both depositional and erosional areas and both surface and subsurface sediments to resistance depth or 2.4 meters (8 feet). If any significant levels of contamination exist within the SBRF study area, they would have to be confined to a relatively small area to have been missed by this project's sampling program.

Within the SBRF study area, NOAA did not find a trend of stations with visible indications of metal debris or paint chips also exhibiting elevated levels in sediment of any of the target analytes potentially in paint formulations (Map 26). However, based on our findings in both surface and subsurface data, it appears that elevated levels of contaminants in sediments within the SBRF study area are patchy and are not necessarily collocated with deposited paint chips or metal debris deposited within the SBRF.

One explanation for the lack of a significant contaminant signal in the SBRF study area is a combination of explanations 3, 4, and 5. Contaminant releases from exfoliated paint from the SBRF would not be concentrated in the way that releases from point sources, such as industrial waste discharges, are, nor are they similar to catastrophic releases, such as oil spills. The potential SBRF releases investigated in this study would have occurred slowly (e.g., paint flaking) over a fairly dispersed area (i.e., the entire area of the SBRF at any point in time). Suisun Bay is a very dynamic system, with water and sediment moving into the bay both from the upstream input of the Sacramento and San Joaquin rivers and from the action of the incoming tide. Water and sediment are removed from the bay on the outgoing tide, with increased removal during storm events. This dynamic hydrology would be capable of both removing contaminants from the area of the SBRF shortly after release and mixing SBRF contaminants with contaminants from other sources. Within the SBRF study area, these three factors—slow release, removal, and mixing—make it extremely difficult to attribute any contamination solely to the SBRF.

This conclusion is supported by the most recent (2002-2007) bathymetric change analysis, which indicates that sediments within the SBRF study area have been net erosional for the last five years, with average erosion of 0.64 meter/year (approximately 2 feet/year) (Section 3.2.2). Although there are areas of shoaling and accumulation within the SBRF, NOAA did not find elevated levels of contaminants in our surface sediment sampling in the SBRF, whether originating there or from upstream sediment loading. It is possible that the net erosion seen from 2002 to 2007 is part of a longer-term pattern of deposition/erosion or reflects a few major storm events. The longer-term (1942-1990) bathymetric change analysis indicates that sediment was generally accreting from the Reserve Fleet Channel shoreward. Subsurface sediment samples taken to depths of 2 meters (6.5 feet) in these areas do not indicate higher contaminant levels at depth. For locations NOAA sampled, this suggests that if elevated levels of contaminants were deposited in the SBRF, whether originating there or from upstream sediment load, they did not remain in the SBRF. Maps 16, 18, 20 and 22 show the combined data sets for surface sediment contamination from NOAA's Query Manager Database for this study, as well as other sediment data for Suisun Bay, Carquinez Strait, and San Pablo Bay.

Part of the design of this study was to judgmentally place sediment grab and core sampling locations in areas where NOAA expected to find areas of deposition and thus potentially higher contaminant levels (near fleet stations; Section 4.2.2). The locations of these stations were based on the bathymetric change analysis of 1942-1990. NOAA also judgmentally placed sediment grab and core sampling locations in areas thought to be potentially influenced by other industrial and municipal contaminant sources (potential source stations; Section 4.2.4). Because these stations were not grouped by likely contaminant type or source (the potential source stations were not expected to have elevated concentrations of the same contaminant), we did not statistically analyze results for surface grab samples. By contrast, reference stations were chosen to represent contaminant levels and grain size of Suisun Bay as a whole (away from other known contaminant sources and the SBRF). Further, as most of these reference stations were associated with previously sampled RMP stations, there was some pre-existing information about contamination in these areas. Figures 3 through 9 and Tables 5 and 6 indicate that the potential source and near fleet stations did not have higher overall contaminant levels than either the SBRF study area stations or reference stations.

From data obtained after sampling in July 2008, NOAA performed a more recent bathymetric change analysis (2002-2007) for a subset of the SBRF study area where these data were available (Appendix 10.2). This analysis continues to show net erosion, but with discrete areas of deposition—often different than areas identified as depositional from the 1942-1990 analysis. This analysis and our chemistry results support the assertion that Suisun Bay hydrodynamics are highly variable both spatially and temporally and difficult to predict for narrow time frames or specific areas. Because of this known variability, NOAA did not consider it appropriate to analyze or display contaminant data from the SBRF study area grid by predicted depositional area.

However, NOAA did review the mean chemical concentrations of all stations determined to fall in predicted depositional areas of the SBRF (Appendix 10.2) relative to the mean chemical concentration within the SBRF study area as a whole. All chemical concentrations from the SBRF depositional station means were within one standard deviation of the overall SBRF study area mean concentrations presented in Table 5, indicating no meaningful difference between stations in depositional or nondepositional areas of the SBRF. These data are available for further review within Query Manager (NOAA 2008a).

NOAA also did not investigate potential migration of contaminants to San Pablo Bay. NOAA's goal was to characterize areas of Suisun Bay that were most likely to be impacted by releases from the SBRF. The project team's conclusion early in the design process for this study was that collecting sediment contaminant data in San Pablo Bay was unlikely to result in a finding of any elevated levels that could be directly attributed to the SBRF, due to the complexity of the area hydrodynamics and the presence of multiple contaminant sources to Suisun Bay, Carquinez Strait, and San Pablo Bay.

Both PAHs and PCBs were raised as potential contaminants of concern within the SBRF study area due to concerns about the potential for PCB-laden paint to flake off or for petroleum to leak from the vessels. NOAA did not find these contaminants in the project area at elevated concentrations.

7.2. Bioavailability of Contaminants

Both measures of bioavailability (deployment of mussels and collection of resident clams) used for this study indicate no clear pattern of increased tissue contaminant concentrations in the SBRF study area compared to other areas of Suisun Bay sampled for this study (Table 12, Table 14). However, sample sizes were small.

Further, overall contaminant levels in mussel tissue are low in this study compared to mussel contaminant levels in other San Francisco Bay studies. This study's maximum concentration never exceeded a mean concentration of mussels from elsewhere in San Francisco Bay (Table 13). While this is consistent with the relatively low contaminant levels found by this study in sediment, definitive conclusions with respect to bioavailability should not be made based on these data. High mortality at some stations (GB01T= 100% mortality; GB02T= 70% to 80% mortality) and low lipid levels in the surviving mussels (Table 12, Table 13) suggest that the deployed mussels may have been stressed due to the low salinity regime or feeding less normally than in their native environment (e.g., GB01T and GB03T station occupation sheets reported salinities between 7 and 15 ppt at the time of deployment). Generally, salinity for mussel deployment should be above 15 ppt.

As detailed in the SAP for this study (NOAA 2008b), several other species were considered for deployment, including *Corbicula fluminea, Crassostrea gigas,* and *Ostreola conchaphilia*. The clam *Corbicula fluminea* was determined to have low tolerance for the salinity encountered at depth in Suisun Bay. The oyster *Crassostrea gigas* could have tolerated the salinity range and has been used in past biomonitoring studies; however, it is not a native species to the bay and efforts are under way to eradicate it. The native West Coast oyster *Ostreola conchaphilia* likely would not have survived well at depth, may have suffered from similar salinity stress, and lacks a local reference supply. Consequently, it was also rejected for deployment. Based on this study's results, *Mytilus* may not have been an ideal species for bioavailability deployment; however, given the limitations outlined above, NOAA does not have an alternative species to suggest for future studies.

Results from the *Corbula* tissue contaminant analysis similarly suggest no clear pattern between the SBRF study area and other areas evaluated in this study. Concentrations between the depurated clams from this study (September 2008) and the 1991-1992 USGS samples are within a standard deviation of one another (Table 15). The exception to this is silver, for which the 1991-1992 concentrations are higher than those found for this study (Table 15). USGS Suisun Bay samples from 1991-1992 were not taken from the SBRF study area. The USGS Suisun Bay stations are at Chipps Island, Honker Bay, Martinez/Carquinez, and near Concord Naval Weapons Station (Brown and Luoma 1995).

Finally, there are differences between NOAA's depurated *Corbula* samples (September 2008) and nondepurated *Corbula* samples (July 2008). NOAA's nondepurated clams had higher means than depurated clams for seven of the eight metals measured, possibly indicating an enrichment from gut contents (Brown and Luoma 1995). The contaminant found at higher concentrations in depurated samples was cadmium (Table 14, Table 15). This finding is consistent with what was found by USGS, where cadmium, silver, and zinc concentrations were no different between depurated and nondepurated samples (Brown and Luoma 1995).

USGS recommends clam depuration for more stable, less variable analysis in monitoring programs (Brown and Luoma 1995). NOAA's findings support this recommendation, depending on the use of the tissue contaminant data. However, if tissue contaminant data are to be used for food web modeling, it may be beneficial to use nondepurated samples for estimating exposure to upper-trophic-level organisms through ingestion.

7.3. Preliminary Ecological Risk Analysis of Reserve Fleet-related Contaminants

This study found rare individual exceedances of ERMs for all contaminants but nickel. Nickel is a major driver of the ΣERMq in this study. Long *et al*. (1995) consider the nickel ERL and ERM to be poor predictors of toxicity, with toxicity observed only 16.9% of the time when the ERM was exceeded. This is virtually identical to the observed toxicity (16.7%) when nickel concentrations were between the ERL and ERM, meaning that the incidence of toxicity did not increase with increasing nickel concentration. Also, nickel is generally at elevated concentrations within the San Francisco Bay system such that the RWQCB ambient concentration of 112 ppm is well above the ERM (51.6 ppm). If nickel were excluded from the ΣERMq calculations, the estimated mean ΣERMq for the entire data set drops to 0.11 and the estimated mean ΣERMq for the 87 samples with both organics and inorganics data drops below 0.1. Excluding nickel, the mean ΣERMq for the three depth classes within the SBRF study area of 0 to 5 cm (0 to approximately 2 inches), 0 to 15 cm (0 to approximately 6 inches), and below 15 cm (approximately 6 inches) are 0.10, 0.14, and 0.12, respectively.

Taking all these factors (ERL and ERM exceedances, ΣERMqs, and the role of nickel) into consideration, sediments sampled in this study from the SBRF study area and the rest of Suisun Bay have a low to moderately low potential for toxicity to benthic invertebrates (Long *et al.* 2000). Exceptions to this might occur in the individual locations where mercury is elevated above its ERM (Map 15, Map 23). Mercury biomagnifies through the food chain, so although it may not be directly acutely toxic, it still may be toxic at higher trophic levels. As discussed in Section 7.1, mercury frequently exceeds SQG and ambient concentrations in Suisun Bay and San Francisco Bay and is considered an estuary-wide problem (SFEI 2008).

NOAA notes that comparisons to ERLs and ERMs, which is a common approach, are considered preliminary indicators of ecological risk from contaminants. The State of California is developing sediment quality objectives, in which sediment chemistry will be only one component of evaluating contaminant impacts to the ecosystem; when final, the sediment quality objectives will provide additional guidance for this type of evaluation. A full ecological and toxicological assessment, which could include bioassays, food web modeling, and benthic or fish community analysis, related to sediment contaminants from the SBRF sediments was beyond the scope of this study.

8.0 Conclusions and Recommendations

NOAA's conclusions and recommendations are summarized as follows:

1. Most contaminants analyzed in sediments in the vicinity of the SBRF were not statistically elevated relative to reference locations or San Francisco Bay ambient concentrations. The exception was manganese, which was statistically significantly greater in the vicinity of the Reserve Fleet than in the reference stations, although appeared to be within the range of concentrations found in San Francisco Bay. At present, there is little or no information available for manganese to allow interpretation of the ecological significance of this finding.

2. Metal debris and paint chips were found in some sediment samples collected from the SBRF study area. Only one station contained both elevated levels of sediment contamination and metal fragments or paint chips.

3. According to NOAA's statistical analyses, concentrations of contaminants in mussels transplanted to the vicinity of the SBRF were not elevated relative to those at reference locations. However, the tissue concentration values should be considered preliminary and interpreted with caution. The transplanted mussels had low lipid levels, which could indicate stress caused by the low salinity regime encountered during the study. This might affect feeding rates and overall uptake of contaminants by the mussels.

4. Concentrations of contaminants in sediments were compared to literature guidelines to indicate the potential for toxicity to sediment dwelling organisms. Of the 18 metals that were analyzed for this study, nine have published sediment quality guideline concentrations for the effects range low (ERL) and the effects range median (ERM). Concentrations of some paint-related contaminants (for example, copper) in individual sediment samples in the vicinity of the SBRF exceeded the ERL, which is defined as a level below which adverse biological effects are rarely observed. Based on available data from previous studies, exceedances of the ERL are common for sediments throughout Suisun Bay and San Pablo Bay. Exceedances of the ERM values, defined as the concentration above which effects are observed in 50% of studies, occurred for nickel, mercury, and lead. Nickel concentrations throughout San Francisco Bay tend to be elevated and often exceed the ERM. Although all sediment samples in this study exceeded the ERM for nickel, previous studies revealed a poor relationship between observed toxicity and nickel concentrations, reducing the confidence in this observation. Nine percent of sediment samples in this study exceeded the guideline for mercury, and one sample exceeded the guideline for lead. Mercury is a known contaminant in San Francisco Bay due to historical use. None of the other metals analyzed exceeded the ERM.

Based on the points above, particularly comparison of the chemistry data collected for this study to sediment quality guidelines, NOAA concludes that sediments from the SBRF study area and the rest of Suisun Bay have a low to moderately low potential for toxicity to benthic invertebrates. The contaminant concentrations observed are largely comparable to values for the same metals and organics measured in other regions of the greater San Francisco Bay. Following this analysis, NOAA does not recommend specific sediment remedial actions in the vicinity of the SBRF at this time.

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