Prepared in cooperation with the City of Palo Alto, California

Near-Field Receiving Water Monitoring of Trace Metals and a Benthic Community Near the Palo Alto Regional Water Quality Control Plant in South San Francisco Bay, California: 2009

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By Jessica L. Dyke, Francis Parchaso, Janet K. Thompson, Daniel J. Cain, Samuel N. Luoma, and Michelle I.
Hornberger

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Conversion Factors

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
gallon (gal)	3.785	liter (L)
inch (in.)	2.54	centimeter
inch (in.)	25,400	micrometer (μm)
micromolar (μM)	molecular weight	micrograms per liter
micron (μm)	1,000,000	meter
mile (mi)	1.609	kilometer
ounce (oz)	28.35	gram (g)
part per million	1	microgram per gram (μg/g)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

NOTE TO USGS USERS: Use of liter (L) as a special name for cubic decimeter (dm³) is restricted to the measurement of liquids and gases. No prefix other than milli should be used with liter.

Abbreviations and Acronyms

Abbreviations and Acronyms	Meaning
mL	milliliter
$\mu\Omega$	microohm
$\mu\text{g/g}$	microgram per gram
μM	micrometer
CI	Condition Index
ERL	Effects Range-Low
ERM	Effects Range-Median
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrophotometry
IRMS	Isotopic Ratio Mass Spectrophotometry
MDL	Method Detection Limit
MLLW	Mean Low Low Water
MRL	Method Reporting Level
NIST	National Institute of Standards and Technology
NPDES	National Pollutant Discharge Elimination System
PARWQCP	Palo Alto Regional Water Quality Control Plant
RWQCB	California Regional Water Quality Control Board
SFEI	San Francisco Estuary Institute
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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Executive Summary of Past Findings

U.S. Geological Survey (USGS) personnel have assessed trace metal concentrations in sediments and sediment-dwelling species since 1977 in the vicinity of the discharge of the Palo Alto Regional Water Quality Control Plant (PARWQCP). They have also profiled that area's benthic community structure since 1974. Ancillary factors that could affect metal concentrations (body weight in animals, characteristics of sediment, salinity) and benthic community structure (exotic species invasions, pelagic food availability, and weather anomalies) have also been measured during this time.

These studies initially found exceptionally high concentrations of copper (Cu) and silver (Ag) in mud-dwelling animals from this area and strong seasonal variability in concentrations that confounded some interpretations. Additional studies associated elevated metal levels in *Macoma petalum*, the clam being monitored for metals, with adverse physiological effects. The annual mean concentrations for

copper and silver in *Macoma petalum* were 287 µg/g and 105 µg/g, respectively, in 1980. These levels were unprecedented in the literature for such species, and the levels were much greater than seen elsewhere in San Francisco Bay. During this period of enriched metal concentrations, reproductive activity in *M. petalum* was very low. USGS scientists believe the low reproductive activity was due to silver inhibition of reproductive tissue development. The benthic community also showed signs of environmental stress during this time. The community was dominated by opportunistic animals (organisms capable of fast invasion and spread in disturbed environments) that lived on the surface of the mud in tubes or as shelled animals, brood their young, and fed on waterborne particles.

Concentrations of copper and silver in both sediments and clams declined significantly during the 1980s, as the PARWQCP improved its waste treatment facilities and conducted source control programs. The downward trends in copper in sediments and in the tissues of *M. petalum* correlated with reduced Cu discharges from the PARWQCP. The mudflat environment where these animals live is quite complex and variable from year to year. Sediment composition, including particle size distribution, organic content, salinity, and other factors varied seasonally and from one year to another, but over the period of this study none of these factors showed unidirectional trends that related to the changes in metal concentrations, metal effects, or benthic community changes. The only unidirectional change in an environmental factor during this period (1980–1990) was the decline in metal inputs from the waste treatment plant. Coincident with the decline in copper and silver in the sediment and clams, the reproductive activity of the clam greatly increased, such that the periods of reproductive activity now exceed the periods with no activity; the increase in reproductive activity has been stable since the mid-1980s and continued to be stable in the 2004–2006 period. The benthic community also responded to this changed environment. Opportunistic species became less dominant and nonopportunistic species became more persistent. The community, which was previously dominated by surface-dwelling,

brooding species, has until recently been composed of species with varying life-history characteristics. In particular, species that lay their eggs in the mud and feed by burrowing through and consuming the mud, which were previously rare in the community, have increased in abundance. This pattern strengthened through 2007, with the less opportunistic species becoming more dominant in abundance. A disturbance occurred on the mudflat in early 2008 that resulted in the loss of the benthic animals, except for those deep-dwelling animals like *Macoma petalum*. Animals immediately returned to the mudflat, which indicates that the disturbance was not due to a persistent toxin or to anoxia. The use of functional ecology was highlighted in the 2009 benthic community data, which show that the animals that have now returned to the mudflat are those that can respond successfully to a physical, nontoxic disturbance. Today we see plenty of animals that consume the sediment, have pelagic larvae that must survive life on the sediment at a young age, and in some cases have eggs that must survive being laid in the sediment. We continue to observe the community's response to the defaunation event because it allows us to examine the response of the community to a natural disturbance (possible causes include sediment accretion or freshwater inundation) and compare this recovery to the longer term recovery we observed in the 1970s when the decline in sediment pollutants was the dominating factor.

Concentrations of Cu and Ag in sediments and clams have remained relatively low, following the significant reductions in the 1980s. Since 1991, concentrations have fluctuated modestly and without a sustained temporal trend. The lowest concentrations of Cu and Ag in the record occurred in 1991, during the period between 2000 and 2005, and more recently during 2008–2009. For *Macoma petalum*, these Cu concentrations were comparable to what can be considered baseline concentrations for this species in San Francisco Bay (20–30 µg/g), and although Ag was still elevated, the most recent results (2008–2009) showed that it was only 2 percent of the maximum values observed in during 1977–1980. Concentrations have varied upward from these minima as much as 4-fold, for example, during the 5-

year period between 1992 and 1996 and in 2006. These changes were not correlated with discharge of Cu and Ag from PARWQCP. A concurrent study was conducted at San Jose for a few years, and those results suggested that trends in the 1990s were driven by regional factors, not by changes at individual waste treatment facilities. Other metal contaminants have also been monitored since the early 1990s (including selenium and mercury). In general, the concentrations of those metals have varied among years but have not exhibited any sustained temporal pattern. This further suggests that cycling of contaminants stored within South Bay sediments and inputs from diffuse sources are now more important in determining metal concentrations at the sampling site than the effluent of the PARWQCP.

Abstract

Results reported herein include trace element concentrations in sediment and in the clam *Macoma petalum* (formerly reported as *Macoma balthica* (Cohen and Carlton, 1995)), clam reproductive activity, and benthic macroinvertebrate community structure for a mudflat one kilometer south of the discharge of the Palo Alto Regional Water Quality Control Plant (PARWQCP) in South San Francisco Bay. This report includes data collected for the period January 2009 to December 2009 and extends a critical long-term biogeochemical record dating back to 1974. These data serve as the basis for the City of Palo Alto's Near-Field Receiving Water Monitoring Program, initiated in 1994.

In 2009, metal concentrations in both sediments and clam tissue were among the lowest concentrations on record and consistent with results observed since 1991. Following significant reductions in the late 1980s, silver (Ag) and copper (Cu) concentrations appeared to have stabilized. Annual mean concentrations have fluctuated modestly (2–4 fold) in a nondirectional manner. Data for other metals, including chromium, mercury, nickel, selenium, vanadium, and zinc, have been collected since 1994. Over this period, concentrations of these elements, which more likely reflect regional inputs and systemwide processes, have remained relatively constant, aside from typical seasonal variation that

is common to all elements. Within years, the winter months (January–March) generally exhibit maximum concentrations, with a decline to annual minima in spring through fall. Mercury (Hg) in sediments and *M. petalum* were comparable to concentrations observed in 2008 and were generally consistent with data from previous years. Selenium (Se) concentrations in sediment varied among years and showed no sustained temporal trend. In 2009, sedimentary Se concentrations declined from the record high concentrations observed in 2008 to concentrations that were among the lowest on record. Selenium in *M. petalum* was unchanged from 2008. Overall, Cu and Ag concentrations in sediments and soft tissues of the clam, *M. petalum*, remained representative of the concentrations observed since 1991 following significant reductions in the discharge of these elements from the PARWQCP. This suggests that, as with other elements of regulatory interest, regional-scale factors now largely influence sedimentary and bioavailable concentrations of Ag and Cu.

Analyses of the benthic community structure of a mudflat in South San Francisco Bay over a 36-year period show that changes in the community have occurred concurrent with reduced concentrations of metals in the sediment and in the tissues of the biosentinel clam, *M. petalum*, from the same area. Analysis of the reproductive activity of *M. petalum* shows increases in reproductive activity concurrent with the decline in metal concentrations in the tissues of this organism. Reproductive activity is presently stable, with almost all animals initiating reproduction in the fall and spawning the following spring of most years. The community has shifted from being dominated by several opportunistic species to a community where the species are more similar in abundance, a pattern that suggests a more stable community that is subjected to fewer stressors. In addition, two of the opportunistic species (*Ampelisca abdita* and *Streblospio benedicti*) that brood their young and live on the surface of the sediment in tubes have shown a continual decline in dominance coincident with the decline in metals; both species had short-lived rebounds in abundance in 2008 and 2009. *Heteromastus filiformis* (a subsurface polychaete

worm that lives in the sediment, consumes sediment and organic particles residing in the sediment, and reproduces by laying its eggs on or in the sediment) showed a concurrent increase in dominance, with the last several years prior to 2008 showing a stable population. An unidentified disturbance occurred on the mudflat in early 2008 that resulted in the loss of the benthic animals, except for those deep-dwelling animals like *Macoma petalum*. Animals immediately returned to the mudflat in 2008, which was the first indication that the disturbance was not due to a persistent toxin or to anoxia. The use of functional ecology was highlighted in the 2009 benthic community data, which show that the animals that have now returned to the mudflat are those that can respond successfully to a physical, nontoxic disturbance. Today we see plenty of animals that consume the sediment, have pelagic larvae that must survive landing on the sediment, and in some cases have eggs that must survive being laid in the sediment. We continue to observe the community's response to the defaunation event, because it allows us to examine the response of the community to a natural disturbance (possible causes include sediment accretion or freshwater inundation) and compare this recovery to the longer term recovery we observed in the 1970s, when the decline in sediment pollutants was the dominating factor.

Introduction

Environmental Monitoring

Determining spatial distributions and temporal trends of metals in sediments and benthic organisms is common practice for monitoring environmental contamination. These data can be the basis for inferring ecological implications of metal contamination. Another common method of environmental monitoring is to examine the community structure of sediment-dwelling benthic organisms (Simon, 2002). Spatial and temporal changes in community structure reflect the response of resident species to environmental conditions, although the underlying cause(s) for the response may be difficult to identify

and quantify. Integrating measurements of metal exposure and biological response can provide a more complete view of anthropogenic disturbances and the associated effects on ecosystem health.

Environmental Exposure to Trace Metals

Sediment particles can strongly bind metals, effectively removing them from solution. As a result, sediments may accumulate and retain metals released to the environment. Thus, concentrations of metals in sediments serve as a record of metal contamination in an estuary, with some integration over time. Fluctuations in the record may be indicative of changes in anthropogenic releases of metals into the environment.

Metals in sediments are also indicative of the level of exposure of benthic animals to metals through contact with, and ingestion of, bottom sediments and suspended particulate materials. However, geochemical conditions of the sediment affect the biological availability of the bound metals. Assimilation of bioavailable sediment-bound metal by digestive processes and the relative contribution of this source of metals relative to metals in the aqueous phase are not well understood. Thus, in order to better estimate bioavailable metal exposures, the tissues of the organisms themselves may be analyzed for trace metals. Benthic organisms concentrate most metals to levels higher than those that occur in solution. Therefore, the record of tissue metal concentrations can be a more sensitive indicator of anthropogenic metal inputs than the sediment record. Different species concentrate metals to different degrees. However, if one species is analyzed consistently, the results can be employed to indicate trace-element exposures to the local food web. For example, silver (Ag), copper (Cu), and selenium (Se) contamination, originally observed in clams (*Macoma petalum*, formerly reported as *Macoma balthica* (Cohen and Carlton, 1995)) at the Palo Alto mudflat, was later found in diving ducks, snails, and mussels also from that region (S.N. Luoma and others, U.S Geological Survey, unpublished data).

Biological Response to Trace Metals

Contaminants can adversely affect benthic organisms at several organizational levels. For example, responses to a pollutant at the cellular or physiological level of an individual can result in changes at the population level, such as reductions in growth, survival, and reproductive success. Community level responses to population level impairment can include overall shifts in species abundance, favoring metal-tolerant species, which can result in changes in predator/prey interactions and competition for available resources. Changes in the benthic community can ultimately result in changes at the ecosystem level due to that community's importance in the cycling of carbon in aquatic environments (Alpine and Cloern, 1992, provides a local example).

In all aquatic environments, benthic organisms may be exposed to contaminants at all life stages through a variety of routes—sediment, water, and food (Wang and Fisher, 1999, provides a summary of the potential transport of trace elements through food). Toxicant exposure is related to contaminant concentration as well as duration. Even at low contaminant levels, long-term exposure can affect benthic organisms. The added complexity of synergistic or antagonistic effects between different contaminants, and between contaminants and natural stressors, makes causal relationships difficult to identify and quantify, even on a site-specific basis. However, a time-integrated picture of ecosystem response to contaminant loading can be provided by field studies that link changes in exposure at multiple time scales (in this case seasonal to decadal) to changes at individual, population, and community levels.

RWQCB and NPDES

The California Regional Water Quality Control Board (RWQCB) has prescribed a Self Monitoring Program with its reissuance of the National Pollutant Discharge Elimination System (NPDES) permits for South San Francisco Bay dischargers. The recommendation includes specific receiving-water monitoring requirements.

Since 1994, the Palo Alto Regional Water Quality Control Plant (PARWQCP) has monitored metals and other specified parameters using sediments and the clam *M. petalum* at an inshore location in South San Francisco Bay. In addition, PARWQCP has undertaken monitoring of the benthic community as a whole. The monitoring protocols have been designed to be compatible with or complement the RWQCB's Regional Monitoring Program. Monitoring efforts are being conducted by the U.S. Geological Survey (USGS) and are coordinated with more than 30 years of previous data collections and investigations by the USGS at this inshore location.

Objectives

The data presented by this study include trace-metal concentrations in sediments and clams, clam reproductive activity, and benthic community structure. These data and those reported earlier (Hornberger and others, 2000a; Luoma and others, 1991, 1992, 1993, 1995a, 1996, 1997, 1998; Wellise and others, 1999; David and others, 2002; Moon and others, 2003, 2004, 2005; Shouse and others, 2003, 2004; Thompson and others, 2002; Cain and others, 2006; Lorenzi and others, 2007, 2008; Cain and others, 2009) were used to meet the following objectives:

- Provide data to assess seasonal and annual trends in trace-element concentrations in sediments and clams, reproductive activity of clams, and benthic community structure at a site designated in the RWQCB's Self-Monitoring Program guidelines for PARWQCP.
- Present the data within the context of historical changes in South San Francisco Bay and within the context of other locations in the Bay published in the international literature.
- Coordinate inshore receiving water monitoring programs for PARWQCP and provide data compatible with relevant aspects of the Regional Monitoring Program. The near-field data will augment the Regional Monitoring Program as suggested by the RWQCB.

- Provide data that could support other South San Francisco Bay issues or programs, such as development of sediment quality standards.

Approach

Despite the complexities inherent in monitoring natural systems, the adopted approach has been effective in relating changes in near-field contamination to changes in reproductive activity of a clam (Hornberger and others, 2000b) and in benthic community structure (Kennish, 1998). This study, with its basis in historical data, provides a context within which future environmental changes can be assessed.

Metal concentrations were monitored in sediments and a resident clam species, *Macoma petalum*. Analysis of trace element concentrations in the sediments provides a record of metal contamination of the site. The concentration and bioavailability of sediment-bound metals are affected by hydrology and geochemical factors (Thomson-Becker and Luoma, 1985; Luoma and others, 1995b). Thus, ancillary data, including grain-size distribution, organic carbon, aluminum and iron content of the sediment, regional rainfall, and surface salinity were collected to interpret seasonal, annual, and interannual variation in metal concentrations. The tissue of *M. petalum* provides a direct measure of exposure to bioavailable metals.

Biological response of the benthic community to metal exposure was examined at three levels of organization: individual, population, and community. At the individual level, concentrations of metals in the tissues of *M. petalum* were compared with physiological indicators. Two common animal responses to environmental stress are reduced reproductive activity and reduced growth. Growth and reproduction in *M. petalum* occur on fairly regular seasonal cycles. Seasonally, a clam of a given shell length will increase somatic tissue weight as it grows during the late winter and spring. Reproductive tissue increases during the early stages of reproduction and subsequently declines during and after reproduction. These cycles can be followed with the condition index (CI), which is an indicator of the

physiological condition of the animal, and specifically is the total soft-tissue weight of a clam standardized to shell length. Interannual differences in growth and reproduction, expressed in the CI, are influenced by the availability and quality of food, as well as other stressors, such as pollutant exposure and salinity extremes. Earlier studies (Hornberger and others, 2000b) have shown that reproductive activity of *M. petalum* has increased with declining metal concentrations in animals from this location. Therefore, CI and reproductive activity of *M. petalum* appear to be useful indicators of physiological stress by pollutants at this location and continue to be monitored for this study.

At the population level, trends of the dominant benthic species were examined to see if certain species have been more affected than others by environmental change. It has been shown that most taxonomic groups have species that are sensitive to elevated silver (Luoma and others, 1995b) and that some crustacean and polychaete species are particularly sensitive to elevated sedimentary copper (Morrissey and others, 1996; Rygg, 1985). In addition, the benthic community was examined for changes in structure: that is, shifts in the species composition of the macroinvertebrate community resulting in a change in the function of the community. We hypothesized that a shift in community composition and potentially in function of the benthic community in the ecosystem would result from changes in the concentrations of specific metals or from a composite of all contaminants for several reasons. First, prior studies have shown that South Bay benthic communities were dominated by opportunistic species in the 1980s (Nichols and Thompson, 1985a). These opportunistic species might become less dominant as environmental stressors decrease. Second, environmental pollutants may differentially affect benthic species that use different feeding and reproductive modes. An intertidal mudflat community, such as this study site, should include a combination of species that feed on particles in the water column, on settled and buried food particles in the mud, and on other organisms. Any absence of one of these feeding groups may show limitations on species due to environmental stressors that target specific feeding

groups. For example, pollutants attached to sediment particles are more likely to affect species that consume the sediment as part of their feeding mode or those species that lay their eggs in the sediment.

Previous analysis of this community has shown no correlation between changes in the community and measured environmental parameters (salinity, air and water temperature, delta outflow, precipitation, chlorophyll *a*, sediment total organic carbon, and biological oxygen demand; Shouse, 2002). Therefore, the community data was only compared to trace-metal data in this report.

Study Site

The Palo Alto site (PA) includes the benthic community sampling site and the *M. petalum* and sediment sampling site, both adjacent to Sand Point in Palo Alto Baylands Park on a mudflat on the western shore of San Francisco Bay (not a slough) (fig. 1). The site is one kilometer southeast of the intertidal discharge point of the PARWQCP. The sampling locations are approximately 12 m from the edge of the marsh and 110 cm above mean low low water (MLLW).

The sediment and biological samples from this location reflect a response of the receiving waters to the effluent just beyond the location of discharge. Earlier studies (Thomson and others, 1984) have shown that dyes, natural organic materials in San Francisquito Creek, and waters in the PARWQCP discharge move predominantly south toward Sand Point and thereby influence the mudflats in the vicinity of Sand Point. Spatial distributions of metal concentrations near the PARWQCP site were described by Thomson and others (1984) (also reported by Hornberger and others, 2000a; Luoma and others, 1991, 1992, 1993, 1995a, 1996, 1997, 1998; Wellise and others, 1999; David and others, 2002; Moon and others, 2003, 2004, 2005; Shouse and others, 2003, 2004; Thompson and others, 2002; Cain and others, 2006; Lorenzi and others, 2007, 2008; Cain and others, 2009). Earlier work by Thomson and others (1984) showed that San Francisquito Creek and the Palo Alto Yacht Harbor were minor sources of most trace elements compared to the PARWQCP. The PARWQCP appeared to be the primary source

of the elevated metal concentrations at the PA site in the spring of 1980, on the basis of spatial and temporal trends of Cu, Ag, and zinc (Zn) in clams and sediments (Thomson and others, 1984; Cain and Luoma, 1990). Metal concentrations in sediments and clams (*M. petalum*), especially Cu and Ag, have declined substantially since the original studies, as more efficient treatment processes and source controls were employed (Hornberger and others, 2000b). Frequent sampling each year was necessary to characterize those trends because there was significant seasonal variability (Cain and Luoma, 1990; Luoma and others, 1985). This report characterizes data for the year 2009, employing the methods described in the succeeding section.

Previous reports (Luoma and others, 1995a, 1996, 1997, 1998; Wellise and others, 1999) also included data for a site in South San Francisco Bay that was influenced by discharge from the San Jose/Santa Clara Water Pollution Control Plant (SJ). Samples were collected from this site from 1994 to September 1999. Comparison of data from this site and the Palo Alto site allowed differentiation of local and regional long-term metal trends.

Methods

Sampling Frequency and Duration

In dynamic ecosystems such as San Francisco Bay, the environmental effects of anthropogenic stressors are difficult to distinguish from natural seasonal changes. Sustained sampling at frequent intervals can characterize seasonal patterns, capture episodic events, and identify longer term trends, thereby increasing the probability that anthropogenic effects can be identified. Analyses of early community data (1974 through 1983; Nichols and Thompson, 1985a, 1985b) showed that benthic samples need to be collected at monthly to bimonthly intervals to distinguish between natural and anthropogenic effects. Therefore, data reported herein are based on samples collected, with a few

exceptions, on a monthly basis from the exposed mudflat at low tide between January and December 2009. Samples collected in the field included surface sediment, the deposit-feeding clam *M. petalum*, surface water, and sediment cores for community analysis. Surface water, surface sediment, and *M. petalum* were not collected during the months of July, August, and November. Cores for benthic community analyses were not collected during the months of January, October, and December. Data for sediments, *M. petalum*, and surface water have been collected continuously since 1977, while community data were collected during 1974–1990 and 1998 to the present.

Measurements of Metal Exposure

Sediment

Sediment samples were scraped from the visibly oxidized (brownish) surface layer (top 1–2 cm) of mud. This surface layer represents recently deposited sediment and detritus, or sediment affected by recent chemical reactions with the water column. The sediment also supports microflora and fauna, a nutritional source ingested by *M. petalum*. Sediment samples were immediately taken to the laboratory and sieved through a 100- μ m mesh polyethylene screen with distilled water to remove large grains that might bias interpretation of concentrations. The mesh size was chosen to match the largest grains typically found in the digestive tract of *M. petalum*. All sediment data reported herein were determined from the fraction that passed through the sieve (<100 μ m), termed the silt/clay fraction. Previous studies have shown little difference between metal concentrations in sieved and unsieved sediments when silt/clay-type sediment dominates at a site. However, where sand-size particles dominate the bed sediment, differences in metal concentrations can be substantial. Sediments in extreme South San Francisco Bay can vary spatially and temporally in their sand content (Luoma and others, 1995a, 1996, 1997, 1998; Wellise and others, 1999; David and others, 2002; Moon and others, 2003, 2004; Cain and

others, 2006; San Francisco Estuary Institute, 1997). Where sand content varies, sieving reduces the likelihood that differences in metal concentrations are the result of sampling sediments of different grain size. Some differences between the USGS and the Regional Monitoring Program results (San Francisco Estuary Institute, 1997) reflect the bias of particle size on the latter's data.

To provide a measure of bulk sediment characteristics at a site, and thus provide some comparability with bulk sediment determinations such as that employed in the Regional Monitoring Program (San Francisco Estuary Institute, 1997), the fraction of sediment that did not pass through the sieve ($\geq 100 \mu\text{m}$) was determined. This fraction is termed the sand fraction. Bulk sediment samples were sieved to determine the percent sand and percent silt/clay ($< 100 \mu\text{m}$) (appendix A). The percentage of the bulk sediment sample composed of sand-size particles (percent sand) was determined by weighing the fraction of sediment that did not pass through the sieve ($\geq 100 \mu\text{m}$), dividing that weight by the total weight of the bulk sample, and multiplying the quotient by 100. The percentage of silt/clay in the sediment was determined similarly by weighing the sediment that passed through the sieve (grain size $< 100 \mu\text{m}$).

The silt/clay fraction was dried at 60°C , weighed, and then subsampled to provide replicates weighing 0.4 to 0.6 g. These were redried (60°C), reweighed, and then digested by hot acid reflux (10 mL of 16 normal (N) nitric acid) until the digest was clear. This method provides a 'near-total' extraction of metals from the sediment and is comparable to the recommended procedures of the U.S. Environmental Protection Agency (USEPA) and to the procedures employed in the Regional Monitoring Program. It also provides data comparable to the historical data available on San Francisco Bay sediments. Although near-total analysis does not result in 100-percent recovery of all metals, recent comparisons between this method and more rigorous complete decomposition show that trends in the two types of data are very similar (Hornberger and others, 1999). After extraction, samples were

evaporated until dry, then reconstituted in dilute hydrochloric acid (10 percent or 0.6 N). The hydrochloric acid matrix was specifically chosen because it mobilizes silver (Ag) into solution through the creation of Ag-chloro-complexes. Sediment extracts were allowed to equilibrate with the hydrochloric acid (minimum of 48 hours) before they were filtered (0.45 μm) into acid-washed polystyrene vials for elemental analysis. Another set of replicate subsamples from the silt/clay fraction were directly extracted with 12 mL of 0.6 N hydrochloric acid (HCl) for 2 hours at room temperature. This partial extraction method extracts metals bound to sediment surfaces and is operationally designed to obtain a crude chemical estimate of bioavailable metal. The extract was pressure filtered (0.45 μm) before elemental analysis.

Organic carbon was determined using a continuous flow isotope ratio mass spectrophotometer (IRMS) (appendix B). Before the analysis, sediment samples were acidified with 12 N HCl vapor to remove inorganic carbon (method described by Harris and others, 2001).

Water pooled on the surface of the mudflat was collected in a bottle and returned to the laboratory, where it was measured for salinity with a handheld refractometer.

Clam Tissue

Specimens of *M. petalum* were collected by hand on each sampling occasion. Typically, 60–120 individuals were collected, representing a range of sizes (shell length). As they were collected, the clams were placed into a screw-cap polypropylene container (previously acid-washed) containing site water. These containers were used to transport the clams to the laboratory.

In the laboratory, the clams were removed from the containers and gently rinsed with deionized water to remove sediment. A small amount of mantle water was collected from randomly selected clams for the determination of salinity with a refractometer. The salinity of the mantle water and the surface water collected from the site (above) were typically within 1 part per thousand (ppt) of each other. Only

surface water values are reported here. Natural sand-filtered seawater (obtained from U.C. Santa Cruz, Long Marine Labs, Santa Cruz, California) was diluted with deionized water to the measured salinity of the site water. Clams were immersed in this water and moved to a constant temperature room (12°C) for 48 hours to allow for the egestion of sediment and undigested material from their digestive tracts. Clams were not fed during this depuration period. After depuration, the clams were returned to the laboratory and further prepared for chemical analysis.

Elemental Analysis, Excluding Mercury and Selenium

The shell length of each clam was measured with electronic calipers and recorded digitally. Clams were separated into 1- or 2-mm size classes (for example, 10.00–10.99 mm or 10.00–11.99 mm). The soft tissues from all of the individuals within a given size class were dissected from the shell and collected in preweighed 20-mL screw-top borosilicate glass vials to form a single composite sample for elemental analysis. The sample for each collection was thus composed of 6 to 12 composites, with each composite consisting of 1 to 41 clams of a similar shell length. The vials were capped with a glass reflux bulb and transferred to a convection oven (70°C). After the tissues were dried to constant weight, they were digested by reflux in subboiling 16 N nitric acid. The tissue digests were then dried and reconstituted in 0.6 N hydrochloric acid for trace element analysis.

Analysis for Mercury and Selenium

Samples collected in winter (December, January, and February), spring (April), and summer (June and September) were analyzed for total mercury (Hg) and selenium (Se). Approximately 40 clams were selected from the collection. The only criterion for selection was that the range of sizes (shell length) within this group was representative of the larger collection. Otherwise, the selection of individuals was random. Selected individuals were grouped according to size to form 3–4 composites,

each containing a minimum of ~1.25 g wet weight. To meet this requirement, especially for the smaller clams, the 1-mm size classes were usually combined to form broader size classes (within 3–4 mm of each other, as appropriate). Once the composites were formed, the clams were dissected as described above, and the soft tissue was placed into preweighed 30-mL screw-top polycarbonate vials. These vials were closed and transferred to a freezer (-20°C). Once frozen, the samples were freeze-dried. After drying, the samples were shipped to the USGS analytical laboratory in Atlanta, Georgia, where they were prepared and analyzed for Se and Hg according to the method described by Elrick and Horowitz (1985).

Analytical

Sediment and tissue concentrations of aluminum (Al), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), silver (Ag), vanadium (V), and zinc (Zn) were determined using Inductively Coupled Plasma Optical Emission Spectrophotometry (ICP-OES). Mercury (Hg) and Selenium (Se) were determined in both sediment and clam tissues by Hydride Atomic Absorption Spectrophotometry. Analytical results are included in appendixes C–E.

Quality Assurance

The polypropylene containers used in the field, depuration containers, glass-reflux bulbs, and all glassware and plastic used for metal analysis were first cleaned to remove contamination. Cleaning consisted of a detergent wash and rinse in deionized water, followed with a 10-percent hydrochloric-acid wash and thorough rinse in double-deionized water (approximately 18 MΩ resistivity). Materials were dried in a dust-free positive pressure environment, sealed, and stored in a dust-free cabinet.

Samples prepared for ICP-OES analysis (that is, all elements except Se and Hg) were accompanied with procedural blanks and standard reference materials issued by the National Institute of

Standards and Technology (NIST). Analysis was preceded by instrument calibration, followed by quality-control checks with prepared quality-control standards before, during (approximately every 10 samples), and after each analytical run. Analyses of reference materials (NIST 2709, San Joaquin soils, and NIST 2976, mussel tissue) were consistent for the method and generally were within the range of certified values reported by NIST; however, recoveries of Al, As, and Pb in NIST 2709 were relatively lower than other metals (appendix H). Recoveries of Cd, Ni, and Pb in NIST 2976 tended to be less than the certified concentrations (appendix I). Method detection limits (MDL) and reporting levels (MRL) were determined using the procedures outlined by Glaser and others (1981), Childress and others (1999), and U.S. Environmental Protection Agency (2004) (appendix J). A full quality-assurance/quality-control plan is available upon request.

A variety of standard reference materials were prepared according to the method used for the determination of Se and Hg. Observed concentrations fell within the range of certified values for these materials (appendix F).

Other Data Sources

Precipitation data for San Francisco Bay are reported from a station at San Francisco International Airport (station identification SFF) and were obtained from the California Data Exchange Center (<http://cdec.water.ca.gov/>).

Biological Response

Condition Index

The condition index (CI) is a measure of the clam's physiological state derived from the relation between soft tissue weight and shell length and reported as the soft tissue dry weight (grams) for a clam of a particular shell length (mm). Specifically, for each collection, the relation between the average shell

length and tissue dry weight of the composites was fit with a linear regression, and from that regression the tissue dry weight was predicted for a normalized shell length of 25 mm.

Reproductive Activity

A minimum of 10 clams of varying sizes (minimum of 5 mm) were processed for reproductive activity concurrent with samples for metal analyses. Clams were immediately preserved in 10-percent formalin at the time of collection. The visceral mass of each clam was removed in the laboratory, stored in 70-percent ethyl alcohol, and then prepared using standard histological techniques. Tissues were dehydrated in a graded series of alcohol, cleared in toluene (twice for 1 hour each), and infiltrated in a saturated solution of toluene and Paraplast® for 1 hour, and two changes of melted Tissuemat® for 1 hour each. Samples were embedded in Paraplast® in a vacuum chamber and then thin sectioned (10 µm) using a microtome (Weesner, 1960). Sections were stained with Harris' hematoxylin and eosin and examined with a light microscope. Each individual was characterized by size (length in mm), sex, developmental stage, and condition of gonads, thus allowing each specimen to be placed in one of five qualitative classes of gonadal development (previously described by Parchaso, 1993) (appendix K).

Community Analysis

Samples for benthic community analysis were collected with an 8.5-cm diameter by 20-cm deep hand-held core. Three replicate samples were taken arbitrarily, within a square-meter area, during each sampling date.

Benthic community samples were washed on a 500-µm screen, fixed in 10-percent formalin and then later preserved in 70-percent ethanol. Samples were stained with rose bengal solution. All animals in all samples were sorted to species level where possible (some groups, such as the oligochaetes, are still not well defined in the bay), and individuals for each species were enumerated. Taxonomic work

was performed in conjunction with a private contractor familiar with the taxonomy of San Francisco Bay invertebrates (Susan McCormick, Colfax, California) (appendix L). McCormick also compared and verified her identifications with previously identified samples.

Results and Discussion

Salinity

Surface-water salinity is related to the seasonal weather pattern in Northern California, which is characterized by a winter rainy season that has been defined as months with rainfall amounts greater than 0.25 inches (November through April) and a summer dry season (May through October) (fig. 2). The average annual rainfall during the record (1994–2009) is 23.2 inches. Rainfall during 2009 was 19.2 inches, an increase from the previous two years but still below the average for the period of record. The maximum monthly rainfall in 2009 occurred in February. Rainfall during that month alone accounted for 42 percent of the yearly total.

Surface-water salinity typically exhibits a seasonal pattern that is generally the inverse of regional rainfall (fig. 3, table 1). This general pattern was again observed in 2009. However, because of the small amount of local rainfall in 2009, the winter-spring decline in salinity was minimal. The range of salinity in 2009 was small, starting at 27 ppt in January and steadily rising to a high of 32 ppt in September–October.

Sediments

Metal concentrations in surface sediments from Palo Alto typically display an annual periodicity of seasonal patterns. Thomson-Becker and Luoma (1985) suggested that this intraannual variation is related to changes in the size distribution of sediment particles caused by deposition of fine-grained particles in the winter and their subsequent wind-driven resuspension in the summer and fall. Because

metal concentrations vary as a function of the ratio of surface area to volume of a particle, metal concentrations of fine-grained particles are typically higher on a weight basis than larger particles. Thomson-Becker and Luoma (1985) showed that the composition of surface sediments was dominated by fine-grained particles, accompanied by high Al and Fe concentrations, during the period of freshwater input (low salinities through April), reflecting annual terrigenous sediment inputs from runoff. Coarser sediments dominated later in the year because the seasonal diurnal winds progressively winnow the fine sediments into suspension through the summer. This typical seasonal pattern of variation in sediment properties was repeated in 2009 (fig. 4, appendix A-1 and A-2).

The percentage of silt/clay in the sediment increased from 41 percent in the fall of 2008 to values of greater than 77 percent following the onset of winter rains. Values were at their maximum in April (95 percent) and thereafter declined to a seasonal minimum (41 percent) in September. The concentrations of Al and Fe changed directly in response to the proportion of silt/clay size particles (maximum concentrations occurred during February through April) (fig. 4, table 1), as described above, reflecting the contribution of clays rich in Al and Fe.

Surface sediments from Palo Alto contain roughly 1 percent (by weight) organic carbon (table 1). Carbon content varied slightly during the year, tracking the seasonal changes in sediment composition described above. Specifically, total organic carbon varied between 1.0 and 1.5 percent during January to April, declined to a minimum of 0.6 percent in September, and increased to 1.1 percent in December.

The metals Cr, Ni, and V are highly enriched in some geologic formations within the watershed. In North San Francisco Bay, studies of sediment cores indicated that concentrations of these elements similar to those reported here were derived from natural geologic inputs (Hornberger and others, 1999; Topping and Kuwabara, 2003). Inputs of minerals bearing Cr, Ni, and V appear to vary seasonally as suggested by the variable concentrations of these metals in surface sediments. Typically, maximum

concentrations coincide with winter/spring maximums in fine sediments, while minimum concentrations occur during the late summer/fall (fig. 5, table 2). The minimum Ni concentration occurred in the fall of 2009 (66 µg/g in September) and the maximum in early spring (109 µg/g in April). The concentration range and timing of variation is typical of the record (1994–2009). Concentrations of Cr and V also declined from their maximum concentrations in April to their minima in summer/fall. Average concentrations of Cr tended to increase during the past 4 years, approaching the record high Cr concentrations in 2003. Average concentrations of V, which increased during 2006–2008 to levels roughly comparable to 2003, decreased in 2009 but have not returned to pre-2003 levels.

Copper concentrations in sediments are shown with sediment guidelines set by the National Oceanic and Atmospheric Administration (Long and others, 1995) in figure 6 and table 2. Long and others (1995) defined values between ERL (Effects Range-Low) and ERM (Effects Range-Median) as concentrations that are occasionally associated with adverse effects (21–47 percent of the time for different metals). Values greater than the ERM were frequently associated with adverse effects (42–93 percent of the time for different metals). It must be remembered, however, that these effects levels were derived mostly from bioassay data and are not accurate estimates of site-specific sediment toxicity. In 2006–2007, Cu concentrations increased to concentrations similar to those observed before 2000, apparently reversing a trend of declining concentrations during the intervening years. In 2008–2009, Cu concentrations were lower, roughly comparable to 2002 values, yet remained above the ERL (34 µg/g) for much of the time. The typical seasonal pattern was evident, as Cu concentrations peaked in April (45 µg/g), fell below the ERL in June (33 µg/g), and reached their minimum concentration (26 µg/g) in September (fig. 6, table 2). The partially extractable concentrations have shown a decreasing trend during 2006–2009. Near-total and partially extractable Zn concentrations were below the Zn ERL (150

µg/g) for most of 2009, with the exception of the spring maximum of 155 µg/g in April (fig. 7, table 2). Zn concentrations have shown a slight decreasing trend over the past 3 years.

Silver extracted from sediments averaged 0.20 µg/g for both 2008 and 2009 (table 2), the lowest concentration recorded (table 4). Intraannual variation was also modest compared to the past (fig. 8; table 2). As with other elements, concentrations were relatively high during the late winter-early spring (March–April) and declined to their minima in summer months (June–September). In 2009, there was no marked increase in Ag concentrations in late fall-winter.

Mercury concentrations throughout all of 2009 were within the range usually observed in San Francisco Bay (0.2–0.4 µg/g). Concentrations in sediment followed the typical seasonal pattern of highest concentration in late winter-early spring (0.32 µg/g in April) and lowest concentration in September (0.20 µg/g) (fig. 9, table 2).

Selenium concentrations remained relatively stable (0.3–0.5 µg/g) in 2009 (fig. 9, table 2). Concentrations were substantially lower than in 2008, the highest annual concentration on record. Sedimentary Se hasn't exhibited a sustained temporal trend. Concentrations have varied annually during the record and since 2004 have alternated from relatively high concentrations (2004, 2006, and 2008) to relatively low concentrations (2005, 2007, and 2009).

Clam Tissue

Metal concentrations in the soft tissues of *Macoma petalum* reflect the combined metal exposures from water and food. Exposures to Cu and Ag at Palo Alto are of special interest because of the high tissue concentrations observed at this site in the past (fig. 10 and fig. 11, table 3 and table 4, respectively). During the period 1977–1987, the ranges in annual concentrations of Cu and Ag were 95–287 and 45–106 µg/g, respectively. Since 1987, concentrations have been considerably lower: 24–71 µg/g for Cu and 2–20 µg/g for Ag. Concentrations were particularly low and stable from 1997 through

2005. Annual mean concentrations of Cu and Ag for 2009 were 26 ± 2 and 1.9 ± 0.3 $\mu\text{g/g}$, respectively, and these were unchanged from concentrations observed in 2008. Concentrations for the past two consecutive years, along with the concentrations observed in 1991 and 2005, are the lowest concentrations observed at the site.

Intraannual variations in Ag and Cu concentrations in clam soft tissues display a consistent seasonal signal characterized by fall/winter maxima and spring/summer minima. The amplitude of this seasonal cycle varies from year to year. For example, the winter maxima and the magnitude of seasonal Ag and Cu concentrations during 1994–1997 and in the 2007 water year were relatively large and bracketed years of less variability (figs. 12, 13). These trends most likely reflect the interaction of the changing exposure regime of the site (the long-term decline in metal concentrations) with the annual growth cycle of *M. petalum* (Cain and Luoma, 1990). In 2009, Ag and Cu concentrations were highest in February (2.8 $\mu\text{g/g}$ Ag) and March (33 $\mu\text{g/g}$ Cu), but thereafter declined through the spring and reached their annual minima of 0.6 $\mu\text{g/g}$ Ag and 18 $\mu\text{g/g}$ Cu in May. Concentrations increased through the fall and early winter and in December were 2.8 $\mu\text{g/g}$ (Ag) and 30 $\mu\text{g/g}$ (Cu).

As with Cu and Ag, tissue concentrations of Cr (fig. 14, table 3), Ni (fig. 15, table 5), and Zn (fig. 16, table 5) also exhibited seasonal cycles. The seasonal cycles of Cr and Ni were very similar in terms of their timing and magnitude throughout the record (1994–2009). Maximum concentrations occurred in the winter of 1996–1997, while 2000–2002 was a period of relatively low winter-maximum concentrations. However, neither element exhibited a clear temporal trend (either decreasing or increasing) in concentration. Cr and Ni concentrations for 2009 were similar in magnitude and timing to the previous year. In addition to the typical seasonal pattern, Zn concentrations exhibited a slight long-term decline through 2005. However, in 2006, the seasonal cycle was weakly expressed and concentrations increased notably to values comparable to those observed in the mid to late 1990s.

During 1994–1997, Zn concentrations were notably higher throughout the year when compared to subsequent years. Seasonal patterns were again evident in 2007–2009. In 2009, maximum Zn concentrations occurred in March (402 $\mu\text{g/g}$) and decreased to their lowest concentration in September (197 $\mu\text{g/g}$). Wellise and others (1999) observed that seasonal and interannual patterns of Cr, Ni, and Zn in *M. petalum* at Palo Alto were generally similar to those from the San Jose site, suggesting that regional-scale processes may be more important than treatment plant inputs in controlling the bioavailability of these elements.

The average Hg concentration in *M. petalum* for 2009 was 0.33 $\mu\text{g/g}$, the lowest annual average since 2006. A seasonal maximum concentration of 0.44 $\mu\text{g/g}$ was observed in January and a minimum of 0.22 $\mu\text{g/g}$ in April. Seasonal variation for 2009 is typical of the record, and a long-term trend in Hg concentrations is not evident (fig. 17).

Selenium concentrations in *M. petalum* varied seasonally like those of other elements (fig. 18, table 5). Long-term trends in the data were not evident. In 2009, the annual minimum concentrations (during summer/fall) were essentially the same as in 2008.

Data on the condition index (CI) for *M. petalum* at Palo Alto extends back to 1988 (fig. 19). As previously discussed, the data fluctuate seasonally in relation to growth and reproductive cycles, and annual cycles differ in magnitude. For example, the maximum value of the CI during 1994–1999 was generally less than in preceding or succeeding years. In 2006, the maximum CI was one of the lowest observed (125 mg) since 1999, but in 2009 the maximum CI (195 mg in May) was consistent with values found since 2000.

Reproduction of *Macoma petalum*

Earlier studies (Hornberger and others, 2000b; Shouse and others, 2004) found that low reproductive activity in *M. petalum* in the late 1970s coincided with highly elevated concentrations of

silver (and perhaps copper) in the soft tissues. During this period, *Macoma* exhibited extended periods (as long as 2 months) of reproductive inactivity. Following the decline in tissue concentrations of Ag and Cu in the 1980s, reproductive activity of *M. petalum* improved (fig. 20). Furthermore, the low reproductive activity observed during the late 1970s has not been observed during the entire period of reduced metal exposures. The temporal coincidence of these events suggests that reproductive activity was related to the concentration of metals in the animal. This finding has implications for the reproductive success of the population.

Data for 2009 show that *M. petalum* continues to be highly reproductive relative to the 1970s, with a high percentage of the animals being reproductively active at any time during the normal seasonal cycle of reproduction. That cycle begins in fall, with spawning occurring the following spring (see appendix K for detailed reproduction data for 2009 and figure 21 for short-term history of reproduction).

Benthic Community

Estimates of species diversity and total animal abundance are simple metrics that are used in assessing environmental stress on biological communities. Species diversity at the Palo Alto site, as estimated by a time series of number of species, has shown an upward trend (with one exception) since the last very wet year in 1998 (fig. 22). Total animal abundance has varied significantly during the sampling period, with the last two years being similar (fig. 23). The difficulty with these types of metrics is that they do not consider the possibility that one species can take the place of another or that high abundance is based on one species. Depending on the characteristics of a species new to the community or newly dominant in the community, the community structure and function may change as a result of this change in species composition or dominance. The details of changes in species composition are important because they may reflect the relative ability of species to accommodate

environmental stress and redistribute site resources. In general, the species composition has changed little since 1998, although there have been seasonal eruptions of several species in some years.

Three common bivalves (*Macoma petalum*, *Mya arenaria*, and *Gemma gemma*) have not shown any consistent trend over the 36-year period of 1974–2009 (figs. 24, 25, and 26). There was significant seasonal and interannual variability in species abundances for all species, and that is well illustrated in these three bivalves—*Gemma gemma* has been particularly volatile since 2005. *Gemma gemma* abundance dropped to near zero in late fall 2007 and has not regained its previous high density, although the abundance rebounded in 2009 relative to the dip in 2008. There were six species that did show trends in their abundance since the 1970s, and these trends continued through 2008. The first species, *Ampelisca abdita*, is a small crustacean that lives above the surface of the mudflat in a tube built from selected sediment particles. *A. abdita* showed a general decline in both the annual average abundances and annual maximum abundances (seasonal peaks in abundance; fig. 27) between 1990 and 1998. That pattern mostly continues through today; there was a small increase in population size in 2008 followed by an increase during only one month in 2009. The second species to show a significant trend was the small polychaete worm *Streblospio benedicti*, which also builds a tube above the surface of the mudflat. As with *A. abdita*, *S. benedicti* annual maximum abundances declined (fig. 40), as well as annual average abundances (fig. 28). The maximum seasonal abundance of the small burrowing crustacean *Grandiderella japonica*, a deposit feeder, declined through the 1980s, but it has since become more abundant (fig. 29) and has shown a consistent peak in abundance in the fall since 1999. *Neanthes succinea*, a burrowing polychaete that feeds on surface deposits and scavenges for detrital food, similarly showed large seasonal fluctuations in abundance through the 1980s. *N. succinea* abundance had increased by the late 1990s, and the annual average abundances and annual maximum abundances (fig. 30) remained relatively stable until 2005, when the abundance decreased. *N. succinea* showed a

small resurgence in 2008 and a larger one in 2009. Two species showed an increase in abundance within the time series. The first was the polychaete worm *Heteromastus filiformis* (fig. 31), a deposit feeding, burrowing species that lives deep in the sediment (usually 5–20 cm below the surface of the mudflat). Abundance increased sharply in 1985 and then partially receded in the late 1980s. Abundances remained higher than in the late 1970s until 2008, when we saw a large drop in the population abundance. The second species showing an increase was *Nippoleucon hinumensis*, a small burrowing crustacean, which appeared in the dataset in 1988 (fig. 32) following its introduction into the bay in 1986 (Cohen and Carlton, 1995). Another nonindigenous species, *Corbula amurensis*, a filter-feeding bivalve that first appeared in the benthic community in significant numbers in April 2005 and persisted into 2006 with peaks in abundance occurring in spring and fall, has shown another small peak in summer 2009 (appendix L).

A sudden drop in animal abundance was observed in February 2008. Very few animals were found at the site, and the mudflat community was evidently stressed by some event between the January and February sampling. Possible causes of the stress include a sedimentation or freshwater inundation event. There was a large storm on January 25, 2008, with rainfall rates exceeding 0.5 cm/hr for more than half the day, including during the low-tide period. No obvious changes in the sediment surface were observed, but sediment changes can occur and be incorporated quickly in this tidal environment. Other possible causes of benthic community death or exodus include a toxic event or anoxia. It is unlikely that either of these occurred because *M. petalum* were present in the deep sediment in February, and animals were found again at the site already in March 2008. This would not happen with toxicity or anoxia. The timeline for recovery from anoxia can be estimated on the basis of observations following an anoxic event at this site in 1975. Macroalgae were deposited on the mudflat surface and began to decay, and the resulting bacterial consumption of oxygen led to anoxia. The benthic community took

many months to recover from this anoxic event. Animals that returned after the disturbance in 2008 included those species with pelagic larvae and mobile adults, as would be expected. In 2009, a return of the nonmobile brooders was observed with the increase in abundance of the brooding clam *G. gemma* and the brooding polychaete *Streblospio benedicti*.

As stated earlier, multivariate analyses of population data of the dominant species with environmental parameters did not reveal any relations, except with the concentration of silver and copper in the sediment and in the tissue of *M. petalum* (using data as reported by David and others, 2002). Therefore, this update will only consider those metals. Comparison of metal concentration and benthic species abundance can be made by plotting the metals and individual species together over the period of the study. The worm *H. filiformis* increased in abundance with the decrease in silver and copper until 2008 (fig. 33). Because the natural spatial variability (that is, the large standard deviations around the monthly means) and seasonal variability of invertebrate abundance and metal concentration can be quite large, the annual average abundances for *H. filiformis* and annual average metal concentrations are shown (figs. 34 and 35). To interpret these plots, life history characteristics of this species must first be examined to determine if there is some mechanism by which this organism could be responding to a decrease in silver or copper in the environment. *H. filiformis* has continual tissue contact with the sediment both at the exterior of its body, as well as within its body, as a result of its lifestyle of burrowing through the sediment and consuming a diet of mud and organic particles. In addition, this is one of the few species in the present community that reproduces exclusively by laying its eggs in the sediment. The larvae hatch after two or three days and spend a very short period (2–3 days) in the plankton before settling back to the mud as juvenile worms (Rasmussen, 1956). The short planktonic period limits the speed of expansion into new areas. The authors hypothesize that once a few individuals successfully arrived at the study site, *H. filiformis* increased in abundance because either the

adult worms or the eggs were less stressed in the current environment than they were in the previous environment. Because of its mode of reproduction and short planktonic larval period, this species is not likely to move into an area quickly after an environmental stressor. A large spike in *H. filiformis* abundance was observed in January 2008 because of the settling of larvae, but these larvae did not survive the event that occurred before the February sampling. So far, the species has not returned in high numbers to the study site. The dynamics of recovery for this species will continue to be monitored closely.

The authors hypothesize that silver, but probably not copper, adversely affected reproduction in *H. filiformis* (Ahn and others, 1995) in the early years of the study, and that the gradual increase in *H. filiformis* abundance through 1984 was a response to the gradual reduction of metals in the environment. In the present environment of much lower metal concentrations, the authors predict that *H. filiformis* will gradually invade and then explosively increase once there are sufficient adults to support a large reproductive effort. *H. filiformis* could then experience “boom and bust” population behavior, whereby a species rises to levels too high for the habitat to support, and then declines in abundance until it levels out to a habitat-supportable abundance (Begon and others, 1986). For this to occur, a reproducing population must first settle, and that did not happen in 2009.

The two species that have declined in abundance coincident with the decline in metals, the crustacean *A. abdita* (figs. 36, 37, and 38) and the worm *S. benedicti* (figs. 39, 40, and 41), have very similar life history characteristics. Both species live on the surface of the sediment in tubes that are built from sediment particles, brood their young, and produce young that are capable of either swimming or settling upon hatching. The authors hypothesize that these opportunistic characteristics make these species ideal for invading a disturbed or stressed environment; thus they are capable of rapid increase in population size and distribution. It is not surprising that both species immediately responded to the near-

empty community in February 2008 and have subsequently declined. This abundance pattern is consistent with the proposed hypothesis. The abundance of *G. gemma* has also declined dramatically since the 1970s and 1980s (figs. 42, 43, and 44). This small clam reproduces by brooding its young and lives on the sediment surface, which makes them fairly resistant to sediment-borne stresses. *G. gemma* abundance has been variable throughout the study. As with *H. filiformis*, the authors hypothesize that the nonpelagic larvae of *G. gemma* will limit the speed of its reintroduction in the benthic community at Palo Alto, and its increase in 2009 relative to 2008 is consistent with that hypothesis.

The change in function of the benthic community over time can be examined by ranking the top 10 species by abundance and plotting the $\ln(\text{abundance} + 1)$ against the rank of each species (fig. 45). The plot for 2009 (fig. 45) is indicative of a healthy benthic community, with species dominance, as revealed by abundance, not showing large differences among the top 10 species. An examination of similar plots for August of four hydrologically dry years during our study (1977, 1989, 2002, and 2009) shows that the shape of the curve has changed greatly and that the curve has rebounded to what we have seen in earlier years, reflecting the establishment of opportunistic species after the defaunation event in 2008. Even with those changes, the 2009 curve is considerably less severe than that seen in 1977 and 1989 (fig. 46). The series of lines shows a community that was heavily dominated by three species, in 1977 and 1989, to the community in 2002, when there was one dominant species. The 1977 community plot is the most extreme and reflects a bimodal species distribution, with three species dominating the community and the remainder having similar but relatively low abundances. The 1977 community was dominated by opportunistic species, but the community was also continuously stressed by metal pollutants. In contrast, the 2009 community plot is dissimilar because the opportunists are present but display less dominance in the community (the curve is less steep).

It is informative to examine the rank-abundance plots within the context of the life history characteristics of each species to determine if shifts in plot shape coincide with a shift in community structure and function that might be indicative of a healthier environment. Two critical life history characteristics are shown here: feeding mode (fig. 46) and reproductive mode (fig. 47). The 1977 community was dominated by filter-feeding species (species that consume particles in the water column), species that have the option of either filter-feeding or feeding on the sediment surface (mixed feeders), and one species that feeds on food particles on the sediment surface. In 1989, the species composition had shifted such that filter-feeding species and subsurface deposit feeding species (those that ingest sediment and strip the food off of the sediment in their gut) dominated the community. In 2002, a shift was observed towards species that could either filter feed or deposit feed (mixed feeders) and those species that feed on subsurface sediment. The most recent data shows that the community continues to be mostly composed of a mix of surface and subsurface deposit feeding species and mixed feeding species. Over the period of this study, a shift has occurred from a community dominated by species that fed either in the water column or on recently settled food particles on the sediment surface to a mixed community of species that feed directly on the subsurface sediment, those capable of feeding in the water column, and those feeding on the sediment surface. The species that returned following the defaunation event in January/February 2008 have maintained this pattern. Thus, it is unlikely that any sediment-borne pollutant caused the collapse of the community last year.

An examination of these rank-abundance plots using reproductive mode as the descriptor for each point is equally informative (fig. 47). The dominant species in 1977 were species that brood their young and release fully functional juveniles into the environment. In 1989, there were still several brooders, but there were also two species that lay their eggs in the sediment. Although brooding species remain in the 10 most abundant species, species that spawn their gametes into the water column and

those that lay eggs in the sediment (oviparous) have become more common. It is possible that some of the metal contaminants found in the sediment in the 1970s at this location limited the success of species that consumed the sediment for food, laid eggs in the sediment, or depended on water-borne larvae to repopulate the community. The reproductive mode of most species present in 2009 is reflective of the species that were available either as pelagic larvae or as mobile adults. Although egg layers were lower in number in this group, the authors hypothesize that these species will return slowly as more species move back into the area.

Summary

Long-Term Observations

Since 1974, USGS personnel have monitored and conducted basic research on the benthic sediments and biological community in the vicinity of the discharge of the Palo Alto Regional Water Quality Control Plant (PARWQCP). The time series presented here update previous findings (Luoma and others, 1991, 1992, 1993, 1995a, 1996, 1997, 1998; Wellise and others, 1999; David and others, 2002; Moon and others, 2003, 2004, 2005; Shouse and others, 2003, 2004; Thompson and others, 2002; Cain and others, 2006; Lorenzi and others, 2007, 2008; Cain and others, 2009) with additional data from January 2009 through December 2009, to create a record spanning 36 years. This long-term dataset includes sediment chemistry, tissue concentrations of metals, condition index, and reproductive activity in *M. petalum* and population dynamics of benthic invertebrate species. The time series encompasses the period when exceptionally high concentrations of copper and silver were found in *M. petalum* (1970s) and the subsequent period when those concentrations declined. The sustained record of biogeochemical data at this site provides a rare opportunity to examine the biological response to metal contamination within this ecosystem.

Studies during the 1970s showed that sediments and *M. petalum* at the Palo Alto site contained highly elevated levels of metals, especially Ag and Cu, as a result of metal-containing effluent being discharged from the Palo Alto Regional Water Quality Control Plant (PARWQCP) to South Bay. In the early 1980s, the point-source metal loading from the nearby PARWQCP was significantly reduced as a result of advanced treatment of influent and source mitigation. Coincident with declines in metal loadings, concentrations of metals in the sediment and in the clam *M. petalum* (serving as a biomonitor of metal exposures) also declined, as previously described by Hornberger and others (2000b). Interannual trends in clams and sediments are highly correlated with copper loadings from PARWQCP. Metal levels in sediments and clams respond relatively quickly to changes in metal loading; the reduction in metal loadings by the PARWQCP resulted in a reduction in metal concentrations in both the sediment and *M. petalum* within a year (Hornberger and others, 2000b).

Biological responses to metal inputs to South Bay were assessed at different levels of organization. These responses are interpreted within the appropriate temporal context. Because metal exposures were already high when the study began, interpretations are based on observed changes in biological attributes as metal inputs declined. In general, discernable responses at the organism level (that is, reproductive activity, a manifestation of a cellular or physiological change) to metal exposure may occur within a relatively short time, while population and community level responses take longer to develop. Stable changes in the benthic community may take a relatively long period of time to be expressed because of the normally high degree of intraannual variability of benthic community dynamics, which reflects the cumulative response to natural and anthropogenic disturbances. It is therefore critical that sampling frequency and duration be conducted at temporal scales appropriate to characterize the different biological responses.

During the first 10 years of this study, when the metal concentrations were high and declining, the benthic community was largely composed of nonindigenous, opportunistic species that dominated because of their ability to survive the many physical disturbances on the mudflat (Nichols and Thompson, 1985a, 1985b). These disturbances included sediment erosion and deposition and aerial exposure at extreme low tides, in addition to less well defined stresses. The possible effects of metal exposure as a disturbance factor were not considered in the analyses by Nichols and Thompson, because the decline in metal concentrations in *M. petalum* and sediment had just begun.

However, data collected throughout the period of declining metal exposure have revealed biological responses to this metal decline. Reproductive activity improved within a year or two of reduced metal exposure, and responses at the population and community levels were observed afterward. Identification of these responses was possible because the frequency of sampling allowed long-term trends related to metal contamination to be identified within the context of repeating seasonal cycles and unrelated intraannual variation.

The ecology of the Palo Alto mudflats is part of the larger South Bay, which has been undergoing some changes in recent years. In 1999–2005, USGS scientists noticed an increase in phytoplankton biomass in the southern bay. Sampling in the deeper water of the southern bay showed that the bivalves were mostly absent from the system during this increase in primary production. Cloern and others (2007) suggested that the cause of the decline in bivalves was an increase in fish predators resulting from increased offshore upwelling activity. The higher reproductive success of demersal fish, crabs, and shrimp during this period resulted in a higher number of juveniles moving into the South Bay to grow. Since 2005, we have seen the large bivalve populations fluctuate more than in previous years, and these fluctuations have been reflected in changes in phytoplankton biomass in the system (primarily through an increase in phytoplankton biomass in late summer and fall). The value of these findings in

greater South Bay to our study is twofold. First, it reinforces the importance of the benthic community in structuring the ecosystem function. Second, it shows that the high intertidal community at the Palo Alto site has not been demonstrably affected by these greater South Bay influences during these years. This finding solidifies our confidence that the changes that we have observed on the benthic community are in large part due to local factors.

2009

Throughout 2009, copper and silver concentrations in sediments and soft tissues of the clam, *M. petalum*, remained representative of the concentrations observed since 1991, following the significant reductions in concentrations during the 1980s that coincided with reductions in the discharge of these elements from PARWQCP. Since 1991, annual mean copper and silver concentrations have fluctuated modestly and without any extended trends. This is also true for other elements. For example, selenium (Se) concentrations in surface sediment declined in 2009 from the record high concentrations observed in 2008. Sedimentary Se concentrations were variable from year to year and showed no sustained temporal trend. Interannual variation in bioavailable Cu and Ag between 1991 and 2006 did not correlate with discharge of Cu and Ag from PARWQCP (Lorenzi and others, 2007), suggesting that, as with other elements of regulatory interest, including Cr, V, Ni, and Zn, regional-scale factors now largely influence sedimentary and bioavailable concentrations (see, for example, Luoma and others, 1998). Factors that influence the seasonal and year-to-year patterns in sedimentary and tissue concentrations may include precipitation, nonpoint-source runoff, cycling of legacy contamination, accelerated erosion of salt marsh banks in recent years, and periods of accretion and erosion of sediment on the mudflat. The influence of these variables should still be investigated.

The long-term dataset demonstrates various adverse impacts of contaminants on benthic organisms. Decreasing particulate concentrations of trace metals in the local environment have

benefited resident populations of invertebrates, as evidenced by increased reproductive activity in *M. petalum* that has been sustained through 2008. The benthic community declined, with few animals present in February 2008. This decline was likely due to a natural stressor, such as a sedimentation or freshwater event, and the composition of the benthic community supports that supposition. Mobile animals such as *M. petalum* that were capable of burrowing down out of the influence of the stressor probably did so, but many other species either relocated or were killed. This natural disturbance gives scientists the opportunity to observe mudflat community recovery from a natural stressor and to compare this recovery to that observed during the long-term decline in metals. Shifts in species abundance at Palo Alto have been interpreted to be a response to decreasing sediment contaminants. These community changes have included a shift from species that live on the surface, filter food out of the water column or consume particles on the sediment surface, and brood their young, to a community dominated by species that live on and below the surface, consume the sediment directly to harvest food particles, and spawn and lay eggs in the sediment. The 2009 data reveal a community that has had a short-term physical stressor, but not one that is subject to unhealthy sediment. This “natural experiment” has given USGS scientists a great opportunity to test various hypotheses on the benthic community response to different stressors. Future data will further refine the understanding of the response of this benthic community to natural and anthropogenic stressors.

Value of Long-Term Monitoring

This study highlights the importance of long-term ecosystem monitoring. The decadal time series produced during the course of sustained efforts at this site have made it possible to describe trends, identify previously undocumented phenomena, and pose hypotheses that have guided past detailed explanatory studies and can guide future studies. Monitoring studies cannot always unambiguously determine the causes of trends in metal concentrations or benthic community structure.

The strength and uniqueness of this study is the integrated analysis of metal exposure and biological response at intra- and interannual time scales over multiple decades. Changes and trends in community structure that may be related to anthropogenic stressors, as was seen in this study, can only be established with a concerted and committed effort of sufficient duration and frequency of sampling. Such rare field designs allow biological responses to natural stressors to be characterized and separated from those introduced by man. Through interpreting time-series data, it has been possible to separate anthropogenic effects from natural annual and interannual variability. The data from the recent record (that is, within the past decade) increasingly appear to be indicative of an integrated regional ecological baseline with indicators of metal contamination and greater physiological well-being of aquatic life and benthic community structure. Changes are occurring in the South Bay watershed. For example, implementation is beginning in the South Bay Salt Ponds Restoration Program; with unknown implications (positive or negative) for all of South Bay. Nanotechnologies, many of which include metal-based products in forms for which we have no experience, are beginning to take hold in consumer products. The long-term, detailed, integrated ecological baseline that has been established at this sampling site will be uniquely valuable in assessing the response of the environment as human activities in the watershed continue to change.

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EXPLANATION

A. Map location the sampling area within the greater San Francisco Bay region. B. The intertidal mudflats are shaded light blue, subtidal in dark blue, and marshland/brackish water in green/brown. The "benthic community" and "*M. petalum* and sediments" points make up the Palo Alto sampling site. The San Jose sampling site (inactive) is also shown for reference. C. Effluent from the Palo Alto Regional Water Quality Control Plant (red thumbtack, insert B) is discharged via underground pipe (dashed red line) until it reaches the mouth of a small channel that connects to the intertidal mudflat approximately 1 km northwest of the sampling sites.

Figure 1. Map showing the location of the Palo Alto sampling site in South San Francisco Bay.

Figure 2. Total monthly rainfall (inches) recorded at San Francisco WB AP in San Mateo County, 1994–2009. The station (identification SFF) is operated by the National Weather Service.

Figure 3. Surface-water salinity at the Palo Alto site, 1994–2009.

EXPLANATION

Percent aluminum ($\blacktriangle$), iron ($\blacksquare$) (extracted by near-total digest), and silt/clay ($<100\ \mu\text{m}$) ($\bullet$). Data for percent fines for 2004 contain unquantifiable biases due to errors in sample processing, and therefore have been censored. Data for 2004 are shown in appendix A-1 for qualitative purposes only.

Figure 4. Aluminum, iron, and silt/clay in sediments, 1994–2009.

Figure 5. Chromium, nickel, and vanadium in sediments, 1994–2009.

EXPLANATION

Near-total (▲) and partial-extractable (○) copper.

The ERL is the concentration below which the expected incidence of adverse effects is low (9 percent).

The ERM is the concentration above which the expected incidence of adverse effects is high (84 percent).

Figure 6. Copper in sediments, 1994–2009.

EXPLANATION

Near-total (●) and partial-extractable (○) zinc.

The ERL is the concentration below which the expected incidence of adverse effects is low (6 percent).

The ERM is the concentration above which the expected incidence of adverse effects is high (70 percent).

Figure 7. Zinc in sediments, 1994–2009.

EXPLANATION

Data represent partial-extractable silver (treatment with 0.6 N hydrochloric acid).

The ERL is the concentration below which the expected incidence of adverse effects is low (3 percent).

The ERM is the concentration above which the expected incidence of adverse effects is high (93 percent).

Figure 8. Silver in sediments, 1994–2009.

Figure 9. Selenium and mercury in sediments, 1994–2009.

EXPLANATION

The error bars are the standard error of the mean (SEM) for samples collected within the year.

Figure 10. Annual mean copper concentrations in the clam *Macoma petalum*, 1977–2009.

EXPLANATION

The error bars are the standard error of the mean (SEM).

Figure 11. Annual mean silver concentrations in the clam *Macoma petalum*, 1977–2009.

EXPLANATION

Each value is the mean concentration for the sample collected on a given date. The error bar is the standard error of the mean (SEM).

Figure 12. Copper concentrations in the clam *Macoma petalum*, 1994–2009.

EXPLANATION

Each value is the mean concentration for the sample collected on a given date. The error bar is the standard error of the mean (SEM).

Figure 13. Silver concentrations in the clam *Macoma petalum*, 1994–2009.

EXPLANATION

Each value is the mean concentration for the sample collected on a given date. The error bar is the standard error of the mean (SEM).

Figure 14. Chromium concentrations in the clam *Macoma petalum*, 1994–2009.

EXPLANATION

Each value is the mean concentration for the sample collected on a given date. The error bar is the standard error of the mean (SEM).

Figure 15. Nickel concentrations in the clam *Macoma petalum*, 1994–2009.

EXPLANATION

Each value is the mean concentration for the sample collected on a given date. The error bar is the standard error of the mean (SEM).

Figure 16. Zinc concentrations in the clam *Macoma petalum*, 1994–2009.

EXPLANATION

Each value is the mean concentration for the sample collected on a given date. The error bar is the standard error of the mean (SEM).

Figure 17. Mercury concentrations in the clam *Macoma petalum*, 1994–2009.

EXPLANATION

Each value is the mean concentration for the sample collected on a given date. The error bar is the standard error of the mean (SEM).

Figure 18. Selenium concentrations in the clam *Macoma petalum*, 1994–2009.

EXPLANATION

The condition index (CI) is defined as the weight (milligrams) of the soft tissues for an individual clam having a shell length of 25 mm.

Figure 19. Condition index of the clam *Macoma petalum*, 1988–2009.

EXPLANATION

Values are the percent of individuals that were either reproductively inactive (non-reproductive; shown in red) or in various stages of reproduction (reproductive; shown in green). The percent of non-reproductive individuals is reported as a negative value.

Figure 20. Reproductive activity of the clam *Macoma petalum*, 1974–2009.

EXPLANATION

Values are the percent of individuals that were either reproductively inactive (non-reproductive; shown in red) or in various stages of reproduction (reproductive; shown in green). The percent of non-reproductive individuals is reported as a negative value.

Figure 21. Reproductive activity of the clam *Macoma petalum*, 2000–2009.

EXPLANATION

Collections were not made between 1991 and 1998.

Figure 22. Total number of species present at the Palo Alto site, 1974–2009.

Figure 23. Total average number of individuals present at the Palo Alto site, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 24. Monthly average abundance of *Macoma petalum*, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 25. Monthly average abundance of *Mya arenaria*, 1974–2009.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 26. Monthly average abundance of *Gemma gemma*, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 27. Monthly average abundance of *Ampelisca abdita*, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 28. Monthly average abundance of *Streblospio benedicti*, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 29. Monthly average abundance of *Grandiderella japonica*, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 30. Monthly average abundance of *Neanthes succinea*, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 31. Monthly average abundance of *Heteromastus filiformis*, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.

Figure 32. Monthly average abundance of *Nippoleucon hinumensis*, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. The number of individuals (●); tissue concentration of silver (□) and copper (○) in *M. petalum*.

Figure 33. *Heteromastus filiformis* abundance with silver and copper concentrations in the clam *Macoma petalum*, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 34. *Heteromastus filiformis* annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 35. *Heteromastus filiformis* annual abundance with copper concentrations in the clam *Macoma petalum* and in sediment, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Number of individuals (●) with silver (□) and copper (○) tissue concentrations in *Macoma petalum*.

Figure 36. *Ampelisca abdita* abundance with silver and copper concentrations in the clam *Macoma petalum*, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 37. *Ampelisca abdita* annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 38. *Ampelisca abdita* annual abundance with copper concentrations in the clam *Macoma petalum* and sediment, 1974–2009.

EXPLANATION

Error bars represent standard deviation from three replicate samplings. Number of individuals (●) with silver (□) and copper (○) tissue concentrations in *Macoma petalum*.

Figure 39. *Streblospio benedicti* abundance with silver and copper concentrations in the clam *Macoma petalum*, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 40. *Streblospio benedicti* annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 41. *Streblospio benedicti* annual abundance with copper concentrations in the clam *Macoma petalum* and in sediment, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 42. *Gemma gemma* abundance with silver and copper concentrations in the clam *Macoma petalum*, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 43. *Gemma gemma* annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, 1974–2009.

EXPLANATION

Error bars for abundance and metals in sediments are the standard deviation of the means. Error bars for metals in clams are the standard error of the mean (SEM).

Figure 44. *Gemma gemma* annual abundance with copper concentrations in the clam *Macoma petalum* and in sediment, 1974–2009.

Figure 45. Species rank-abundance for the benthic community, 2009.

EXPLANATION

The feeding mode for each species at each rank is shown: Filter: filters food particles from water column; SubSurface Deposit: ingests subsurface sediment and removes food from sediment in gut; Surface Deposit: ingests food particles on surface sediment; Mixed: capable of filter feeding and surface deposit feeding; Carnivore: predator on other fauna.

Figure 46. Species rank-abundance identified by feeding mode for 1977, 1989, 2002, and 2009.

Reproductive Types

EXPLANATION

Reproductive mode for each species at each rank is shown: Brooder: broods young and release juveniles as fully functional "miniature adults"; Oviparous: lays eggs in or on sediment; Spawner: releases gametes into water column and juveniles settle out of plankton onto sediment surface after growth in the plankton.

Figure 47. Species rank-abundance data identified by reproductive mode for 1977, 1989, 2002, and 2009.

Table 1. Sediment characteristics and salinity, 2009.

[Units for Al, Fe, total organic carbon (TOC), and sand are percent of dry weight. Sand is operationally determined as $\geq 100 \mu\text{m}$ grain size. Salinity is reported in units of parts per thousand (ppt) for water pooled at the sediment surface during low tide. Data for Al and Fe are reported as the mean $\pm$ 1 standard deviation (std) for replicate subsamples (n=2); results for other constituents are for a single (n=1) measurement. Means for monthly samples were summarized and reported as the annual mean $\pm$ the standard error (sem) (n=9).]

Date	Al (percent)		Fe (percent)		TOC (percent)	Sand (percent)	Salinity (ppt)
	mean	std	mean	std			
1/7/2009	5.2	0.2	4.3	0.2	1.0	23	27
2/6/2009	5.5	0.5	4.6	0.3	1.2	14	27
3/4/2009	5.9	0.4	4.8	0.3	1.3	22	26
4/14/2009	6.5	0.4	5.5	0.3	1.5	6	29
5/12/2009	5.4	0.04	4.4	0.04	1.3	13	27
6/9/2009	4.5	0.1	4.0	0.1	0.9	30	30
9/2/2009	3.7	0.1	3.6	0.01	0.6	59	32
10/2/2009	4.3	0.2	4.0	0.01	0.8	42	32
12/29/2009	5.3	0.1	4.7	0.01	1.1	35	26
Annual Mean:	5.2		4.4		1.08	27	28
SEM:	0.3		0.2		0.09	6	1

Table 2. Concentrations of trace elements in sediments in 2009.

[Elemental concentrations for the monthly samples are reported as the mean $\pm$ 1 standard deviation (std) for replicate subsamples (n=2). The standard deviation is not reported for a single measurement (n=1). Units are micrograms per gram dry weight. Means are summarized as the annual mean (the average of monthly means) and the standard error of the monthly means (SEM) (n=9). All concentrations are based on near-total extracts, except for silver (Ag), which is based on partial extraction (see text section on Methods). ND means No Data.]

Date	Ag		Cr		Cu		Hg	Ni		Se	V		Zn	
	mean	std	mean	std	mean	std	mean	mean	std	mean	mean	std	mean	std
January 2, 2009	0.23	0.008	147	7.2	35	0.4	0.25	83	2.0	0.3	128	6	125	3
February 6, 2009	0.22	0.002	155	12.6	37	0.7	0.29	89	4.4	0.3	136	9	132	7
March 4, 2009	0.24	0.003	166	11.4	43	2.4	ND	91	2.4	ND	138	6	137	4
April 14, 2009	0.26	0.013	179	5.9	45	4.3	0.32	109	3.1	0.5	162	7	155	4
May 12, 2008	0.19	0.000	150	1.5	41	1.2	ND	89	0.7	ND	127	1	131	1
June 9, 2009	0.14	0.001	138	0.7	33	2.7	0.29	75	0.5	0.3	117	2	110	1
September 2, 2009	0.15	0.000	124	1.2	26	1.8	0.20	66	0.9	0.3	103	2	97	1
October 2, 2009	0.19	0.001	137	2.6	31	0.1	ND	74	0.6	ND	113	3	109	1
December 29, 2009	0.15	0.002	154	2.9	36	3.0	0.31	86	1.0	0.4	131	2	129	1
Annual Mean:	0.20		150		36		0.28	85		0.35	128		125	
SEM:	0.01		5		2		0.02	4		0.03	6		6	

Table 3. Annual mean copper concentration in sediments and the clam *Macoma petalum*, 1977–2009.

[Values are the annual (grand) means for 7 to 12 separate samples per year and standard errors of those means. Samples were collected between January and December of each year. Units are micrograms per gram dry weight of soft tissue for the clam (*Macoma petalum*) and microgram per gram dry weight for sediment. HCl refers to hydrochloric acid extractable copper.]

Year	Copper in sediment		Copper in clams
	HCl	Total	
1977	28±6	45±13	130±23
1978	42±11	57±13	187±104
1979	55±13	86±18	248±114
1980	47±5	66±9	287±66
1981	48±7	57±22	206±55
1982	35±4	34±24	168±35
1983	22±9	38±21	191±48
1984	26±10	40±16	159±55
1985	27±3	45±7	138±22
1986	24±3	49±9	114±49
1987	21±3	47±6	95±25
1988	27±3	53±5	53±24
1989	23±6	44±13	35±10
1990	23±2	51±4	35±11
1991	25±2	52±5	24±8
1992	27±6	52±5	46±14
1993	21±3	43±7	60±14
1994	19±2	45±4	59±12
1995	19±2	44±5	61±16
1996	19±2	43±4	71±11
1997	18±1	43±3	32±7
1998	20±1	46±2	35±4
1999	18±1	44±2	34±2
2000	18±1	39±3	32±3
2001	17±1	35±2	31±3
2002	13±1	38±2	36±4
2003	19±4	34±8	29±16
2004	17±4	34±8	33±11
2005	16±2	30±2	26±2
2006	18±2	46±2	45±8
2007	17±1	47±2	43±7
2008	13±1	38±2	28±3
2009	13±1	36±2	26±2

Table 4. Annual mean silver in sediments and the clam *Macoma petalum*, 1977–2009.

[Values are annual (grand) means for 7 to 12 separate samples per year and standard errors of those means. Samples were collected between January and December of each year. Units are micrograms per gram dry weight of soft tissue for the clam (*Macoma petalum*) and microgram per gram dry weight for sediment. Sediment was extracted with 0.6 N hydrochloric acid. ND means No Data.]

Year	Silver in sediment	Silver in clams
1977	0.65 ± 0.59	87 ± 21
1978	1.39 ± 0.35	106 ± 17
1979	1.62 ± 0.28	96 ± 29
1980	1.28 ± 0.38	105 ± 24
1981	1.41 ± 0.15	63 ± 18
1982	0.74 ± 0.21	45 ± 13
1983	0.56 ± 0.26	56 ± 11
1984	0.64 ± 0.20	57 ± 18
1985	0.78 ± 0.14	58 ± 6
1986	0.61 ± 0.14	50 ± 20
1987	ND	55 ± 18
1988	ND	20 ± 10
1989	ND	11 ± 4
1990	0.39 ± 0.09	7.7 ± 3.4
1991	0.25 ± 0.07	3.3 ± 2.0
1992	0.35 ± 0.11	5.9 ± 1.9
1993	0.36 ± 0.09	6.9 ± 3.2
1994	0.46 ± 0.07	5.4 ± 1.1
1995	0.27 ± 0.05	5.5 ± 1.2
1996	0.24 ± 0.06	7.5 ± 1.6
1997	0.34 ± 0.04	3.6 ± 1.0
1998	0.34 ± 0.04	3.3 ± 0.6
1999	0.22 ± 0.01	3.6 ± 0.3
2000	0.34 ± 0.02	3.0 ± 0.4
2001	0.43 ± 0.03	3.0 ± 0.4
2002	0.31 ± 0.02	3.0 ± 0.5
2003	0.49 ± 0.03	2.1 ± 0.5
2004	0.29 ± 0.06	2.4 ± 1.3
2005	0.41 ± 0.04	1.8 ± 0.3
2006	0.36 ± 0.05	3.8 ± 0.8
2007	0.37 ± 0.02	4.5 ± 0.9
2008	0.20 ± 0.01	1.8 ± 0.3
2009	0.20 ± 0.01	1.9 ± 0.3

Table 5. Concentrations of trace elements in the clam *Macoma petalum*, 2009.

[Monthly data are the mean and standard error (*SEM) for replicate composites (n= 6-14). The monthly means are summarized as the grand annual mean (the average of monthly means) and the standard error (SEM) (n=9). Elemental concentrations are microgram per gram soft tissue dry weight. The condition index (CI) is the soft tissue weight in milligrams of a clam of 25-mm shell length. ND means No Data.]

Date		Ag	Cr	Cu	Hg	Ni	Se	Zn	Condition Index
1/7/2009	mean	2.6	3.7	31	0.44	5.9	5.9	250	101
	*sem	0.2	0.4	2	0.01	0.3	0.5	20	
2/6/2009	mean	2.8	4.3	32	0.38	6.4	6.0	292	99
	*sem	0.3	0.4	2	0.03	0.4	0.3	22	
3/4/2009	mean	2.6	3.9	33	ND	6.9	ND	402	85
	*sem	0.3	0.4	2	ND	0.4	ND	39	
4/14/2009	mean	0.8	3.0	19	0.22	4.2	4.4	250	173
	*sem	0.1	0.3	1	0.02	0.3	0.3	18	
5/12/2009	mean	0.6	2.0	18	ND	3.2	ND	225	195
	*sem	0.0	0.4	1	ND	0.2	ND	18	
6/9/2009	mean	1.3	1.5	24	0.24	3.7	3.5	214	169
	*sem	0.5	0.3	4	0.003	0.4	0.1	43	
9/2/2009	mean	1.7	2.3	26	0.35	5.1	4.2	197	118
	*sem	0.3	0.3	2	0.04	0.4	0.4	13	
10/2/2009	mean	1.9	2.8	24	ND	5.5	ND	207	119
	*sem	0.2	0.2	1	ND	0.4	ND	13	
12/29/2009	mean	2.8	3.6	30	0.35	7.0	6.5	279	93
	*sem	0.4	0.4	3	0.05	0.4	1.0	29	
Annual Mean:		1.9	3.0	26	0.33	5.3	5.1	257	128
SEM:		0.3	0.3	2	0.03	0.5	0.5	21	13

Appendixes A–L

Appendix A-1. Percent of sediment composed of clay- and silt-sized particles, 1994–2009.

[Results are for percent fine-grained particles (silt and clay, <100 µm). Data for percent fines for 2004 (shaded) contain unquantifiable biases due to errors in sample processing. These data are shown for qualitative purposes only.]

Year	Date	%<100µm	Year	Date	%<100µm	Year	Date	%<100µm	Year	Date	%<100µm
1994	01/10/94	61	1998	01/07/98	94	2002	01/08/02	55	2006	01/09/06	74
	02/08/94	48		02/04/98	87		02/08/02	62		02/07/06	86
	03/22/94	88		03/03/98	91		03/07/02	96		03/22/06	67
	04/20/94	82		04/13/98	81		04/15/02	86		04/24/06	87
	06/13/94	90		06/15/98	67		05/15/02	80		05/31/06	35
	09/20/94	60		09/09/98	78		06/11/02	89		06/27/06	67
	10/17/94	83		10/20/98	74		09/09/02	65		09/07/06	76
	12/12/94	84		12/14/98	71		10/07/02	41		10/19/06	84
							12/16/02	77		12/18/06	63
1995	01/18/95	59	1999	01/15/99	89	2003	01/14/03	95	2007	01/17/07	55
	02/22/95	98		02/26/99	91		02/24/03	53		02/13/07	87
	03/27/95	76		03/22/99	92		03/25/03	79		03/14/07	87
	04/25/95	78		04/18/99	96		04/22/03	50		04/11/07	83
	06/06/95	90		05/19/99	71		05/05/03	48		05/09/07	75
	07/01/95	69		06/16/99	68		06/04/03	56		06/05/07	64
	08/01/95	48		09/13/99	32		09/11/03	25		09/25/07	65
	09/25/95	56		11/23/99	61		10/09/03	39		10/24/07	52
	10/24/95	80		12/20/99	95		12/18/03	48		12/19/07	82
	12/05/95	76									
1996	01/17/96	85	2000	01/18/00	87	2004	01/20/04	45	2008	01/16/08	73
	02/13/96	96		02/15/00	83		02/27/04	42		02/12/08	76
	03/13/96	98		03/22/00	84		03/16/04	49		03/25/08	87
	04/10/96	86		04/10/00	92		04/12/04	49		04/21/08	74
	06/18/96	79		06/19/00	60		05/24/04	64		05/21/08	81
	09/26/96	84		09/13/00	70		06/22/04	71		06/24/08	73
	12/09/96	70		11/09/00	66		09/13/04	24		09/16/08	41
				12/12/00	61		10/13/04	28		10/27/08	82
							12/08/04	15		12/10/08	85
1997	01/08/97	75	2001	01/09/01	59	2005	01/18/05	46	2009	01/07/09	78
	02/19/97	92		02/05/01	68		02/15/05	32		02/06/09	86
	03/19/97	53		03/05/01	71		03/07/05	24		03/04/09	78
	04/14/97	86		04/10/01	88		04/25/05	95		04/14/09	95
	06/11/97	93		05/08/01	79		05/25/05	92		05/12/09	87
	09/17/97	54		06/12/01	61		06/28/05	76		06/09/09	70
	10/15/97	59		09/18/01	41		09/20/05	46		09/02/09	41
	12/09/97	84		10/15/01	61		10/01/05	50		10/02/09	58
				12/11/01	84		12/13/05	79		12/29/09	65

Appendix A-2. Percent of sediment composed of clay- and silt-sized particles, 1994–2009.

[Results are for percent fine-grained particles (silt and clay, $<100\ \mu\text{m}$). Data for 2004 were not plotted (see appendix A-1).]

Appendix B. Total organic carbon (TOC) content (expressed as percent of dry weight) of sediment collected in 2009.

Date of collection	TOC (%)
1/7/2009	1.01
2/6/2009	1.17
3/4/2009	1.25
4/14/2009	1.51
5/12/2009	1.33
6/9/2009	0.94
9/2/2009	0.64
10/2/2009	0.75
12/29/2009	1.08

Appendix C. Metal concentrations in sediment samples collected at the Palo Alto mudflat during 2009.

[For each collection, replicate subsamples were digested in nitric acid (near-total metal extraction) and in dilute hydrochloric acid (partial metal extraction). The dry weight, reconstitution volume, and dilution factor (if applicable) are shown for each replicate and extraction method. Concentrations are reported for sample solutions (in micrograms per milliliter, $\mu\text{g/mL}$) and the calculated weight-standardized concentration (reported as microgram per gram dry sediment, $\mu\text{g/g}$). The sample mean and standard deviation for the weight-standardized concentration are also reported.]

Near-total metal extractions

1/7/2009: 77.5% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.3637	10	10	194	0.553	0.127	162	4.63	0.308	0.071	0.480	0.461
Tot2	0.4509	10	10	231	0.640	0.154	189	5.33	0.369	0.080	0.558	0.555
				Concentration, µg/g								
Tot1				53341	152	34.8	44460	1272	84.7	19.4	132	127
Tot2				51209	142	34.2	41894	1181	81.9	17.6	124	123
Average				52275	147	34.5	43177	1227	83.3	18.5	128	125
Std				1508	7	0.4	1814	64	2.0	1.3	6	3

2/6/2009: 85.8% < 100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.3732	10	10	193	0.546	0.136	164	4.90	0.319	0.073	0.482	0.476
Tot2	0.4065	10	10	238	0.667	0.152	196	5.89	0.373	0.079	0.577	0.557
				Concentration, µg/g								
Tot1				51742	146	36.3	43864	1313	85.5	19.5	129	128
Tot2				58426	164	37.3	48315	1448	91.6	19.5	142	137
Average				55084	155	36.8	46089	1381	88.6	19.5	136	132
Std				4726	13	0.7	3147	96	4.4	0.0	9	7

3/4/2009: 77.6% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5354	10	10	333	0.930	0.240	271	7.11	0.496	0.103	0.763	0.749
Tot2	0.5284	10	10	298	0.833	0.219	245	6.48	0.471	0.101	0.708	0.708
				Concentration, µg/g								
Tot1				62253	174	44.9	50523	1328	93	19.3	142	140
Tot2				56416	158	41.4	46329	1226	89	19.0	134	134
Average				59334	166	43.2	48426	1277	91	19.1	138	137
Std				4127	11	2.4	2966	73	2	0.2	6	4

Near-total metal extractions, continued

4/14/2009: 94.5% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.2125	10	10	144	0.390	0.103	120	3.53	0.236	0.055	0.355	0.336
Tot2	0.2174	10	10	136	0.381	0.092	115	3.39	0.232	0.055	0.340	0.331

				Concentration, µg/g								
Tot1				67812	184	48.3	56471	1661	111	25.9	167	158
Tot2				62695	175	42.1	52806	1560	107	25.1	156	152
Average				65254	179	45.2	54638	1610	109	25.5	162	155
Std				3618	6	4.3	2591	71	3	0.5	7	4

5/12/2009: 87.1% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5632	10	10	307	0.850	0.233	252	4.02	0.503	0.092	0.718	0.739
Tot2	0.5757	10	10	311	0.856	0.229	254	4.08	0.509	0.093	0.728	0.749

				Concentration, µg/g								
Tot1				54545	151	41.4	44656	713	89.4	16.3	128	131
Tot2				53969	149	39.7	44155	708	88.4	16.1	127	130
Average				54257	150	40.5	44405	710	88.9	16.2	127	131
Std				408	2	1.2	354	4	0.7	0.2	1	1

6/9/2009: 69.9% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5414	10	10	248	0.748	0.191	219	3.83	0.403	0.073	0.638	0.596
Tot2	0.5477	10	10	243	0.752	0.172	217	3.78	0.412	0.077	0.633	0.608

				Concentration, µg/g								
Tot1				45863	138	35.2	40506	707	74.5	13.6	118	110
Tot2				44440	137	31.5	39638	691	75.1	14.0	116	111
Average				45151	138	33.4	40072	699	74.8	13.8	117	110
Std				1006	1	2.7	613	12	0.5	0.3	2	1

Near-total metal extractions, continued

9/2/2009: 40.9% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5031	10	10	187	0.621	0.126	180	3.69	0.336	0.063	0.526	0.490
Tot2	0.5323	10	10	191	0.667	0.146	190	3.89	0.348	0.066	0.539	0.510
				Concentration, µg/g								
Tot1				37150	123.494	24.965	35858	734.25	66.726	12.562	104.572	97.317
Tot2				35957	125.249	27.485	35769	730.98	65.433	12.474	101.240	95.867
Average				36553	124	26.2	35813	733	66.1	12.5	103	97
Std				843	1	1.8	62	2	0.9	0.1	2	1

10/2/2009: 58.4% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5444	10	10	240	0.758	0.167	218	5.56	0.405	0.075	0.624	0.601
Tot2	0.5316	10	10	222	0.720	0.162	212	5.25	0.391	0.080	0.587	0.576
				Concentration, µg/g								
Tot1				44104	139	30.6	40118	1020	74.3	13.8	115	110
Tot2				41704	135	30.5	39936	988	73.5	15.1	110	108
Average				42904	137	30.5	40027	1004	73.9	14.4	113	109
Std				1697	3	0.1	128	23	0.6	0.9	3	1

12/29/2009: 64.6% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5212	10	10	283	0.816	0.198	243	6.66	0.446	0.086	0.691	0.669
Tot2	0.5034	10	10	263	0.767	0.170	235	6.48	0.439	0.091	0.650	0.652
				Concentration, µg/g								
Tot1				54336	157	38.0	46623	1278	85.6	16.4	133	128
Tot2				52225	152	33.8	46762	1287	87.1	18.1	129	129
Average				53281	154	35.9	46693	1283	86.4	17.2	131	129
Std				1493	3	3.0	98	7	1.0	1.2	2	1

Partial metal extraction

1/7/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.2437	10	0.0057	34.6	0.118	0.308	95	15.3	0.126	0.384	0.168	0.734
HCl2	0.2208	10	0.0048	30.7	0.115	0.282	85	13.5	0.113	0.341	0.151	0.630
			Concentration, µg/g									
HCl1			0.23	1421	4.85	12.6	3906	628	5.17	15.8	6.91	30.1
HCl2			0.22	1390	5.19	12.7	3852	612	5.12	15.4	6.83	28.5
Average			0.23	1405	5.02	12.7	3879	620	5.15	15.6	6.87	29.3
Std			0.01	16	0.17	0.1	27	8	0.02	0.2	0.04	0.8

2/6/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.2478	10	0.0053	36.9	0.126	0.307	94	17.2	0.132	0.396	0.175	0.782
HCl2	0.1749	10	0.0038	26.7	0.095	0.222	68	12.1	0.097	0.288	0.128	0.550
			Concentration, µg/g									
HCl1			0.21	1490	5.07	12.4	3807	695	5.31	16.0	7.08	31.5
HCl2			0.22	1525	5.43	12.7	3909	692	5.52	16.4	7.34	31.4
Average			0.22	1508	5.25	12.5	3858	694	5.41	16.2	7.21	31.5
Std			0.002	18	0.18	0.1	51	1	0.11	0.2	0.13	0.1

3/4/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.5454	10	0.0127	82.3	0.261	0.754	197	31.2	0.298	0.852	0.376	1.694
HCl2	0.5273	10	0.0126	80.4	0.255	0.733	189	30.2	0.287	0.847	0.363	1.645
			Concentration, µg/g									
HCl1			0.23	1509	4.78	13.8	3608	573	5.46	15.6	6.89	31.1
HCl2			0.24	1525	4.84	13.9	3584	572	5.44	16.1	6.89	31.2
Average			0.24	1517	4.81	13.9	3596	572	5.45	15.8	6.89	31.1
Std			0.003	8	0.03	0.04	12	0.1	0.01	0.2	0.004	0.1

Partial metal extraction, continued

4/14/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.2146	10	0.0059	39.9	0.126	0.333	99	17.0	0.150	0.394	0.181	0.799
HCl2	0.1924	10	0.0048	35.7	0.128	0.322	89	15.1	0.139	0.350	0.169	0.721
			Concentration, µg/g									
HCl1			0.27	1858	5.86	15.5	4598	790	7.00	18.4	8.42	37.2
HCl2			0.25	1856	6.65	16.7	4626	782	7.21	18.2	8.78	37.5
Average			0.26	1857	6.26	16.1	4612	786	7.11	18.3	8.60	37.3
Std			0.01	1	0.40	0.6	14	4	0.11	0.1	0.18	0.1
5/12/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.5798	10	0.0110	94.9	0.316	0.891	238	16.4	0.336	0.869	0.415	1.955
HCl2	0.5338	10	0.0101	88.3	0.311	0.817	222	15.1	0.312	0.802	0.382	1.788
			Concentration, µg/g									
HCl1			0.19	1636	5.44	15.4	4110	283	5.80	15.0	7.16	33.7
HCl2			0.19	1655	5.82	15.3	4149	282	5.84	15.0	7.16	33.5
Average			0.19	1645	5.63	15.3	4130	282	5.82	15.0	7.16	33.6
Std			0.0003	9	0.19	0.03	20	0.4	0.02	0.02	0.00	0.1
6/9/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.5258	10	0.0076	68.6	0.216	0.614	171	13.8	0.260	0.633	0.273	1.411
HCl2	0.5252	10	0.0075	66.1	0.200	0.619	165	13.4	0.253	0.611	0.270	1.372
			Concentration, µg/g									
HCl1			0.14	1304	4.11	11.7	3248	262	4.94	12.0	5.19	26.8
HCl2			0.14	1259	3.81	11.8	3147	255	4.81	11.6	5.14	26.1
Average			0.14	1282	3.96	11.7	3198	258	4.87	11.8	5.17	26.5
Std			0.001	23	0.15	0.1	51	4	0.06	0.2	0.02	0.4

Partial metal extraction, continued

9/2/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.4325	10	0.0066	44.6	0.158	0.450	131	13.4	0.190	0.473	0.199	0.913
HCl2	0.4113	10	0.0063	41.5	0.151	0.417	124	12.2	0.180	0.445	0.187	0.858
			Concentration, µg/g									
HCl1			0.15	1030	3.65	10.4	3031	310	4.40	10.9	4.61	21.1
HCl2			0.15	1009	3.66	10.1	3003	296	4.37	10.8	4.53	20.9
Average			0.15	1020	3.65	10.3	3017	303	4.38	10.9	4.57	21.0
Std			0.0003	11	0.01	0.1	14	7	0.01	0.1	0.04	0.1
10/2/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.5153	10	0.0096	57	0.179	0.519	163	22.9	0.221	0.607	0.258	1.180
HCl2	0.5303	10	0.0098	59	0.202	0.564	167	23.1	0.225	0.606	0.264	1.212
			Concentration, µg/g									
HCl1			0.19	1107	3.47	10.1	3163	444	4.28	11.8	5.00	22.9
HCl2			0.18	1104	3.81	10.6	3151	436	4.24	11.4	4.97	22.9
Average			0.19	1106	3.64	10.4	3157	440	4.26	11.6	4.99	22.9
Std			0.00	1	0.17	0.3	6	4	0.02	0.2	0.02	0.02
12/29/2009			Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)	Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.5053	10	0.0076	66	0.220	0.514	175	28.2	0.215	0.695	0.341	1.238
HCl2	0.5043	10	0.0078	66	0.220	0.510	175	28.3	0.215	0.715	0.342	1.257
			Concentration, µg/g									
HCl1			0.15	1297	4.36	10.2	3467	559	4.25	13.8	6.75	24.5
HCl2			0.15	1302	4.37	10.1	3474	562	4.26	14.2	6.77	24.9
Average			0.15	1300	4.36	10.2	3471	560	4.25	14.0	6.76	24.7
Std			0.002	3	0.004	0.03	3	1	0.01	0.2	0.01	0.2

Appendix D. Metal concentrations in the clam *Macoma petalum* collected at the Palo Alto mudflat.

[Each monthly collection is reported on two pages. The first page contains the following summary statistics:

- Mean concentrations in microgram per gram dry tissue weight ($\mu\text{g/g}$).
- STD is the standard deviation of the mean.
- SEM is the standard error of the mean.
- CV percent is the coefficient of variation.
- $r_{wt \times []}$ is the correlation coefficient for the concentration versus weight correlation for each element.
- X 100 mg is the concentration interpolated from the above regression for a 100-mg animal.
- $r_{l \times []}$ is the correlation coefficient for the concentration versus shell length regression.
- X 20 mm and X 25 mm are concentrations interpolated from the regression for 20-mm and 25-mm animals, respectively.

Soft-tissue weights for animals having shell lengths of 15, 20, and 25mm shell length were predicted from a linear regression of log tissue dry weight vs log average shell length for each monthly collection. Predicted tissue weights for a 25-mm clam defined the condition index (CI), which was used to interpret the physiological condition of the population. Content (a measure of metal bioaccumulation that is standardized to tissue mass) is shown for 15-mm, 20-mm, and 25-mm animals. The second page shows the analysis of each composite within the sample, the number of animals in each composite, concentration as calculated from sample dry weight and the dilution factor and the metal content for each composite.]

Station: Palo Alto
Date: 1/7/2009

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	2.6077	0.2785	3.6955	30.9170	5.8591	1.1664	3.1865	249.9625
STD	0.7669	0.0575	1.2667	5.9524	0.8672	0.2445	0.8981	68.2877
SEM	0.221	0.017	0.366	1.718	0.250	0.071	0.259	19.713
CV%	29.410	20.634	34.276	19.253	14.800	20.963	28.184	27.319
n	12	12	12	12	12	12	12	12
r wt x []	0.011	0.505	0.691	0.423	0.587	0.538	0.628	0.585
X 100mg	2.611	0.266	3.333	31.960	5.648	1.112	2.953	233.411
r l x []	0.143	0.687	0.760	0.544	0.744	0.657	0.719	0.725
X 20mm	2.601	0.281	3.753	30.722	5.898	1.176	3.225	252.941
X 25mm	2.680	0.252	3.058	33.063	5.432	1.060	2.759	217.161

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.1315	0.0140	0.1760	1.6014	0.2984	0.0585	0.1554	12.2072
25mm	0.2587	0.0250	0.2939	3.2909	0.5441	0.1045	0.2675	20.9750

Estimated weight for 15mm clam

0.022 gm
22.140 mg

Estimated weight for 20mm clam

0.052 gm
52.049 mg

Estimated weight for 25mm clam

0.101 gm
101.010 mg

Station: Palo Alto
Date: 1/7/2009

Macoma petalum

Sample #	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (ug/ml) - Blank Corrected from ICP-OES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	9.52	0.1355	0.0059	10	0.0394	0.0052	0.0715	0.3962	0.1043	0.0216	0.0608	4.5760
Mp2	10.51	0.3387	0.0083	10	0.0678	0.0111	0.1605	0.8158	0.2210	0.0438	0.1366	10.8900
Mp3	11.53	0.3909	0.0100	10	0.1034	0.0132	0.1989	1.0440	0.2679	0.0543	0.1523	12.9000
Mp4	18.60	0.1903	0.0381	10	0.0388	0.0043	0.0481	0.4471	0.0914	0.0186	0.0478	4.5580
Mp5	19.55	0.4606	0.0512	10	0.0946	0.0121	0.2078	1.3550	0.2408	0.0548	0.1534	10.9800
Mp6	20.60	0.4068	0.0509	10	0.0866	0.0124	0.2040	1.3610	0.2304	0.0516	0.1565	10.9600
Mp7	21.83	0.2782	0.0696	10	0.0685	0.0084	0.1215	0.8604	0.1760	0.0376	0.1065	4.7990
Mp8	23.72	0.1670	0.0835	10	0.0432	0.0044	0.0579	0.4415	0.0993	0.0186	0.0561	3.9100
Mp9	24.49	0.2576	0.0859	10	0.0922	0.0052	0.0604	0.9669	0.1379	0.0232	0.0546	6.1020
Mp10	25.45	0.1911	0.0956	10	0.0854	0.0045	0.0409	0.8523	0.1045	0.0181	0.0398	3.6150
Mp11	28.22	0.1778	0.1778	10	0.0473	0.0035	0.0351	0.5980	0.1014	0.0128	0.0301	5.5540
Mp12	30.97	0.2069	0.2069	10	0.0364	0.0062	0.0599	0.6511	0.0981	0.0259	0.0631	2.4400
MDL					0.0006	0.0001	0.0115	0.0171	0.0003	0.0006	0.0004	0.0006
MRL					0.0013	0.0003	0.0230	0.0341	0.0006	0.0013	0.0008	0.0012
Sample #												

Concentration (ug/g) ==>		Mp1	2.9077	0.3838	5.2768	29.2399	7.6974	1.5941	4.4871	337.7122
		Mp2	2.0018	0.3277	4.7387	24.0862	6.5249	1.2932	4.0331	321.5235
		Mp3	2.6452	0.3377	5.0883	26.7076	6.8534	1.3891	3.8961	330.0077
		Mp4	2.0389	0.2260	2.5276	23.4945	4.8029	0.9774	2.5118	239.5166
		Mp5	2.0538	0.2627	4.5115	29.4182	5.2280	1.1898	3.3304	238.3847
		Mp6	2.1288	0.3048	5.0147	33.4562	5.6637	1.2684	3.8471	269.4199
		Mp7	2.4623	0.3019	4.3674	30.9274	6.3264	1.3515	3.8282	172.5018
		Mp8	2.5868	0.2635	3.4671	26.4371	5.9461	1.1138	3.3593	234.1317
		Mp9	3.5792	0.2019	2.3447	37.5349	5.3533	0.9006	2.1196	236.8789
		Mp10	4.4689	0.2355	2.1402	44.5997	5.4683	0.9471	2.0827	189.1680
		Mp11	2.6603	0.1969	1.9741	33.6333	5.7030	0.7199	1.6929	312.3735
		Mp12	1.7593	0.2997	2.8951	31.4693	4.7414	1.2518	3.0498	117.9314
		Sample #								
Content (ug) ==>		Mp1	0.0171	0.0023	0.0311	0.1723	0.0453	0.0094	0.0264	1.9896
		Mp2	0.0165	0.0027	0.0391	0.1990	0.0539	0.0107	0.0333	2.6561
		Mp3	0.0265	0.0034	0.0510	0.2677	0.0687	0.0139	0.0391	3.3077
		Mp4	0.0776	0.0086	0.0962	0.8942	0.1828	0.0372	0.0956	9.1160
		Mp5	0.1051	0.0134	0.2309	1.5056	0.2676	0.0609	0.1704	12.2000
		Mp6	0.1083	0.0155	0.2550	1.7013	0.2880	0.0645	0.1956	13.7000
		Mp7	0.1713	0.0210	0.3038	2.1510	0.4400	0.0940	0.2663	11.9975
		Mp8	0.2160	0.0220	0.2895	2.2075	0.4965	0.0930	0.2805	19.5500
		Mp9	0.3073	0.0173	0.2013	3.2230	0.4597	0.0773	0.1820	20.3400
		Mp10	0.4270	0.0225	0.2045	4.2615	0.5225	0.0905	0.1990	18.0750
		Mp11	0.4730	0.0350	0.3510	5.9800	1.0140	0.1280	0.3010	55.5400
		Mp12	0.3640	0.0620	0.5990	6.5110	0.9810	0.2590	0.6310	24.4000

Station: Palo Alto
Date: 2/6/2009

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	2.8020	0.3022	4.3204	32.0437	6.3610	1.2924	3.9358	291.7630
STD	1.0783	0.0678	1.3979	6.2220	1.1424	0.3558	1.4077	70.3603
SEM	0.341	0.021	0.442	1.968	0.361	0.113	0.445	22.250
CV%	38.484	22.439	32.356	19.417	17.960	27.527	35.766	24.116
n	10	10	10	10	10	10	10	10
r wt x []	0.901	0.085	0.161	0.907	0.495	0.203	0.246	0.746
X 100mg	4.319	0.293	4.672	40.857	7.243	1.405	4.477	209.794
r l x []	0.852	0.104	0.278	0.929	0.594	0.388	0.395	0.659
X 20mm	3.337	0.306	4.546	35.411	6.756	1.373	4.259	264.739
X 25mm	4.215	0.313	4.918	40.941	7.405	1.505	4.791	220.366

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.1753	0.0165	0.2406	1.9453	0.3696	0.0743	0.2258	13.7443
25mm	0.3823	0.0300	0.4591	3.9518	0.7145	0.1444	0.4473	21.6609

Estimated weight for 15mm clam

Estimated weight for 20mm clam

0.026 gm
25.846 mg

0.055 gm
55.039 mg

Estimated weight for 25mm clam

0.099 gm
98.922 mg

Station: Palo Alto

Macoma petalum

Date: 2/6/2009

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (ug/ml) - Blank Corrected from ICP-OES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	10.51	0.2791	0.0107	10	0.0601	0.0083	0.1254	0.7212	0.1600	0.0314	0.1007	9.1940
Mp2	11.55	0.4389	0.0129	10	0.0899	0.0118	0.1797	1.2060	0.2452	0.0453	0.1425	13.0300
Mp3	12.39	0.2257	0.0161	10	0.0450	0.0061	0.0780	0.6297	0.1262	0.0241	0.0700	7.7580
Mp4	13.41	0.0891	0.0178	10	0.0211	0.0025	0.0228	0.2370	0.0563	0.0095	0.0222	3.3400
Mp5	15.49	0.1219	0.0305	10	0.0263	0.0041	0.0634	0.3382	0.0716	0.0183	0.0565	2.6750
Mp6	17.59	0.1070	0.0357	10	0.0309	0.0030	0.0347	0.3845	0.0549	0.0118	0.0319	3.4200
Mp7	19.70	0.1125	0.0563	10	0.0260	0.0026	0.0368	0.3431	0.0651	0.0123	0.0346	3.9750
Mp8	20.46	0.1011	0.0506	10	0.0378	0.0045	0.0730	0.3707	0.0868	0.0206	0.0712	2.7350
Mp9	21.59	0.0680	0.0680	10	0.0197	0.0026	0.0391	0.2524	0.0545	0.0121	0.0377	1.8280
Mp10	26.85	0.1305	0.1305	10	0.0713	0.0030	0.0511	0.5828	0.0912	0.0146	0.0474	1.8400
MDL					0.0006	0.0001	0.0115	0.0171	0.0003	0.0006	0.0004	0.0006
MRL					0.0013	0.0003	0.0230	0.0341	0.0006	0.0013	0.0008	0.0012
Sample #												

Concentration (ug/g) ==>		Mp1	2.1534	0.2974	4.4930	25.8402	5.7327	1.1250	3.6080	329.4160
		Mp2	2.0483	0.2689	4.0943	27.4778	5.5867	1.0321	3.2468	296.8786
		Mp3	1.9938	0.2703	3.4559	27.8999	5.5915	1.0678	3.1015	343.7306
		Mp4	2.3681	0.2806	2.5589	26.5993	6.3187	1.0662	2.4916	374.8597
		Mp5	2.1575	0.3363	5.2010	27.7441	5.8737	1.5012	4.6349	219.4422
		Mp6	2.8879	0.2804	3.2430	35.9346	5.1308	1.1028	2.9813	319.6262
		Mp7	2.3111	0.2311	3.2711	30.4978	5.7867	1.0933	3.0756	353.3333
		Mp8	3.7389	0.4451	7.2206	36.6667	8.5856	2.0376	7.0425	270.5242
		Mp9	2.8971	0.3824	5.7500	37.1176	8.0147	1.7794	5.5441	268.8235
		Mp10	5.4636	0.2299	3.9157	44.6590	6.9885	1.1188	3.6322	140.9962
		Sample #								
Content (ug) ==>		Mp1	0.0231	0.0032	0.0482	0.2774	0.0615	0.0121	0.0387	3.5362
		Mp2	0.0264	0.0035	0.0529	0.3547	0.0721	0.0133	0.0419	3.8324
		Mp3	0.0321	0.0044	0.0557	0.4498	0.0901	0.0172	0.0500	5.5414
		Mp4	0.0422	0.0050	0.0456	0.4740	0.1126	0.0190	0.0444	6.6800
		Mp5	0.0658	0.0103	0.1585	0.8455	0.1790	0.0458	0.1413	6.6875
		Mp6	0.1030	0.0100	0.1157	1.2817	0.1830	0.0393	0.1063	11.4000
		Mp7	0.1300	0.0130	0.1840	1.7155	0.3255	0.0615	0.1730	19.8750
		Mp8	0.1890	0.0225	0.3650	1.8535	0.4340	0.1030	0.3560	13.6750
		Mp9	0.1970	0.0260	0.3910	2.5240	0.5450	0.1210	0.3770	18.2800
		Mp10	0.7130	0.0300	0.5110	5.8280	0.9120	0.1460	0.4740	18.4000

Station: Palo Alto
 Date: 3/4/2009

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	2.6030	0.3337	3.9491	32.9906	6.8809	1.4637	3.8686	402.4011
STD	0.9105	0.0407	1.3074	8.1863	1.4964	0.3257	1.1121	133.6108
SEM	0.263	0.012	0.377	2.363	0.432	0.094	0.321	38.570
CV%	34.979	12.198	33.106	24.814	21.747	22.249	28.748	33.203
n	12	12	12	12	12	12	12	12
r wt x []	0.792	0.253	0.591	0.787	0.312	0.207	0.486	0.499
X 100mg	3.464	0.321	3.027	40.679	6.324	1.383	3.223	481.915
r l x []	0.714	0.264	0.451	0.804	0.167	0.047	0.342	0.356
X 20mm	2.681	0.332	3.878	33.781	6.851	1.462	3.823	408.109
X 25mm	3.197	0.324	3.410	39.004	6.653	1.450	3.521	445.835

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.1236	0.0156	0.1644	1.6047	0.3153	0.0678	0.1676	18.6570
25mm	0.2506	0.0273	0.2582	3.2629	0.5477	0.1207	0.2751	34.6508

Estimated weight for 15mm clam

Estimated weight for 20mm clam

0.022 gm
 22.337 mg

0.047 gm
 47.441 mg

Estimated weight for 25mm clam

0.085 gm
 85.094 mg

Station: Palo Alto
Date: 3/4/2009

Macoma petalum

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (ug/ml) - Blank Corrected from ICP-OES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	10.52	0.2682	0.0092	10	0.0609	0.0088	0.0998	0.7042	0.1789	0.0347	0.0990	9.3710
Mp2	11.53	0.2355	0.0102	10	0.0465	0.0081	0.0899	0.5287	0.1548	0.0290	0.0853	9.0130
Mp3	12.39	0.1946	0.0130	10	0.0401	0.0080	0.1157	0.5156	0.1574	0.0334	0.0992	8.4730
Mp4	13.77	0.2056	0.0187	10	0.0465	0.0072	0.0934	0.5144	0.1531	0.0290	0.0937	8.3200
Mp5	16.60	0.2162	0.0309	10	0.0450	0.0073	0.1066	0.6732	0.1645	0.0331	0.0981	7.8340
Mp6	19.55	0.2979	0.0497	10	0.0821	0.0087	0.1059	1.2240	0.1816	0.0384	0.1000	9.5170
Mp7	20.51	0.2133	0.0533	10	0.0369	0.0056	0.0549	0.7626	0.1059	0.0327	0.0523	6.5000
Mp8	21.53	0.2025	0.0506	10	0.0409	0.0060	0.0848	0.6463	0.1338	0.0298	0.0871	6.9140
Mp9	23.03	0.1413	0.0707	10	0.0274	0.0052	0.0589	0.4299	0.1026	0.0318	0.0605	6.9620
Mp10	25.34	0.1445	0.0723	10	0.0556	0.0054	0.0794	0.6063	0.1488	0.0240	0.0764	4.8810
Mp11	26.90	0.2229	0.1115	10	0.0891	0.0075	0.0767	0.7308	0.1448	0.0273	0.0871	6.8940
Mp12	29.25	0.1345	0.1345	10	0.0578	0.0041	0.0136	0.6806	0.0600	0.0128	0.0179	10.6100
MDL					0.0006	0.0001	0.0115	0.0171	0.0003	0.0006	0.0004	0.0006
MRL					0.0013	0.0003	0.0230	0.0341	0.0006	0.0013	0.0008	0.0012
Sample #												

Concentration (ug/g) ==>									
	Mp1	2.2707	0.3281	3.7211	26.2565	6.6704	1.2938	3.6913	349.4034
	Mp2	1.9745	0.3439	3.8174	22.4501	6.5732	1.2314	3.6221	382.7176
	Mp3	2.0606	0.4111	5.9455	26.4954	8.0884	1.7163	5.0976	435.4060
	Mp4	2.2617	0.3502	4.5428	25.0195	7.4465	1.4105	4.5574	404.6693
	Mp5	2.0814	0.3377	4.9306	31.1378	7.6087	1.5310	4.5375	362.3497
	Mp6	2.7560	0.2920	3.5549	41.0876	6.0960	1.2890	3.3568	319.4696
	Mp7	1.7300	0.2625	2.5738	35.7525	4.9648	1.5331	2.4519	304.7351
	Mp8	2.0198	0.2963	4.1877	31.9160	6.6074	1.4716	4.3012	341.4321
	Mp9	1.9391	0.3680	4.1684	30.4246	7.2611	2.2505	4.2817	492.7105
	Mp10	3.8478	0.3737	5.4948	41.9585	10.2976	1.6609	5.2872	337.7855
	Mp11	3.9973	0.3365	3.4410	32.7860	6.4962	1.2248	3.9076	309.2867
	Mp12	4.2974	0.3048	1.0112	50.6022	4.4610	0.9517	1.3309	788.8476

Station: Palo Alto
Date: 4/14/2009

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	0.7543	0.1377	3.0154	18.5198	4.2174	0.8460	2.3406	249.7078
STD	0.2083	0.0189	0.9626	4.4544	0.9686	0.1819	0.7209	56.7679
SEM	0.066	0.006	0.304	1.409	0.306	0.058	0.228	17.952
CV%	27.610	13.757	31.924	24.052	22.966	21.496	30.798	22.734
n	10	10	10	10	10	10	10	10
r wt x []	0.376	0.230	0.160	0.106	0.284	0.216	0.088	0.210
X 100mg	0.781	0.136	2.964	18.678	4.310	0.833	2.319	253.710
r l x []	0.378	0.073	0.197	0.519	0.338	0.093	0.070	0.548
X 20mm	0.798	0.137	2.909	19.814	4.401	0.837	2.312	267.107
X 25mm	0.871	0.136	2.735	21.943	4.702	0.821	2.266	295.732

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0698	0.0121	0.2397	1.7536	0.3869	0.0727	0.1944	23.5861
25mm	0.1458	0.0233	0.4348	3.7085	0.7905	0.1388	0.3660	49.6187

Estimated weight for 15mm clam

Estimated weight for 20mm clam

0.038 gm
37.947 mg

0.089 gm
89.256 mg

Estimated weight for 25mm clam

0.173 gm
173.289 mg

Station: Palo Alto
Date: 4/14/2009

Macoma petalum

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (ug/ml) - Blank Corrected from ICP-OES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	10.65	0.2564	0.0142	10	0.0160	0.0039	0.0900	0.3983	0.1056	0.0238	0.0655	6.1350
Mp2	11.44	0.2657	0.0190	10	0.0188	0.0038	0.0874	0.4027	0.1051	0.0220	0.0618	5.9860
Mp3	12.65	0.5221	0.0201	10	0.0296	0.0060	0.1329	0.8354	0.1686	0.0363	0.0986	10.4800
Mp4	13.51	0.6377	0.0220	15	0.0225	0.0055	0.1360	0.7068	0.1561	0.0354	0.0940	8.8910
Mp5	14.30	0.2637	0.0377	10	0.0202	0.0039	0.0911	0.4397	0.1163	0.0270	0.0768	6.0470
Mp6	16.02	0.3383	0.0564	10	0.0316	0.0040	0.0611	0.6278	0.1191	0.0206	0.0534	7.4550
Mp7	20.45	0.3475	0.0869	10	0.0352	0.0054	0.1504	0.7185	0.1852	0.0383	0.1140	9.0830
Mp8	21.34	0.2509	0.1255	10	0.0277	0.0042	0.1069	0.5135	0.1606	0.0270	0.0882	6.9330
Mp9	26.58	0.2710	0.2710	10	0.0215	0.0030	0.0607	0.4243	0.1098	0.0168	0.0468	6.4310
Mp10	22.68	0.1664	0.0832	10	0.0084	0.0023	0.0253	0.4967	0.0580	0.0124	0.0235	6.6220
MDL					0.0006	0.0001	0.0115	0.0171	0.0003	0.0006	0.0004	0.0006
MRL					0.0013	0.0003	0.0230	0.0341	0.0006	0.0013	0.0008	0.0012
Sample #												

Concentration (ug/g) ==>									
	Mp1	0.6240	0.1521	3.5101	15.5343	4.1186	0.9282	2.5546	239.2746
	Mp2	0.7076	0.1430	3.2894	15.1562	3.9556	0.8280	2.3259	225.2917
	Mp3	0.5669	0.1149	2.5455	16.0008	3.2293	0.6953	1.8885	200.7278
	Mp4	0.5292	0.1294	3.1990	16.6254	3.6718	0.8327	2.2111	209.1344
	Mp5	0.7660	0.1479	3.4547	16.6743	4.4103	1.0239	2.9124	229.3136
	Mp6	0.9341	0.1182	1.8061	18.5575	3.5205	0.6089	1.5785	220.3665
	Mp7	1.0129	0.1554	4.3281	20.6763	5.3295	1.1022	3.2806	261.3813
	Mp8	1.1040	0.1674	4.2607	20.4663	6.4010	1.0761	3.5153	276.3252
	Mp9	0.7934	0.1107	2.2399	15.6568	4.0517	0.6199	1.7269	237.3063
	Mp10	0.5048	0.1382	1.5204	29.8498	3.4856	0.7452	1.4123	397.9567
	Sample #								
Content (ug) ==>	Mp1	0.0089	0.0022	0.0500	0.2213	0.0587	0.0132	0.0364	3.4083
	Mp2	0.0134	0.0027	0.0624	0.2876	0.0751	0.0157	0.0441	4.2757
	Mp3	0.0114	0.0023	0.0511	0.3213	0.0648	0.0140	0.0379	4.0308
	Mp4	0.0116	0.0028	0.0703	0.3656	0.0807	0.0183	0.0486	4.5988
	Mp5	0.0289	0.0056	0.1301	0.6281	0.1661	0.0386	0.1097	8.6386
	Mp6	0.0527	0.0067	0.1018	1.0463	0.1985	0.0343	0.0890	12.4250
	Mp7	0.0880	0.0135	0.3760	1.7963	0.4630	0.0958	0.2850	22.7075
	Mp8	0.1385	0.0210	0.5345	2.5675	0.8030	0.1350	0.4410	34.6650
	Mp9	0.2150	0.0300	0.6070	4.2430	1.0980	0.1680	0.4680	64.3100
	Mp10	0.0420	0.0115	0.1265	2.4835	0.2900	0.0620	0.1175	33.1100

Station:	Palo Alto		<u>Statistical Summary</u>					
Date:	5/12/2009							
	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	0.5719	0.1004	1.9744	17.5185	3.1872	0.7897	1.5008	224.6224
STD	0.1115	0.0239	1.1196	2.9902	0.5558	0.2119	0.7323	57.1197
SEM	0.035	0.008	0.354	0.946	0.176	0.067	0.232	18.063
CV%	19.489	23.782	56.704	17.069	17.440	26.828	48.793	25.429
n	10	10	10	10	10	10	10	10
r wt x []	0.357	0.073	0.244	0.171	0.055	0.278	0.312	0.401
X 100mg	0.547	0.099	2.148	17.842	3.206	0.752	1.646	239.147
r l x []	0.341	0.163	0.173	0.128	0.065	0.373	0.222	0.346
X 20mm	0.547	0.098	2.103	17.773	3.163	0.737	1.609	237.764
X 25mm	0.496	0.093	2.361	18.283	3.115	0.632	1.825	264.040

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0522	0.0093	0.1741	1.7122	0.3034	0.0691	0.1374	22.2192
25mm	0.0954	0.0175	0.3511	3.4292	0.5848	0.1210	0.2783	46.1751

Estimated weight for 15mm clam

Estimated weight for 20mm clam

0.041 gm
40.674 mg

0.098 gm
98.226 mg

Estimated weight for 25mm clam

0.195 gm
194.642 mg

Station: Palo Alto
Date: 5/12/2009

Macoma petalum

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (ug/ml) - Blank Corrected from ICP-OES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	11.57	0.2230	0.0159	10	0.0165	0.0033	0.0638	0.4801	0.0912	0.0250	0.0460	6.1940
Mp2	13.56	0.2769	0.0308	10	0.0148	0.0025	0.0371	0.4134	0.0899	0.0252	0.0380	5.6260
Mp3	14.53	0.3914	0.0391	10	0.0198	0.0041	0.0674	0.6045	0.1187	0.0346	0.0504	7.5280
Mp4	16.13	0.3774	0.0539	10	0.0240	0.0032	0.0452	0.6006	0.1098	0.0254	0.0376	7.0620
Mp5	17.21	0.4488	0.0641	10	0.0272	0.0046	0.1371	0.9464	0.1318	0.0350	0.0773	9.7450
Mp6	18.13	0.4233	0.0706	10	0.0267	0.0038	0.0486	0.6420	0.1093	0.0265	0.0383	9.2290
Mp7	18.41	0.5059	0.0843	10	0.0287	0.0038	0.0518	0.8616	0.1443	0.0299	0.0448	9.3490
Mp8	19.44	0.4705	0.0941	10	0.0205	0.0034	0.0616	0.6873	0.1359	0.0277	0.0469	7.3730
Mp9	22.55	0.1376	0.1376	10	0.0052	0.0018	0.0612	0.2352	0.0590	0.0155	0.0451	3.5350
Mp10	23.45	0.2830	0.1415	10	0.0194	0.0030	0.0464	0.6334	0.0862	0.0169	0.0425	9.9690
MDL					0.0006	0.0001	0.0115	0.0171	0.0003	0.0006	0.0004	0.0006
MRL					0.0013	0.0003	0.0230	0.0341	0.0006	0.0013	0.0008	0.0012
Sample #												

Concentration (ug/g) ==>		Mp1	0.7399	0.1480	2.8610	21.5291	4.0897	1.1211	2.0628	277.7578	
		Mp2	0.5345	0.0903	1.3398	14.9296	3.2467	0.9101	1.3723	203.1780	
		Mp3	0.5059	0.1048	1.7220	15.4446	3.0327	0.8840	1.2877	192.3352	
		Mp4	0.6359	0.0848	1.1977	15.9141	2.9094	0.6730	0.9963	187.1224	
		Mp5	0.6061	0.1025	3.0548	21.0873	2.9367	0.7799	1.7224	217.1346	
		Mp6	0.6308	0.0898	1.1481	15.1665	2.5821	0.6260	0.9048	218.0250	
		Mp7	0.5673	0.0751	1.0239	17.0310	2.8523	0.5910	0.8856	184.7994	
		Mp8	0.4357	0.0723	1.3092	14.6079	2.8884	0.5887	0.9968	156.7056	
		Mp9	0.3779	0.1308	4.4477	17.0930	4.2878	1.1265	3.2776	256.9041	
		Mp10	0.6855	0.1060	1.6396	22.3816	3.0459	0.5972	1.5018	352.2615	
		Sample #									
Content (ug) ==>		Mp1	0.0118	0.0024	0.0456	0.3429	0.0651	0.0179	0.0329	4.4243	
		Mp2	0.0164	0.0028	0.0412	0.4593	0.0999	0.0280	0.0422	6.2511	
		Mp3	0.0198	0.0041	0.0674	0.6045	0.1187	0.0346	0.0504	7.5280	
		Mp4	0.0343	0.0046	0.0646	0.8580	0.1569	0.0363	0.0537	10.0886	
		Mp5	0.0389	0.0066	0.1959	1.3520	0.1883	0.0500	0.1104	13.9214	
		Mp6	0.0445	0.0063	0.0810	1.0700	0.1822	0.0442	0.0638	15.3817	
		Mp7	0.0478	0.0063	0.0863	1.4360	0.2405	0.0498	0.0747	15.5817	
		Mp8	0.0410	0.0068	0.1232	1.3746	0.2718	0.0554	0.0938	14.7460	
		Mp9	0.0520	0.0180	0.6120	2.3520	0.5900	0.1550	0.4510	35.3500	
		Mp10	0.0970	0.0150	0.2320	3.1670	0.4310	0.0845	0.2125	49.8450	

Station:	Palo Alto		Statistical Summary					
Date:	6/9/2009							
	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	1.2949	0.1155	1.4770	23.7605	3.6538	1.0000	1.1863	213.5794
STD	1.5342	0.0878	1.0052	13.4636	1.3507	0.5194	0.7317	144.1742
SEM	0.463	0.026	0.303	4.059	0.407	0.157	0.221	43.470
CV%	118.477	76.028	68.061	56.664	36.968	51.942	61.679	67.504
n	11	11	11	11	11	11	11	11
r wt x []	0.571	0.379	0.382	0.730	0.117	0.351	0.358	0.158
X 100mg	1.728	0.099	1.287	28.624	3.732	0.910	1.057	224.872
r l x []	0.670	0.429	0.475	0.761	0.200	0.373	0.413	0.316
X 20mm	1.694	0.101	1.292	27.741	3.759	0.925	1.069	231.311
X 25mm	2.836	0.059	0.761	39.123	4.059	0.709	0.733	282.007

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.1023	0.0075	0.0984	2.1068	0.3003	0.0720	0.0823	16.6737
25mm	0.3282	0.0120	0.1556	5.4468	0.6048	0.1214	0.1356	34.8167

Estimated weight for 15mm clam

Estimated weight for 20mm clam

0.035 gm
35.317 mg

0.085 gm
85.223 mg

Estimated weight for 25mm clam

0.169 gm
168.773 mg

Station: Palo Alto
Date: 6/9/2009

Macoma petalum

Sample #	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (ug/ml) - Blank Corrected from ICP-OES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	11.29	0.1223	0.0111	10	0.0082	0.0045	0.0538	0.2438	0.0615	0.0293	0.0397	2.3880
Mp2	14.00	0.3338	0.0303	10	0.0184	0.0030	0.0488	0.5268	0.1152	0.0296	0.0343	6.2110
Mp3	15.45	0.5750	0.0411	10	0.0341	0.0047	0.0592	1.1570	0.1645	0.0473	0.0486	9.3740
Mp4	15.91	0.6768	0.0451	15	0.0317	0.0040	0.0574	0.8071	0.1518	0.0380	0.0431	7.7660
Mp5	16.93	0.6941	0.0578	15	0.0318	0.0041	0.0655	0.7836	0.1377	0.0404	0.0585	8.5010
Mp6	17.50	0.5020	0.0628	10	0.0362	0.0041	0.0580	0.8211	0.1544	0.0396	0.0416	9.6960
Mp7	18.21	0.4852	0.0693	10	0.0336	0.0041	0.0489	0.8321	0.1412	0.0354	0.0403	8.1980
Mp8	19.58	0.2428	0.0809	10	0.0168	0.0019	0.0181	0.3944	0.0703	0.0188	0.0181	3.4510
Mp9	20.63	0.4196	0.1049	10	0.0372	0.0032	0.0355	0.8441	0.1258	0.0284	0.0338	8.2210
Mp10	24.27	0.1199	0.1199	10	0.0677	0.0020	0.0196	0.6647	0.0873	0.0184	0.0197	7.6850
Mp11	27.00	0.1970	0.1970	10	0.0473	0.0013	0.0252	0.8944	0.0660	0.0133	0.0169	2.1290
MDL					0.0006	0.0001	0.0115	0.0171	0.0003	0.0006	0.0004	0.0006
MRL					0.0013	0.0003	0.0230	0.0341	0.0006	0.0013	0.0008	0.0012
Sample #												

Concentration (ug/g) ==>		Mp1	0.6705	0.3679	4.3990	19.9346	5.0286	2.3957	3.2461	195.2576
		Mp2	0.5512	0.0899	1.4620	15.7819	3.4512	0.8868	1.0276	186.0695
		Mp3	0.5930	0.0817	1.0296	20.1217	2.8609	0.8226	0.8452	163.0261
		Mp4	0.7026	0.0887	1.2722	17.8879	3.3644	0.8422	0.9552	172.1188
		Mp5	0.6872	0.0886	1.4155	16.9342	2.9758	0.8731	1.2642	183.7127
		Mp6	0.7211	0.0817	1.1554	16.3566	3.0757	0.7888	0.8287	193.1474
		Mp7	0.6925	0.0845	1.0078	17.1496	2.9101	0.7296	0.8306	168.9613
		Mp8	0.6919	0.0783	0.7455	16.2438	2.8954	0.7743	0.7455	142.1334
		Mp9	0.8866	0.0763	0.8460	20.1168	2.9981	0.6768	0.8055	195.9247
		Mp10	5.6464	0.1668	1.6347	55.4379	7.2811	1.5346	1.6430	640.9508
		Mp11	2.4010	0.0660	1.2792	45.4010	3.3503	0.6751	0.8579	108.0711
		Sample #								
Content (ug) ==>		Mp1	0.0075	0.0041	0.0489	0.2216	0.0559	0.0266	0.0361	2.1709
		Mp2	0.0167	0.0027	0.0444	0.4789	0.1047	0.0269	0.0312	5.6464
		Mp3	0.0244	0.0034	0.0423	0.8264	0.1175	0.0338	0.0347	6.6957
		Mp4	0.0317	0.0040	0.0574	0.8071	0.1518	0.0380	0.0431	7.7660
		Mp5	0.0398	0.0051	0.0819	0.9795	0.1721	0.0505	0.0731	10.6263
		Mp6	0.0453	0.0051	0.0725	1.0264	0.1930	0.0495	0.0520	12.1200
		Mp7	0.0480	0.0059	0.0699	1.1887	0.2017	0.0506	0.0576	11.7114
		Mp8	0.0560	0.0063	0.0603	1.3147	0.2343	0.0627	0.0603	11.5033
		Mp9	0.0930	0.0080	0.0888	2.1103	0.3145	0.0710	0.0845	20.5525
		Mp10	0.6770	0.0200	0.1960	6.6470	0.8730	0.1840	0.1970	76.8500
		Mp11	0.4730	0.0130	0.2520	8.9440	0.6600	0.1330	0.1690	21.2900

Station:	Palo Alto		<u>Statistical Summary</u>					
Date:	9/2/2009							
	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	1.7166	0.2352	2.3004	25.7736	5.1205	1.3002	1.9073	197.1952
STD	0.8783	0.0808	1.0494	5.0881	1.3097	0.3477	0.6759	42.9032
SEM	0.265	0.024	0.316	1.534	0.395	0.105	0.204	12.936
CV%	51.166	34.361	45.618	19.742	25.578	26.741	35.437	21.757
n	11	11	11	11	11	11	11	11
r wt x []	0.338	0.647	0.529	0.660	0.602	0.174	0.440	0.283
X 100mg	2.039	0.178	1.696	29.428	4.262	1.234	1.584	183.996
r l x []	0.224	0.832	0.635	0.599	0.784	0.367	0.648	0.547
X 20mm	1.810	0.203	1.983	27.225	4.631	1.239	1.699	186.019
X 25mm	1.976	0.147	1.424	29.784	3.769	1.132	1.331	166.321

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0919	0.0115	0.0999	1.6088	0.2676	0.0705	0.0939	10.7440
25mm	0.1752	0.0190	0.1579	3.3210	0.4651	0.1283	0.1587	19.4061

Estimated weight for 15mm clam

Estimated weight for 20mm clam

0.025 gm
25.327 mg

0.060 gm
60.143 mg

Estimated weight for 25mm clam

0.118 gm
117.633 mg

Station: Palo Alto
Date: 9/2/2009

Macoma petalum

Sample #	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (ug/ml) - Blank Corrected from ICP-OES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	8.57	0.1736	0.0050	10	0.0294	0.0058	0.0457	0.3470	0.1213	0.0258	0.0436	4.4460
Mp2	9.43	0.1471	0.0061	10	0.0281	0.0055	0.0428	0.3762	0.1076	0.0245	0.0416	3.7110
Mp3	10.73	0.1095	0.0091	10	0.0211	0.0038	0.0461	0.2748	0.0755	0.0178	0.0305	2.6190
Mp4	15.04	0.2033	0.0254	10	0.0313	0.0045	0.0492	0.4977	0.0850	0.0226	0.0360	3.7050
Mp5	16.41	0.1835	0.0306	10	0.0280	0.0043	0.0528	0.4780	0.0923	0.0257	0.0384	3.1300
Mp6	17.54	0.2423	0.0404	10	0.0290	0.0049	0.0492	0.6315	0.1072	0.0269	0.0387	3.9620
Mp7	18.44	0.2885	0.0481	10	0.0560	0.0043	0.0479	0.6964	0.1144	0.0258	0.0304	5.8780
Mp8	20.22	0.2486	0.0622	10	0.0327	0.0038	0.0432	0.5434	0.0929	0.0198	0.0318	3.5090
Mp9	21.52	0.0714	0.0714	10	0.0066	0.0013	0.0061	0.1825	0.0357	0.0096	0.0086	0.9612
Mp10	23.55	0.1176	0.1176	10	0.0096	0.0027	0.0388	0.2899	0.0527	0.0221	0.0302	2.6860
Mp11	27.35	0.1427	0.1427	10	0.0584	0.0023	0.0096	0.5715	0.0615	0.0141	0.0184	2.8160
MDL					0.0006	0.0001	0.0115	0.0171	0.0003	0.0006	0.0004	0.0006
MRL					0.0013	0.0003	0.0230	0.0341	0.0006	0.0013	0.0008	0.0012
Sample #												

Concentration (ug/g) ==>		Mp1	1.6935	0.3341	2.6325	19.9885	6.9873	1.4862	2.5115	256.1060
		Mp2	1.9103	0.3739	2.9096	25.5744	7.3148	1.6655	2.8280	252.2774
		Mp3	1.9269	0.3470	4.2100	25.0959	6.8950	1.6256	2.7854	239.1781
		Mp4	1.5396	0.2213	2.4201	24.4811	4.1810	1.1117	1.7708	182.2430
		Mp5	1.5259	0.2343	2.8774	26.0490	5.0300	1.4005	2.0926	170.5722
		Mp6	1.1969	0.2022	2.0305	26.0627	4.4243	1.1102	1.5972	163.5163
		Mp7	1.9411	0.1490	1.6603	24.1386	3.9653	0.8943	1.0537	203.7435
		Mp8	1.3154	0.1529	1.7377	21.8584	3.7369	0.7965	1.2792	141.1504
		Mp9	0.9244	0.1821	0.8543	25.5602	5.0000	1.3445	1.2045	134.6218
		Mp10	0.8163	0.2296	3.2993	24.6514	4.4813	1.8793	2.5680	228.4014
		Mp11	4.0925	0.1612	0.6727	40.0491	4.3097	0.9881	1.2894	197.3371
		Sample #								
Content (ug) ==>		Mp1	0.0084	0.0017	0.0131	0.0991	0.0347	0.0074	0.0125	1.2703
		Mp2	0.0117	0.0023	0.0178	0.1568	0.0448	0.0102	0.0173	1.5463
		Mp3	0.0176	0.0032	0.0384	0.2290	0.0629	0.0148	0.0254	2.1825
		Mp4	0.0391	0.0056	0.0615	0.6221	0.1063	0.0283	0.0450	4.6313
		Mp5	0.0467	0.0072	0.0880	0.7967	0.1538	0.0428	0.0640	5.2167
		Mp6	0.0483	0.0082	0.0820	1.0525	0.1787	0.0448	0.0645	6.6033
		Mp7	0.0933	0.0072	0.0798	1.1607	0.1907	0.0430	0.0507	9.7967
		Mp8	0.0818	0.0095	0.1080	1.3585	0.2323	0.0495	0.0795	8.7725
		Mp9	0.0660	0.0130	0.0610	1.8250	0.3570	0.0960	0.0860	9.6120
		Mp10	0.0960	0.0270	0.3880	2.8990	0.5270	0.2210	0.3020	26.8600
		Mp11	0.5840	0.0230	0.0960	5.7150	0.6150	0.1410	0.1840	28.1600

Station:	Palo Alto		<u>Statistical Summary</u>					
Date:	10/2/2009							
	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	1.9433	0.2336	2.7713	24.4357	5.5000	1.0416	1.8186	206.7408
STD	0.5363	0.0553	0.7185	4.2147	1.1335	0.1928	0.5960	39.5562
SEM	0.170	0.017	0.227	1.333	0.358	0.061	0.188	12.509
CV%	27.598	23.659	25.926	17.248	20.610	18.514	32.771	19.133
n	10	10	10	10	10	10	10	10
r wt x []	0.563	0.546	0.185	0.246	0.252	0.670	0.318	0.075
X 100mg	1.055	0.145	3.162	27.482	6.341	0.661	1.260	197.974
r l x []	0.505	0.689	0.081	0.320	0.013	0.723	0.405	0.287
X 20mm	1.611	0.187	2.843	26.090	5.519	0.870	1.523	192.793
X 25mm	1.297	0.143	2.910	27.654	5.536	0.708	1.242	179.601

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0977	0.0114	0.1608	1.5784	0.3137	0.0531	0.0888	11.2941
25mm	0.1736	0.0198	0.3145	3.2574	0.5999	0.0944	0.1565	20.9950

Estimated weight for 15mm clam

Estimated weight for 20mm clam

0.025 gm
25.382 mg

0.061 gm
60.550 mg

Estimated weight for 25mm clam

0.119 gm
118.850 mg

Station: Palo Alto
Date: 10/2/2009

Macoma petalum

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (ug/ml) - Blank Corrected from ICP-OES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	8.71	0.1406	0.0050	10	0.0282	0.0044	0.0439	0.2603	0.0846	0.0182	0.0346	3.6880
Mp2	9.49	0.2402	0.0060	10	0.0447	0.0072	0.0756	0.4986	0.1521	0.0279	0.0576	5.6190
Mp3	10.60	0.1737	0.0087	10	0.0396	0.0043	0.0324	0.4489	0.1021	0.0187	0.0273	4.0880
Mp4	13.43	0.0768	0.0192	10	0.0244	0.0023	0.0258	0.2204	0.0431	0.0102	0.0177	1.4620
Mp5	14.76	0.0784	0.0261	10	0.0155	0.0014	0.0160	0.2250	0.0370	0.0074	0.0093	1.0200
Mp6	15.45	0.1079	0.0270	10	0.0190	0.0021	0.0321	0.2259	0.0526	0.0111	0.0153	2.2790
Mp7	16.54	0.1011	0.0337	10	0.0213	0.0019	0.0296	0.3128	0.0416	0.0091	0.0131	1.9170
Mp8	17.50	0.1659	0.0415	10	0.0219	0.0040	0.0547	0.3644	0.0975	0.0185	0.0460	3.2790
Mp9	18.10	0.1294	0.0431	10	0.0211	0.0021	0.0187	0.2790	0.0503	0.0095	0.0162	2.2050
Mp10	22.57	0.0852	0.0852	10	0.0112	0.0018	0.0301	0.2253	0.0655	0.0071	0.0130	2.1000
MDL					0.0006	0.0001	0.0115	0.0171	0.0003	0.0006	0.0004	0.0006
MRL					0.0013	0.0003	0.0230	0.0341	0.0006	0.0013	0.0008	0.0012
Sample #												

Concentration (ug/g) ==>		Mp1	2.0057	0.3129	3.1223	18.5135	6.0171	1.2945	2.4609	262.3044
		Mp2	1.8609	0.2998	3.1474	20.7577	6.3322	1.1615	2.3980	233.9301
		Mp3	2.2798	0.2476	1.8653	25.8434	5.8780	1.0766	1.5717	235.3483
		Mp4	3.1771	0.2995	3.3594	28.6979	5.6120	1.3281	2.3047	190.3646
		Mp5	1.9770	0.1786	2.0408	28.6990	4.7194	0.9439	1.1862	130.1020
		Mp6	1.7609	0.1946	2.9750	20.9361	4.8749	1.0287	1.4180	211.2141
		Mp7	2.1068	0.1879	2.9278	30.9397	4.1147	0.9001	1.2957	189.6142
		Mp8	1.3201	0.2411	3.2972	21.9650	5.8770	1.1151	2.7728	197.6492
		Mp9	1.6306	0.1623	1.4451	21.5611	3.8872	0.7342	1.2519	170.4019
		Mp10	1.3146	0.2113	3.5329	26.4437	7.6878	0.8333	1.5258	246.4789
		Sample #								
Content (ug) ==>		Mp1	0.0101	0.0016	0.0157	0.0930	0.0302	0.0065	0.0124	1.3171
		Mp2	0.0112	0.0018	0.0189	0.1247	0.0380	0.0070	0.0144	1.4048
		Mp3	0.0198	0.0022	0.0162	0.2245	0.0511	0.0094	0.0137	2.0440
		Mp4	0.0610	0.0058	0.0645	0.5510	0.1078	0.0255	0.0443	3.6550
		Mp5	0.0517	0.0047	0.0533	0.7500	0.1233	0.0247	0.0310	3.4000
		Mp6	0.0475	0.0053	0.0803	0.5648	0.1315	0.0278	0.0383	5.6975
		Mp7	0.0710	0.0063	0.0987	1.0427	0.1387	0.0303	0.0437	6.3900
		Mp8	0.0548	0.0100	0.1368	0.9110	0.2438	0.0463	0.1150	8.1975
		Mp9	0.0703	0.0070	0.0623	0.9300	0.1677	0.0317	0.0540	7.3500
		Mp10	0.1120	0.0180	0.3010	2.2530	0.6550	0.0710	0.1300	21.0000

Station: Palo Alto
Date: 12/29/2009

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(ug/g)	2.7754	0.3305	3.6472	29.9303	7.0242	1.4082	3.3590	278.6833
STD	0.8846	0.0511	0.9739	7.2779	0.8588	0.1292	0.6608	72.0673
SEM	0.361	0.021	0.398	2.971	0.351	0.053	0.270	29.421
CV%	31.873	15.476	26.702	24.316	12.226	9.177	19.673	25.860
n	6	6	6	6	6	6	6	6
r wt x []	0.341	0.509	0.419	0.180	0.710	0.147	0.262	0.868
X 100mg	1.671	0.235	5.144	34.730	4.790	1.339	3.994	49.299
r l x []	0.162	0.598	0.219	0.432	0.718	0.274	0.082	0.716
X 20mm	2.616	0.296	3.885	33.428	6.338	1.369	3.419	221.231
X 25mm	2.452	0.261	4.130	37.030	5.631	1.328	3.481	162.049

Estimated content (ug) for 15mm and 20mm clam

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.1227	0.0150	0.1816	1.6386	0.3222	0.0686	0.1668	10.8309
25mm	0.2134	0.0259	0.3407	3.2674	0.5596	0.1242	0.3088	17.1223

Estimated weight for 15mm clam

Estimated weight for 20mm clam

0.023 gm
22.818 mg

0.050 gm
50.308 mg

Estimated weight for 25mm clam

0.093 gm
92.890 mg

Station: Palo Alto
Date: 12/29/2009

Macoma petalum

Sample #-n	Average	Total	Average	Recon	Concentration (ug/ml) - Blank Corrected from ICP-OES							
	Length (mm)	Dry Wt (gm)	Dry Wt (gm)	Amt (ml)	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	9.59	0.2028	0.0068	10	0.0591	0.0075	0.0701	0.5011	0.1449	0.0285	0.0657	6.8490
Mp2	11.09	0.1385	0.0099	10	0.0423	0.0057	0.0570	0.3373	0.1197	0.0222	0.0564	4.1550
Mp3	13.51	0.0703	0.0176	10	0.0150	0.0019	0.0215	0.2150	0.0481	0.0093	0.0186	2.2210
Mp4	17.73	0.0991	0.0330	10	0.0416	0.0030	0.0218	0.3858	0.0682	0.0121	0.0257	3.0700
Mp5	18.83	0.1192	0.0397	10	0.0328	0.0038	0.0480	0.4576	0.0753	0.0173	0.0418	3.2180
Mp6	20.13	0.0581	0.0581	10	0.0093	0.0018	0.0292	0.1314	0.0367	0.0084	0.0238	0.8058
					</							

Appendix E. Mercury and selenium concentrations ($\mu\text{g/g}$ dry weight) determined in surface sediments and *Macoma petalum*, 2009.

[Analyses were conducted on homogenized sediment. Values for *Macoma petalum* are the mean and 1 std (n=2-3).]

Date	Sediment		<i>M. petalum</i>	
	mercury	selenium	mercury	selenium
1/07/2009	0.25	0.3	0.44 ± 0.02	5.9 ± 0.8
2/06/2009	0.29	0.3	0.38 ± 0.05	6.0 ± 0.5
4/14/2009	0.32	0.5	0.22 ± 0.03	4.4 ± 0.5
6/09/2009	0.29	0.3	0.24 ± 0.01	3.5 ± 0.2
9/02/2009	0.2	0.3	0.35 ± 0.06	4.2 ± 0.7
12/29/2009	0.31	0.4	0.35 ± 0.09	6.5 ± 1.7

Appendix F. Mercury and selenium concentrations ($\mu\text{g/g}$ dry weight) determined in sample splits of surface sediments and *Macoma petalum* collected in 2009.

[ND means No Data.]

Date	Sediment		<i>M. petalum</i>	
	mercury	selenium	mercury	selenium
1/7/2009	ND	ND	ND	5.5 \ 5.3
2/6/2009	0.29 \ 0.29	0.3 \ 0.3	ND	ND
12/29/2009	ND	ND	0.39 \ 0.41	ND

Appendix G. Observed and certified concentrations of mercury and selenium in standard reference materials (SRM) analyzed in 2009.

[The certified concentration as reported by National Research Council Canada (CRC) and the National Institute of Standards and Technology (NIST) are the mean and 95-percent confidence interval. Selenium in USGS GSP-2 has not been certified.]

SRM	Mercury		Selenium	
	Observed	Certified	Observed	Certified
NIST 2709	1.4	1.4±0.1	1.7	1.6±0.1
NIST 2711	6.4	6.3±0.2	1.4	1.5±0.1
NIST 1646A	0.03	0.04	0.2	0.2±0.1
NRC MESS-3	0.09	0.09±0.01	0.8	0.7±0.1
NIST 1566B	0.04	0.04±0.01	2.1	2.1±0.2
CRC DOLT-2	2.1	2.0±0.1	6.1	6.1±0.5
CRC DOLT-3	3.4	3.4±0.1	6.9	7.1±0.5
CRC DORM-2	4.5	4.6±0.3	1.5	1.4±0.1

Appendix H. Results of the analyses of National Institute of Science and Technology (NIST)

standard reference material 2709 (San Joaquin Soil) for elements, excluding selenium and

mercury.

[Recoveries are reported as the observed concentrations (microgram per gram, dry weight (µg/g)) and the percent recoveries relative to the certified values for the standard.]

Month	Rep	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Observed concentration												
1/7/2009	1	47,522	6	0.37	119	31	36,779	581	84	10	116	109
	2	46,834	6	0.34	118	28	36,294	574	82	10	114	107
2/6/2009	1	48,200	6	0.36	121	30	36,828	584	83	10	118	109
	2	48,496	6	0.36	120	30	36,202	573	83	10	119	110
3/4/2009	1	49,213	6	0.35	127	30	38,066	596	85	10	121	110
	2	45,816	6	0.34	120	31	35,897	566	82	10	115	106
4/14/2009	1	53,572	7	0.37	135	33	40,199	632	89	11	129	117
	2	48,548	7	0.34	126	32	37,068	584	83	10	119	108
5/12/2009	1	49,635	7	0.34	127	31	37,384	590	85	10	122	112
	2	45,747	6	0.32	118	30	35,179	556	82	10	117	106
6/9/2009	1	48,230	6	0.36	126	31	37,488	590	84	10	121	110
	2	48,629	7	0.36	126	33	37,108	589	84	10	120	110
9/2/2009	1	49,808	7	0.37	124	31	37,283	591	86	10	122	113
	2	46,814	6	0.35	120	29	35,623	564	83	10	117	109
10/2/2009	1	46,556	6	0.34	120	29	35,750	561	81	10	117	108
	2	47,696	7	0.34	123	29	37,283	590	84	10	118	108
12/29/2009	1	50,893	6	0.34	130	32	38,012	604	84	10	122	111
	2	49,841	6	0.35	128	31	37,844	600	87	10	122	114
Certified concentration												
Mean		75000	18	0.38	130	35	35000	538	88	19	112	106
CI		0.06	1	0.01	4	1	0.11	17	5	1	5	3

Month	Rep	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Percent recovery												
1/7/2009	1	63	34	96	92	89	105	108	95	53	104	103
	2	62	35	91	91	82	104	107	93	51	102	101
2/6/2009	1	64	36	94	93	87	105	109	95	53	106	103
	2	65	34	94	93	86	103	106	94	54	106	104
3/4/2009	1	66	35	92	97	86	109	111	96	54	108	104
	2	61	36	89	92	91	103	105	93	52	102	100
4/14/2009	1	71	37	96	104	95	115	117	101	56	116	110
	2	65	38	88	97	91	106	109	94	52	106	102
5/12/2009	1	66	37	88	98	89	107	110	97	53	109	105
	2	61	36	85	91	88	101	103	93	52	104	100
6/9/2009	1	64	35	94	97	88	107	110	96	54	108	104
	2	65	37	94	97	95	106	110	95	53	107	104
9/2/2009	1	66	38	96	95	90	107	110	98	54	109	107
	2	62	35	92	92	85	102	105	94	52	105	102
10/2/2009	1	62	32	90	92	85	102	104	92	53	104	101
	2	64	39	89	95	83	107	110	95	54	105	102
12/29/2009	1	68	37	90	100	94	109	112	96	54	109	104
	2	66	36	93	98	89	108	111	99	54	109	107
Mean		65	36	92	95	88	106	109	95	53	107	104
STD		3	2	3	4	4	3	3	2	1	3	3

Appendix I. Observed and certified values for inorganic elements in NIST Standard Reference Material 2976 (mussel tissue)

prepared in 2009.

[Observed Concentrations in NIST SRM 2976 in 2009. Concentration unit is $\mu\text{g/g}$ (dry weight). Observed concentrations for different dates are the mean and 1 standard deviation. Certified concentrations are the mean and 95% confidence interval. MRL means Method Reporting Level.]

Date	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Observed Concentrations								
1/7/2009	<MRL	0.70 ± 0.02	0.47 ± 0.15	3.67 ± 0.37	0.72 ± 0.01	1.09 ± 0.21	0.61 ± 0.01	133 ± 2.6
2/6/2009	<MRL	0.71 ± 0.02	0.23 ± 0.16	3.66 ± 0.11	0.72 ± 0.02	1.00 ± 0.04	0.61 ± 0.02	135 ± 5.0
3/4/2009	<MRL	0.71 ± 0.01	0.22 ± 0.04	3.57 ± 0.13	0.72 ± 0.01	0.99 ± 0.03	0.62 ± 0.01	133 ± 1.8
4/14/2009	<MRL	0.68 ± 0.03	0.53 ± 0.12	3.96 ± 0.33	0.69 ± 0.03	0.95 ± 0.06	0.59 ± 0.02	129 ± 4.2
5/12/2009	<MRL	0.68 ± 0.02	0.84 ± 0.31	4.15 ± 0.18	0.68 ± 0.01	0.96 ± 0.02	0.59 ± 0.01	129 ± 2.1
6/9/2009	<MRL	0.66 ± 0.00	0.73 ± 0.28	3.57 ± 0.44	0.67 ± 0.00	0.92 ± 0.02	0.56 ± 0.01	126 ± 0.6
9/2/2009	<MRL	0.70 ± 0.01	0.68 ± 0.22	3.44 ± 0.20	0.69 ± 0.02	0.94 ± 0.04	0.58 ± 0.01	126 ± 4.0
10/2/2009	<MRL	0.72 ± 0.01	0.42 ± 0.33	3.48 ± 0.51	0.70 ± 0.02	0.93 ± 0.01	0.56 ± 0.02	126 ± 1.6
12/29/2009	<MRL	0.70 ± 0.02	0.29 ± 0.26	3.75 ± 0.14	0.69 ± 0.04	0.91 ± 0.09	0.54 ± 0.01	125 ± 2.9
Mean		0.70	0.49	3.69	0.70	0.96	0.58	129
Median		0.70	0.47	3.66	0.69	0.95	0.59	129
Certified Concentrations								
	0.011	0.82 ± 0.16	0.5 ± 0.16	4.02 ± 0.33	0.93 ± 0.12	1.19 ± 0.18	nc	137 ± 13

Appendix J. Method detection limits (MDL) and reporting levels (MRL) for ICP-OES methods.

[Concentration is reported as microgram per milliliter (µg/mL).]

Method	Marker	Ag	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Sediment	MDL	0.00083	0.03217	0.00010	0.01858	0.01531	0.01829	0.00465	0.00022	0.00117	0.00034	0.00274
	MRL	0.00166	0.06433	0.00020	0.03716	0.03062	0.03659	0.00930	0.00045	0.00233	0.00067	0.00549
Tissue	MDL	0.00063	0.03646	0.00014	0.01150	0.01706	0.03009	0.00330	0.00030	0.00065	0.00042	0.00060
	MRL	0.00125	0.07291	0.00028	0.02300	0.03411	0.06018	0.00660	0.00061	0.00130	0.00083	0.00120

Appendix K. Reproduction data for *Macoma petalum* for the year 2009.

Date	Inactive	Active	Ripe	Spawning	Spent	Spawned	N	Reproductive	Non-Reproductive
1/7/2009	0	0	100	0	0	0	10	100	0
2/6/2009	0	0	100	0	0	0	10	100	0
3/4/2009	0	0	100	0	0	0	10	100	0
4/14/2009	11	0	11	22	56	0	9	33	-67
5/12/2009	0	0	0	20	80	0	10	20	-80
6/9/2009	100	0	0	0	0	0	10	0	-100
7/1/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
8/1/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/2/2009	0	100	0	0	0	0	10	100	0
10/2/2009	0	100	0	0	0	0	10	100	0
11/1/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
12/29/2009	0	50	50	0	0	0	8	100	0

Appendix L. Complete list of benthic species found at Palo Alto in the year 2009.

[Three samples are taken at each sampling event. The mean and standard deviation of the three samples are shown.]

Species	2/6/2009		3/6/2009		4/13/2009		5/12/2009		6/10/2009		7/24/2009		8/20/2009		9/17/2009		11/16/2009	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Acari	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ampelisca abdita</i>	12.7	2.5	1.7	2.1	2.7	1.2	1.3	0.6	65.0	9.2	2.0	1.7	1.7	0.6	0.7	0.6	0.0	0.0
<i>Ampithoe spp.</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anthozoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Balanus ?aquila</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Balanus improvisus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Balanus spp.</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Boonea bisuturalis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	1.3	1.2	0.0	0.0	0.0	0.0
Calinoida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Callianassidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Capitella "capitata"</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Caprella californica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chironomidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cirratulidae	0.0	0.0	0.0	0.0	0.3	0.6	0.3	0.6	0.3	0.6	1.3	1.5	1.3	0.6	0.0	0.0	1.0	1.0
Cirripedia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Corophium ?insidiosum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Corophium acherusicum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Corophium insidiosum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species	2/6/2009		3/6/2009		4/13/2009		5/12/2009		6/10/2009		7/24/2009		8/20/2009		9/17/2009		11/16/2009	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
<i>Corophium spinicorne</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Corophium</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Corophium</i> spp. (female & juvenile)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Corophium</i> spp. (male)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cumella vulgaris</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cyprideis</i> spp.	1.3	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0
<i>Dynamenella</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eogammarus confervicolus</i>	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eteone</i> ?californica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eteone lighti</i>	4.0	1.0	2.0	2.6	1.0	1.7	10.0	5.6	9.7	1.5	5.0	1.7	2.7	0.6	4.0	1.0	6.0	4.6
<i>Eteone</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Euchone limnicola</i>	0.3	0.6	0.7	0.6	0.0	0.0	0.7	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Euchone</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eusarsiella zostericola</i>	10.3	3.8	7.7	4.0	13.3	2.5	4.3	3.1	5.3	2.5	4.0	2.0	6.0	1.0	9.7	4.5	2.7	1.2
<i>Gemma gemma</i>	8.0	1.7	10.7	3.2	13.3	11.0	23.3	10.7	23.3	2.1	118.0	25.1	164.0	86.4	163.7	197.0	57.3	34.2
<i>Glycera</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species	2/6/2009		3/6/2009		4/13/2009		5/12/2009		6/10/2009		7/24/2009		8/20/2009		9/17/2009		11/16/2009	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
<i>Glycinde armigera</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Glycinde polygnatha</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Glycinde spp.</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gnorisphaerom a oregonensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Grandidierella japonica</i>	2.0	1.0	0.0	0.0	0.3	0.6	0.7	1.2	2.7	2.3	10.0	5.0	8.3	2.3	12.7	5.0	15.3	5.1
<i>Harmothoe imbricata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Harpacticoida Hemigrapsus oregonensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Heteromastus filiformis</i>	1.0	1.0	0.7	0.6	0.7	0.6	0.7	0.6	0.7	1.2	1.7	2.1	1.3	1.5	2.0	1.0	1.3	1.2
<i>Ilyanassa obsoleta</i>	0.0	0.0	1.3	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Macoma petalum</i>	6.7	2.9	3.7	1.5	2.7	2.5	8.0	4.6	13.3	12.7	7.0	2.0	3.7	1.5	4.7	2.3	5.7	5.5
<i>Macoma spp.</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Marphysa sanguinea</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Melita nitida</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Monocorophium acherusicum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.6	1.7	2.9	2.0	2.6	1.3	1.5	0.0	0.0

Species	2/6/2009		3/6/2009		4/13/2009		5/12/2009		6/10/2009		7/24/2009		8/20/2009		9/17/2009		11/16/2009	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
<i>Monocorophium insidiosum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Monocorophium</i> spp.	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	3.0	1.0	2.7	4.6	2.0	1.0	2.0	1.7	0.7	0.6
<i>Musculista senhousia</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Mya arenaria</i>	0.0	0.0	0.0	0.0	2.0	1.7	4.7	2.5	0.7	1.2	0.3	0.6	1.0	0.0	0.7	0.6	0.3	0.6
Mysidacea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Naididae	0.0	0.0	0.0	0.0	0.7	1.2	0.0	0.0	0.0	0.0	10.3	10.7	0.0	0.0	0.0	0.0	0.0	0.0
<i>Neanthes succinea</i>	1.0	1.0	5.0	6.1	0.3	0.6	0.0	0.0	1.0	0.0	1.3	2.3	1.3	1.2	3.3	0.6	0.7	0.6
Nematoda	12.7	11.1	10.3	8.5	33.7	34.1	11.3	7.2	32.3	20.5	6.3	2.1	23.7	18.2	7.7	4.2	4.7	2.1
<i>Nippoleucon hinumensis</i>	52.3	16.3	30.3	5.9	92.3	15.0	111.0	25.0	198.3	98.0	105.0	19.2	54.7	8.1	28.3	8.1	8.0	3.0
<i>Odostomia fetella</i>	0.0	0.0	0.3	0.6	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0
<i>Odostomia</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.2	0.0	0.0	0.0	0.0
Oligochaeta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Planariidae A	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Polydora cornuta</i>	0.0	0.0	0.0	0.0	3.7	2.9	0.7	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Polydora</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Potamocorbula amurensis</i>	0.0	0.0	1.0	1.7	0.0	0.0	2.3	0.6	3.3	0.6	9.7	3.1	3.3	2.3	3.3	4.0	1.7	0.6
<i>Pseudopolydora kempii</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rocheftia grippi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species	2/6/2009		3/6/2009		4/13/2009		5/12/2009		6/10/2009		7/24/2009		8/20/2009		9/17/2009		11/16/2009	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
<i>Rochefortia</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Sabaco elongatus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Sinelobus stanfordi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Sphaeromatidae</i> (juv.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0
<i>Sphaerosyllis californiensis</i>	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Sphaerosyllis erinaceus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Streblospio benedicti</i>	24.0	19.3	24.0	5.6	26.7	9.2	29.3	5.9	7.3	5.9	12.7	1.5	9.7	6.7	9.7	5.9	13.7	8.1
<i>Synidotea laevidorsalis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	1.0	1.0	0.0	0.0
Tellinidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Tharyx</i> spp. ?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tubificidae	66.3	54.9	66.7	35.5	84.7	24.5	84.0	41.7	55.3	11.0	35.3	13.6	37.3	16.8	69.0	66.2	32.7	24.5
Turbellaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Actiniaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Amphipod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Balanomorpha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Bivalvia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Copepod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species	2/6/2009		3/6/2009		4/13/2009		5/12/2009		6/10/2009		7/24/2009		8/20/2009		9/17/2009		11/16/2009	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Unid. Cumacea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Gastropoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0
Unid. Isopoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Malanidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Nudibranchia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Ostracoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Polychaeta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Spionidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Syllidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Tanaidacea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Urosalpinx cinerea</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0