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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: 2011

Open-File Report 2012-1165

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Prepared in cooperation with the City of Palo Alto, California

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U.S. Department of the Interior
U.S. Geological Survey

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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 (cm)
inch (in)	25,400	micrometer (μm)
meter (m)	1,000,000	micrometer (μm)
mile (mi)	1.609	kilometer (km)
ounce (oz)	28.35	gram (g)
part per million (ppm)	1	microgram per gram (μg/g)
milligram per kilogram (mg/kg)	1	microgram per gram (μg/g)

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

°F=(1.8×°C)+32

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

°C=(°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 (dm^3) 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
μΩ	microohm
μg/g	microgram per gram
mg/kg	milligram per kilogram
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 at an intertidal site 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 biotic and abiotic factors that could affect metal concentrations and benthic community structure (exotic species invasions, pelagic food availability, and weather anomalies) have also been measured during this time.

Initially, these studies found exceptionally high concentrations of copper (Cu) and silver (Ag) in mud-dwelling animals in this area, with strong seasonal variability. Additional studies identified the PARWQCP as a point source for Cu and Ag and established the clam *Macoma petalum* as a biological indicator of metal exposure. The annual mean concentrations of Cu and Ag in *Macoma petalum* were 287 mg/kg and 105 mg/kg, respectively, in 1980. These levels exceeded tissue concentrations reported in the literature for this species and were much greater than seen elsewhere in San Francisco Bay. Elevated metal concentrations coincided with reduced reproductive activity in *M. petalum.* Related studies supported the view of USGS scientists that elevated Ag concentrations inhibited the development of reproductive tissue. 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 live on the surface of the mud in tubes or as shelled animals, brood their young, and feed on waterborne particles.

Concentrations of Cu and Ag 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 Cu in sediments and in the tissues of *M. petalum* correlated with reduced Cu discharge from the PARWQCP. Coincident with the decline in Cu and Ag in the sediment and clams, the reproductive activity of the clam greatly increased. The composition of the benthic community also shifted during this period. Opportunistic species became less dominant and nonopportunistic species became more persistent. Other environmental factors that vary seasonally and annually (for example, sediment composition, including percent of fine particles, organic content, and salinity), were not associated with the observed temporal trends in metal concentrations, metal effects, and benthic community changes. The only unidirectional change in an environmental factor during this period (1980–1990) was the decline in metals in discharge from the waste treatment plant.

Following the significant reductions in the 1980s, concentrations of Cu and Ag in sediments and clams have remained relatively low and stable. Concentrations have fluctuated modestly and without a sustained temporal trend. However, Ag in sediments remains greater than what may be considered the regional background (0.09 mg/kg). This persistent, low level of contamination likely derives from Ag introduced to the site before the 1990s. The concentrations of Cu and Ag in *M. petalum* have fluctuated as much as four-fold. Concentration minima for Cu observed during this period (1991, 2000–2005, and 2008–2011) were comparable to what can be considered baseline concentrations for this species in San Francisco Bay (20–30 mg/kg).

Two lines of evidence suggest that the effluent of the PARWQCP is no longer the main driver of temporal patterns in metals at the sampling site. First, since the 1990s, annual variations in Ag and Cu in *M. petalum* have not correlated with discharge of Cu and Ag from PARWQCP. Second, temporal patterns in Ag and Cu at the site are generally similar to patterns for other major and minor elements that derive from terrigenous inputs and multiple discrete and diffuse anthropogenic sources to South San Francisco Bay. Thus, metal concentrations in sediments and tissue of *M. petulum* are more likely a combination of inputs from the PARWQP and other regional sources, cycling of contaminants stored within South Bay sediments, and regionally-scaled physical and biogeochemical processes controlling the distribution and bioavailability of metals.

As concentrations of Ag and Cu in *M. petalum* declined, reproductive activity increased both in terms of the percentage of individuals that were in a reproductively active stage and the frequency of reproductive activity during the year. Overall, the reproductive status of the population has improved and stabilized over the 20 years of reduced exposure to Ag and Cu at the site.

Over the same period, the composition of the infaunal community shifted from a dominance of surface-dwelling, brooding species to species with various life-history characteristics. In particular, species that lay their eggs in the mud and feed by burrowing through and consuming the mud, which were rare in the community in the 1970s and 1980s, 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 (possible causes include sediment accretion or freshwater inundation) that resulted in the loss of the benthic animals, except for those deep-dwelling animals like *M. 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. The most recent community surveys show a mix of animals that consume the sediment, filter feed, brood their young, and have pelagic larvae that must survive life on the sediment at a young age. The 2008 defaunation event allowed examination of the response of the community to a natural disturbance and a comparison of this recovery to the long-term recovery observed in the 1970s, when the decline in sediment pollutants was the dominating factor. Today, the community at this site is very similar to the benthic community observed by Thompson and Parchaso (2012) throughout South Bay: although small filter feeding species are numerically dominant, there is a significant proportion of the community that feeds on surface and subsurface sediment particles. This does not occur when the sediment has a high concentration of toxicants.

When this study started in the late 1970s, the site was already heavily contaminated with metals. Although the authors assume that the biological conditions reflected the consequences of elevated metal exposures, there is a scarcity of preexisting data to evaluate impacts due to elevated metals. However, the long-term record contained in this study provides a unique opportunity to document biological response when the stress of metal exposure is relaxed. The data make a compelling case that the

mitigation of Ag and Cu in waste-water effluent during the 1980s allowed for biological recovery and the establishment of a more diverse and stable infaunal community.

Abstract

Trace-metal concentrations in sediment and in the clam *Macoma petalum* (formerly reported as *Macoma balthica*), clam reproductive activity, and benthic macroinvertebrate community structure were investigated in a mudflat 1 kilometer south of the discharge of the Palo Alto Regional Water Quality Control Plant (PARWQCP) in South San Francisco Bay, Calif. This report includes the data collected by U.S. Geological Survey (USGS) scientists for the period January 2011 to December 2011. These data serve as the basis for the City of Palo Alto's Near-Field Receiving Water Monitoring Program, initiated in 1994.

Following significant reductions in the late 1980s, silver (Ag) and copper (Cu) concentrations in sediment and *M. petalum* appear to have stabilized. Data for other metals, including chromium, mercury, nickel, selenium, and zinc, have been collected since 1994. Over this period, concentrations of these elements have remained relatively constant, aside from seasonal variation that is common to all elements. In 2011, concentrations of Ag and Cu in *M. petalum* varied seasonally in response to a combination of site-specific metal exposures and annual growth and reproduction, as reported previously. Seasonal patterns for other elements, including Cr, Hg, Ni, Se, and Zn, were generally similar in timing and magnitude as those for Ag and Cu. In 2011, metal concentrations in both sediments and clam tissue were among the lowest concentrations on record. This record suggests that regional-scale factors now largely control sedimentary and bioavailable concentrations of Ag and Cu, as well as other elements of regulatory interest, at the Palo Alto site.

Analyses of the benthic community structure of a mudflat in South San Francisco Bay over a 38-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 *M. petalum* community shows increases in reproductive activity concurrent with the decline in metal concentrations in the tissues of this organism. Reproductive activity is presently stable (2011), with almost all animals initiating reproduction in the fall and spawning the following spring. 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 indicates 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, 2009, and 2010. *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 and, in the last several years before 2008, showed a stable population. *H. filiformis* abundance increased slightly in 2011. 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 reproductive mode of most species present in 2011 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. The use of functional ecology was highlighted in the 2011 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,

community data show a mix of animals that consume the sediment, filter feed, have pelagic larvae that must survive landing on the sediment, and brood their young. USGS scientists continue to observe the community's response to the 2008 defaunation event because it allows them 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 long-term recovery observed in the 1970s when the decline in sediment pollutants was the dominating factor.

Introduction

Determining spatial distributions and temporal trends in trace 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. Contaminated sediments may become a chronic source of metals 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 metal concentrations in clam tissue 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 used to indicate trace-element exposures to the local food web.

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) (fig. 1) has been required to monitor metals and other specified parameters in sediments and the clam *M. petalum* at an inshore location in South San Francisco Bay, Calif. In addition to the required monitoring, 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 collected during this study include trace-metal concentrations in sediments and clams, clam reproductive activity, and benthic community structure. These data and those reported earlier (for example, Hornberger and others, 2000a; Luoma and others, 1991, 1995a, 1996; Moon and others, 2005; Shouse and others, 2003, 2004; Thompson and others, 2002; Cain and others, 2006; Dyke and others, 2010, 2011) 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-metal 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 affected by the availability and quality of food, as well as other stressors, such as pollutant exposure and salinity extremes. An earlier study (Hornberger and others, 2000b) has 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 Ag (Luoma and others, 1995b) and that some crustacean and polychaete species are particularly sensitive to elevated sedimentary Cu (Morrisey 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. The authors hypothesized that a shift in community composition and potentially in the 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. The absence of any one of these feeding groups may show limitations on species as a result of 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 are compared only 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 1 kilometer southeast of the

intertidal discharge point of the PARWQCP. The sampling locations are approximately 12 meters (m) from the edge of the marsh and 110 centimeters (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, affect the mudflats in the vicinity of Sand Point. Spatial distributions of metal concentrations near the PARWQCP site were described by Thomson and others (1984), who 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 2011, 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. 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 2011. Samples collected in the field include 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 on 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 (2011).

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-micrometer (μm) 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 μm), 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 (Dyke and others, 2010). 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 (≥100 μm) was determined. This fraction is termed the sand fraction. Bulk sediment samples were sieved to determine the percent sand and percent silt/clay (<100 μm) (appendix 1, table 1). 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 (≥100 μm), 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 μm).

The silt/clay fraction was dried at 60 degrees Celsius (ºC), weighed, and then subsampled to provide replicates weighing 0.4 to 0.6 g. These were redried (60ºC), reweighed, and then digested by hot acid reflux (10 milliliters (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 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.

Total organic carbon (TOC) concentration was determined using a continuous flow isotope ratio mass spectrophotometer (IRMS) (table 1). 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 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 (12ºC) 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-millimeter (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 8 to 13 composites, with each composite consisting of 1 to 21 clams of a similar shell length. The vials were capped with a glass reflux bulb and transferred to a convection oven (70ºC). 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-metal analysis.

Analysis for Mercury and Selenium

Samples collected during 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 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 (–20ºC). 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 (1986).

Analytical

Sediment and tissue concentrations of aluminum (Al), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), silver (Ag), and zinc (Zn) were determined using Inductively Coupled Plasma Optical Emission Spectrophotometry (ICP-OES). Mercury (Hg) and Selenium (Se) were determined in

sediment and clam tissues by Hydride Atomic Absorption Spectrophotometry. Analytical results are included in appendixes 2–4.

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 mega-ohm (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 by 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 2709a, San Joaquin soils, and NIST 2976, mussel tissue) were consistent for the method and were mostly within the range of certified values reported by NIST; however, recovery of Al in NIST 2709a was relatively lower than other metals while recovery of vanadium (V) was relatively high (appendix 5). Recoveries of Ni and Pb in NIST 2976 tended to be less than the certified concentrations (appendix 6). 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 7). 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 8).

Other Data Sources

Precipitation data (fig. 2) 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 10 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).

Community Analysis

Samples for benthic community analysis were collected with hand-held core 8.5-cm in diameter and 20-cm deep. 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 10). McCormick also compared and verified her identifications with previously identified samples.

Results

Salinity

Surface-water salinity in the Bay 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 period of record (1994–2011) is 23.1 inches. Rainfall during 2011 was below average at 16.8 inches. Above average rainfall occurred in February–March 2011, with a cumulative total of 10.5 inches, and also in June (1.49 inches). Rainfall in December 2011 was the lowest of the record at just 0.14 inches.

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 2011. Salinity declined to 15 ppt in April because of high February–March rainfall and then climbed to 28 ppt in September. The range of salinity in 2011 was larger than in the previous 4 years. The tight salinity range for the period of 2007–2009 coincided with 3 consecutive years of low total precipitation. The above average rainfall in 2010 and for the first half of 2011 likely contributed to the larger salinity range seen in 2011. The lowest spring declines in salinity in this record were during the period of 1995–2000 and again in 2006, when salinity minima were 10 ppt or less.

Sediments

Metal concentrations in surface sediments from Palo Alto typically display an annual periodicity of seasonal patterns that generally corresponds to the relative abundance of fine particles (figs. 4*C*–8*C*). Thomson-Becker and Luoma (1985) suggest that this intra-annual 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 in fine-grained particles are typically higher on a weight basis than in 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 stir the water and the fine sediments into suspension through the summer. This typical seasonal pattern of variation in sediment properties was mostly repeated in 2011 (fig. 4, appendix 1) with one exception. All elements (except Ag, Hg, and Se) displayed a pronounced dip in concentration in April 2011 following the typical high concentrations observed during the wet winter months of December 2010–March 2011. This dip coincided with the annual minimum in salinity. Metal concentrations returned to winter levels in May, then followed typical seasonal patterns for the remainder of the year.

The percentage of silt/clay in the sediment increased from 46 percent in October 2010 to a maximum value of 97 percent in February 2011, following the onset of winter rains. High percentages of silt/clay persisted into June 2011 (95 percent). The concentrations of Al and Fe followed the same general trend as the silt/clay size particles (maximum concentrations occurred in May) (fig. 4, table 1), as described above, reflecting the contribution of clays rich in Al and Fe. The April dip in metal concentrations occurred in Al and Fe as well; however, this dip in metal concentrations did not directly correspond to the presence of larger particles (table 1). The April dip in metal concentrations does not seem to be related to a particle-size effect.

Surface sediments from Palo Alto in 2011 contained about 1.16 percent (by weight) total organic carbon (table1). Carbon content varied slightly during the year, tracking the seasonal changes in sediment composition described above. Specifically, TOC ranged from 1.13 to 1.62 percent during January to May and declined to a minimum of 0.81 percent in October.

The metals chromium (Cr) and nickel (Ni) 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 and Ni appear to vary seasonally as indicated by the varying concentrations of these metals in surface sediments. Typically, maximum concentrations coincide with winter/spring maxima in fine sediments, whereas minimum concentrations occur during the late summer/fall (fig. 5, table 1). The minimum Ni concentration occurred in the fall of 2011 (67.2 mg/kg in October) and the maximum in spring of 2011(98.0 mg/kg in May). The concentration range and timing of variation is typical of the record (1994–2011). The concentration of Cr also declined from its maximum concentration in May to its minimum in fall (September-October). Both elements (Cr and Ni) showed a concurrent dip in concentrations in April 2011 before hitting their maxima in May. Average concentrations of Cr tended to increase during 2006–2010, approaching the record high Cr concentrations in 2003; this trend was not sustained in 2011.

Concentrations of Cu and Zn in sediments are shown with sediment guidelines set by the National Oceanic and Atmospheric Administration (Long and others, 1995) in figures 6 and 7 and table 1. 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 on sensitive species (21–47 percent of the time for different metals). Values greater than the ERM were frequently associated with adverse effects on sensitive species (42–93 percent of the time for different metals). It is important to note, however, that these effects levels were derived mostly from bioassay data and are not accurate estimates of site-specific sediment toxicity. During 2006–2007, Cu concentrations increased to concentrations similar to those observed before 2000, apparently reversing a trend of declining concentrations during the intervening years. During 2008–2011, Cu concentrations decreased from 2006–2007 values and were slightly higher than those observed during 2000–2005. Concentrations remained above the ERL (34 mg/kg) for most of 2011. The typical seasonal pattern was evident, with

the exception of a dip in Cu in April (36 mg/kg) before Cu concentrations peaked in May (50 mg/kg), then fell below the ERL in September (30 mg/kg) and October (31 mg/kg) (fig. 6, table 1). The higher partial-extractable Cu concentrations in 2011 appear to reverse the downward trend observed from 2006 to 2010. Partial-extractable Zn concentrations were below the Zn ERL (150 mg/kg) for all of 2011, while near-total Zn concentrations just barely exceeded the Zn ERL in March and May (151 mg/kg for both months) (fig. 7, 1). Zn concentrations in 2011 were slightly higher than those observed in 2008–2010, but remain below the highs observed in 2006–2007.

Silver extracted from sediments averaged 0.29 mg/kg in 2011, higher than the record's lowest annual averages in 2008–2009 (0.20 mg) but still lower than the average for 1994–2011 record. The seasonal pattern in 2011 showed an anomaly (fig. 8, table 1). A high Ag concentration in January was followed by 3 months of low concentrations followed by the annual maxima in May and June (0.43 mg/kg and 0.38 mg/kg, respectively). The annual minimum was observed in September (0.21 mg/kg).

Mercury concentrations throughout all of 2011 were within the range usually observed in San Francisco Bay (0.2–0.4 mg/kg). The annual average of 0.27 mg/kg is typical of the record. Concentrations in sediment deviated slightly from the typical seasonal pattern. The highest concentration occurred in June (0.32 mg/kg), after the late spring/early summer maxima shown in many of the elements in 2011. Additionally, the lowest concentration of Hg was observed in December (0.19 mg/kg), somewhat later than in most years (fig. 9, 1).

Selenium concentrations increased substantially in 2011 (annual average 0.6 mg/kg) from the record low concentrations observed in 2010 (annual average 0.2 mg/kg) (fig. 9, table 1), yet they remained below the highest annual average concentration on record in 2008 (0.8 mg/kg). 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, 2008, and 2011) to relatively low concentrations (2005, 2007, and 2009–2010).

Clam Tissue

Metal concentrations in the soft tissues of *Macoma petalum* reflect a combination of metal exposures from water and food and the diluting and concentrating effects of gaining and losing tissue mass. 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 (figs. 10 and 11, appendix 9). During 1977–1987, the ranges in annual concentrations of Cu and Ag were 95–287 mg/kg and 45–106 mg/kg, respectively. Since 1987, concentrations have been considerably lower, 24–71 mg/kg for Cu and 1.8–20 mg/kg for Ag. Concentrations were particularly low and stable from 1997 through 2005, followed by a 2-year period of elevated concentrations in 2006–2007. Annual mean concentrations of Cu and Ag for 2011 were 28.7 ± 4.4 mg/kg and 2.02 ± 0.41 mg/kg, respectively; these are within the range of concentrations observed since 2008. Concentrations of Ag for 2008–2011, along with the concentrations observed in 2003–2005, are the lowest concentrations observed at the site. Copper concentrations for 2008–2011 are also among the lowest concentrations observed at the site.

Intra-annual 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 2007 were relatively large and bracketed years of less variability (figs. 12 and 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 2011, Ag and Cu concentrations were highest in October (3.74 mg/kg and 48.9 mg/kg, respectively). Concentrations reached their annual minima of 0.509 mg/kg

Ag and 12.0 mg/kg Cu in March (table 2). Copper concentrations increased slightly through the spring/summer with a more dramatic increase from September to December.

As with Cu and Ag, tissue concentrations of Cr (fig. 14, table 2), Ni (fig. 15, table 2), and Zn (fig. 16, table 2) also exhibited seasonal cycles. The seasonal cycles of Cr and Ni were very similar in terms of their timing and magnitude throughout the record (1994–2011). Maximum concentrations occurred in the winters of 1996–1997 and 2006–2007, whereas 2000–2002 was a period of relatively low winter-maximum concentrations. However, neither element exhibited a clear temporal trend (either downward or upward) in concentration. Cr and Ni concentrations for 2011 were similar in magnitude to the previous year, but the timing of the annual minima shifted from June in 2010 to March in 2011. In addition to the typical seasonal pattern, Zn concentrations exhibited a slight long-term decline of seasonal maxima through 2005. During 1994–1997, Zn concentrations were notably higher throughout the year than in subsequent years. In 2006, the seasonal cycle was weakly expressed, and concentrations increased notably to values comparable to those observed in the mid to late 1990s. Seasonal patterns were again evident in 2007–2009 but weakly expressed in 2010–2011. Concentrations of Zn over the past 4 years (2008–2011) are similar to those observed during 2000–2005. In 2011, maximum Zn concentrations occurred in January (344 mg/kg), and they decreased to their lowest concentrations in March (204 mg/kg), earlier in the year than in the typical seasonal pattern. 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 observed near the San Jose/Santa Clara Water Pollution Control Plant, indicating that regional-scale processes may be more important than treatment plant inputs in controlling the bioavailability of these elements.

Average Hg concentration in *M. petalum* for 2011 was typical of the record, at 0.28 mg/kg, and was the lowest annual average since 2005. Seasonal variation for 2011 was typical of the record, with a minimum of 0.19 mg/kg in June, bracketed by winter maxima in January and December (0.39 mg/kg and 0.41 mg/kg, respectively). A long-term trend in Hg concentration is not evident (fig. 17).

Selenium concentrations in *M. petalum* in 2011 did not display a strong seasonal pattern. Selenium was highest in January (5.4 mg/kg), then declined in February to 3.9 mg/kg and remained relatively unchanged for the rest of the year (fig. 18, table 2). Average Se concentrations had shown an increasing trend from 2007 to 2010, but average selenium in 2011 (4.0 mg/kg) was the lowest since 2005 and typical of the record. Long-term trends in the data are not evident.

Data on the condition index (CI) for *M. petalum* at Palo Alto extends back to 1988 (fig. 19, table 2). As previously discussed, the data fluctuate seasonally in relation to growth and reproductive cycles, and annual cycles differ in magnitude. Maximum CI (225 mg) and average CI (133 mg) in 2011 were higher than is typical for the record and consistent with values observed since 2007.

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 Ag (and perhaps Cu) 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 indicates that reproductive activity was related to the concentration of metals in the animal. This finding has implications for the reproductive success of the population.

The time series of reproductive activity (figs. 20 and 21) 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 one time during the normal seasonal cycle of reproduction. That cycle begins in fall, with spawning occurring the following spring (see table 3 for detailed reproduction data for 2011). A closer look at the last 6 years of data demonstrates this seasonality of reproduction—unlike the earlier periods, animals do not stay reproductively inactive for longer than a month or two.

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, continues to show 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 latest 4 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 at the study site 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 38-year period from 1974 to 2011 (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 has now rebounded to levels seen in the early 2000s. There were six species that did show trends in their abundance since the 1970s, and these trends continued through 2011. 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 abundance (fig. 27) after 1998. That pattern mostly continues through today. The second species to show a significant trend is the small polychaete worm *Streblospio benedicti*, which also builds a tube above the surface of the mudflat. As with *A. abdita*, *S. benedicti* abundance has declined and, over the past 4 years, the species has settled into a seasonal pattern of increasing fall abundance followed by a winter decline (fig. 28). The abundance of the small burrowing crustacean *Grandiderella japonica*, a deposit feeder, became more seasonally consistent after 2000 (fig. 29), although the population abundance was particularly low in 2011. This species 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, showed large seasonal fluctuations in abundance through the 1980s. *N. succinea* abundance became more stable in the late 1990s and remained so until 2005, when the abundance decreased (fig. 30). *N. succinea* abundance declined further in 2011. Two species showed an increase in abundance within the time series. The first was the polychaete worm *Heteromastus filiformis* (fig. 31), a sub surface 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. Abundance remained higher than in the late 1970s until 2008, when there was a large decline in *H. filiformis* abundance (fig. 22). *H. filiformis* abundance increased slightly in 2011; as was seen in the 1980s, this is a species that increases slowly, possibly because of their egg-laying mode of recruitment. The second species showing an increase was *Nippoleucon hinumensis*, a small, burrowing, surface-deposit-feeding 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 continued to be present in 2011. A complete list of the benthic species found at the Palo Alto site in the year 2011 is shown in appendix 10. The benthic species name changes (as of 2011) for appendix 10 are shown in appendix 11 .

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 sedimentation or freshwater inundation. 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 2008, and animals were found again at the site 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 include 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*. This trend continued into 2011, when brooders and oviparous species were more than half of the top 10 most abundant species.

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 Ag and Cu in the sediment and in the tissue of *M. petalum* (using data reported by David and others, 2002). Therefore, this update will consider only those metals. Metal concentration and abundance of species with the most susceptible mode of feeding and reproduction will be compared over the period of the study. One such susceptible species, the worm *H. filiformis*, increased in abundance with the decrease in Ag and Cu until 2008. This was of interest because *H. filiformis* has continual tissue contact with the sediment 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 2 or 3 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 species' 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 now found the environment agreeable. 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.

Two species that have shown the opposite trend of *H. filiformis*, the crustacean *A. abdita* (fig. 27) and the worm *S. benedicti* (fig. 28), have declined in abundance coincident with the decline in metals. These species have very similar life-history characteristics that make them less susceptible to high Ag and Cu concentrations in sediment. Both species live on the surface of the sediment in tubes

that are built from sediment particles. They feed on particles in the water column or on particles that have settled to the sediment surface, brood their young, and produce young that are capable of either swimming or settling upon hatching. 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 what is expected of an opportunistic species.

Other species share the characteristics highlighted in our discussion of *H. filiformis*, *S. benedicti*, and *A. abdita*; the species with similar characteristics have been combined into plots that examine the percent of abundance represented by each feeding and reproductive mode (figs. 33–36). Because the natural spatial variability (that is, the large standard deviations around the monthly means) and seasonal variability of invertebrate abundance can be quite large, the average percentages for the month of August of each characteristic reproductive and feeding mode are shown in figures 33–36. To interpret these plots, the life-history characteristics must first be examined to determine if there is some mechanism by which this organism could be responding to a decrease in Ag or Cu in the environment. It is likely that Ag, but probably not Cu, adversely affected reproduction of all animals, but it was most obvious in species with juveniles that were not transported from outside the area as pelagic larvae. Therefore, the species having oviparous and mixed (species capable of oviparity and brooding) reproductive modes (Ahn and others, 1995; Hornberger and others, 2000b) are worth examining in the early years of the study. The gradual increase in abundance of this group through 1983 was a response to the gradual reduction of metals in the environment during that time. In the present environment of much lower metal concentrations, these species respond to a variety of stresses, and their percentage in the community reflects those stresses (figs. 33 and 34). Although the percentage is volatile, it never stays as low as it was in the early 1970s. The authors interpret this as being a reflection of the general health of the benthic environment. In a similar manner, we can examine the feeding modes of the majority of the individuals (figs. 35 and 36). High concentrations of either Cu or Ag are unlikely to be healthy for species that ingest the sediment in order to consume the interstitial and attached carbon; thus, it is reasonable to expect species that consume particles from the water column to be more protected from the contaminants in the sediment. Filter feeding species are usually the dominant group throughout the data-set, and the subsurface deposit feeders are the group that shows the largest increase in dominance after the 1970s. This is consistent with the conceptual model posed here.

The change in function of the benthic community over time can be examined by ranking the top 10 species by abundance and plotting the log (n + 1) of mean abundance against the rank of each species. The plot for 2011 (fig. 37) 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 three hydrologically dry years during this study (1977, 1989, and 2002) shows that the shape of the curve has changed greatly and that the curve is now similar to that seen in 2002. The effect of the 2008 defaunation event is not as clearly visible in 2011 as it was in 2009–2010, when opportunistic species were again dominant and the shape of the curve was more similar, but not identical to, what was observed in the early years. The series of lines shows a community that was heavily dominated by three species in 1977 and 1989, and a community with 1–2 dominant species in 2002 and 2011. 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. In contrast, the 2011 community plot is dissimilar because the opportunists are present but display less dominance in the community (the most opportunistic species rank 1, 9, and 10).

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: feeding mode in fig. 38 and reproductive mode in fig. 39. 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 two species that feed on food particles on the sediment surface. In 1989, the species composition had shifted such that filter feeding species, subsurface deposit and surface 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 (2011) show the community to be almost evenly composed of a mix of subsurface deposit and surface deposit feeding species, filter feeding species, and mixed feeding species. Over the period of this study, a shift has occurred from a community dominated by species that feed 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 in early 2008.

An examination of these rank-abundance plots using reproductive mode as the descriptor for each point is equally informative (fig. 39). 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 in combination with those that lay eggs in the sediment (oviparous) have equal presence. 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 2011 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 (for example, Hornberger and others, 2000a; Luoma and others, 1991, 1995a, 1996; Moon and others, 2005; Shouse and others, 2003, 2004; Thompson and others, 2002; Cain and others, 2006; Dyke and others, 2010, 2011) with additional data from January 2011 through December 2011 to create a record spanning 38 years. This long-term dataset includes sediment chemistry and tissue concentrations of metals (1977–2011 for Cu and Ag, 1994–2011 for other metals), condition index (1988–2011), and reproductive activity in *M. petalum* and population dynamics of benthic invertebrate species (1974–2011). The time series encompasses the period when exceptionally high concentrations of Cu and Ag 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 San Francisco 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 were highly correlated with Cu loadings from PARWQCP (concurrent loading data for Ag were not available). Metal levels in sediments and clams responded 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 San Francisco 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, whereas 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 intra-annual 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, as well as 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 intra-annual variation.

The ecology of the Palo Alto mudflats is part of the larger South San Francisco Bay, which has been undergoing some changes in recent years. During 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) indicate 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 San Francisco Bay to grow. Since 2005, scientists 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 this 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 San Francisco Bay influences during these years. This finding solidifies the authors' confidence that the changes observed in the benthic community are in large part due to local factors.

2011 Observations

Throughout 2011, Cu and Ag 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 Cu and Ag 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 2009–2010 from the record high concentrations observed in 2008, but sediment Se concentrations in 2011 increased to levels similar to 2006. Sedimentary Se concentrations have been variable from year to year and showed no sustained temporal trend. In another example, annual average concentrations of Cu and Ag in *M. petalum* were relatively low from 1997 to 2005, increased notably in 2006–2007, and have since returned to 1997–2005 levels in the past 4 consecutive years (2008–2011). The most recent results (2011) show that Ag and Cu in *M. petalum* are only 2 percent and 12 percent, respectively, of the maximum values observed during 1978–1980. Concentrations of Ag and Cu in sediments in 2011 were 18 percent and 48 percent, respectively, of the record high concentrations observed in 1979. Interannual variation in bioavailable Cu and Ag from 1991 to 2006 did not correlate with discharge of Cu and Ag from PARWQCP (Lorenzi and others, 2007), indicating that, as with other elements of regulatory interest, including Cr, Ni, and Zn, regional-scale factors now largely influence sedimentary and bioavailable concentrations (see, for example, Luoma and others, 1998). Factors that affect 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. Ideally, the effects of these variables will continue to be investigated.

The long-term dataset demonstrates various adverse effects 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 2011. In early 2008, the benthic community declined, with few animals present in February. This decline was likely the result of 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 to avoid 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 2009–2010 data revealed a community that had had a short-term physical stressor but not one that was subject to unhealthy sediment. In 2011, the data

continue to show signs of recovery and further examples of the community dynamics in terms of the species present as well as the stability of the ecosystem in terms of functional group consistency. 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 be established only 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 to stressors introduced by humans. 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 San Francisco 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 San Francisco Bay. Nanomaterials, many of which include metal-based products in forms for which environmental researchers have little or no experience, are being used in an increasing number of common 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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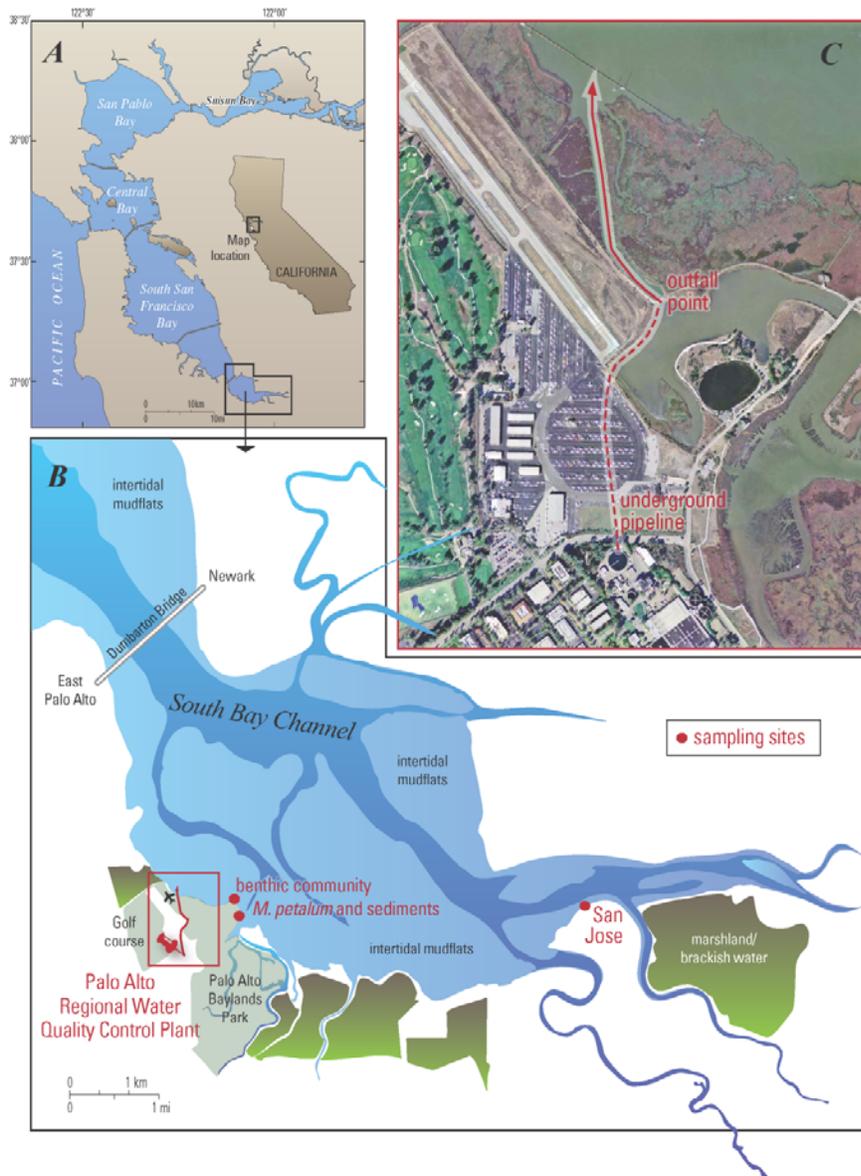
Figure 1. Location of the Palo Alto sampling site in South San Francisco Bay, Calif.

A. 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.
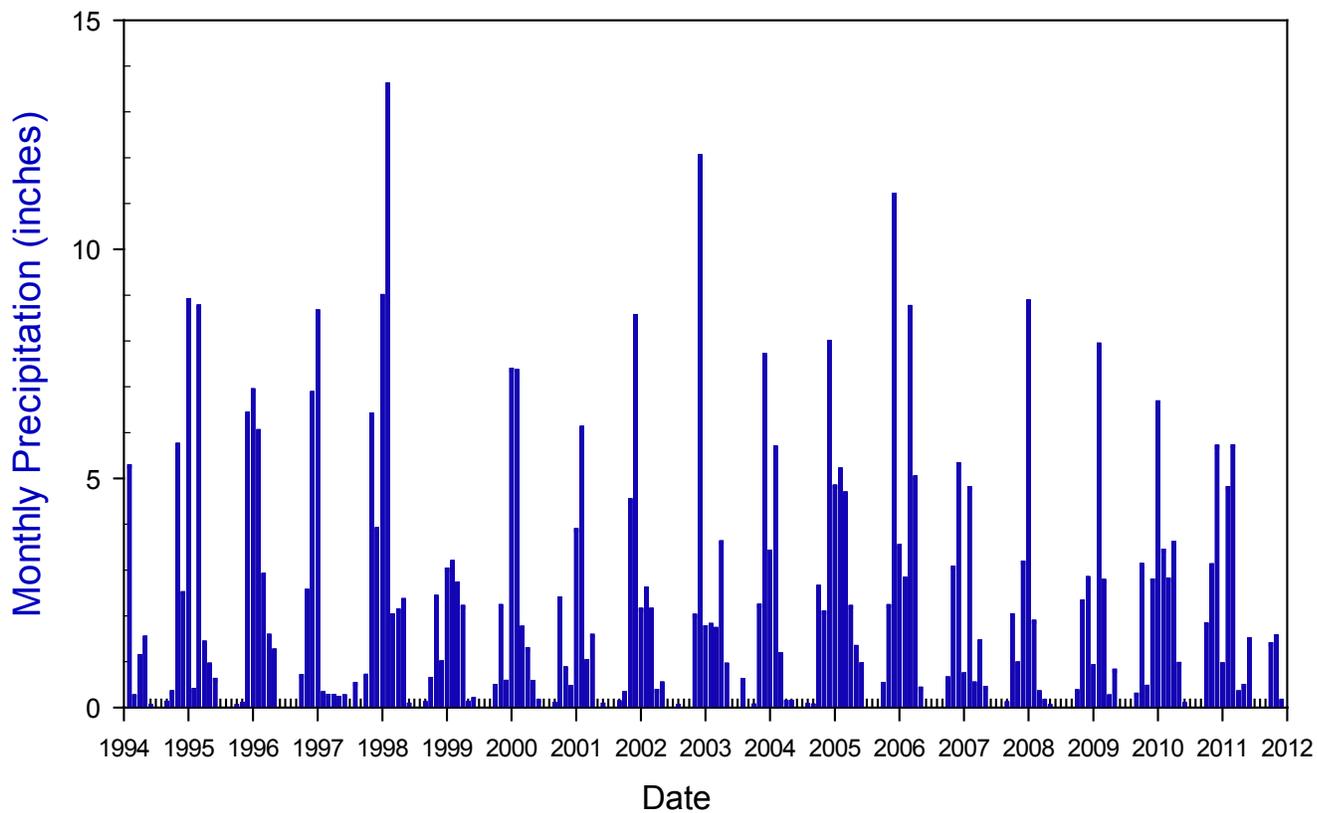
Figure 2. Total monthly rainfall recorded at San Francisco WB AP in San Mateo County, Calif., 1994–2011. The station (identification SFF) is operated by the National Weather Service.
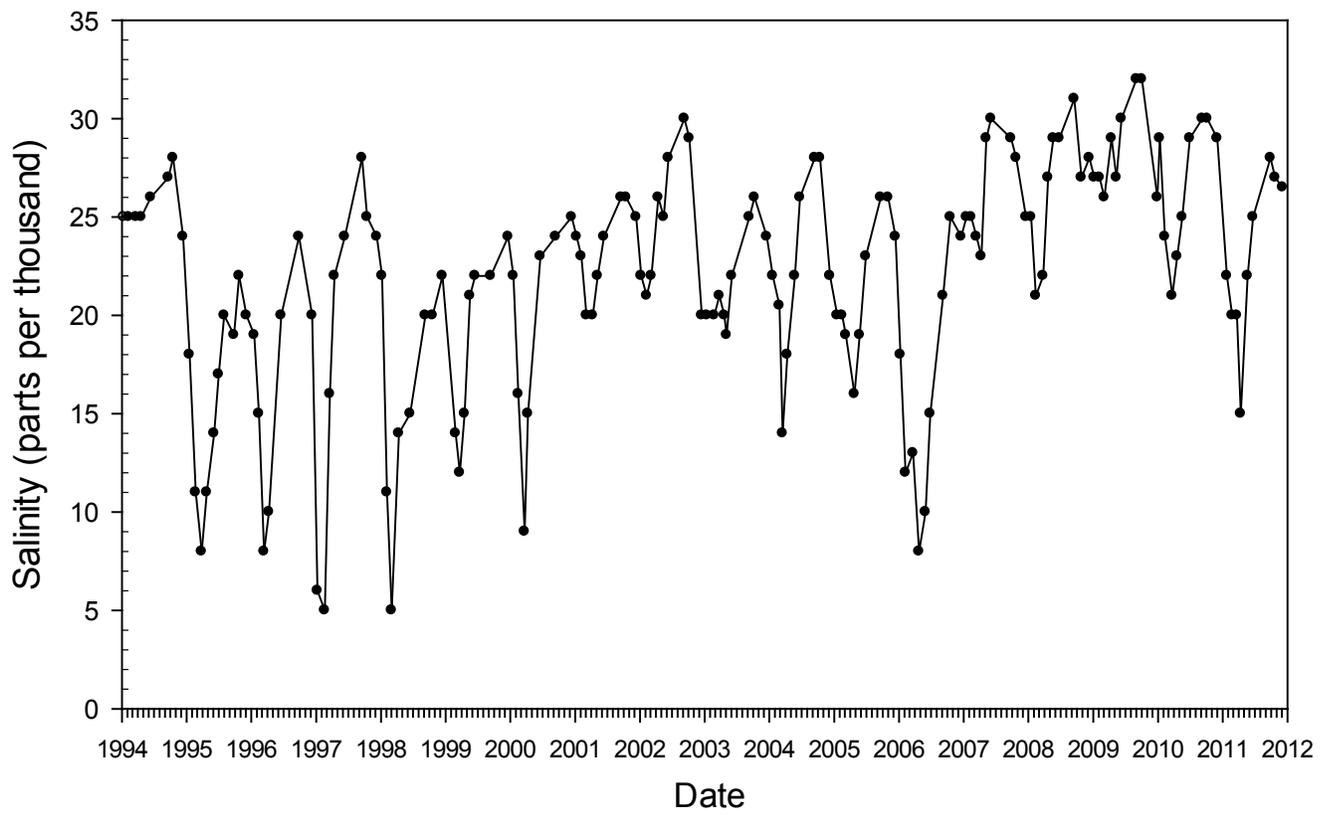
Figure 3. Surface-water salinity at the Palo Alto site, Calif.,1994–2011.
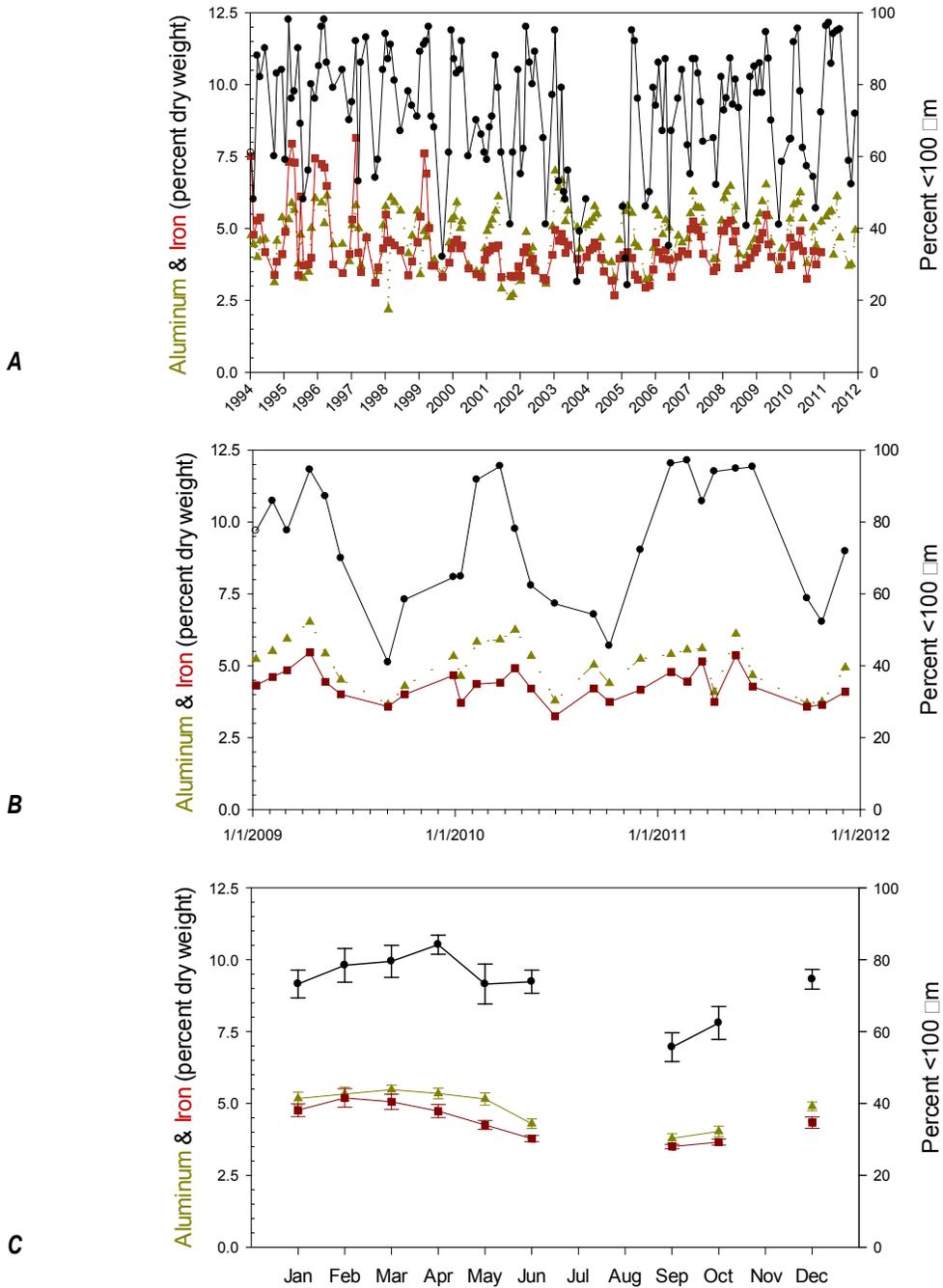
Figure 4. Aluminum, iron, and silt/clay in sediments, Palo Alto, Calif.,1994–2011.

A. Percent aluminum (▲), iron (■) (extracted by near-total digest), and silt/clay (<100 μm) (●). Data on percent fines for 2004 contain unquantifiable biases due to errors in sample processing and, therefore, have been censored.

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Al, Fe, and percent fine sediments. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).
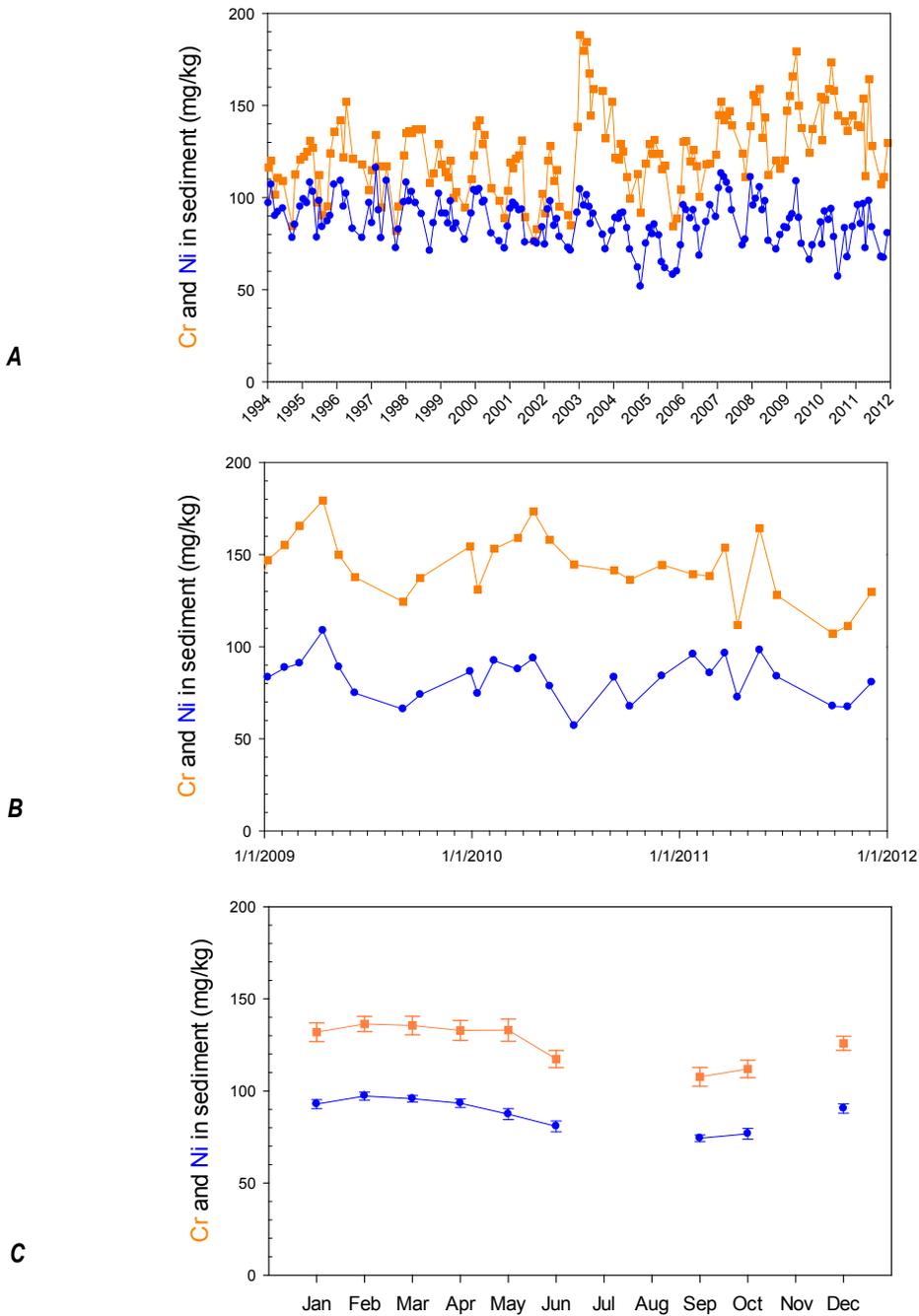
Figure 5. Chromium and nickel in sediments, Palo Alto, Calif., 1994–2011.

A. Concentrations of chromium (Cr) (■) and nickel (Ni) (●) extracted by near-total digest.

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Cr and Ni. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).
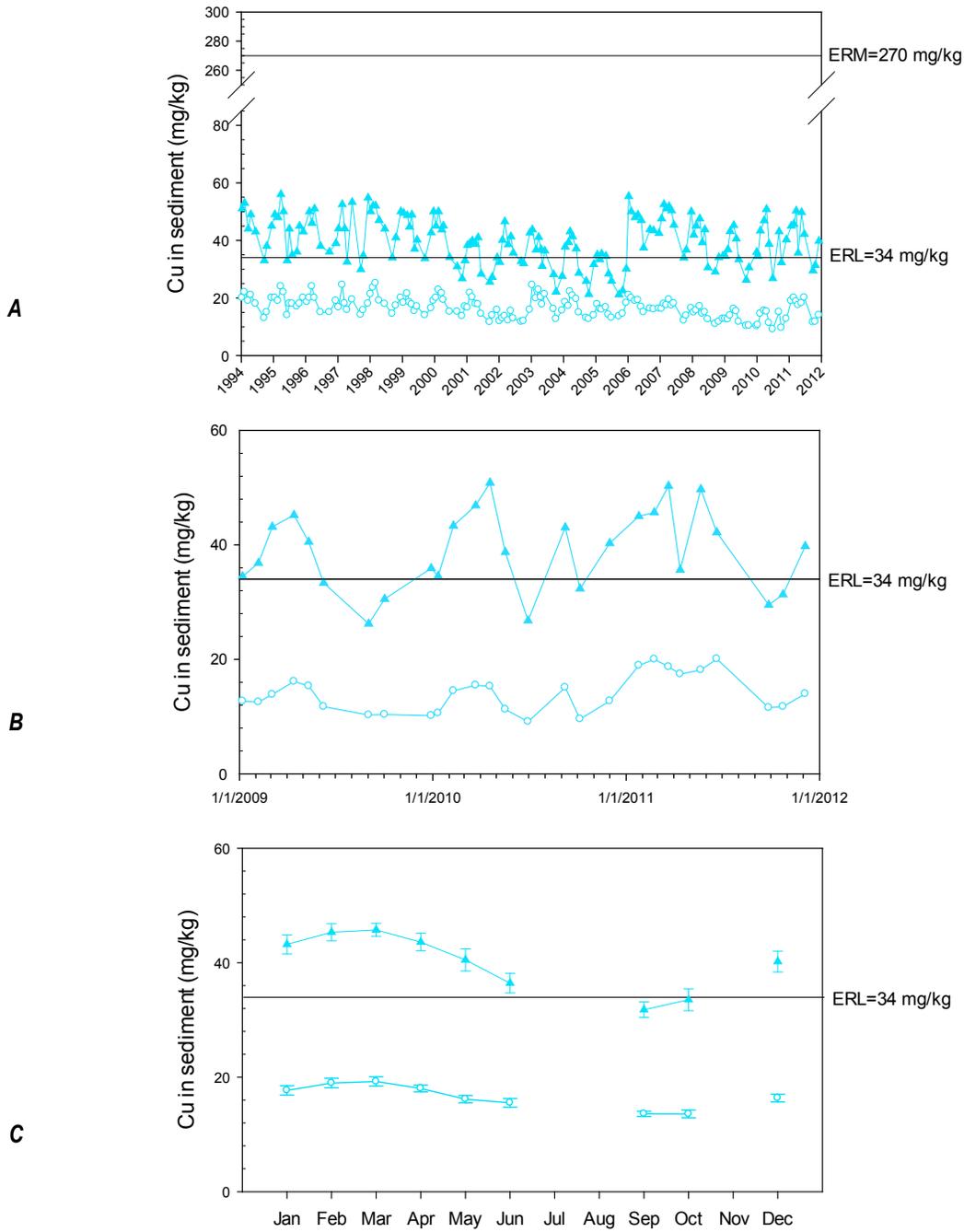
Figure 6. Copper in sediments, Palo Alto, Calif., 1994–2011.

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

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Cu. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).

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).
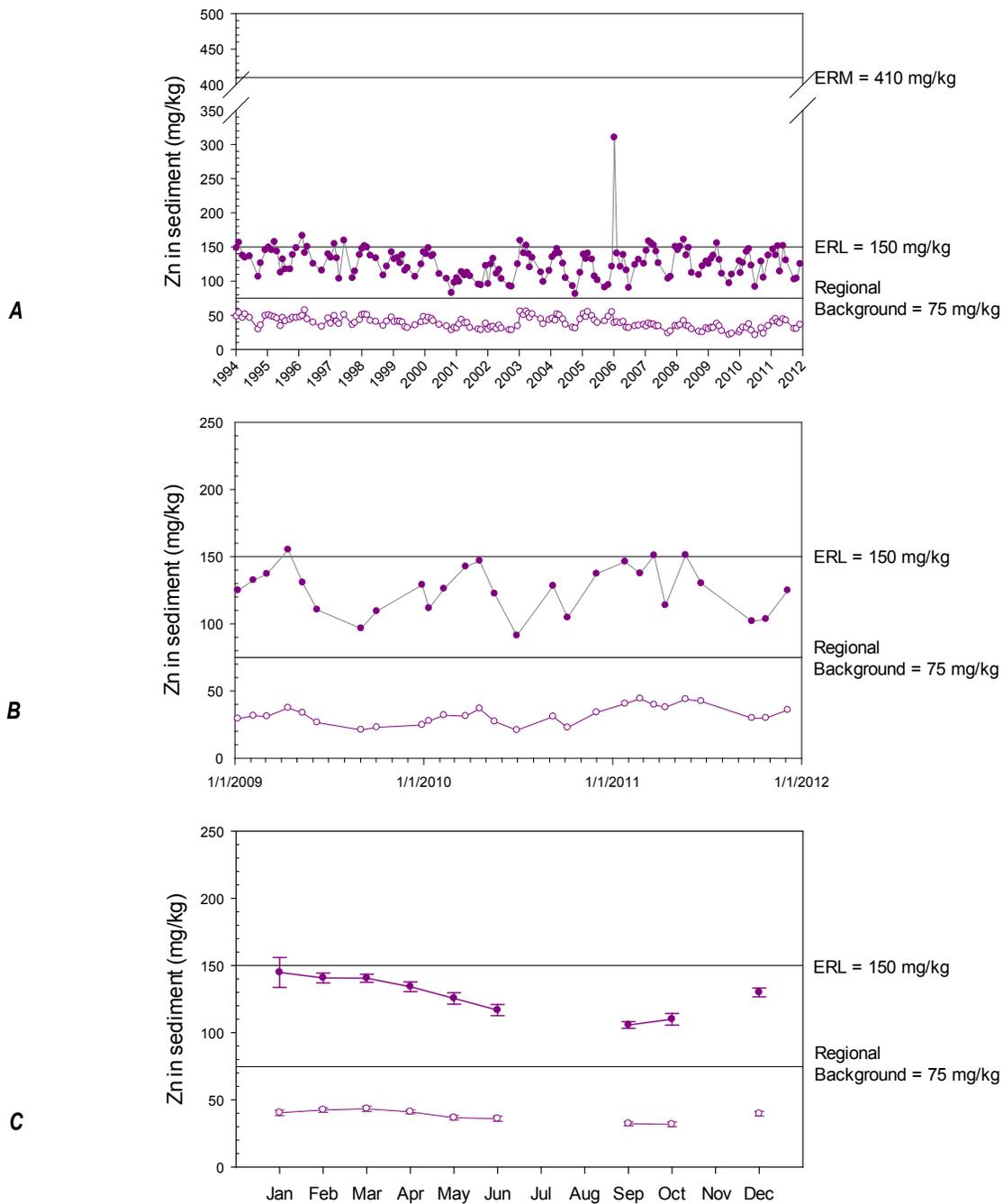
Figure 7. Zinc in sediments, Palo Alto, Calif., 1994–2011.

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

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Zn. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).

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).
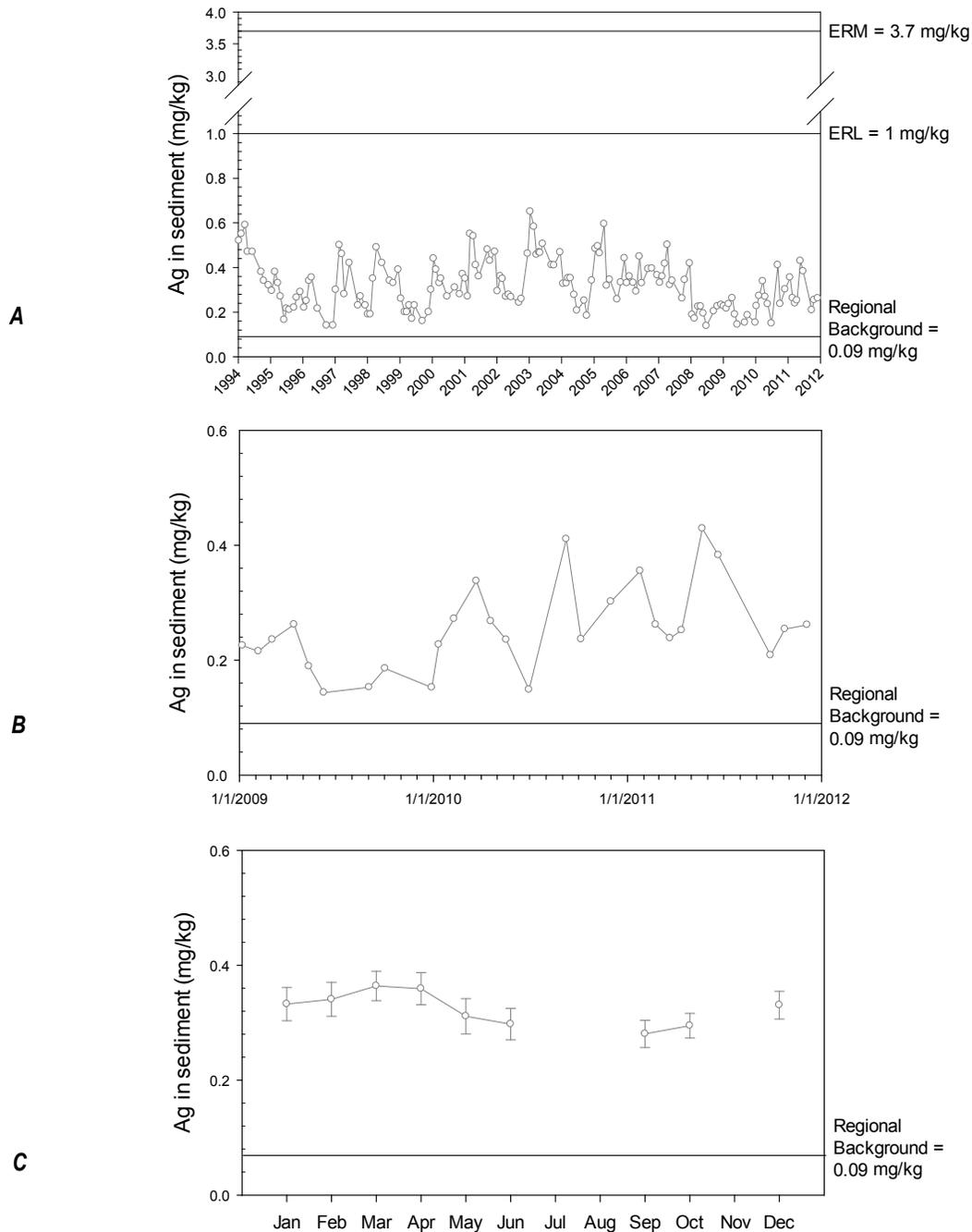
Figure 8. Silver in sediments, Palo Alto, Calif., 1994–2011.

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

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Ag. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).

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).
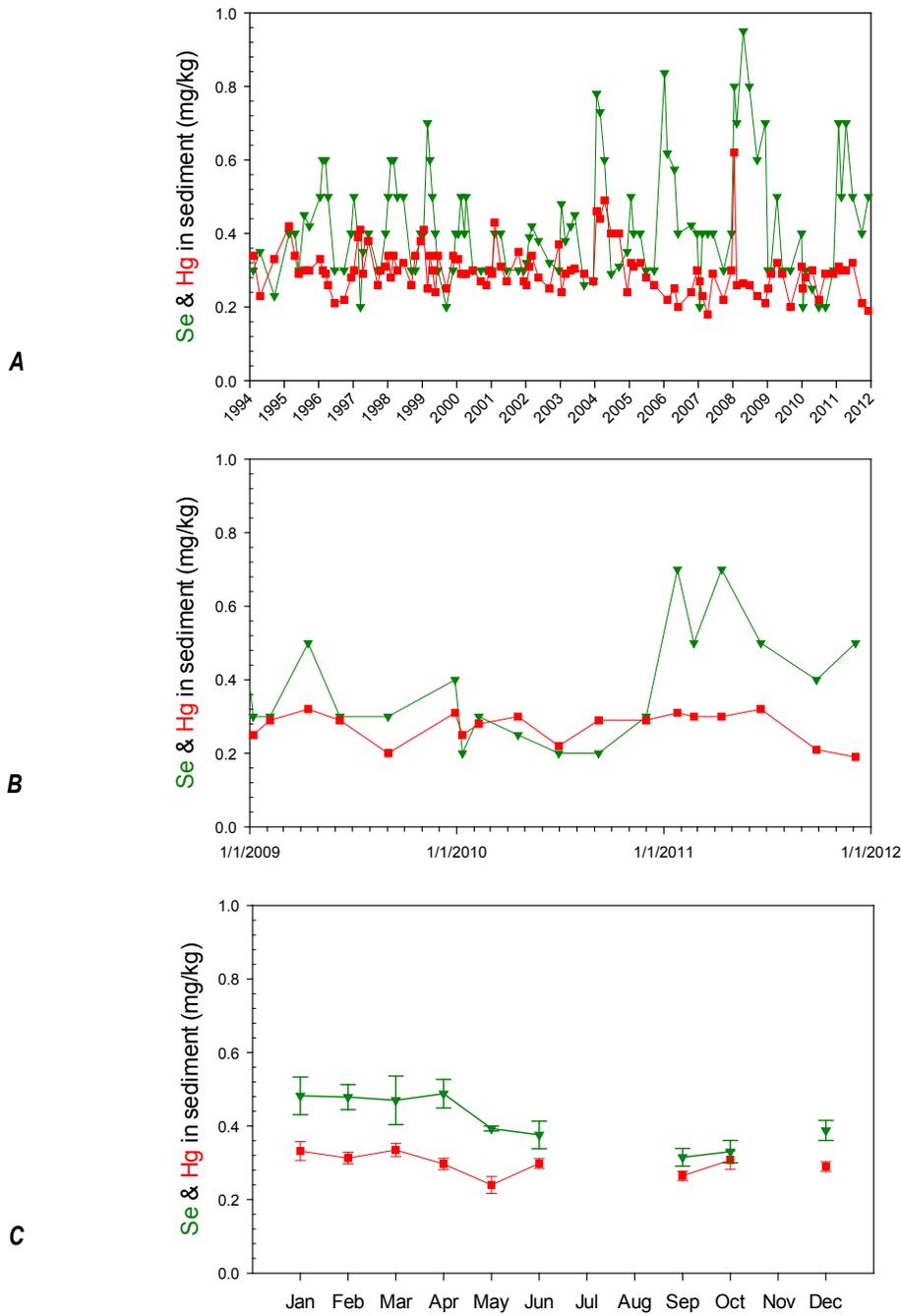
Figure 9. Selenium and mercury in sediments, Palo Alto, Calif., 1994–2011.

A. Selenium (▼); mercury (■).

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Se and Hg. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).
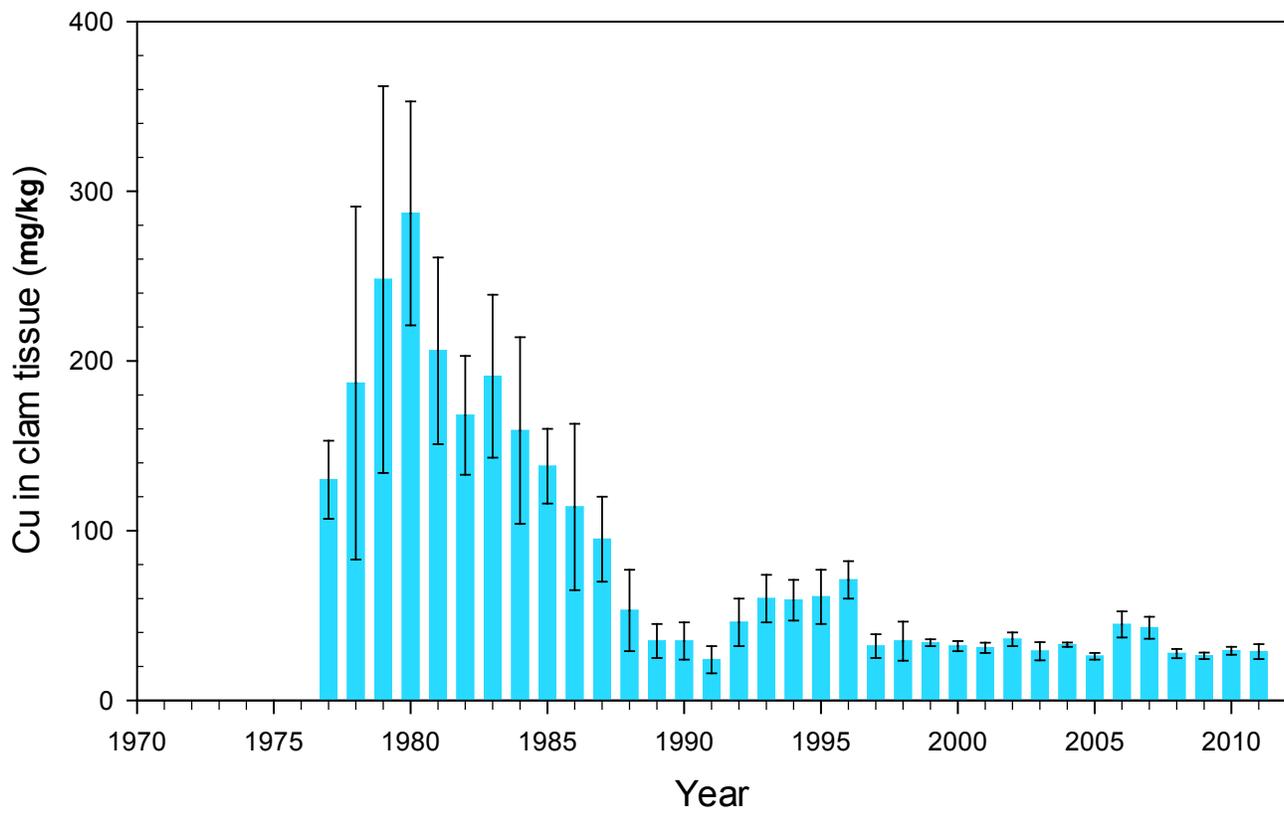
Figure 10. Annual mean copper concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1977–2011.

Values are the annual (grand) means for 7 to 12 separate samples per year and error bars are standard errors of those means (SEM).
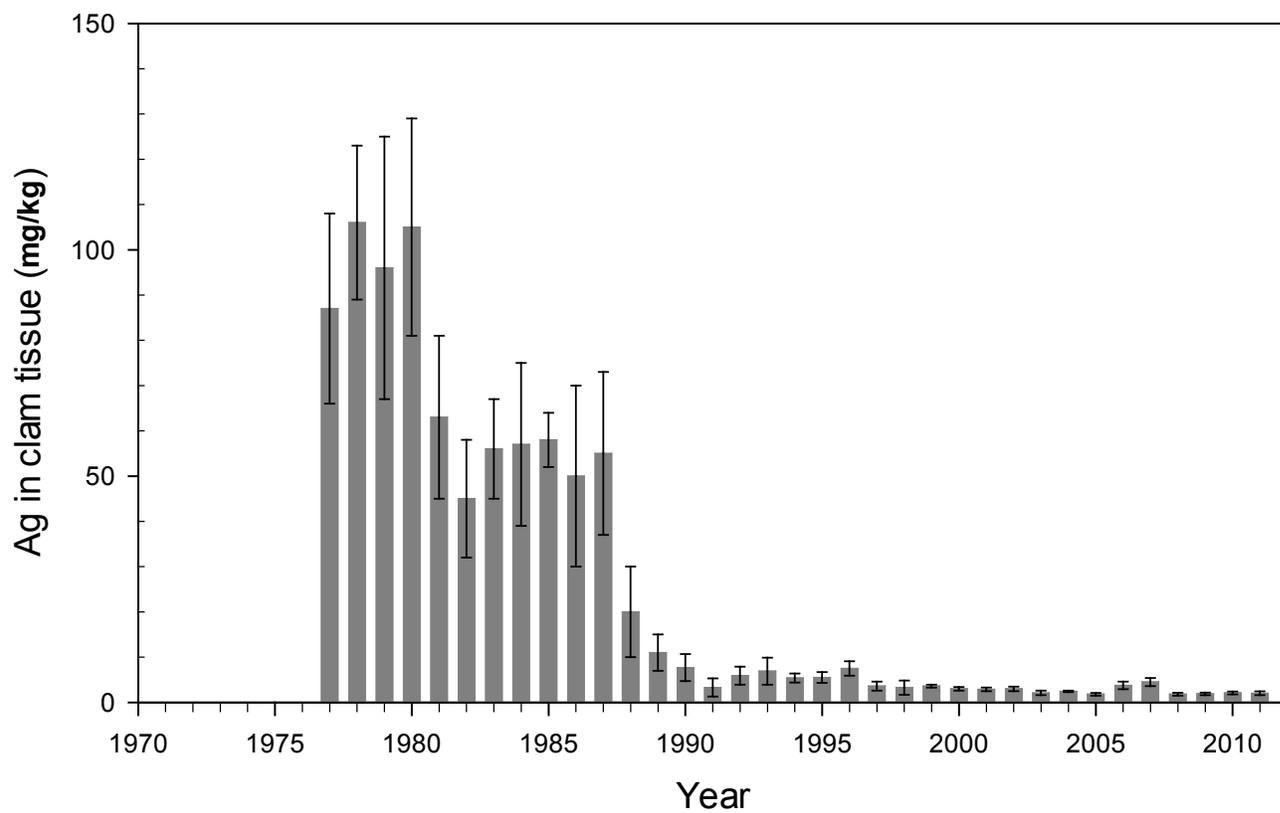
Figure 11. Annual mean silver concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1977–2011.

Values are the annual (grand) means for 7 to 12 separate samples per year and error bars are standard errors of those means (SEM).
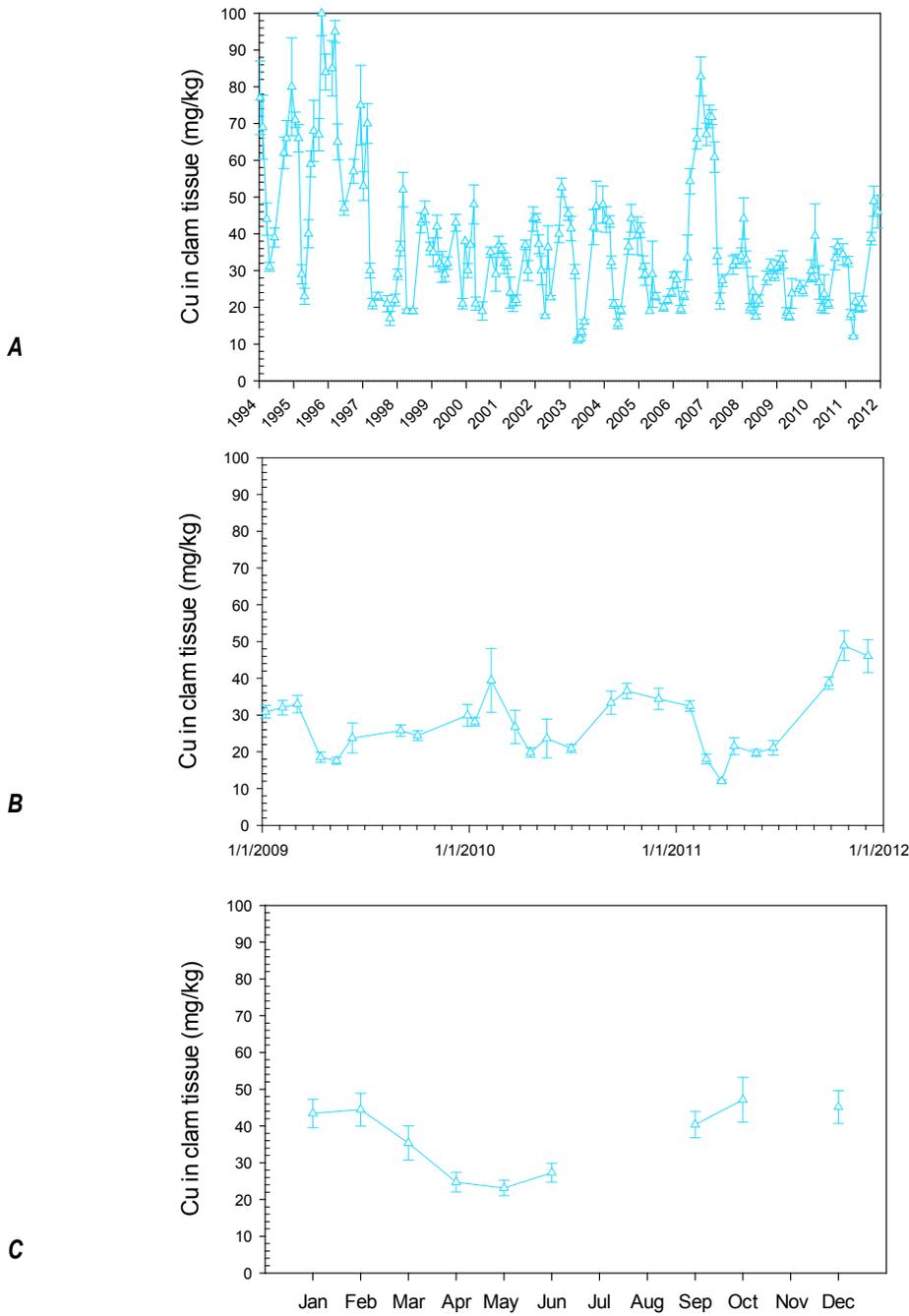
Figure 12. Copper concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2011.

A. 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).

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Cu. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).
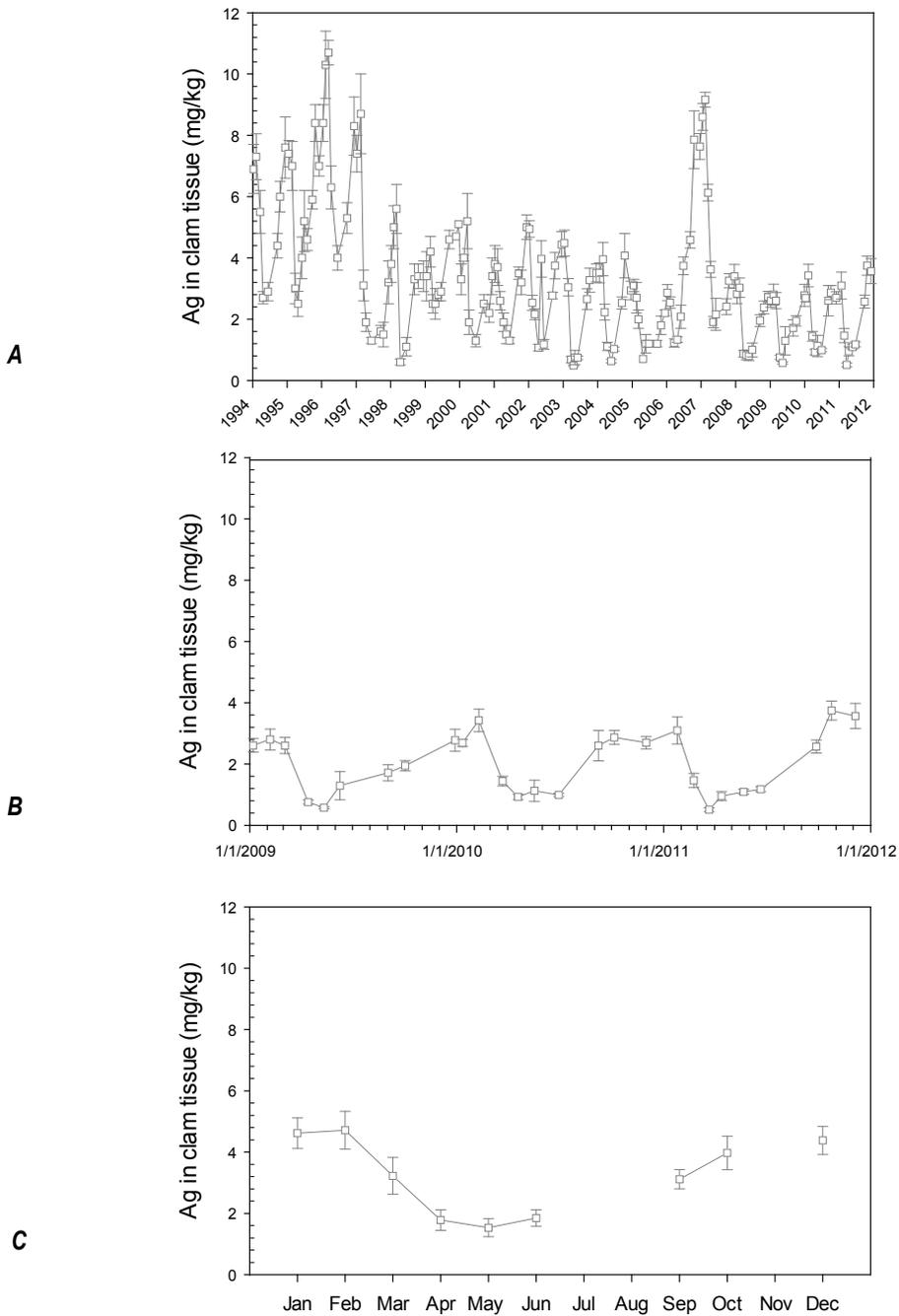
Figure 13. Silver concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2011.

A. 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).

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Ag. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).
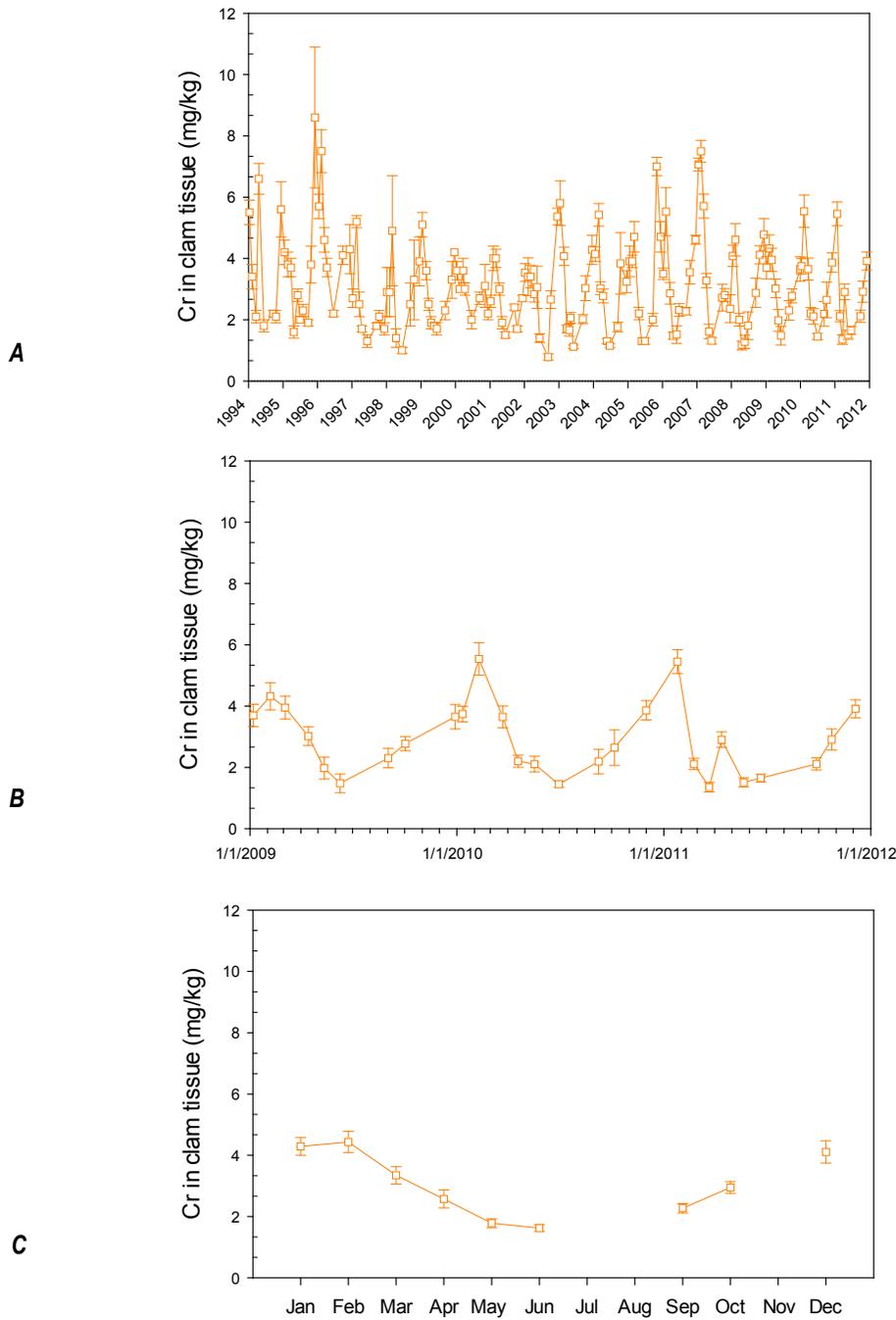
Figure 14. Chromium concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2011.

A. 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).

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Cr. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).
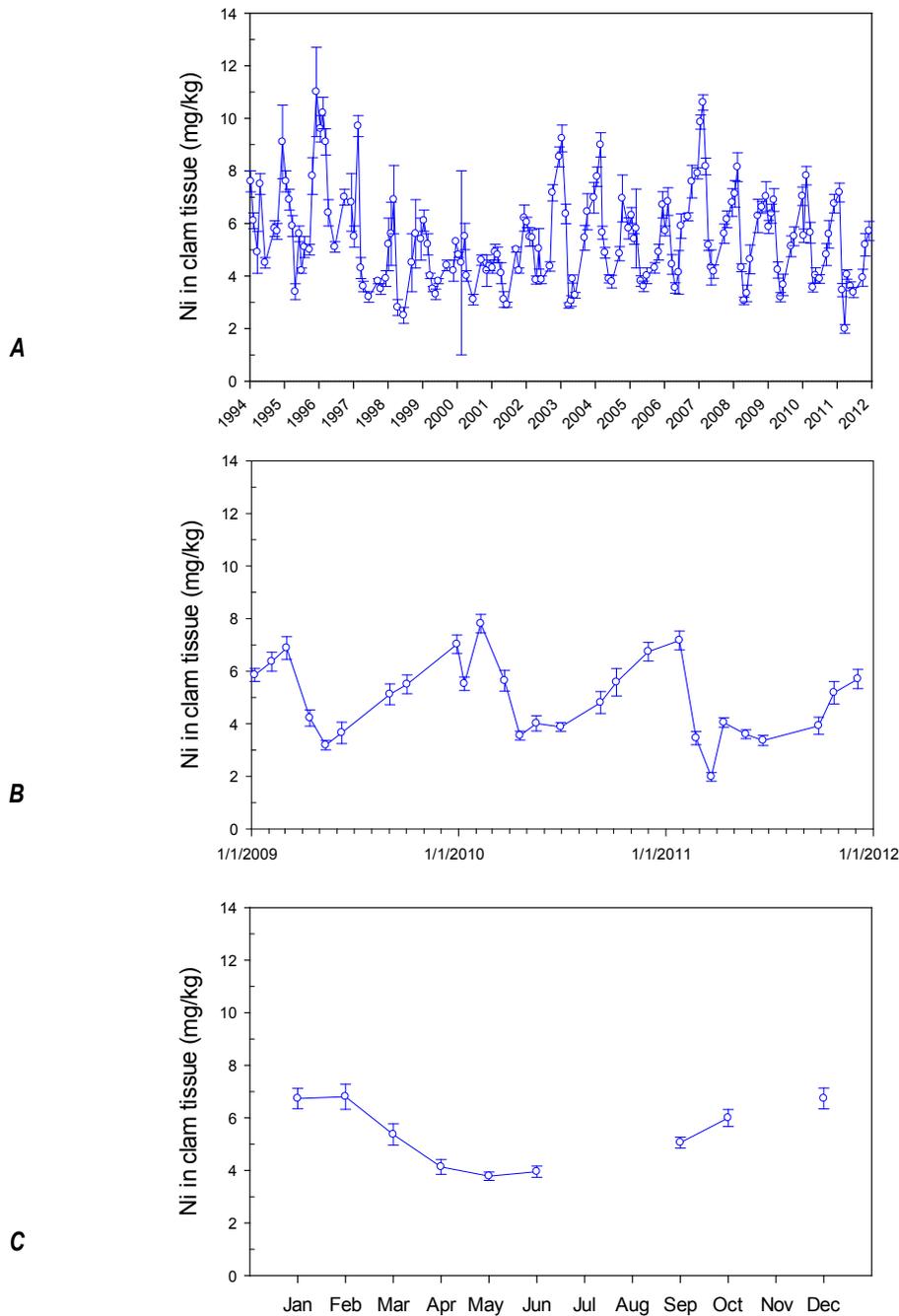
Figure 15. Nickel concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2011.

A. 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).

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Ni. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).
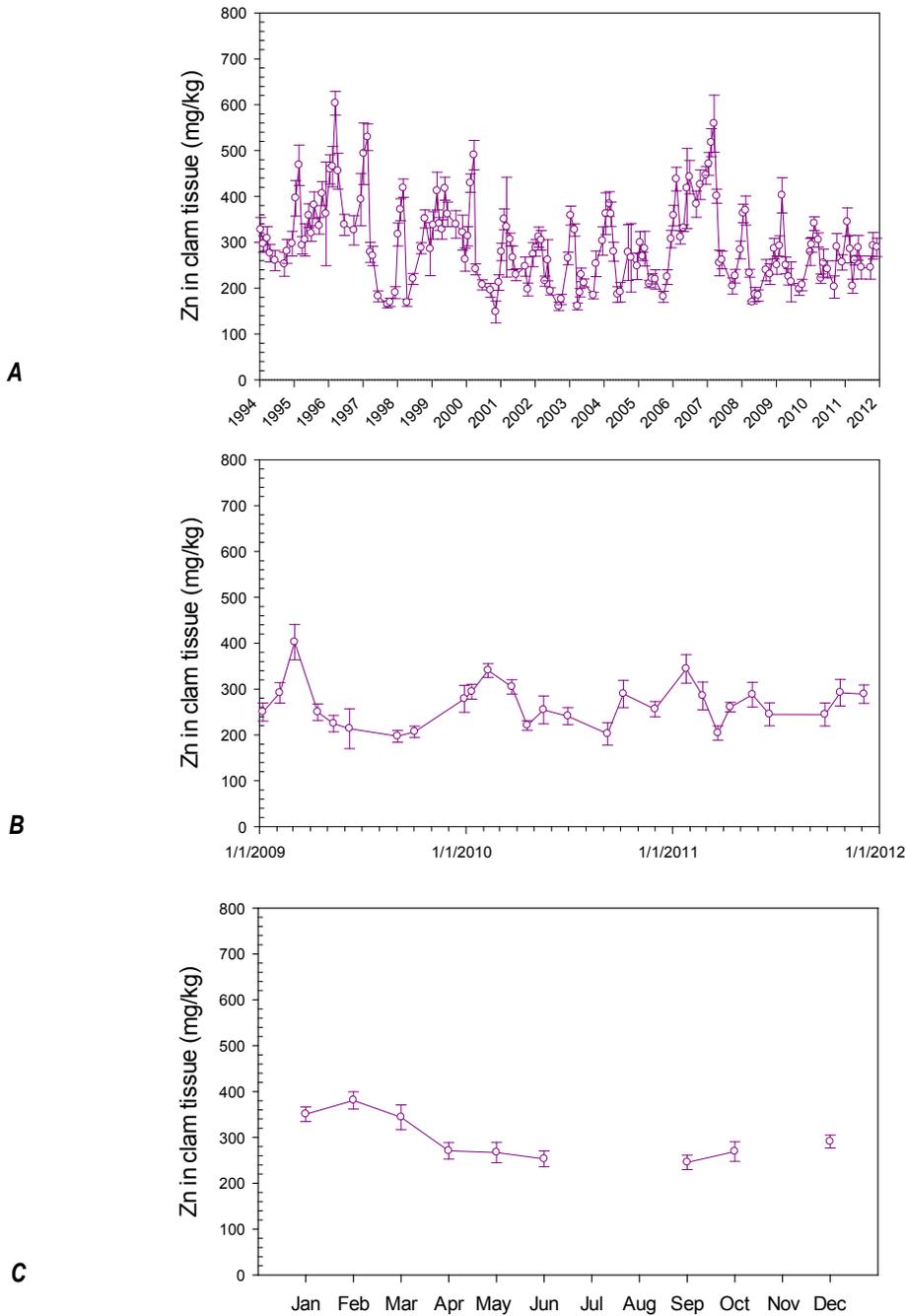
Figure 16. Zinc concentrations in the clam *Macoma petalum,* Palo Alto, Calif., 1994–2011.

A. 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).

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Zn. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).
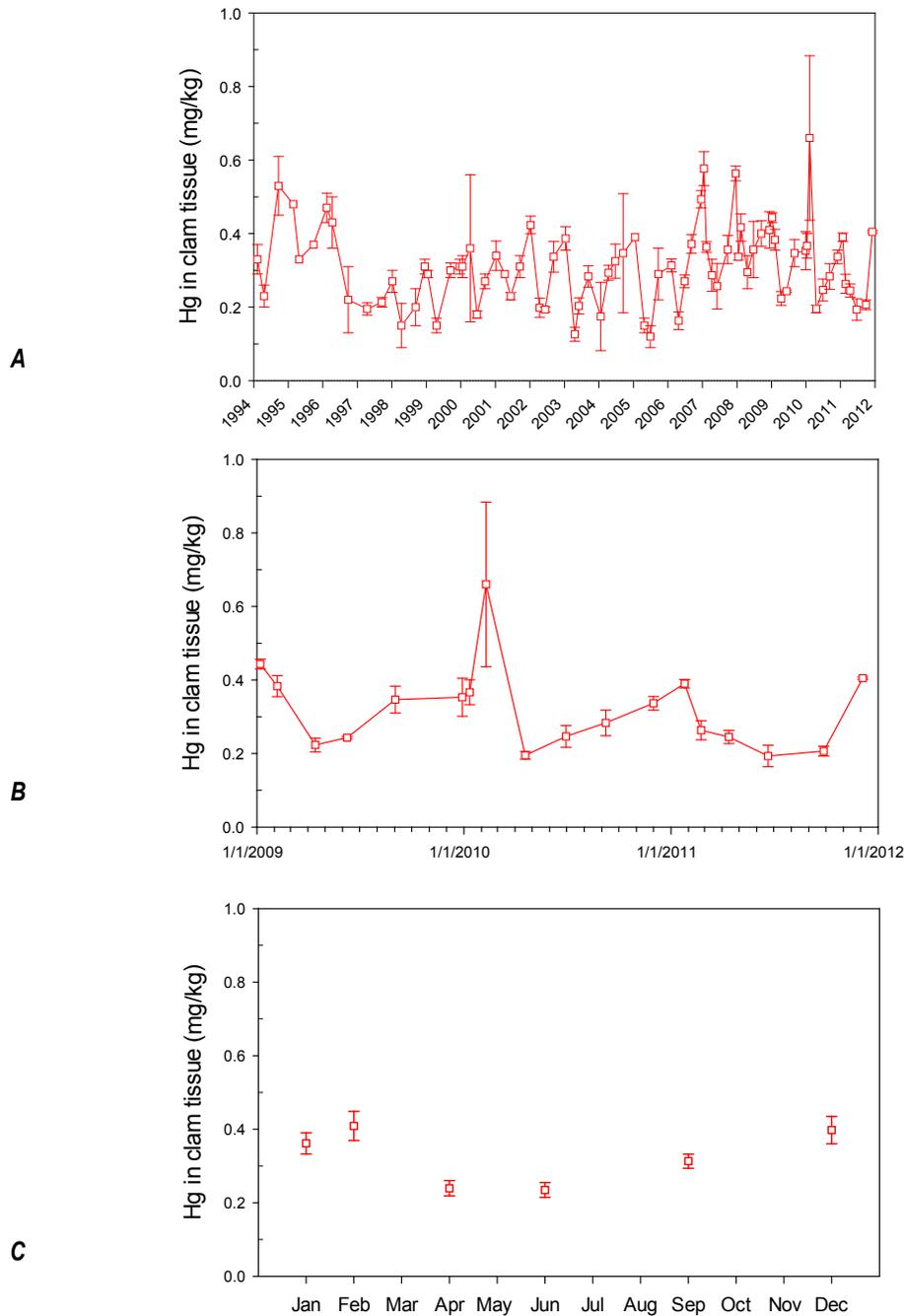
Figure 17. Mercury concentrations in the clam *Macoma petalum,* Palo Alto, Calif., 1994–2011.

A. 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).

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Hg. Collections are not made in March, May, July, August, October, and November. The error bar is the standard error of the mean (SEM).
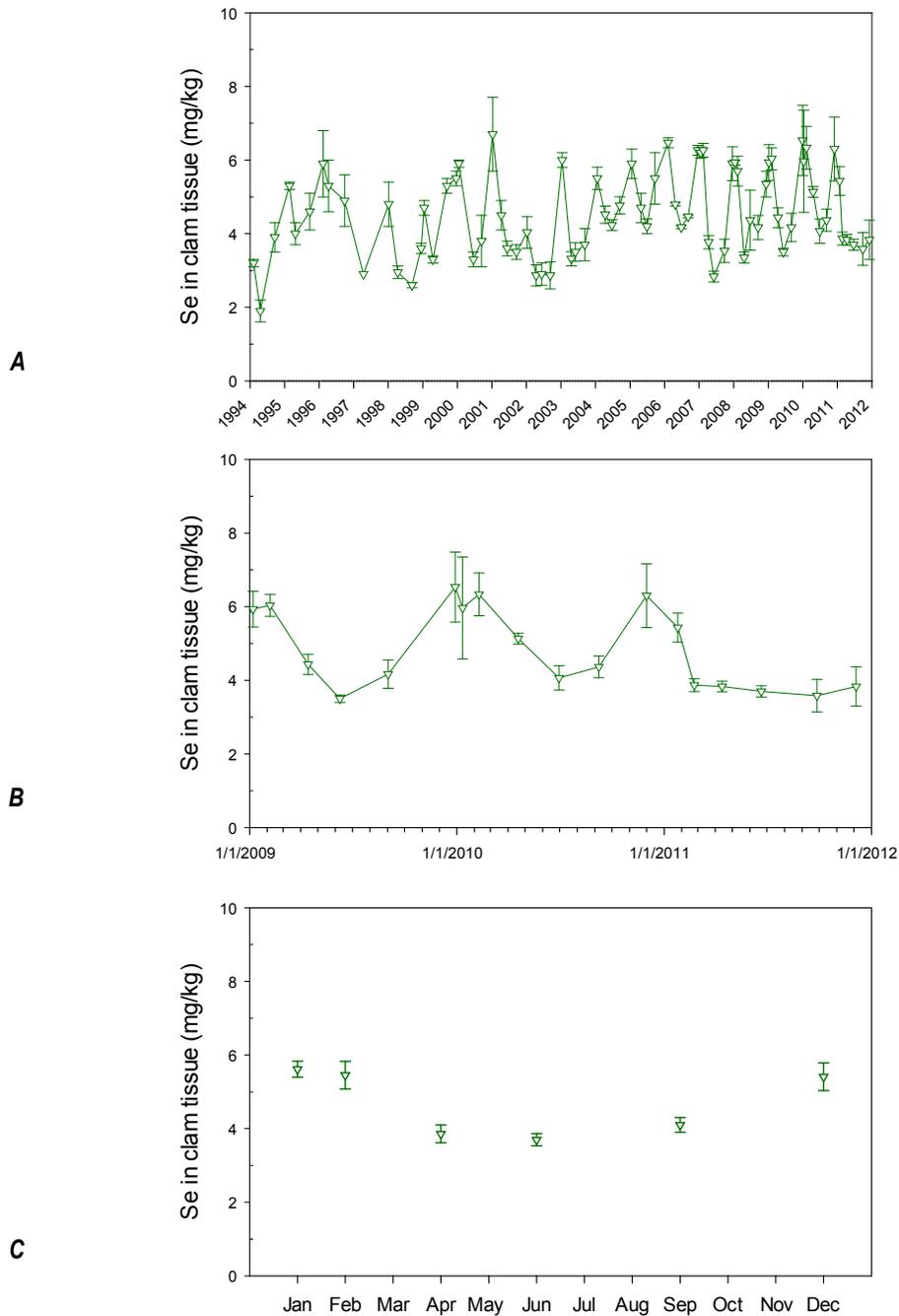
Figure 18. Selenium concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2011.

A. 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).

B. Data for the past 3 years (2009–2011).

C. The monthly mean of all samples collected from 1994–2011, illustrating the general seasonal variation in Se. Collections are not made in March, May, July, August, October, and November. The error bar is the standard error of the mean (SEM).
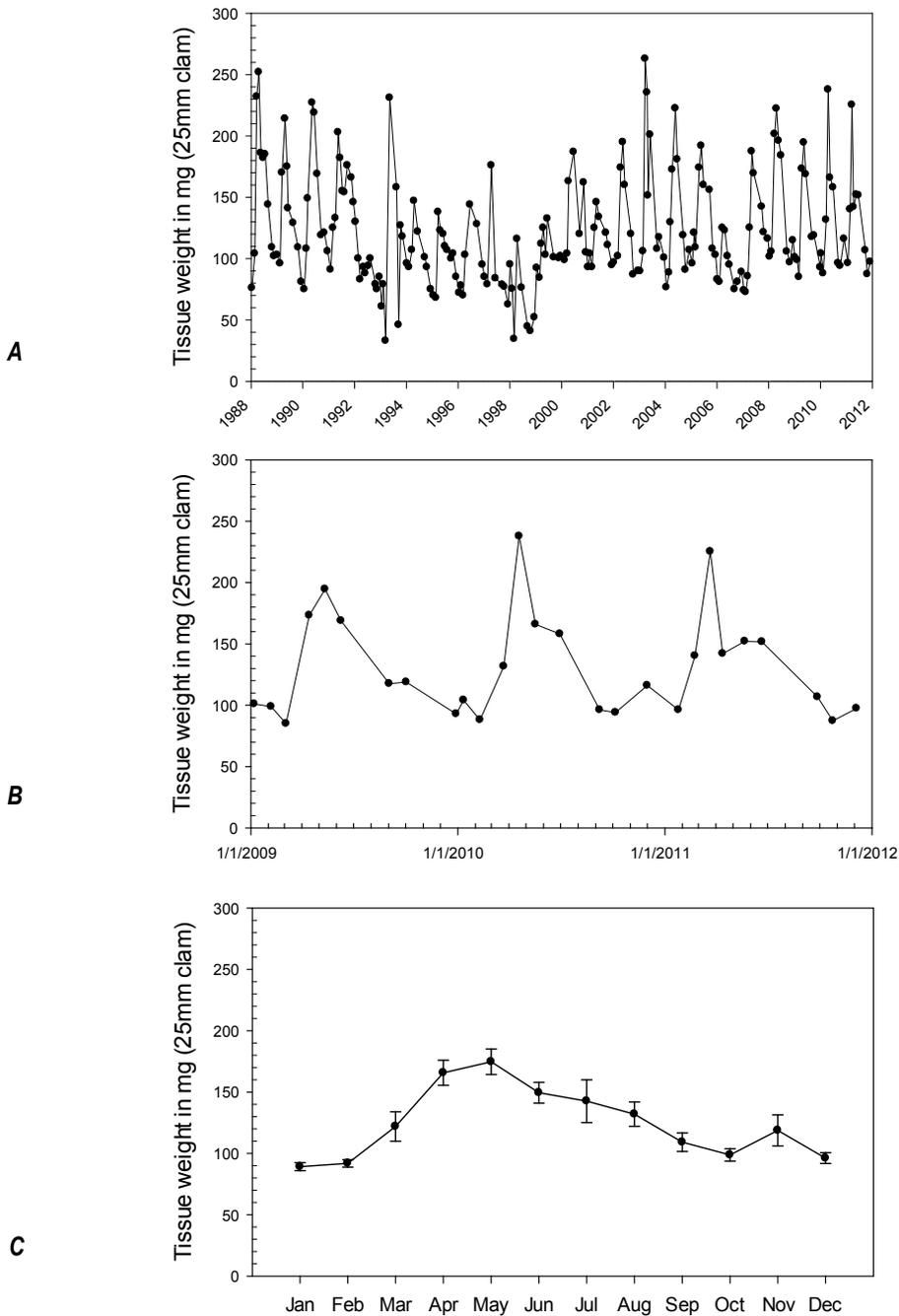
Figure 19.   Condition index of the clam *Macoma petalum*, Palo Alto, Calif., 1988–2011.

A.   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.

B.   Condition index over the past 3 years (2009–2011).

C.   The monthly mean of all samples collected from 1988–2011, illustrating the general seasonal variation in condition index. The error bar is the standard error of the mean (SEM).
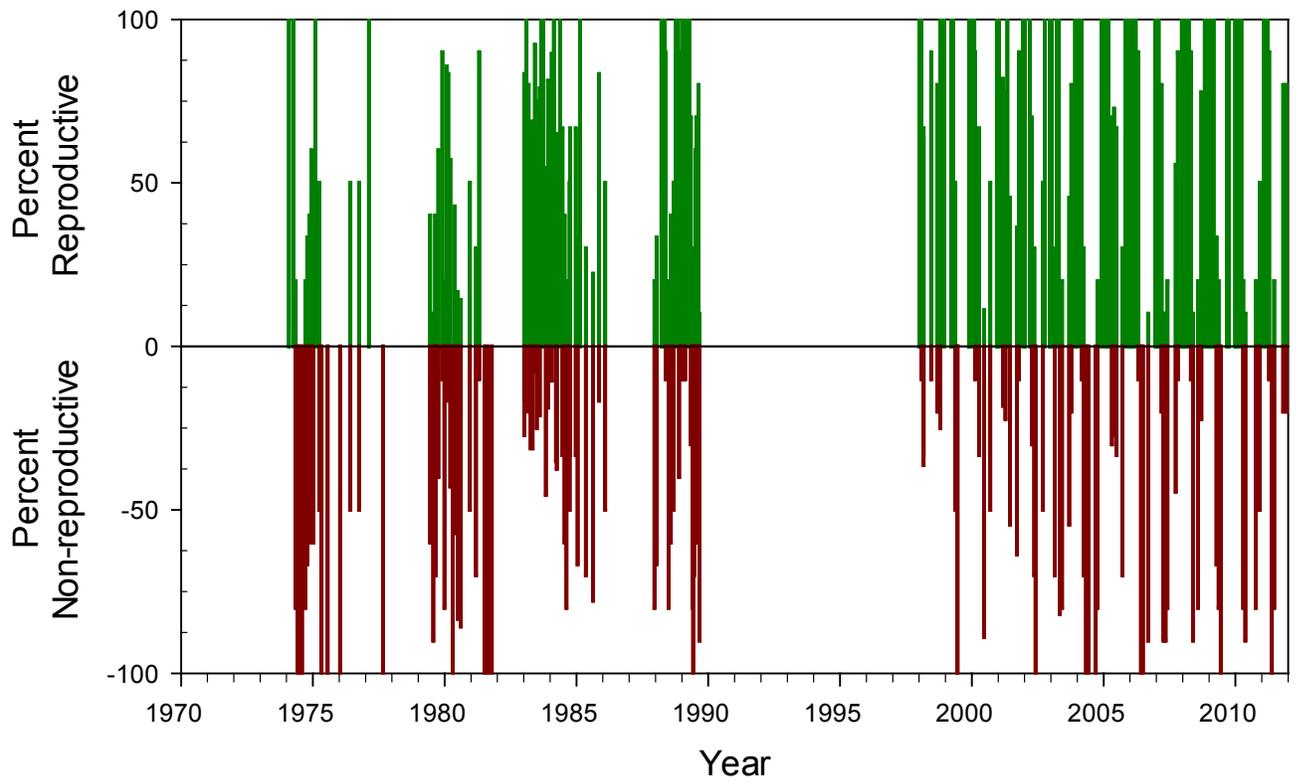
Figure 20.   Reproductive activity of the clam *Macoma petalum*, Palo Alto, Calif., 1974–2011.

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.
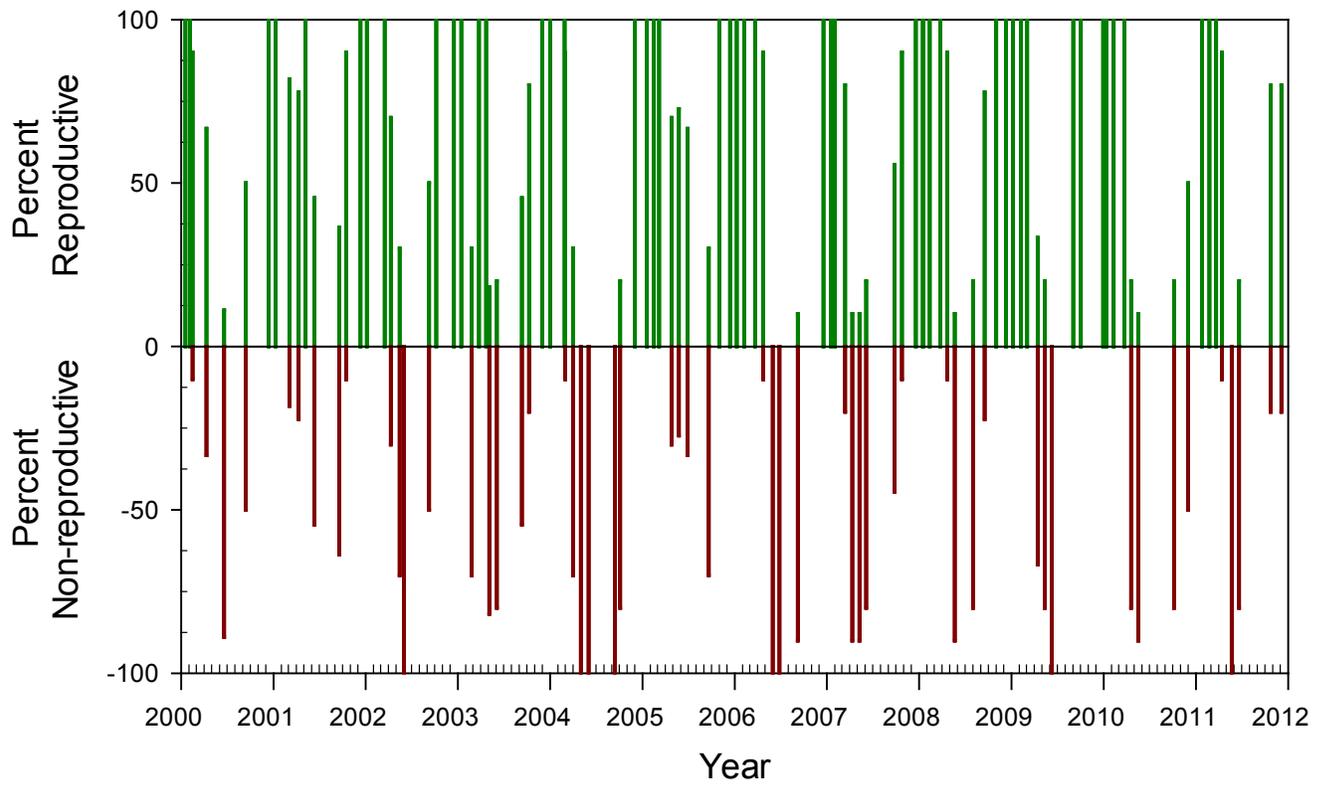
Figure 21. Reproductive activity of the clam *Macoma petalum*, Palo Alto, Calif., 2000–2011.

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.
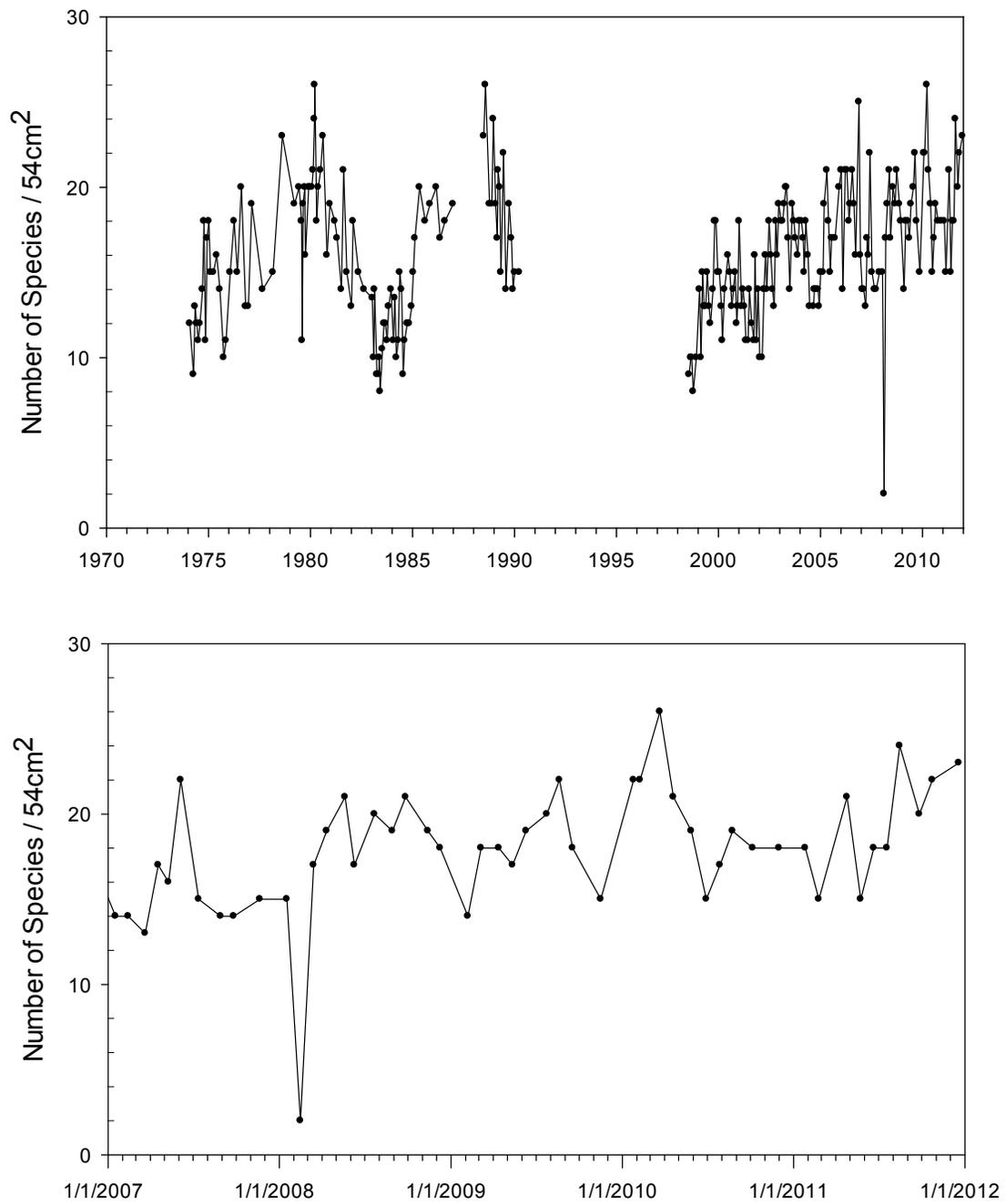
Figure 22. Total number of species present at the Palo Alto site, Calif., 1974–2011.

Collections were not made between 1991 and 1998.
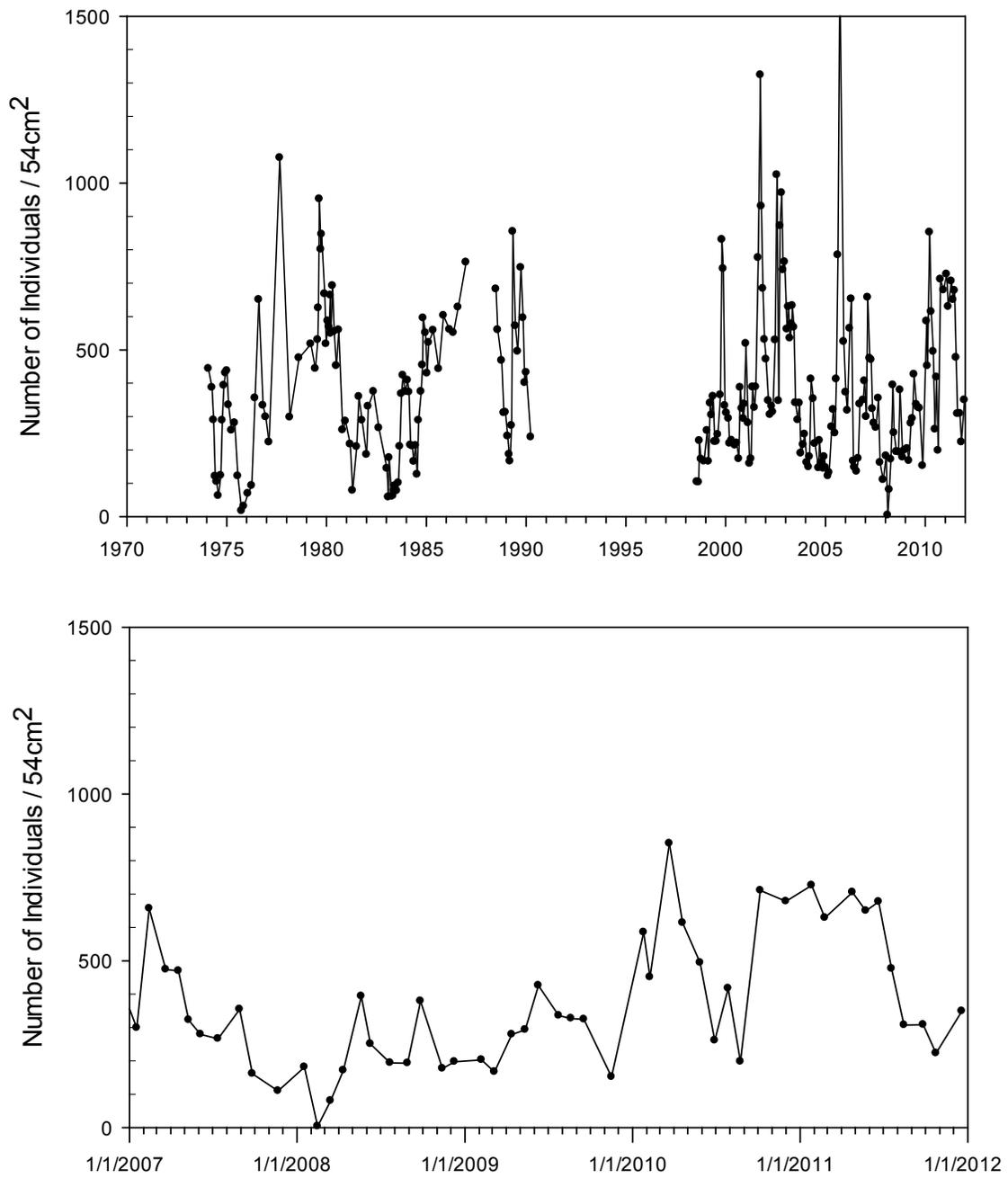
Figure 23. Total average number of individuals present at the Palo Alto site, Calif., 1974–2011.

Collections were not made between 1991 and 1998.
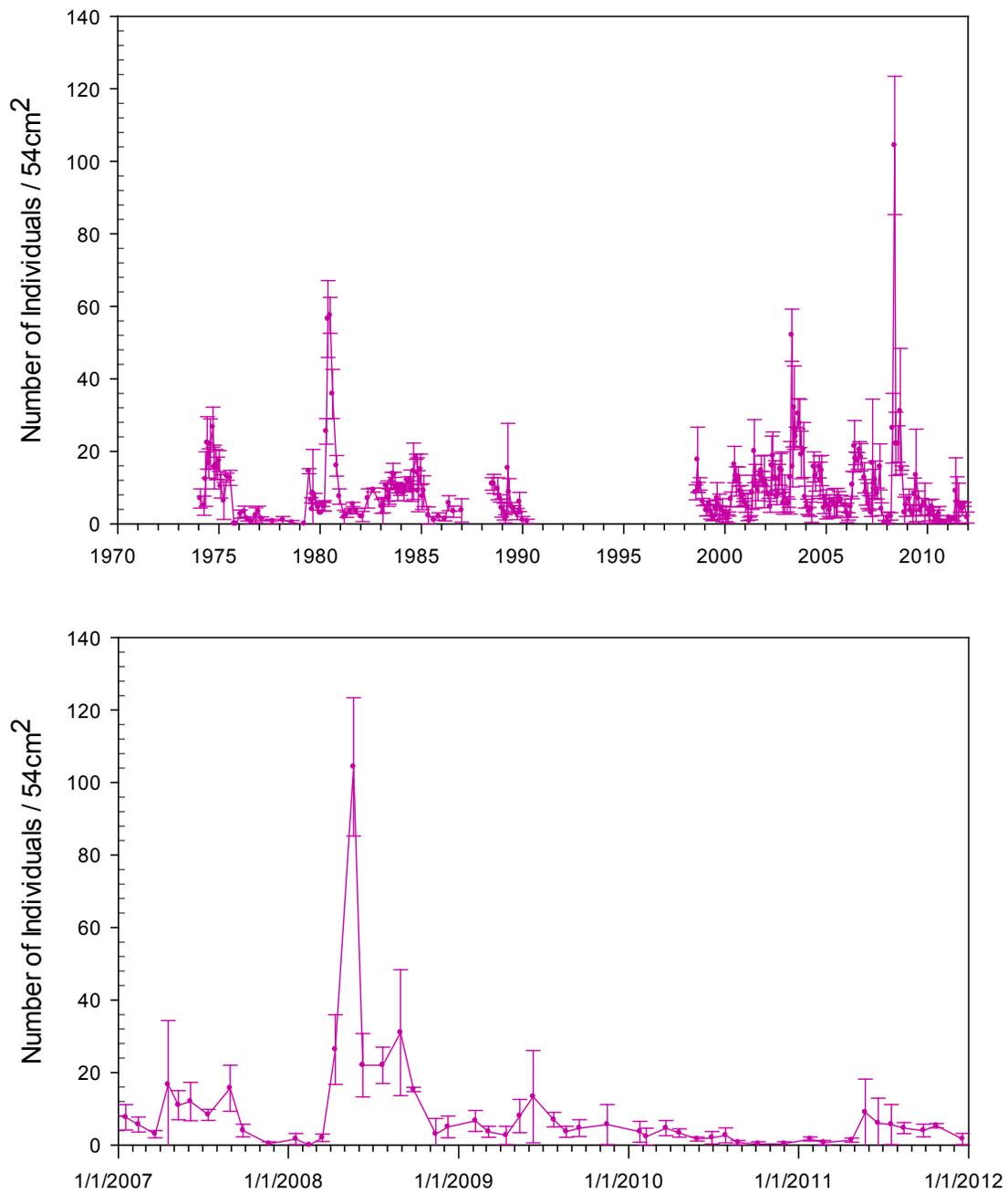
Figure 24. Monthly average abundance of *Macoma petalum*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
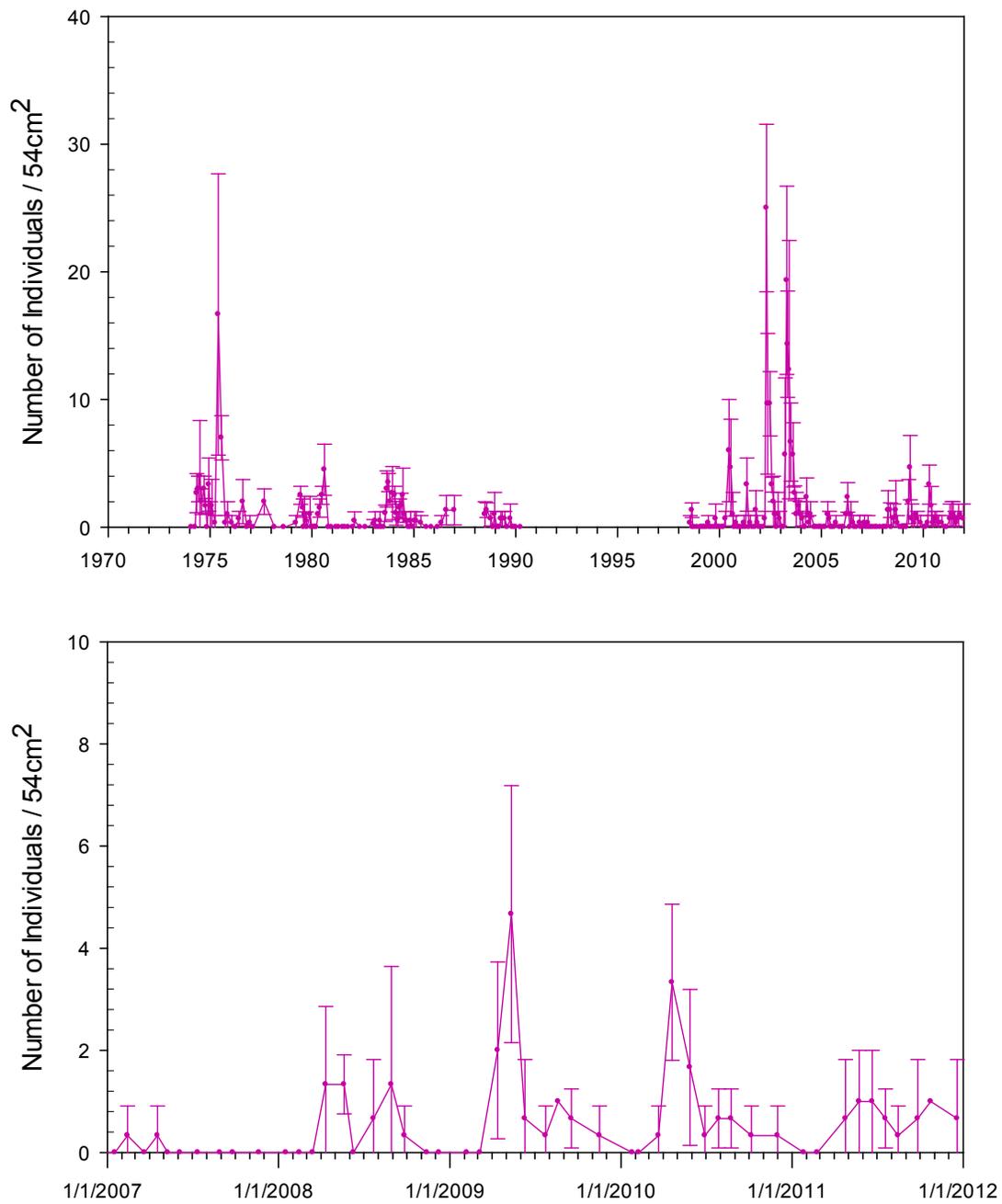
Figure 25. Monthly average abundance of *Mya arenaria*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
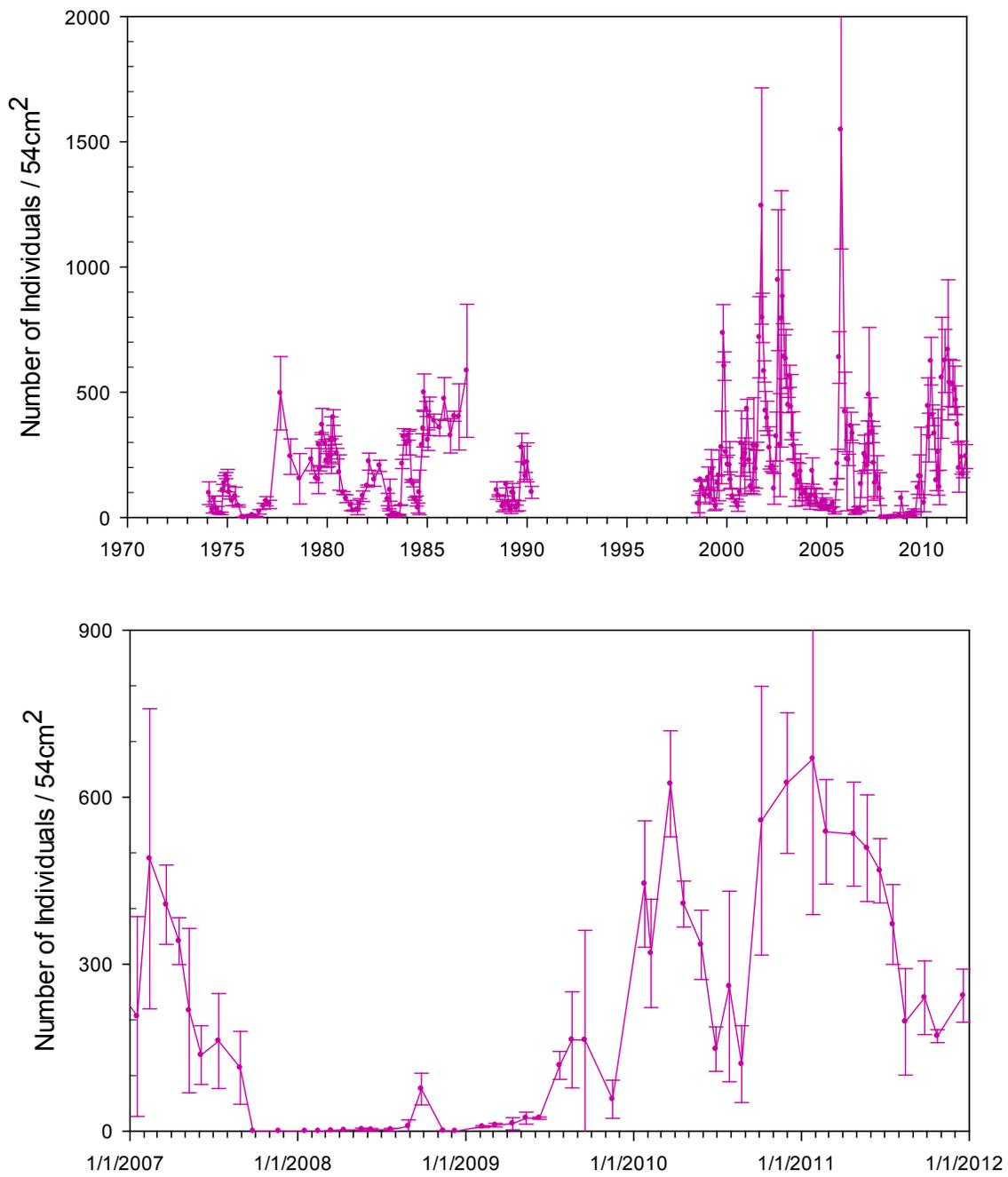
Figure 26. Monthly average abundance of *Gemma gemma*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
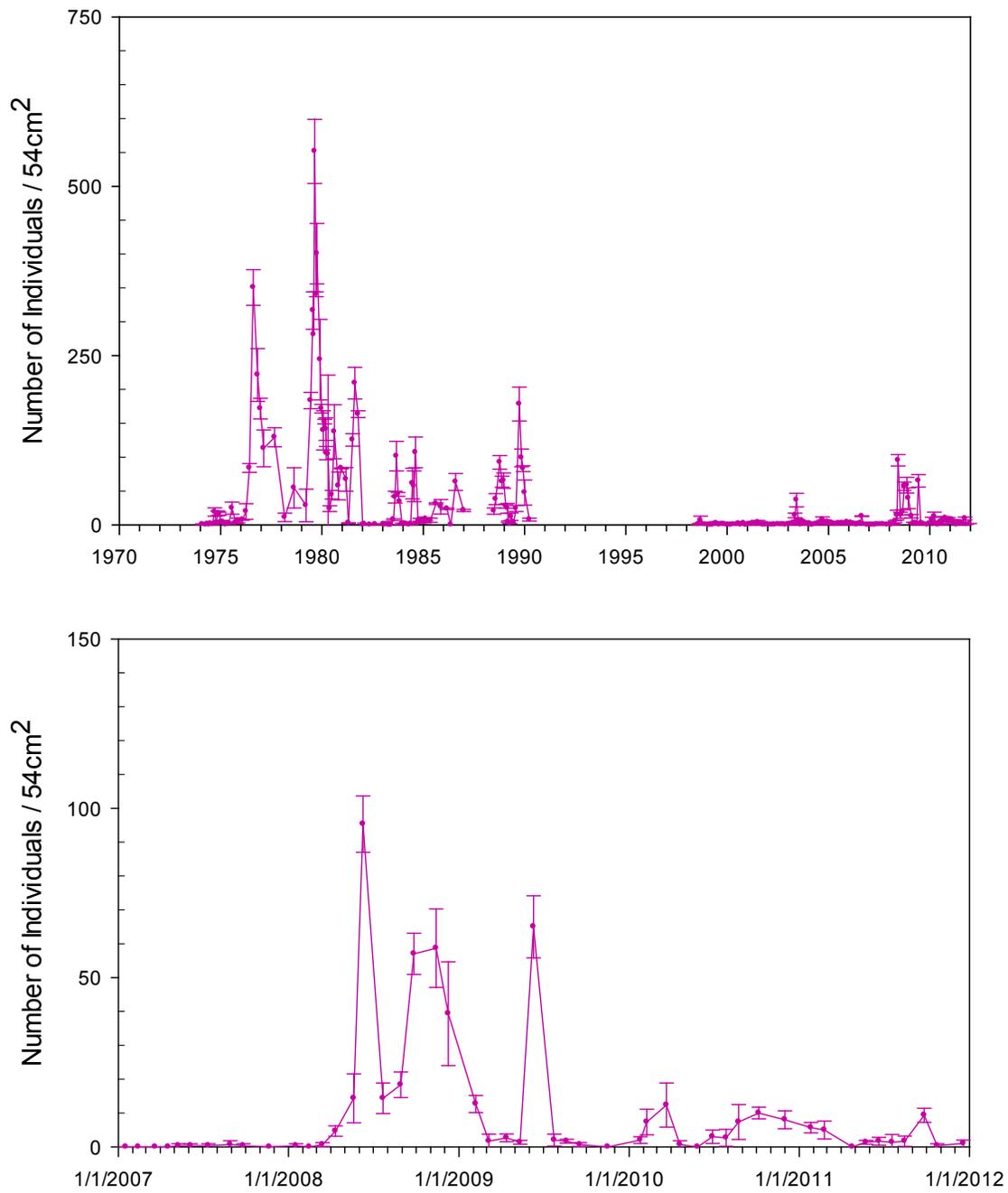
Figure 27. Monthly average abundance of *Ampelisca abdita*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
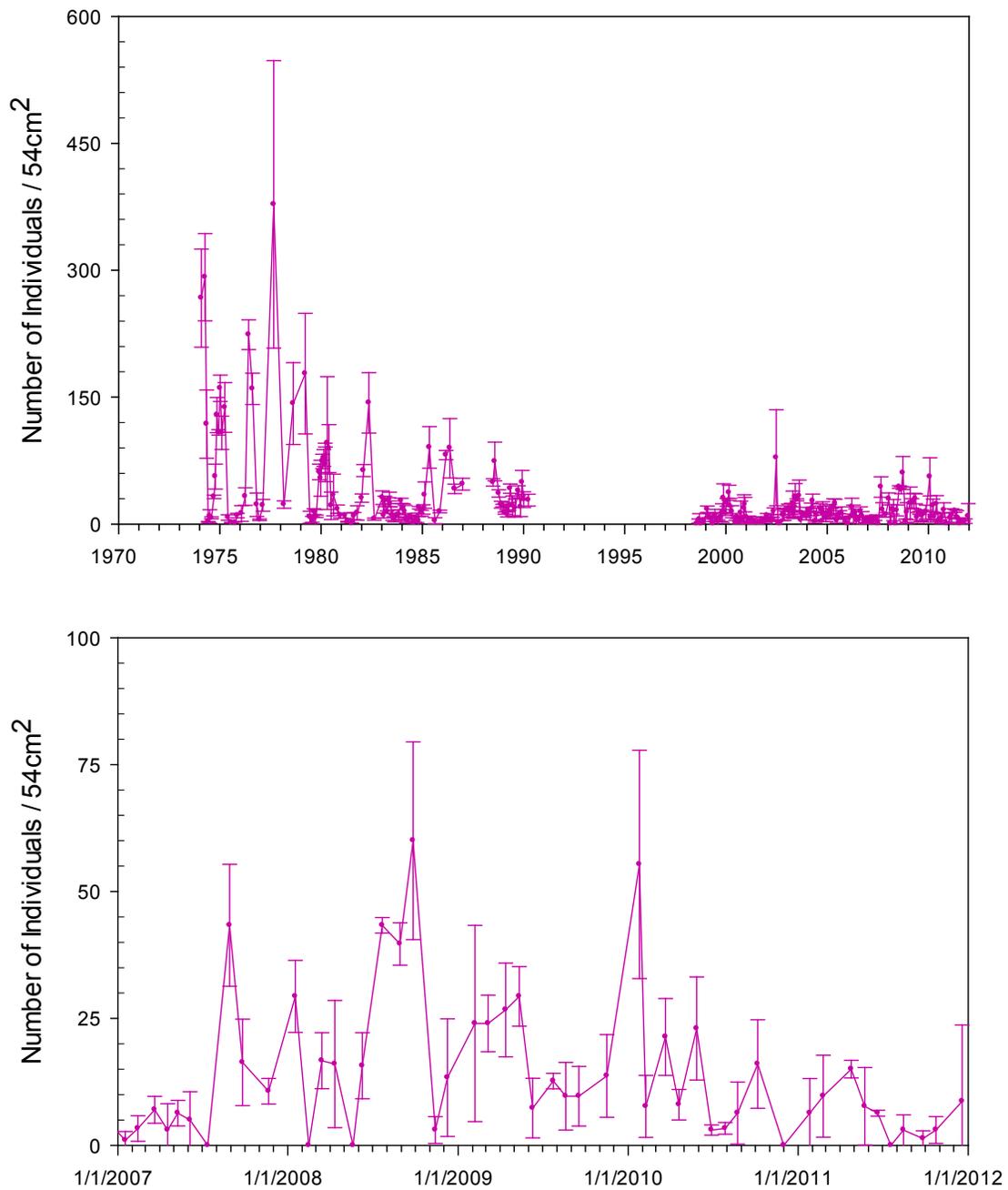
Figure 28. Monthly average abundance of *Streblospio benedicti*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
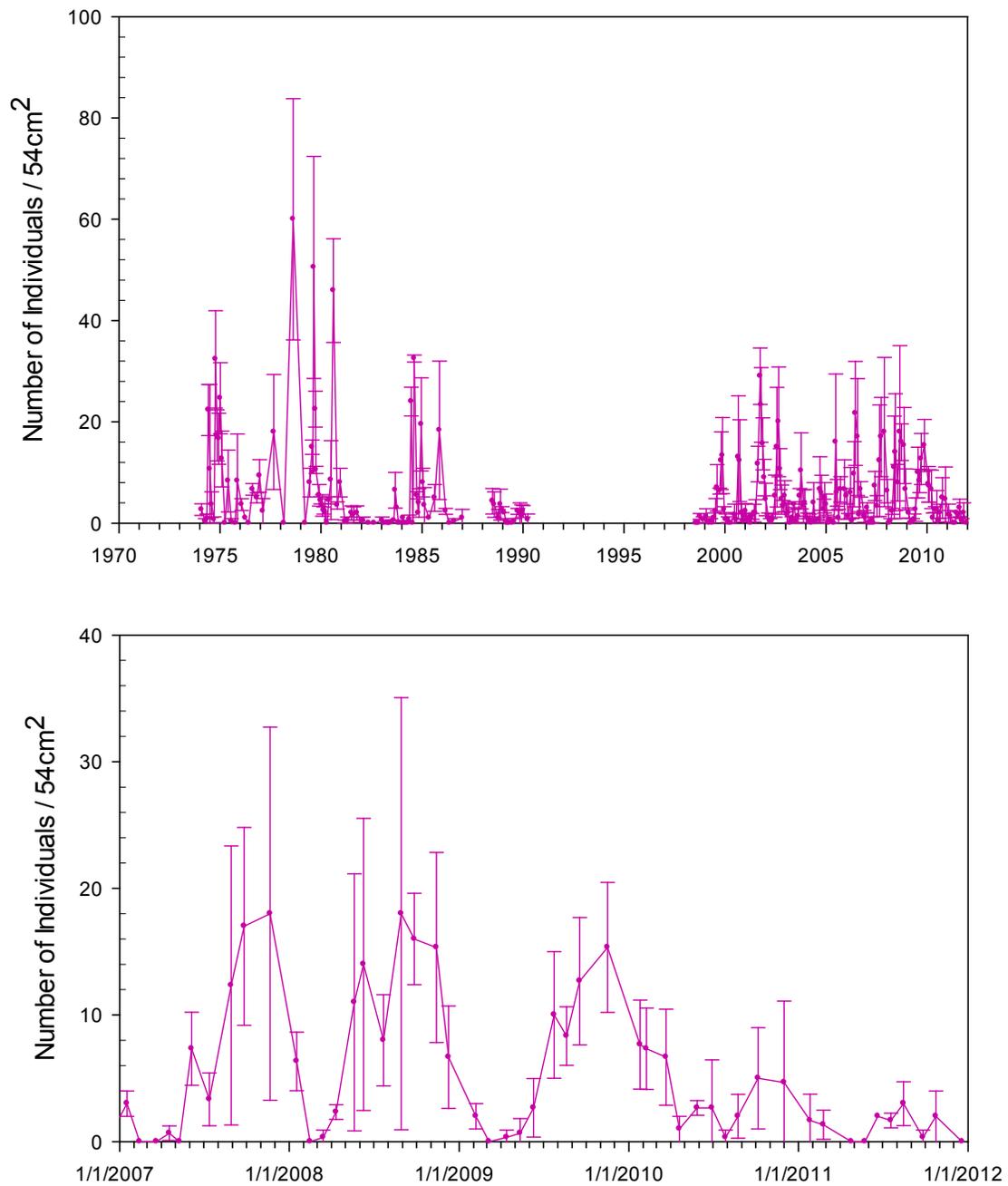
Figure 29. Monthly average abundance of *Grandiderella japonica*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
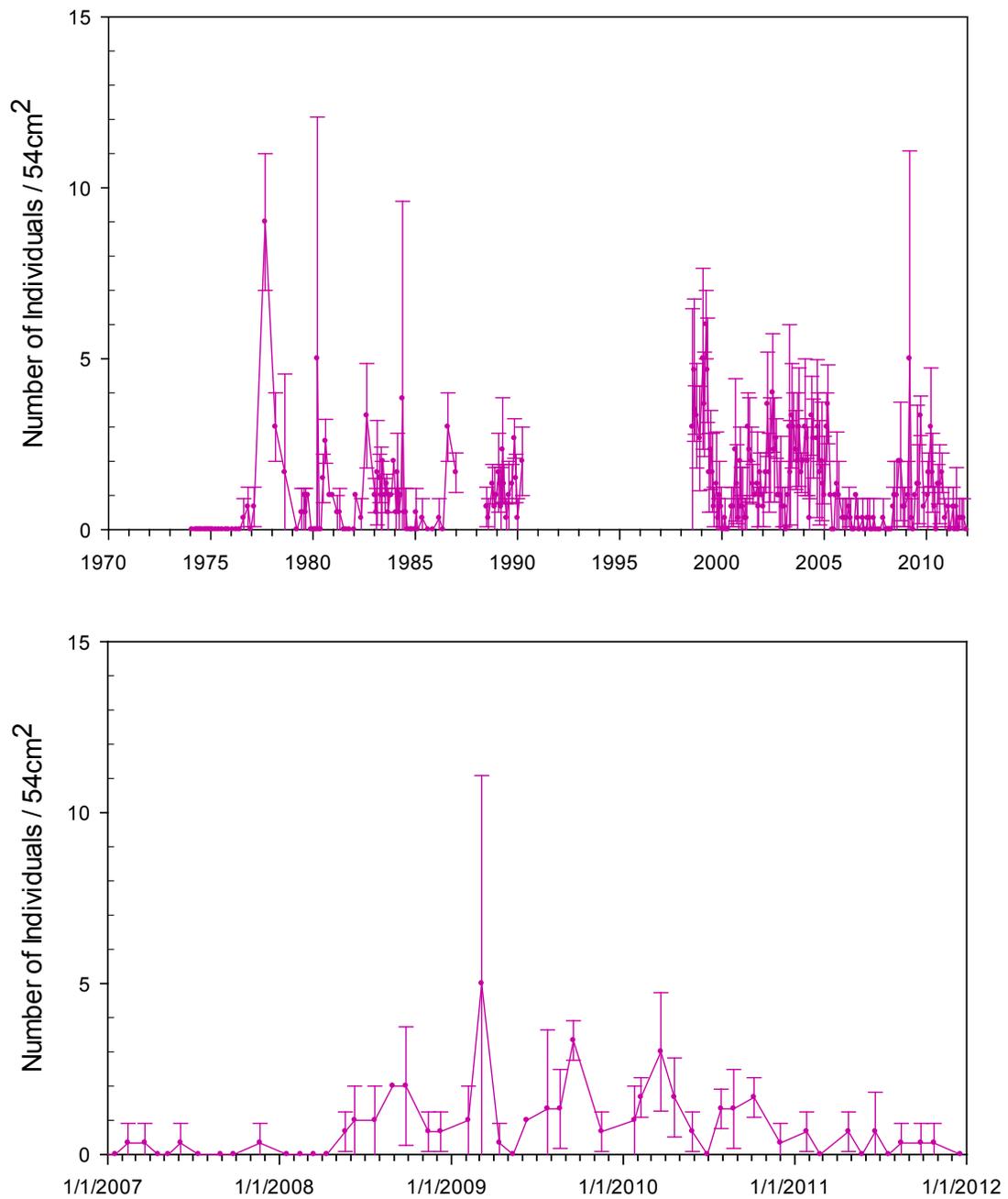
Figure 30. Monthly average abundance of *Neanthes succinea*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
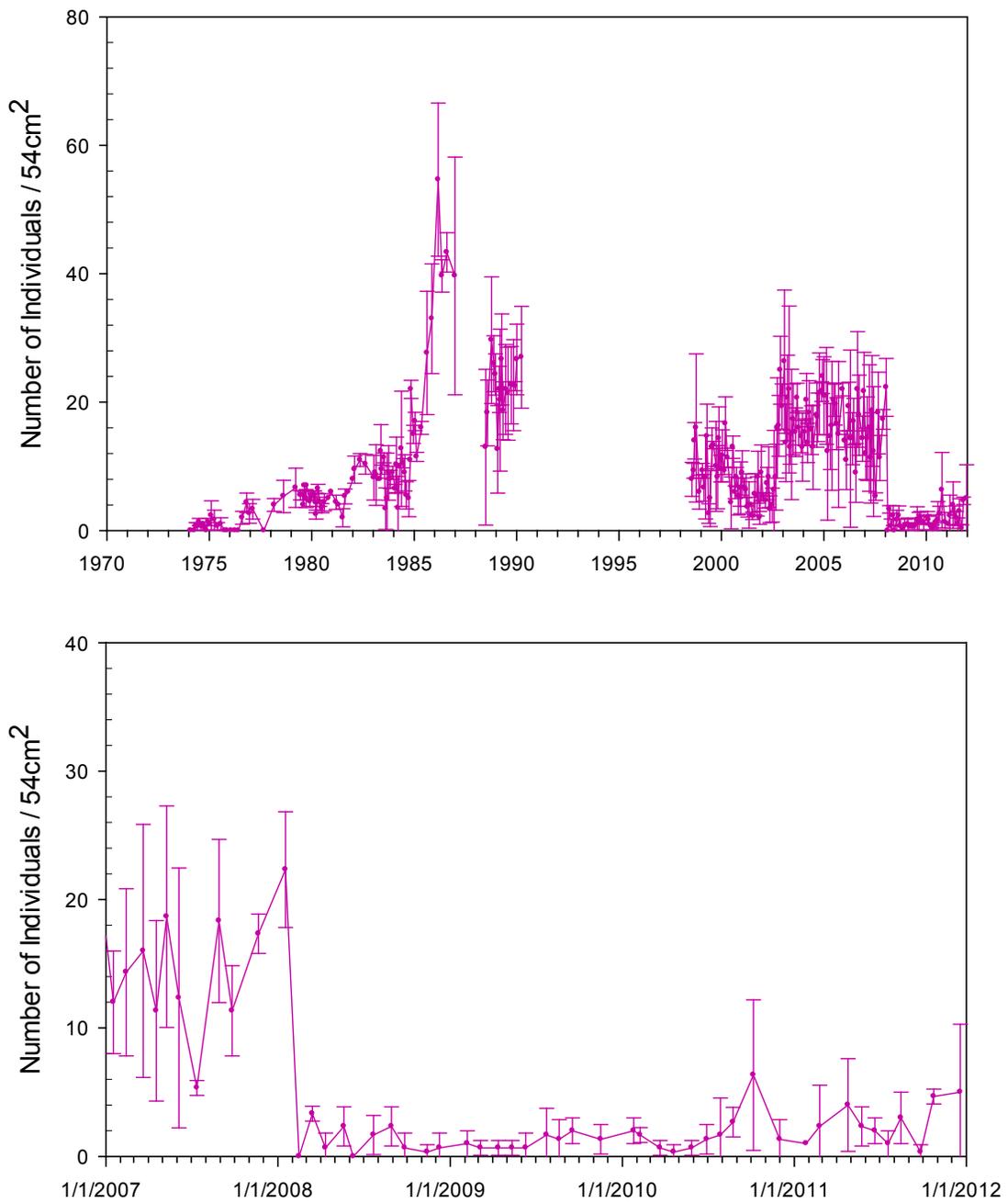
Figure 31. Monthly average abundance of *Heteromastus filiformis*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
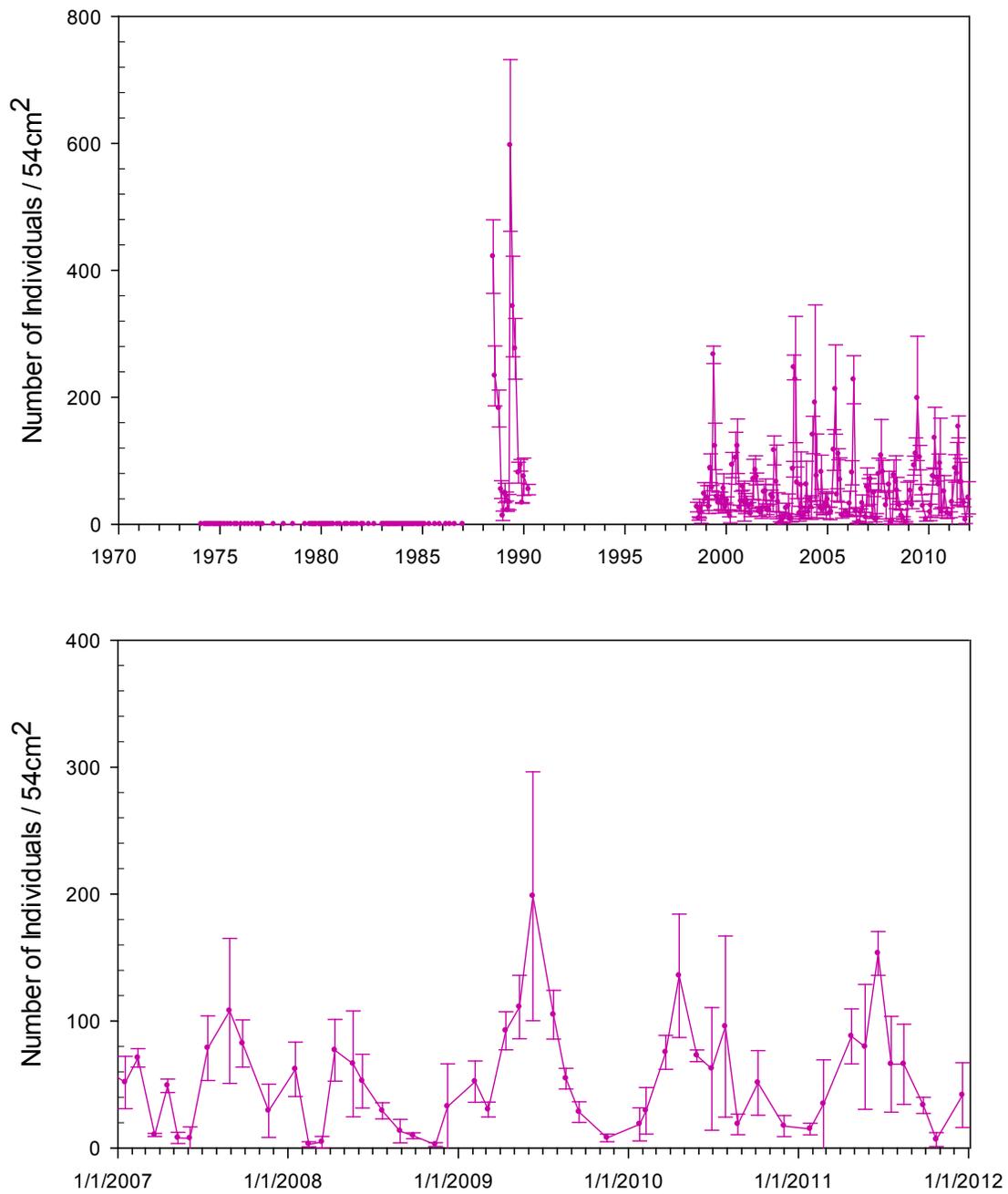
Figure 32. Monthly average abundance of *Nippoleucon hinumensis*, Palo Alto, Calif., 1974–2011.

Error bars represent standard deviation from three replicate samplings. Collections were not made between 1991 and 1998.
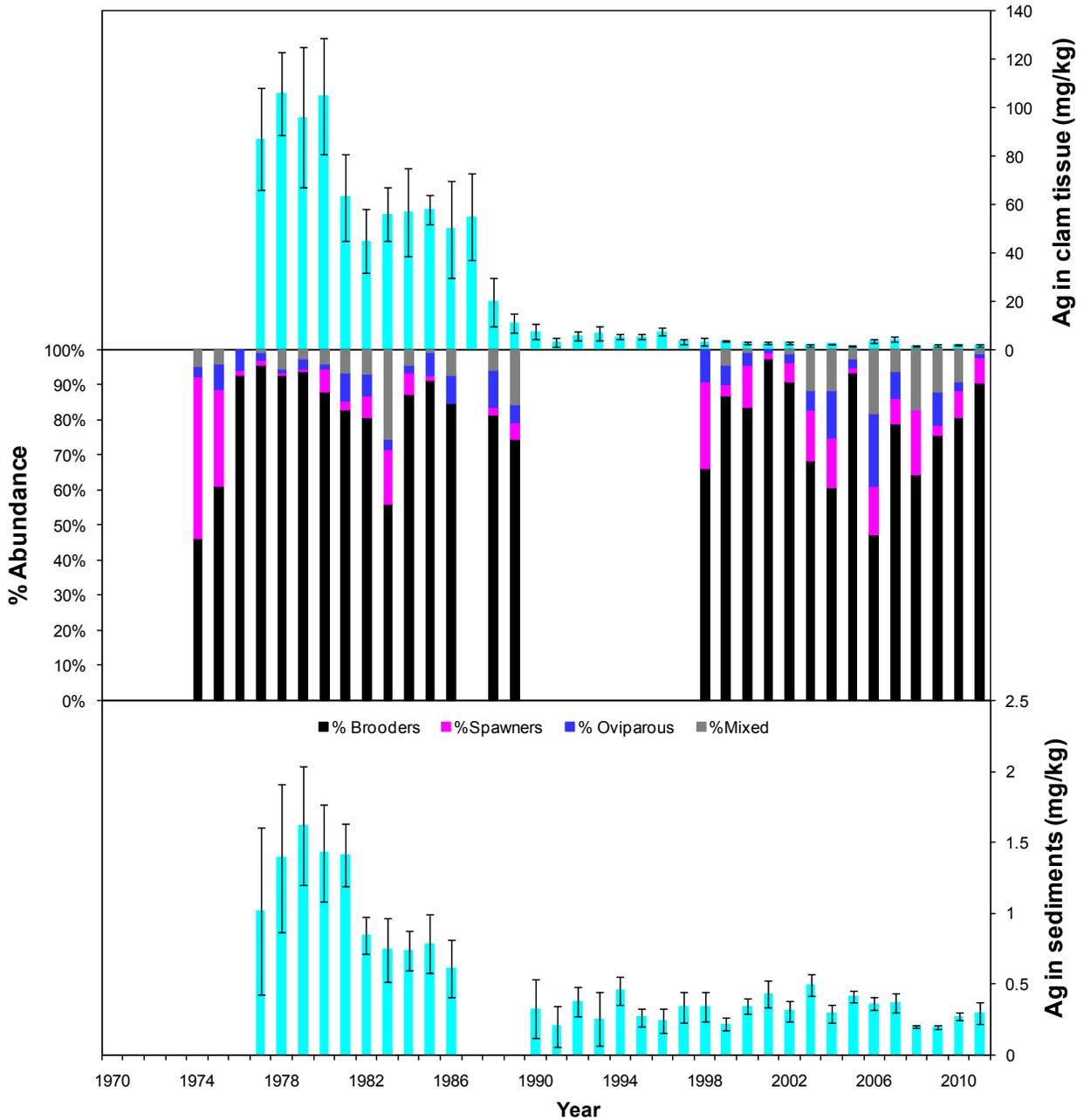
Figure 33. Reproductive mode annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2011.

The reproductive mode of the top ten ranked species for each year 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.

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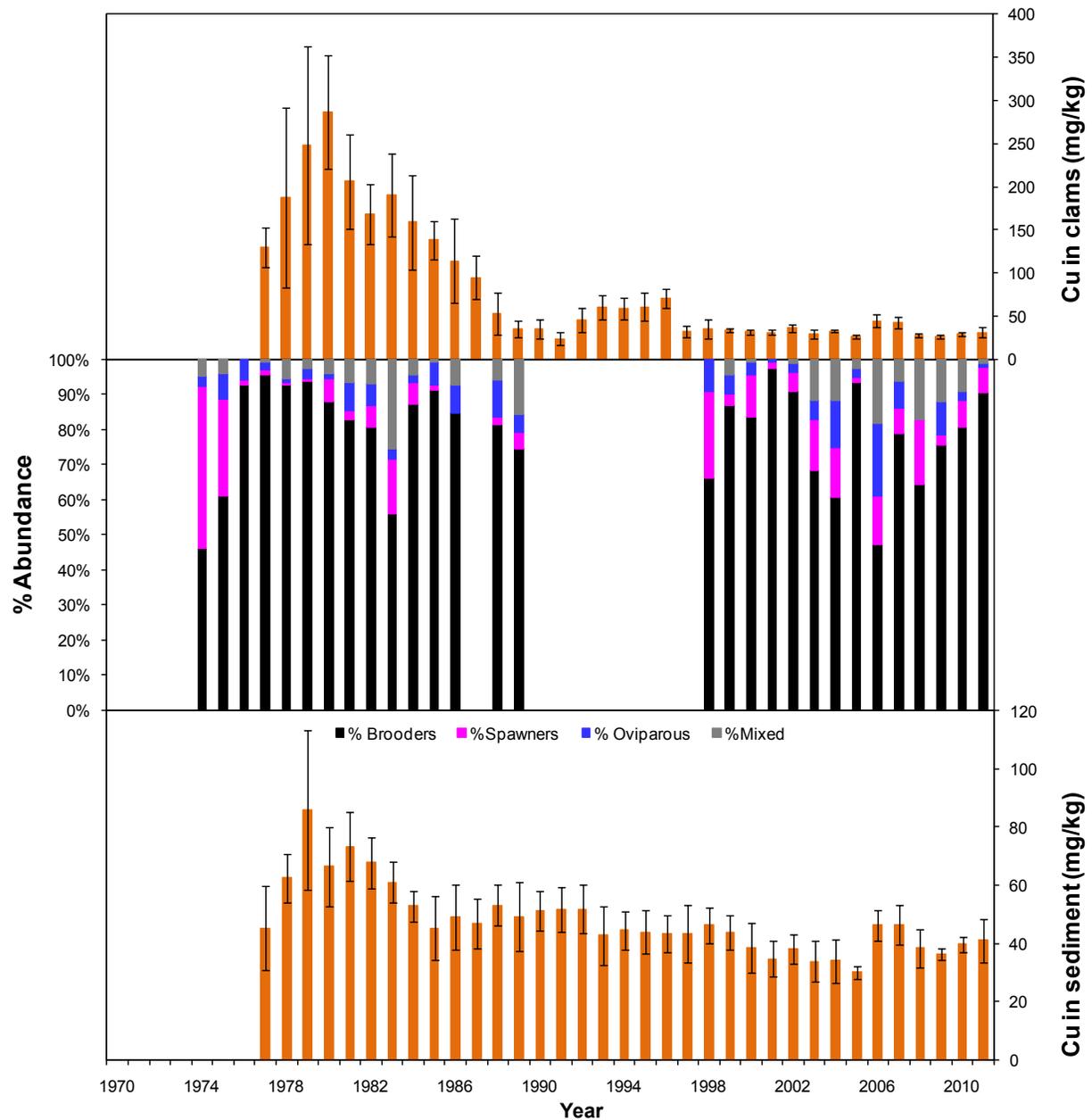
Figure 34. Reproductive mode annual abundance with copper concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2011.

The reproductive mode of the top ten ranked species for each year 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.
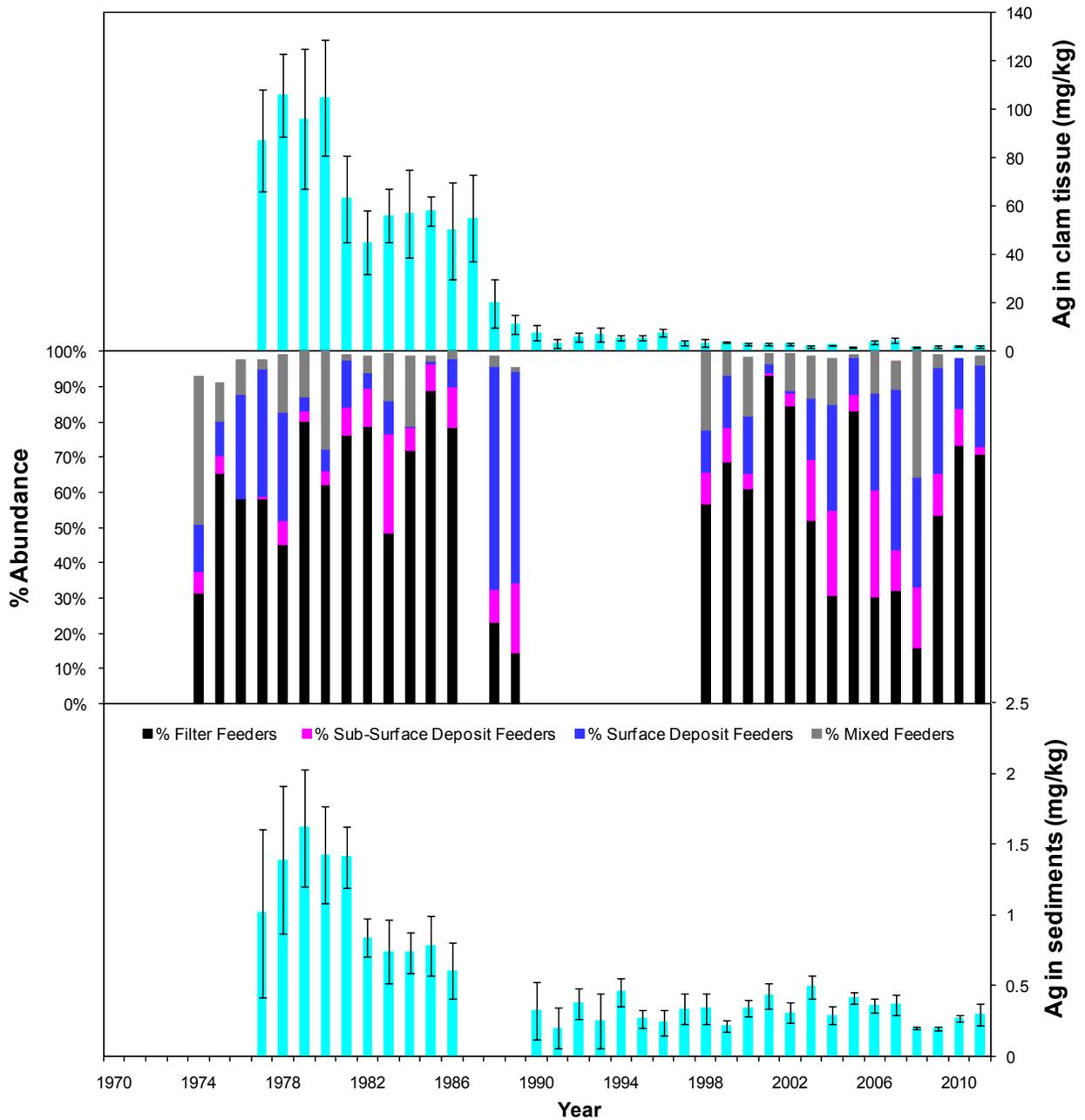
Figure 35. Feeding mode annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2011.

The feeding mode of the top ten ranked species for each year 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;
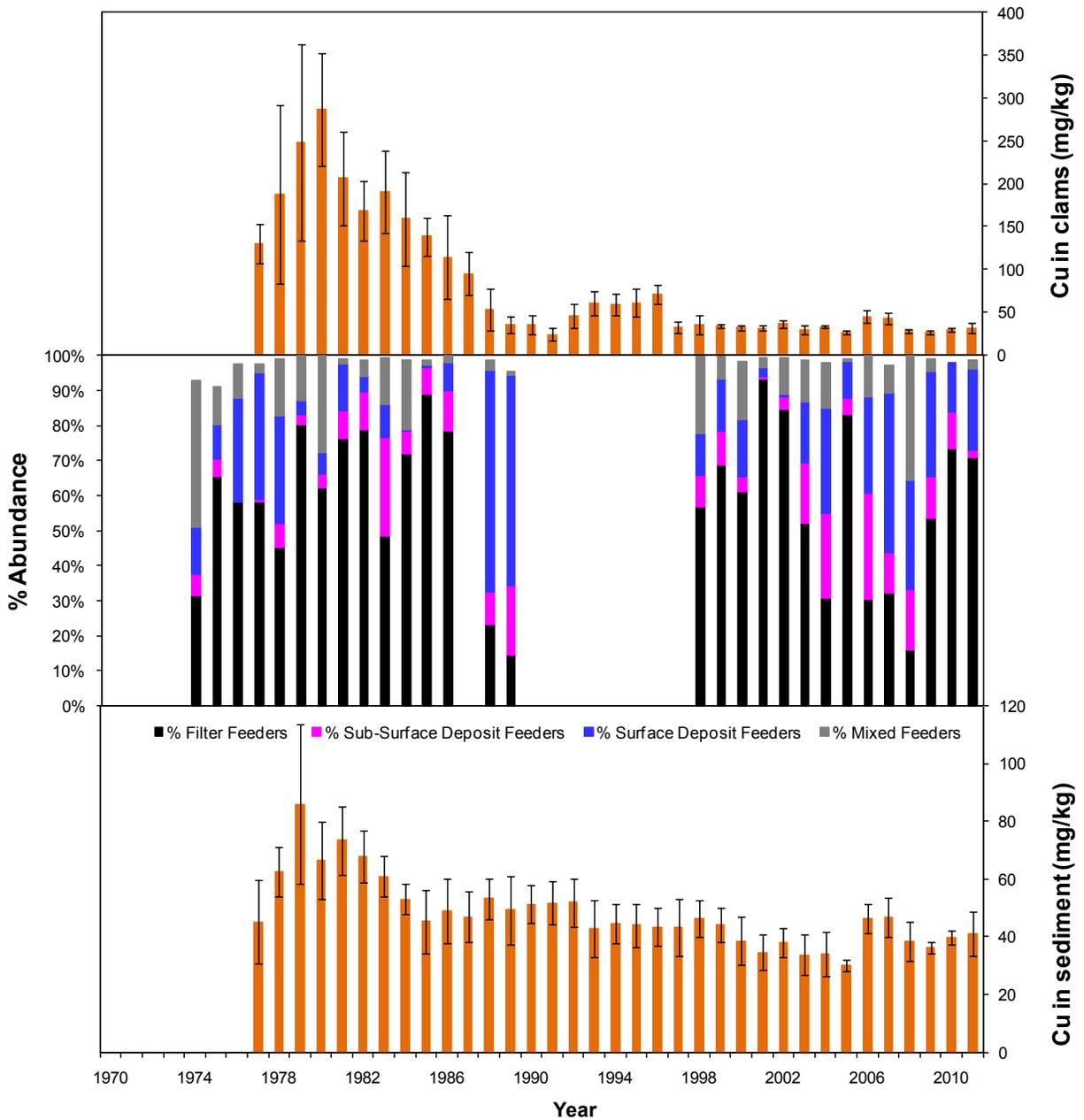
Figure 36. Feeding mode annual abundance with copper concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2011.

The feeding mode of the top ten ranked species for each year 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;

Figure 37. Species rank-abundance for the benthic community, Palo Alto, Calif., 2011.
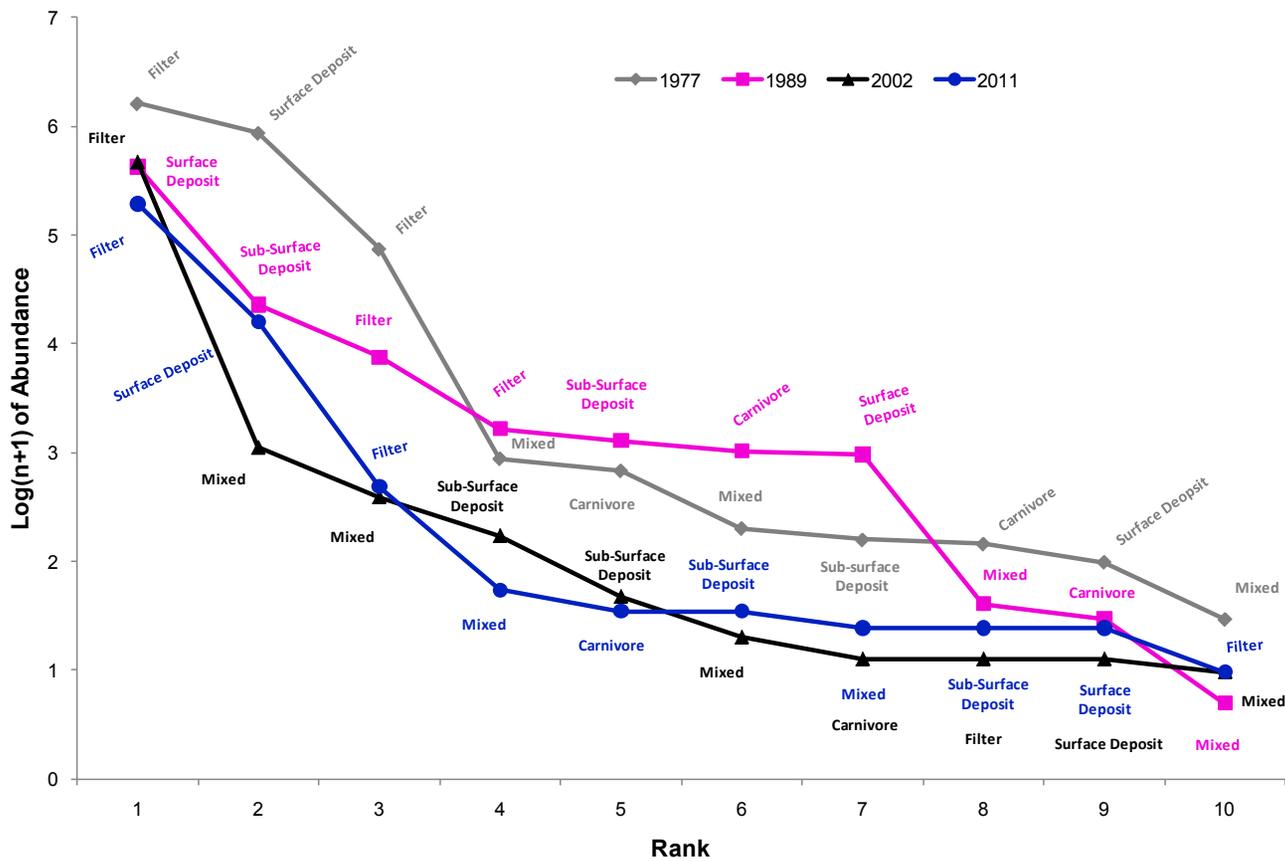
Figure 38. Species rank-abundance identified by feeding mode, Palo Alto, Calif., for 1977, 1989, 2002, and 2011.

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.

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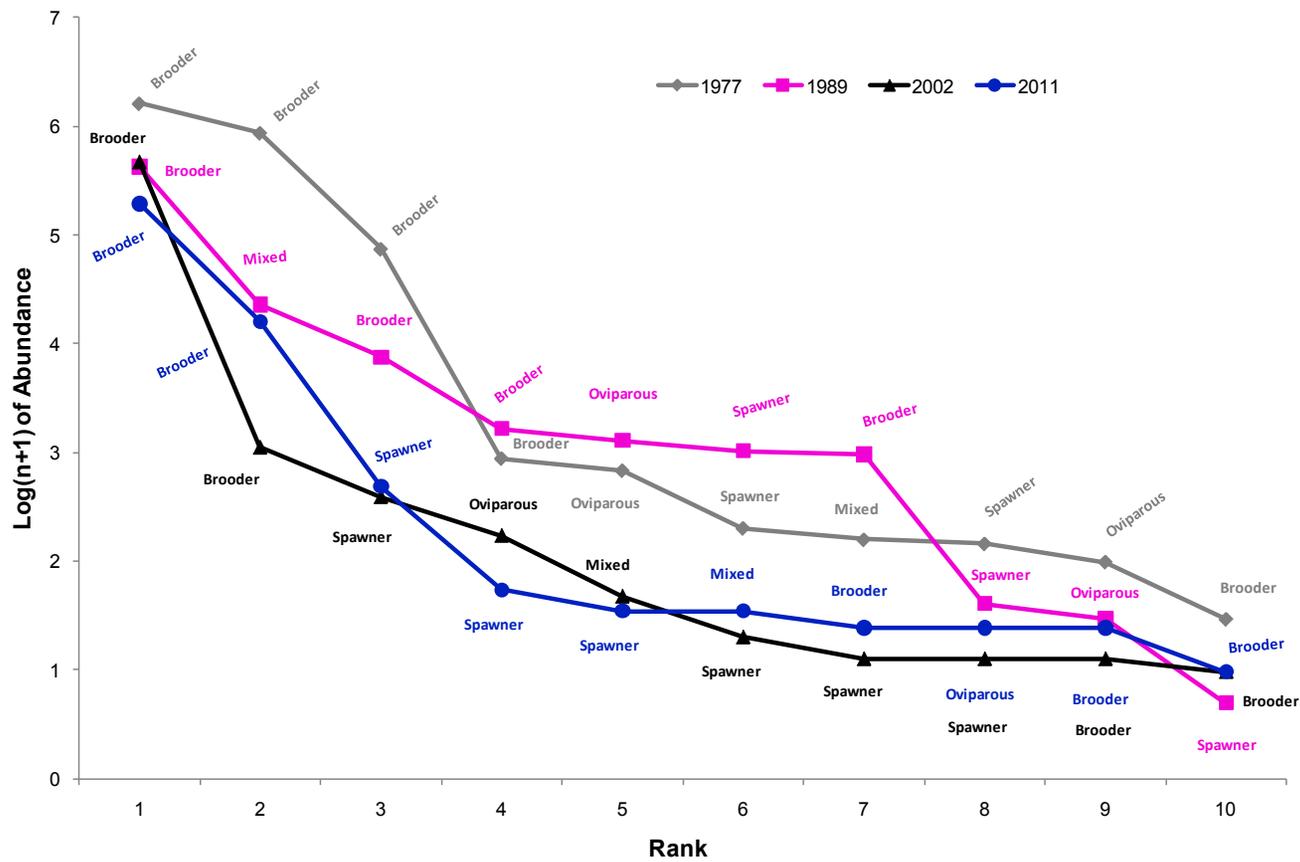
Figure 39. Species rank-abundance data identified by reproductive mode, Palo Alto, Calif., for 1977, 1989, 2002, and 2011.

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.

Table 1. Sediment characteristics, salinity, and concentrations of trace metals in sediments, Palo Alto, Calif., 2011.

[Units for Al, Fe, total organic carbon (TOC), and silt/clay are percent of dry weight. Silt/Clay is operationally determined as ≤100 micrometer grain size. Salinity is reported in units of parts per thousand (ppt) for water pooled at the sediment surface during low tide. Elemental concentrations for the monthly samples are reported as the mean ±1 standard deviation (std) for replicate subsamples (n=2). No replicate sample was analyzed for March 2011, therefore there is no standard deviation reported. Units are milligram per kilogram dry weight. Results for TOC, silt/clay, and salinity are for a single (n=1) measurement. Means for monthly samples were summarized and reported as the annual mean ± the standard error (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	Zn	Al (%)	Fe (%)	TOC (%)	Silt/ Clay (%)	Salinity (ppt)
1/25/2011	0.36 ± 0.002	139 ± 1	45.0 ± 0.5	0.31	95.8 ± 1.7	0.7	146 ± 3	5.4 ± 0.03	4.8 ± 0.1	1.31	96	22
2/23/2011	0.26 ± 0.0002	138 ± 3	45.7 ± 2.6	0.30	85.6 ± 2.6	0.5	137 ± 5	5.6 ± 0.02	4.5 ± 0.1	1.62	97	20
3/22/2011	0.24 ± 0.003	154 ± -	50.3 ± -	ND	96.4 ± -	ND	151 ± -	5.6 ± -	5.2 ± -	1.33	86	20
4/13/2011	0.25 ± 0.005	112 ± 3	35.6 ± 1.5	0.30	72.5 ± 2.4	0.7	114 ± 4	4.1 ± 0.2	3.7 ± 0.1	1.13	94	15
5/22/2011	0.43 ± 0.004	164 ± 6	49.7 ± 1.5	ND	98.0 ± 0.3	ND	151 ± 1	6.1 ± 0.3	5.4 ± 0.1	1.44	95	22
6/21/2011	0.38 ± 0.002	128 ± 10	42.2 ± 0.8	0.32	83.8 ± 1.5	0.5	130 ± 0.01	4.7 ± 0.1	4.3 ± 0.2	1.09	95	25
9/27/2011	0.21 ± 0.002	107 ± 5	29.5 ± 1.2	0.21	67.7 ± 1.6	0.4	102 ± 2	3.7 ± 0.2	3.6 ± 0.1	0.85	59	28
10/24/2011	0.25 ± 0.0002	111 ± 7	31.3 ± 1.4	ND	67.2 ± 2.4	ND	103 ± 5	3.7 ± 0.2	3.6 ± 0.2	0.81	52	27
12/5/2011	0.26 ± 0.003	130 ± 2	39.8 ± 0.4	0.19	80.6 ± 0.3	0.5	125 ± 1	4.9 ± 0.04	4.1 ± 0.004	0.84	72	27
Annual Mean:	0.29	132	41.0	0.27	83.1	0.6	129	4.9	4.3	1.16	83	23
SEM:	0.03	7	2.5	0.02	4.0	0.05	6	0.3	0.2	0.10	6	1

Table 2. Concentrations of trace metals in the clam *Macoma petalum*, Palo Alto, Calif., 2011.

[Monthly data are the mean and standard deviation for replicate composites (n=8–13). Means for monthly samples were summarized and reported as the annual mean ± the standard error (SEM) (n=9). All concentrations are based on near-total extracts. Elemental concentrations are milligram per kilogram soft tissue dry weight. The condition index (CI) is the soft tissue weight in milligrams of a clam of 25-millimeter shell length. ND means No Data.]

Date	Ag	Cr	Cu	Hg	Ni	Se	Zn	Condition Index
1/25/2011	3.09 ± 1.32	5.45 ± 1.17	32.5 ± 4.3	0.39 ± 0.02	7.17 ± 1.07	5.4 ± 0.7	344 ± 93	96
2/23/2011	1.47 ± 0.66	2.11 ± 0.51	18.0 ± 3.8	0.26 ± 0.05	3.45 ± 0.71	3.9 ± 0.3	285 ± 85	140
3/22/2011	0.509 ± 0.199	1.35 ± 0.44	12.0 ± 1.1	ND	1.98 ± 0.55	ND	204 ± 51	225
4/13/2011	0.952 ± 0.488	2.90 ± 0.84	21.5 ± 7.7	0.25 ± 0.03	4.05 ± 0.59	3.8 ± 0.3	261 ± 34	142
5/22/2011	1.09 ± 0.27	1.51 ± 0.52	19.7 ± 3.3	ND	3.60 ± 0.58	ND	288 ± 94	152
6/21/2011	1.18 ± 0.25	1.65 ± 0.36	21.1 ± 6.2	0.19 ± 0.05	3.36 ± 0.62	3.7 ± 0.3	245 ± 80	152
9/27/2011	2.60 ± 0.74	2.10 ± 0.69	38.7 ± 5.3	0.21 ± 0.02	3.92 ± 1.01	3.6 ± 0.8	244 ± 88	108
10/24/2011	3.74 ± 1.12	2.91 ± 1.23	48.9 ± 14.7	ND	5.18 ± 1.54	ND	292 ± 105	87
12/5/2011	3.57 ± 1.42	3.91 ± 1.01	46.0 ± 15.5	0.41 ± 0.005	5.70 ± 1.27	3.8 ± 0.9	289 ± 70	97
Annual Mean:	2.02	2.65	28.7	0.28	4.27	4.0	272	133
SEM:	0.41	0.44	4.4	0.04	0.51	0.3	13	14

Table 3.   Reproduction data for *Macoma petalum*, Palo Alto, Calif., 2011.

[Data are percentage of clams in each stage of reproduction. Reproductive = the percentage of clams in Active, Ripe, and Spawning stages. Non-Reproductive = the percentage of clams in Inactive and Spent stages. Spent means the clams have released all their gametes. N refers to the number of clams that were analyzed. ND means No Data.]

Date	Inactive	Active	Ripe	Spawning	Spent	N	Reproductive	Non-Reproductive
1/25/2011	0	10	90	0	0	10	100	0
2/23/2011	0	0	100	0	0	10	100	0
3/22/2011	0	0	100	0	0	10	100	0
4/13/2011	0	0	50	40	10	10	90	-10
5/22/2011	0	0	0	0	100	10	0	-100
6/21/2011	0	0	0	20	80	10	20	-80
9/27/2011	ND	ND	ND	ND	ND	ND	ND	ND
10/24/2011	20	80	0	0	0	10	80	-20
12/5/2011	20	70	10	0	0	10	80	-20

Appendixes

Appendix 1.   Statistical summary of percentage of sediment in samples composed of clay- and silt-sized particles, collected from Palo Alto, Calif., 1994–2011.

[Statistical results are for percent fine-grained particles (silt and clay, ≤100 micrometer) observed each month from 1994–2011. Data for percent fines for 2004, which contain unquantifiable biases due to errors in sample processing, are not included in these statistical calculations. # of samples refers to the number of times data were collected in that respective month during the span of collection years.]

Month	# of samples	Maximum	Minimum	Mean	Median
January	16	96	46	74	75
February	16	98	32	80	87
March	16	98	24	79	85
April	16	96	50	84	86
May	11	95	35	73	79
June	16	95	56	73	69
July	1	-	-	-	69
August	1	-	-	-	48
September	16	84	25	55	55
October	12	84	39	61	59
November	3	66	50	59	61
December	16	95	48	74	74

Appendix 2.   Trace-metal concentrations in sediment samples collected at the Palo Alto, Calif., mudflat, 2011.

[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, μg/mL) and the calculated weight-standardized concentration (reported as milligram per kilogram dry sediment, mg/kg). The sample mean and standard deviation for the weight-standardized concentration are also reported.]

Near-total metal extractions

1/25/2011: 96.2% <100 µm

				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.4858	10	10*	264	0.681	0.220	236	7.29	0.471	0.1124	0.391	0.722
Tot2	0.5080	10	10	273	0.702	0.227	240	7.34	0.480	0.1120	0.740	0.731

*Dilution Factor is 20 for V in Tot1

				Concentration, mg/kg								
Tot1				54,282	140.18	45.3	48,477	1,501	97.0	23.1	161	149
Tot2				53,799	138.27	44.6	47,205	1,445	94.6	22.0	146	144
			Average	54,000	139	45.0	47,800	1473	95.8	22.6	153	146
			Std	341	1	0.5	899	40	1.7	0.8	11	3

2/23/2011: 97.1% < 100 µm

				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5479	10	10*	304	0.746	0.240	238	5.43	0.459	0.1059	0.542	0.732
Tot2	0.5274	10	10	294	0.742	0.251	240	5.55	0.461	0.1138	0.850	0.745

*Dilution Factor is 20 for V in Tot1

				Concentration, mg/kg								
Tot1				55,430	136	43.8	43,475	991	83.8	19.3	198	134
Tot2				55,688	141	47.5	45,563	1,052	87.5	21.6	161	141
			Average	55,600	138	45.7	44,500	1,022	85.6	20.5	179	137
			Std	183	3	2.6	1,480	43	2.6	1.6	26	5

3/22/2011: 85.7% <100 µm

				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.2248	10	10	126	0.346	0.113	116	2.13	0.217	0.053	0.407	0.339
Tot2	-	-	-	-	-	-	-	-	-	-	-	-

				Concentration, mg/kg								
Tot1				56,050	154	50.3	51,512	948	96.4	23.4	181	151
Tot2				-	-	-	-	-	-	-	-	-
			Average	56,000	154	50.3	51,500	948	96.4	23.4	181	151
			Std	-	-	-	-	-	-	-	-	-

Near-total metal extractions, continued

4/13/2011: 94.0% <100 μm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Concentration, μg/mL								
				Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.4860	10	10	192	0.532	0.168	177	4.03	0.344	0.0805	0.651	0.538
Tot2	0.5004	10	10	211	0.571	0.184	193	4.43	0.371	0.0870	0.694	0.584
				Concentration, mg/kg								
Tot1				39,547	110	34.6	36,399	829	70.8	16.6	134	111
Tot2				42,086	114	36.7	38,489	885	74.2	17.4	139	117
			Average	40,800	112	35.6	37,400	857	72.5	17.0	136	114
			Std	1,800	3	1.5	1,480	39	2.4	0.6	3	4

5/22/2011: 94.8% < 100 μm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Concentration, μg/mL								
				Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.4168	10	10	262	0.701	0.212	226	5.70	0.408	0.0994	0.846	0.626
Tot2	0.3968	10	10	236	0.636	0.193	210	5.29	0.390	0.0939	0.770	0.604
				Concentration, mg/kg								
Tot1				62,956	168	50.8	54,295	1369	97.8	23.8	203	150
Tot2				59,350	160	48.6	52,898	1332	98.2	23.7	194	152
			Average	61,200	164	49.7	53,600	1350	98.0	23.8	198	151
			Std	2,550	6	1.5	987	26	0.3	0.1	6	1

6/21/2011: 95.3% <100 μm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Concentration, μg/mL								
				Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.4999	10	10	238	0.676	0.208	220	4.64	0.414	0.1011	0.814	0.650
Tot2	0.4968	10	10	228	0.600	0.213	207	4.31	0.422	0.1046	0.746	0.646
				Concentration, mg/kg								
Tot1				47,590	135	41.6	43,949	928	82.8	20.2	163	130
Tot2				45,833	121	42.8	41,566	868	84.9	21.1	150	130
			Average	46,700	128	42.2	42,800	898	83.8	20.6	156	130
			Std	1,240	10	0.8	1,680	42	1.5	0.6	9	0.01

Near-total metal extractions, continued

9/27/2011: 58.7% <100 µm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Concentration, µg/mL								
				Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5170	10	10	184	0.538	0.148	183	4.11	0.344	0.0742	0.633	0.518
Tot2	0.5057	10	10	194	0.558	0.154	183	4.20	0.348	0.0762	0.663	0.524
				Concentration, mg/kg								
Tot1				35,513	104	28.6	35,397	796	66.6	14.4	122	100
Tot2				38,363	110	30.4	36,247	830	68.8	15.1	131	104
			Average	36,900	107	29.5	35,800	813	67.7	14.7	127	102
			Std	2,020	5	1.2	601	24	1.6	0.5	6	2

10/24/2011: 52.2% <100 µm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Concentration, µg/mL								
				Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5309	10	10	208	0.616	0.172	200	3.81	0.366	0.0840	0.697	0.569
Tot2	0.5147	10	10	184	0.549	0.156	180	3.41	0.337	0.0791	0.626	0.513
				Concentration, mg/kg								
Tot1				39,216	116	32.3	37,634	717	69.0	15.8	131	107
Tot2				35,730	107	30.3	35,030	663	65.5	15.4	122	100
			Average	37,500	111	31.3	36,300	690	67.2	15.6	127	103
			Std	2,470	7	1.4	1,840	39	2.4	0.3	7	5

12/5/2011: 71.8% <100 µm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Concentration, µg/mL								
				Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5363	10	10	263	0.686	0.215	219	5.11	0.431	0.104	0.847	0.667
Tot2	0.5332	10	10	265	0.700	0.211	218	5.08	0.431	0.106	0.849	0.668
				Concentration, mg/kg								
Tot1				49,077	128	40.0	40,910	952	80.4	19.4	158	124
Tot2				49,662	131	39.5	40,960	953	80.8	19.8	159	125
			Average	49,400	130	39.8	40,900	953	80.6	19.6	159	125
			Std	414	2	0.4	36	1	0.3	0.3	1	1

Partial metal extraction

1/25/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
								Concentration, µg/mL					
HCl1	0.5221	12		0.015	90.8	0.248	0.821	210	39.5	0.281	0.761	0.472	1.78
HCL2	0.5311	12		0.016	92.6	0.250	0.841	212	40.6	0.283	0.769	0.481	1.78
								Concentration, mg/kg					
HCl1				0.35	2,086	5.71	18.9	4,822	907	6.45	17.5	10.84	40.8
HCl2				0.36	2,092	5.65	19.0	4,790	916	6.39	17.4	10.87	40.1
			Average	0.36	2,090	5.68	18.9	4,810	912	6.42	17.4	10.86	40.5
			Std	0.002	3	0.03	0.1	16	5	0.03	0.1	0.01	0.4

2/23/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
								Concentration, µg/mL					
HCl1	0.5226	12		0.0114	96.1	0.244	0.871	216.7	26.6	0.299	0.765	0.493	1.896
HCL2	0.5262	12		0.0115	97.8	0.247	0.879	218.6	26.7	0.303	0.760	0.495	1.968
								Concentration, mg/kg					
HCl1				0.26	2,206	5.61	20.0	4,976	611	6.87	17.6	11.32	43.5
HCl2				0.26	2,231	5.63	20.0	4,985	608	6.90	17.3	11.29	44.9
			Average	0.26	2,220	5.62	20.0	4,980	610	6.89	17.4	11.30	44.2
			Std	0.0002	13	0.01	0.02	5	1	0.01	0.1	0.02	0.7

3/22/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
								Concentration, µg/mL					
HCl1	0.5198	12		0.0102	91.7	0.232	0.811	202	18.2	0.320	0.686	0.467	1.69
HCL2	0.5069	12		0.0102	90.2	0.232	0.790	200	17.9	0.319	0.671	0.460	1.71
								Concentration, mg/kg					
HCl1				0.24	2,116	5.34	18.7	4,673	420	7.38	15.8	10.79	38.9
HCl2				0.24	2,134	5.49	18.7	4,723	424	7.55	15.9	10.90	40.4
			Average	0.24	2,130	5.42	18.7	4,700	422	7.47	15.9	10.84	39.7
			Std	0.003	9	0.07	0.02	25	2	0.09	0.02	0.05	0.7

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Partial metal extraction, continued

4/13/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Concentration, µg/mL Fe	Mn	Ni	Pb	V	Zn
HCl1	0.4988	12		0.0107	79.8	0.224	0.723	192.6	23.2	0.312	0.657	0.423	1.577
HCL2	0.5198	12		0.0107	83.1	0.228	0.759	201.8	23.7	0.322	0.671	0.440	1.639
								Concentration, mg/kg					
HCl1				0.26	1,919	5.38	17.4	4,634	557	7.50	15.8	10.18	37.9
HCl2				0.25	1,919	5.25	17.5	4,659	547	7.43	15.5	10.17	37.8
			Average	0.25	1,920	5.31	17.4	4,650	552	7.47	15.7	10.18	37.9
			Std	0.01	0.3	0.06	0.1	13	5	0.03	0.2	0.01	0.1

5/22/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Concentration, µg/mL Fe	Mn	Ni	Pb	V	Zn
HCl1	0.3443	12		0.0122	60.3	0.171	0.511	150	21.1	0.209	0.573	0.334	1.22
HCL2	0.2853	12		0.0103	51.2	0.148	0.439	128	17.8	0.181	0.492	0.280	1.08
								Concentration, mg/kg					
HCl1				0.43	2,100	5.97	17.8	5,214	736	7.29	20.0	11.62	42.5
HCl2				0.43	2,152	6.21	18.4	5,392	749	7.63	20.7	11.77	45.3
			Average	0.43	2,130	6.09	18.1	5,300	742	7.46	20.3	11.70	43.9
			Std	0.004	26	0.12	0.3	89	6	0.17	0.4	0.07	1.4

6/21/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Concentration, µg/mL Fe	Mn	Ni	Pb	V	Zn
HCl1	0.5018	12		0.0161	86.2	0.244	0.838	189	21.44	0.291	0.710	0.423	1.78
HCl2	0.5105	12		0.0162	89.3	0.255	0.856	194	21.78	0.298	0.707	0.437	1.79
								Concentration, mg/kg					
HCl1				0.39	2,061	5.84	20.04	4,525	513	6.95	16.97	10.12	42.6
HCl2				0.38	2,098	5.99	20.12	4,570	512	7.00	16.61	10.26	42.0
			Average	0.38	2,080	5.92	20.08	4,550	512	6.97	16.79	10.19	42.3
			Std	0.002	19	0.07	0.04	23	0.4	0.02	0.18	0.07	0.3

Partial metal extraction, continued

9/27/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
								Concentration, μg/mL					
HCl1	0.5269	12		0.0091	67.5	0.189	0.503	177.7	20.2	0.251	0.585	0.343	1.298
HCl2	0.5364	12		0.0094	69.5	0.192	0.520	180.4	20.7	0.255	0.579	0.353	1.341
								Concentration, mg/kg					
HCl1				0.21	1,538	4.30	11.5	4,047	459	5.72	13.3	7.81	29.6
HCl2				0.21	1,555	4.29	11.6	4,036	463	5.69	12.9	7.89	30.0
			Average	0.21	1,550	4.30	11.5	4,040	461	5.71	13.1	7.85	29.8
			Std	0.002	8	0.01	0.1	6	2	0.01	0.2	0.04	0.2

10/24/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
								Concentration, μg/mL					
HCl1	0.4959	12		0.0105	62.4	0.178	0.483	168	14.3	0.228	0.568	0.333	1.25
HCl2	0.5094	12		0.0108	66.6	0.191	0.499	178	14.8	0.242	0.578	0.350	1.24
								Concentration, mg/kg					
HCl1				0.25	1,510	4.31	11.68	4,068	346	5.52	13.7	8.06	30.3
HCl2				0.25	1,568	4.50	11.76	4,184	349	5.69	13.6	8.25	29.3
			Average	0.25	1,540	4.41	11.72	4,130	348	5.60	13.7	8.15	29.8
			Std	0.0002	29	0.09	0.04	58	2	0.09	0.1	0.10	0.5

12/5/2011

Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
								Concentration, μg/mL					
HCl1	0.463	12		0.0102	72.1	0.210	0.543	184	22.3	0.248	0.617	0.403	1.43
HCl2	0.4363	12		0.0094	66.0	0.188	0.505	167	20.8	0.224	0.597	0.373	1.27
								Concentration, mg/kg					
HCl1				0.26	1,867	5.45	14.1	4,756	577	6.44	16.0	10.43	37.0
HCl2				0.26	1,815	5.16	13.9	4,590	572	6.17	16.4	10.26	34.8
			Average	0.26	1,840	5.31	14.0	4,670	575	6.30	16.2	10.35	35.9
			Std	0.003	26	0.14	0.1	83	2	0.13	0.2	0.09	1.1

Appendix 3.   Trace-metal concentrations in the clam *Macoma petalum* collected at the Palo Alto, Calif.,

mudflat, 2011.

[Each monthly collection is reported on two pages. The first page contains the following summary statistics:
- Mean concentrations in milligram per kilogram dry tissue weight (mg/kg).
- 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 x [] 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-milligram animal.
- r l x [] 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-millimeter and 25-millimeter animals, respectively.

Soft-tissue weights for animals having shell lengths of 15, 20, and 25 mm 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   Statistical Summary

Date: 1/25/2011

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	3.09	0.72	5.45	32.5	7.17	1.52	5.45	344
STD	1.32	0.15	1.17	4.3	1.07	0.33	1.39	93
SEM	0.44	0.05	0.39	1.4	0.36	0.11	0.46	31
CV%	42.5	21	21.5	13.2	15.0	22.0	25.6	27.1
n	9	9	9	9	9	9	9	9
r wt x [ ]	0.388	0.30	0.537	0.838	0.631	0.328	0.344	0.567
X 100mg	4.61	0.59	3.59	43.0	5.17	1.19	4.03	188
r l x [ ]	0.491	0.14	0.427	0.760	0.567	0.193	0.229	0.632
X 20mm	3.55	0.71	5.10	34.7	6.74	1.47	5.22	303
X 25mm	4.38	0.68	4.46	38.9	5.96	1.39	4.82	227

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.168	0.037	0.265	1.85	0.358	0.077	0.269	15.7
25mm	0.334	0.063	0.431	3.64	0.593	0.131	0.452	23.7

Estimated weight for 15mm clam   Estimated weight for 20mm clam

      0.025 gm   0.054 gm

        25 mg   54 mg

Estimated weight for 25mm clam

      0.096 gm

        96 mg

					Concentration (µg/ml) - Blank Corrected from ICP-AES							

Station: Palo Alto   *Macoma petalum*
Date: 1/25/2011

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	11.40	0.1007	0.0112	10	0.0305	0.0070	0.0588	0.2798	0.0728	0.0140	0.0526	3.9580
Mp2	12.93	0.0661	0.0165	10	0.0233	0.0051	0.0404	0.2104	0.0549	0.0123	0.0378	3.2990
Mp3	14.70	0.1206	0.0241	10	0.0295	0.0103	0.0783	0.3581	0.1032	0.0232	0.0811	3.8900
Mp4	16.69	0.1817	0.0363	10	0.0440	0.0167	0.1299	0.5342	0.1572	0.0327	0.1426	5.2430
Mp5	17.35	0.1481	0.0370	10	0.0310	0.0087	0.0628	0.4201	0.0989	0.0174	0.0590	6.5100
Mp6	18.36	0.2736	0.0456	10	0.0552	0.0195	0.1345	0.8705	0.1621	0.0347	0.1440	8.1820
Mp7	19.42	0.1554	0.0518	10	0.0554	0.0115	0.0863	0.5648	0.0979	0.0223	0.0853	3.7830
Mp8	20.30	0.1314	0.0657	10	0.0327	0.0054	0.0431	0.5198	0.0807	0.0134	0.0400	5.1640
Mp9	24.12	0.1379	0.0690	10	0.0864	0.0115	0.0755	0.5152	0.0930	0.0248	0.0793	3.0150

				MDL	0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
				MRL	0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052

Concentration (mg/kg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	3.03	0.70	5.84	27.8	7.23	1.39	5.22	393
	Mp2	3.52	0.77	6.11	31.8	8.31	1.861	5.72	499
	Mp3	2.45	0.85	6.49	29.7	8.56	1.924	6.72	323
	Mp4	2.42	0.92	7.15	29.4	8.65	1.800	7.85	289
	Mp5	2.09	0.59	4.24	28.4	6.68	1.17	3.98	440
	Mp6	2.02	0.71	4.92	31.8	5.92	1.27	5.26	299
	Mp7	3.56	0.74	5.55	36.3	6.30	1.44	5.49	243
	Mp8	2.49	0.41	3.28	39.6	6.14	1.02	3.04	393
	Mp9	6.27	0.83	5.47	37.4	6.74	1.80	5.75	219

Content (µg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	0.0339	0.0078	0.0653	0.311	0.0809	0.0156	0.0584	4.40
	Mp2	0.0583	0.013	0.101	0.526	0.137	0.0308	0.0945	8.25
	Mp3	0.0590	0.021	0.157	0.716	0.206	0.0464	0.162	7.78
	Mp4	0.0880	0.033	0.260	1.07	0.314	0.0654	0.285	10.5
	Mp5	0.0775	0.022	0.157	1.05	0.247	0.0435	0.148	16.3
	Mp6	0.0920	0.033	0.224	1.45	0.270	0.0578	0.240	13.6
	Mp7	0.185	0.038	0.288	1.88	0.326	0.0743	0.284	12.6
	Mp8	0.164	0.027	0.216	2.60	0.404	0.0670	0.200	25.8
	Mp9	0.432	0.058	0.378	2.58	0.465	0.124	0.397	15

Station: Palo Alto   Statistical Summary

Date: 2/23/2011

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	1.47	0.37	2.11	18.0	3.45	0.633	1.53	285
STD	0.66	0.08	0.51	3.8	0.71	0.091	0.54	85
SEM	0.23	0.03	0.18	1.4	0.25	0.046	0.19	30
CV%	45.1	23	24.0	21.3	20.6	14.4	35.6	30.0
n	8	6	8	8	8	4	8	8
r wt x [ ]	0.010	0.60	0.434	0.330	0.231	0.540	0.554	0.253
X 100mg	1.48	0.08	1.68	20.5	3.13	1.07	0.936	328
r l x [ ]	0.566	0.65	0.353	0.754	0.242	0.493	0.539	0.715
X 20mm	2.14	0.22	1.79	23.3	3.76	0.844	1.00	395
X 25mm	2.65	0.13	1.55	27.2	4.00	0.968	0.602	478

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.141	0.020	0.139	1.73	0.276	0.079	0.082	28.2
25mm	0.299	0.032	0.239	3.55	0.519	0.175	0.127	59.5

Estimated weight for 15mm clam   Estimated weight for 20mm clam

     0.035 gm   0.077 gm

     35 mg   77 mg

Estimated weight for 25mm clam

     0.140 gm

     140 mg

Station: Palo Alto
Date: 2/23/2011

Macoma petalum

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (µg/ml) - Blank Corrected from ICP-AES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	8.54	0.0555	0.0079	10	0.0068	0.0028	0.0167	0.0898	0.0225	0.0048	0.0097	1.3560
Mp2	9.58	0.1509	0.0108	10	0.0182	0.0058	0.0304	0.2109	0.0451	0.0096	0.0244	3.7120
Mp3	10.54	0.2353	0.0124	10	0.0264	0.0072	0.0374	0.3488	0.0639	0.0120	0.0309	5.3640
Mp4	12.37	0.3773	0.0222	10	0.0457	0.0166	0.0954	0.6849	0.1205	0.0275	0.0996	8.3890
Mp5	13.60	0.1525	0.0305	10	0.0120	0.0048	0.0282	0.2338	0.0484	0.0100	0.0255	3.2020
Mp6	16.55	0.0847	0.0424	10	0.0189	0.0025	0.0145	0.2118	0.0380	0.0060	0.0104	3.4430
Mp7	17.49	0.0539	0.0270	10	0.0148	0.0016	0.0134	0.1194	0.0231	0.0051	0.0063	2.3030
Mp8	18.03	0.1126	0.1126	10	0.0135	0.0025	0.0191	0.2107	0.0307	0.0059	0.0093	3.3450
MDL					0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
MRL					0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052

Concentration (mg/kg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	1.2	0.50	3.0	16	4.1		1.7	240
	Mp2	1.2	0.38	2.01	14.0	2.99	0.64	1.6	246
	Mp3	1.1	0.31	1.59	14.8	2.72	0.51	1.3	228
	Mp4	1.2	0.44	2.53	18.2	3.19	0.73	2.6	222
	Mp5	0.79	0.31	1.85	15.3	3.17	0.66	1.7	210
	Mp6	2.2	0.30	1.71	25.0	4.49		1.2	406
	Mp7	2.7		2.49	22.2	4.29		1.2	427
	Mp8	1.2		1.70	18.7	2.73		0.83	297

Content (µg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	0.010	0.0040	0.024	0.13	0.032		0.014	1.9
	Mp2	0.013	0.0041	0.0217	0.151	0.0322	0.0069	0.017	2.65
	Mp3	0.014	0.0038	0.0197	0.184	0.0336	0.0063	0.016	2.82
	Mp4	0.027	0.0098	0.0561	0.403	0.0709	0.016	0.059	4.93
	Mp5	0.024	0.0096	0.0564	0.468	0.0968	0.020	0.051	6.40
	Mp6	0.095	0.013	0.0725	1.06	0.190		0.052	17.2
	Mp7	0.074		0.0670	0.597	0.116		0.032	11.5
	Mp8	0.14		0.191	2.11	0.307		0.093	33.5

		Statistical Summary						
Station:	Palo Alto							
Date:	3/22/2011							
	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	0.509	0.54	1.35	12.0	1.98	0.486	0.633	204
STD	0.199	0.16	0.44	1.1	0.55	0.123	0.101	51
SEM	0.060	0.05	0.16	0.3	0.16	0.039	0.031	15
CV%	39.0	30	32.6	9.1	27.6	25.3	16.0	25.1
n	11	11	8	11	11	10	11	11
r wt x [ ]	0.053	0.77	0.606	0.319	0.329	0.369	0.026	0.567
X 100mg	0.501	0.45	0.598	12.3	2.11	0.515	0.634	225
r l x [ ]	0.0192	0.90	0.701	0.171	0.352	0.115	0.269	0.352
X 20mm	0.513	0.39	0.660	12.2	2.18	0.500	0.604	223
X 25mm	0.518	0.21	0.076	12.4	2.43	0.519	0.569	246

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0477	0.043	0.0903	1.30	0.224	0.0514	0.0636	22.5
25mm	0.0935	0.070	0.144	2.73	0.497	0.108	0.126	49.0

Estimated weight for 15mm clam   Estimated weight for 20mm clam

0.042 gm   0.108 gm
42 mg   108 mg

Estimated weight for 25mm clam

0.225 gm
225 mg

Station:	Palo Alto		*Macoma petalum*
Date:	3/22/2011		

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (µg/ml) - Blank Corrected from ICP-AES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	10.60	0.0641	0.0128	10	0.0035	0.0054	0.0151	0.0811	0.0123	~~0.0044~~	0.0049	1.6010
Mp2	11.43	0.1365	0.0195	10	0.0073	0.0104	0.0208	0.1759	0.0277	0.0091	0.0105	2.6040
Mp3	12.40	0.1425	0.0204	10	0.0069	0.0092	0.0200	0.1706	0.0311	0.0082	0.0090	2.6380
Mp4	13.41	0.3399	0.0309	10	0.0173	0.0217	0.0380	0.4116	0.0574	0.0141	0.0204	6.2310
Mp5	14.43	0.5328	0.0355	10	0.0273	0.0264	0.0565	0.5585	0.0731	0.0182	0.0307	9.0540
Mp6	15.43	0.4619	0.0462	10	0.0224	0.0228	0.0489	0.5230	0.0711	0.0168	0.0287	8.1930
Mp7	16.59	0.2371	0.0593	10	0.0073	0.0109	0.0261	0.2493	0.0378	0.0095	0.0130	4.2980
Mp8	18.36	0.3092	0.0773	10	0.0218	0.0145	0.0367	0.3712	0.0533	0.0126	0.0182	5.6520
Mp9	19.54	0.0923	0.0923	10	0.0019	0.0032	~~0.0094~~	0.1038	0.0313	0.0049	0.0041	1.2790
Mp10	20.68	0.3276	0.1092	10	0.0312	0.0155	0.0359	0.4594	0.0731	0.0157	0.0213	9.1620
Mp11	22.33	0.186	0.1860	10	0.0066	0.0064	~~0.0270~~	0.2417	0.0393	0.0127	0.0142	5.6830
MDL					0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
MRL					0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052

Concentration (mg/kg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	0.55	0.84	2.36	12.7	1.92		0.76	250
	Mp2	0.53	0.76	1.52	12.9	2.03	0.67	0.77	191
	Mp3	0.48	0.65	1.40	12.0	2.18	0.58	0.63	185
	Mp4	0.51	0.64	1.12	12.1	1.69	0.41	0.60	183
	Mp5	0.51	0.50	1.06	10.5	1.37	0.34	0.58	170
	Mp6	0.48	0.49	1.06	11.3	1.54	0.36	0.62	177
	Mp7	0.31	0.46	1.10	10.5	1.59	0.40	0.55	181
	Mp8	0.71	0.47	1.19	12.0	1.72	0.41	0.59	183
	Mp9	0.21	0.35		11.2	3.39	0.53	0.44	139
	Mp10	0.95	0.47		14.0	2.23	0.48	0.65	280
	Mp11	0.35	0.34		13.0	2.11	0.68	0.76	306

Content (µg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	0.0070	0.011	0.0302	0.162	0.0246		0.010	3.20
	Mp2	0.010	0.015	0.0297	0.251	0.0396	0.013	0.015	3.72
	Mp3	0.010	0.013	0.0286	0.244	0.0444	0.012	0.013	3.77
	Mp4	0.016	0.020	0.0345	0.374	0.0522	0.013	0.019	5.66
	Mp5	0.018	0.018	0.0377	0.372	0.0487	0.012	0.020	6.04
	Mp6	0.022	0.023	0.0489	0.523	0.0711	0.017	0.029	8.19
	Mp7	0.018	0.027	0.0653	0.623	0.0945	0.024	0.033	10.7
	Mp8	0.055	0.036	0.0918	0.928	0.133	0.032	0.046	14.1
	Mp9	0.019	0.032		1.04	0.313	0.049	0.041	12.8
	Mp10	0.104	0.052		1.53	0.244	0.052	0.071	30.5
	Mp11	0.066	0.064		2.42	0.393	0.13	0.14	56.8

Station: Palo Alto Statistical Summary

Date: 4/13/2011

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	0.952	0.47	2.90	21.5	4.05	0.918	2.73	261
STD	0.488	0.11	0.84	7.7	0.59	0.203	0.93	34
SEM	0.147	0.03	0.25	2.3	0.18	0.061	0.28	10
CV%	51.2	23	29.1	35.8	14.6	22.1	34.0	13.2
n	11	11	11	11	11	11	11	11
r wt x [ ]	0.681	0.32	0.227	0.585	0.0718	0.248	0.249	0.487
X 100mg	1.39	0.43	2.65	27.4	4.10	0.852	2.43	283
r l x [ ]	0.679	0.30	0.231	0.580	0.0556	0.260	0.241	0.431
X 20mm	1.15	0.45	2.78	24.2	4.07	0.886	2.60	270
X 25mm	1.58	0.41	2.53	30.0	4.11	0.818	2.30	289

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0747	0.032	0.190	1.64	0.290	0.0622	0.175	19.4
25mm	0.183	0.057	0.337	3.64	0.564	0.113	0.306	39.6

Estimated weight for 15mm clam   Estimated weight for 20mm clam

0.031 gm   0.073 gm

31 mg   73 mg

Estimated weight for 25mm clam

0.142 gm

142 mg

Station: Palo Alto — *Macoma petalum*
Date: 4/13/2011

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (µg/ml) - Blank Corrected from ICP-AES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	12.03	0.2107	0.0151	10	0.0160	0.0096	0.0613	0.4149	0.0902	0.0194	0.0551	5.6120
Mp2	13.42	0.2066	0.0207	10	0.0168	0.0102	0.0618	0.3813	0.0850	0.0206	0.0620	5.5670
Mp3	14.33	0.2284	0.0286	10	0.0190	0.0124	0.0732	0.4626	0.0910	0.0232	0.0639	5.8950
Mp4	15.44	0.3293	0.0329	10	0.0216	0.0214	0.1302	0.6121	0.1463	0.0388	0.1427	7.8710
Mp5	16.41	0.4464	0.0372	10	0.0313	0.0195	0.1172	0.8623	0.1587	0.0359	0.1047	9.5310
Mp6	17.61	0.3583	0.0512	10	0.0317	0.0153	0.0949	0.7029	0.1434	0.0291	0.0868	7.5700
Mp7	18.84	0.2673	0.0668	10	0.0217	0.0152	0.0938	0.5324	0.1165	0.0293	0.0917	8.2330
Mp8	19.28	0.3004	0.0751	10	0.0232	0.0082	0.0458	0.5891	0.0859	0.0184	0.0370	7.3470
Mp9	20.75	0.2621	0.0874	10	0.0208	0.0155	0.1114	0.5209	0.1259	0.0307	0.1026	6.6490
Mp10	21.65	0.3564	0.0891	10	0.0377	0.0124	0.0576	0.5993	0.1199	0.0207	0.0537	10.1400
Mp11	24.74	0.352	0.1173	10	0.0841	0.0148	0.0943	1.5680	0.1666	0.0320	0.0863	11.2400
				MDL	0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
				MRL	0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052

Concentration (mg/kg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	0.759	0.46	2.91	19.7	4.28	0.921	2.62	266
	Mp2	0.813	0.49	2.99	18.5	4.11	0.997	3.00	269
	Mp3	0.832	0.54	3.20	20.3	3.98	1.02	2.80	258
	Mp4	0.656	0.65	3.95	18.6	4.44	1.18	4.33	239
	Mp5	0.701	0.44	2.63	19.3	3.56	0.804	2.35	214
	Mp6	0.885	0.43	2.65	19.6	4.00	0.812	2.42	211
	Mp7	0.812	0.57	3.51	19.9	4.36	1.10	3.43	308
	Mp8	0.772	0.27	1.52	19.6	2.86	0.613	1.23	245
	Mp9	0.794	0.59	4.25	19.9	4.80	1.17	3.91	254
	Mp10	1.06	0.35	1.62	16.8	3.36	0.581	1.51	285
	Mp11	2.39	0.42	2.68	44.5	4.73	0.909	2.45	319

Content (µg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	0.0114	0.0069	0.0438	0.296	0.0644	0.0139	0.0394	4.01
	Mp2	0.0168	0.010	0.0618	0.381	0.0850	0.0206	0.0620	5.57
	Mp3	0.0238	0.016	0.0915	0.578	0.114	0.0290	0.0799	7.37
	Mp4	0.0216	0.021	0.130	0.612	0.146	0.0388	0.143	7.87
	Mp5	0.0261	0.016	0.0977	0.719	0.132	0.0299	0.0873	7.94
	Mp6	0.0453	0.022	0.136	1.00	0.205	0.0416	0.124	10.8
	Mp7	0.0543	0.038	0.235	1.33	0.291	0.0733	0.229	20.6
	Mp8	0.0580	0.021	0.115	1.47	0.215	0.0460	0.0925	18.4
	Mp9	0.069	0.052	0.371	1.74	0.420	0.102	0.342	22.2
	Mp10	0.094	0.031	0.144	1.50	0.300	0.0518	0.134	25.4
	Mp11	0.280	0.049	0.314	5.23	0.555	0.107	0.288	37.5

Station: Palo Alto <u>Statistical Summary</u>

Date: 5/22/2011

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	1.09	0.24	1.51	19.7	3.60	0.571	1.25	288
STD	0.27	0.07	0.52	3.3	0.58	0.138	0.57	94
SEM	0.08	0.02	0.15	0.9	0.17	0.042	0.16	27
CV%	25.1	30	34.3	16.6	16.0	24.2	45.2	32.6
n	12	12	12	12	12	11	12	12
r wt x [ ]	0.142	0.61	0.663	0.322	0.328	0.723	0.700	0.575
X 100mg	1.10	0.24	1.47	19.8	3.58	0.534	1.21	294
r l x [ ]	0.253	0.64	0.686	0.368	0.283	0.716	0.727	0.653
X 20mm	1.08	0.25	1.55	19.5	3.62	0.566	1.30	281
X 25mm	1.16	0.20	1.16	20.8	3.44	0.443	0.846	348

<u>Estimated content (ug) for 15mm and 20mm clam</u>

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0767	0.017	0.104	1.40	0.257	0.0393	0.0831	19.9
25mm	0.169	0.030	0.174	3.08	0.516	0.0684	0.125	49.3

<u>Estimated weight for 15mm clam</u>   <u>Estimated weight for 20mm clam</u>

0.028 gm   0.072 gm

28 mg   72 mg

<u>Estimated weight for 25mm clam</u>

0.152 gm

152 mg

							Concentration (µg/ml) - Blank Corrected from ICP-AES					
					Station:	Palo Alto	*Macoma petalum*						
					Date:	5/22/2011							
Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	13.79	0.3749	0.0187	10	0.0462	0.0157	0.1047	0.8404	0.1805	0.0334	0.0997	9.9010
Mp2	15.69	0.2192	0.0365	10	0.0174	0.0056	0.0360	0.3534	0.0766	0.0136	0.0319	5.0670
Mp3	16.42	0.4326	0.0361	10	0.0487	0.0108	0.0662	0.8174	0.1495	0.0259	0.0586	10.5400
Mp4	17.49	0.6589	0.0439	10	0.0649	0.0140	0.0757	1.3700	0.2049	0.0326	0.0637	14.5600
Mp5	18.58	0.4509	0.0564	10	0.0412	0.0126	0.0717	0.8813	0.1401	0.0276	0.0619	10.9200
Mp6	19.45	0.3004	0.0601	10	0.0369	0.0097	0.0586	0.5720	0.1338	0.0198	0.0515	9.8390
Mp7	20.49	0.2532	0.0844	10	0.0358	0.0064	0.0440	0.4349	0.0865	0.0144	0.0348	8.0130
Mp8	21.45	0.1931	0.0966	10	0.0163	0.0033	0.0224	0.3497	0.0731	0.0081	0.0145	3.8140
Mp9	22.70	0.2325	0.1163	10	0.0183	0.0048	0.0335	0.3911	0.0784	0.0130	0.0276	5.1770
Mp10	24.50	0.3562	0.1781	10	0.0367	0.0052	0.0297	0.5774	0.0997	0.0132	0.0190	8.9760
Mp11	27.26	0.3154	0.1577	10	0.0542	0.0062	0.0372	0.8210	0.1248	0.0154	0.0285	16.1300
Mp12	28.35	0.2288	0.2288	10	0.0236	0.0051	0.0245	0.5642	0.0780	~~0.0101~~	0.0169	9.6970
				MDL	0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
				MRL	0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052
				Sample #								
		Concentration (mg/kg) ==>		Mp1	1.23	0.42	2.79	22.4	4.81	0.89	2.66	264
				Mp2	0.794	0.26	1.64	16.1	3.49	0.62	1.46	231
				Mp3	1.13	0.25	1.53	18.9	3.46	0.60	1.35	244
				Mp4	0.985	0.21	1.15	20.8	3.11	0.49	0.967	221
				Mp5	0.914	0.28	1.59	19.5	3.11	0.61	1.37	242
				Mp6	1.23	0.32	1.95	19.0	4.45	0.66	1.71	328
				Mp7	1.41	0.25	1.74	17.2	3.42	0.57	1.37	316
				Mp8	0.844	0.17	1.16	18.1	3.79	0.42	0.751	198
				Mp9	0.787	0.21	1.44	16.8	3.37	0.56	1.19	223
				Mp10	1.03	0.15	0.834	16.2	2.80	0.37	0.533	252
				Mp11	1.72	0.20	1.18	26.0	3.96	0.49	0.904	511
				Mp12	1.03	0.22	1.07	24.7	3.41		0.739	424
				Sample #								
		Content (µg) ==>		Mp1	0.0231	0.0079	0.0524	0.420	0.0903	0.017	0.0499	4.95
				Mp2	0.0290	0.0093	0.0600	0.589	0.128	0.023	0.0532	8.45
				Mp3	0.0406	0.0090	0.0552	0.681	0.125	0.022	0.0488	8.78
				Mp4	0.0433	0.0093	0.0505	0.913	0.137	0.022	0.0425	9.71
				Mp5	0.0515	0.016	0.0896	1.10	0.175	0.035	0.0774	13.7
				Mp6	0.0738	0.019	0.117	1.14	0.268	0.040	0.103	19.7
				Mp7	0.119	0.021	0.147	1.45	0.288	0.048	0.116	26.7
				Mp8	0.0815	0.017	0.112	1.75	0.366	0.041	0.0725	19.1
				Mp9	0.0915	0.024	0.168	1.96	0.392	0.065	0.138	25.9
				Mp10	0.184	0.026	0.149	2.89	0.499	0.066	0.0950	44.9
				Mp11	0.271	0.031	0.186	4.11	0.624	0.077	0.143	80.7
				Mp12	0.236	0.051	0.245	5.64	0.780		0.169	97.0

Station:	Palo Alto		Statistical Summary					
Date:	6/21/2011							
	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	1.18	0.22	1.65	21.1	3.36	0.647	1.21	245
STD	0.25	0.05	0.36	6.2	0.62	0.207	0.32	80
SEM	0.08	0.02	0.13	2.0	0.20	0.065	0.10	25
CV%	21.6	25	22.1	29.6	18.4	32.0	26.6	32.6
n	10	10	8	10	10	10	10	10
r wt x []	0.230	0.57	0.768	0.364	0.157	0.391	0.525	0.442
X 100mg	1.23	0.19	0.767	23.2	3.27	0.569	1.05	279
r l x []	0.119	0.64	0.736	0.217	0.323	0.516	0.542	0.342
X 20mm	1.20	0.20	1.21	21.9	3.25	0.584	1.11	261
X 25mm	1.23	0.16	0.705	23.4	3.02	0.462	0.910	292

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0838	0.014	0.0989	1.49	0.230	0.0405	0.0774	17.4
25mm	0.174	0.025	0.175	3.16	0.447	0.0724	0.140	37.1

Estimated weight for 15mm clam   Estimated weight for 20mm clam

0.028 gm   0.073 gm
28 mg   73 mg

Estimated weight for 25mm clam

0.152 gm
152 mg

					Concentration (µg/ml) - Blank Corrected from ICP-AES							

Station: Palo Alto *Macoma petalum*
Date: 6/21/2011

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	11.30	0.1068	0.0107	10	0.0145	0.0031	0.0229	0.2866	0.0484	0.0110	0.0157	2.7830
Mp2	13.51	0.1900	0.0190	10	0.0255	0.0061	0.0388	0.4636	0.0762	0.0174	0.0330	5.1920
Mp3	14.54	0.2448	0.0245	10	0.0291	0.0059	0.0427	0.6044	0.0891	0.0193	0.0338	6.0390
Mp4	15.39	0.3411	0.0341	10	0.0391	0.0059	0.0439	0.4983	0.1017	0.0155	0.0295	7.0310
Mp5	16.36	0.4064	0.0406	10	0.0362	0.0079	0.0588	0.6315	0.1164	0.0190	0.0438	9.2890
Mp6	17.32	0.3028	0.0433	10	0.0403	0.0073	0.0519	0.5475	0.0962	0.0195	0.0432	7.2940
Mp7	18.32	0.3912	0.0559	10	0.0295	0.0079	0.0678	0.4693	0.1022	0.0198	0.0568	6.0930
Mp8	19.30	0.3568	0.0714	10	0.0311	0.0055	0.0381	0.6237	0.1053	0.0147	0.0283	8.8750
Mp9	22.16	0.2126	0.1063	10	0.0311	0.0035	0.0248	0.5745	0.0634	0.0138	0.0183	3.1850
Mp10	26.26	0.1582	0.1582	10	0.0226	0.0031	0.0219	0.4749	0.0614	0.0095	0.0168	6.9360

					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
				MDL	0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
				MRL	0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052

Concentration (mg/kg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	1.36	0.29	2.14	26.8	4.53	1.0	1.47	261
	Mp2	1.34	0.32	2.04	24.4	4.01	0.92	1.74	273
	Mp3	1.19	0.24	1.74	24.7	3.64	0.79	1.38	247
	Mp4	1.15	0.17	1.29	14.6	2.98	0.45	0.865	206
	Mp5	0.89	0.19	1.45	15.5	2.86	0.47	1.08	229
	Mp6	1.33	0.24	1.71	18.1	3.18	0.64	1.43	241
	Mp7	0.754	0.20	1.73	12.0	2.61	0.51	1.45	156
	Mp8	0.872	0.15	1.07	17.5	2.95	0.41	0.793	249
	Mp9	1.46	0.16		27.0	2.98	0.65	0.861	150
	Mp10	1.43	0.20		30.0	3.88	0.60	1.06	438

Content (µg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	0.0145	0.0031	0.0229	0.287	0.0484	0.011	0.0157	2.78
	Mp2	0.0255	0.0061	0.0388	0.464	0.0762	0.017	0.0330	5.19
	Mp3	0.0291	0.0059	0.0427	0.604	0.0891	0.019	0.0338	6.04
	Mp4	0.0391	0.0059	0.0439	0.498	0.102	0.016	0.0295	7.03
	Mp5	0.0362	0.0079	0.0588	0.632	0.116	0.019	0.0438	9.29
	Mp6	0.0576	0.010	0.0741	0.782	0.137	0.028	0.0617	10.4
	Mp7	0.0421	0.011	0.0969	0.670	0.146	0.028	0.0811	8.70
	Mp8	0.0622	0.011	0.0762	1.25	0.211	0.029	0.0566	17.8
	Mp9	0.156	0.018		2.87	0.317	0.069	0.0915	15.9
	Mp10	0.226	0.031		4.75	0.614	0.095	0.168	69.4

Station:	Palo Alto		Statistical Summary					
Date:	9/27/2011							
	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	2.60	0.31	2.10	38.7	3.92	0.742	1.78	244
STD	0.74	0.10	0.69	5.3	1.01	0.081	0.54	88
SEM	0.23	0.03	0.22	1.7	0.32	0.036	0.17	28
CV%	28.3	31	32.9	14	26	10.9	30.4	36.0
n	10	10	10	10	10	5	10	10
r wt x [ ]	0.513	0.64	0.685	0.613	0.560	0.9803	0.715	0.407
X 100mg	1.79	0.18	0.09	32	2.7	0.616	0.94	167
r l x [ ]	0.632	0.75	0.749	0.661	0.684	0.975	0.803	0.521
X 20mm	2.36	0.28	1.57	36.9	3.56	0.774	1.55	220
X 25mm	1.67	0.17	0.45	32	2.5	0.603	0.907	152

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.119	0.014	0.0874	1.91	0.182	0.0403	0.0782	11.1
25mm	0.198	0.022	0.128	3.53	0.306	0.0662	0.121	18.7

Estimated weight for 15mm clam   Estimated weight for 20mm clam

0.021 gm   0.052 gm
21 mg   52 mg

Estimated weight for 25mm clam

0.108 gm
108 mg

Station:	Palo Alto				*Macoma petalum*							
Date:	9/27/2011											

					Concentration (µg/ml) - Blank Corrected from ICP-AES							
Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	13.72	0.0463	0.0154	10	0.0203	0.0026	0.0180	0.2009	0.0303	0.0072	0.0144	2.1970
Mp2	14.56	0.1291	0.0184	10	0.0374	0.0046	0.0298	0.6487	0.0580	0.0172	0.0263	2.7690
Mp3	15.51	0.2331	0.0233	10	0.0666	0.0083	0.0501	0.8395	0.1002	0.0242	0.0459	6.7350
Mp4	16.66	0.2927	0.0293	10	0.0701	0.0089	0.0624	1.1350	0.1078	0.0257	0.0534	6.1310
Mp5	17.52	0.3652	0.0332	10	0.0732	0.0095	0.0688	1.2610	0.1215	0.0339	0.0565	7.8600
Mp6	18.54	0.4413	0.0401	10	0.1057	0.0128	0.0785	1.7960	0.1471	0.0364	0.0742	10.3800
Mp7	19.43	0.3319	0.0474	10	0.0851	0.0099	0.0718	1.3320	0.1121	0.0269	0.0557	5.7500
Mp8	20.55	0.2416	0.0604	10	0.0609	0.0060	0.0370	0.8907	0.0795	0.0175	0.0304	4.1930
Mp9	21.56	0.2632	0.0658	10	0.0416	0.0056	0.0465	0.8548	0.0900	0.0192	0.0355	5.6540
Mp10	23.55	0.2569	0.0856	10	0.0590	0.0064	0.0566	7.4120	0.8408	0.0319	0.0353	6.5630
Mp11	24.52	0.4019	0.1005	10	0.0962	0.0102	0.0569	1.3670	0.1392	0.0250	0.0526	9.4700

NOTE: Since data for Mp10 are extreme outliers, it is likely this sample has been contaminated. Data for Mp10 is not included in concentration calculations.

					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
				MDL	0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
				MRL	0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052

Concentration (mg/kg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	4.38	0.56	3.89	43.4	6.54		3.11	475
	Mp2	2.90	0.36	2.31	50.2	4.49		2.04	214
	Mp3	2.86	0.36	2.15	36.0	4.30		1.97	289
	Mp4	2.39	0.30	2.13	38.8	3.68		1.82	209
	Mp5	2.00	0.26	1.88	34.5	3.33		1.55	215
	Mp6	2.40	0.29	1.78	40.7	3.33	0.82	1.68	235
	Mp7	2.56	0.30	2.16	40.1	3.38	0.81	1.68	173
	Mp8	2.52	0.25	1.53	36.9	3.29	0.72	1.2583	173.551
	Mp9	1.58	0.21	1.77	32.5	3.42	0.73	1.3488	214.818
	Mp10								
	Mp11	2.39	0.25	1.42	34.0	3.46	0.62	1.3088	235.631

Content (µg) ==>	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
	Mp1	0.0677	0.0087	0.0600	0.670	0.101		0.0480	7.32
	Mp2	0.0534	0.0066	0.0426	0.927	0.0829		0.0376	3.96
	Mp3	0.0666	0.0083	0.0501	0.840	0.100		0.0459	6.74
	Mp4	0.0701	0.0089	0.0624	1.14	0.108		0.0534	6.13
	Mp5	0.0665	0.0086	0.0625	1.15	0.110		0.0514	7.15
	Mp6	0.0961	0.012	0.0714	1.63	0.134	0.033	0.0675	9.44
	Mp7	0.122	0.014	0.103	1.90	0.160	0.038	0.0796	8.21
	Mp8	0.152	0.015	0.0925	2.23	0.199	0.044	0.0760	10.5
	Mp9	0.104	0.014	0.116	2.14	0.225	0.048	0.0888	14.1
	Mp10								
	Mp11	0.241	0.026	0.142	3.42	0.348	0.063	0.132	23.7

Station:	Palo Alto		Statistical Summary					
Date:	10/24/2011							
	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	3.74	0.45	2.91	48.9	5.18	1.12	2.62	292
STD	1.12	0.17	1.23	14.7	1.54	0.21	0.91	105
SEM	0.31	0.05	0.34	4.1	0.43	0.08	0.25	29
CV%	29.9	37	42.3	30.1	29.7	18.5	34.9	35.9
n	13	13	13	13	13	6	13	13
r wt x [ ]	0.519	0.72	0.502	0.513	0.617	0.402	0.473	0.676
X 100mg	2.37	0.17	1.45	31.1	2.94	0.449	1.60	125
r l x [ ]	0.610	0.84	0.650	0.582	0.758	0.421	0.583	0.775
X 20mm	3.47	0.40	2.59	45.5	4.72	1.02	2.41	260
X 25mm	2.67	0.23	1.65	35.4	3.34	0.778	1.78	164

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.146	0.017	0.108	1.93	0.199	0.0405	0.100	10.4
25mm	0.249	0.026	0.175	3.37	0.332	0.0649	0.170	15.9

Estimated weight for 15mm clam   Estimated weight for 20mm clam

0.018 gm   0.044 gm

18 mg   44 mg

Estimated weight for 25mm clam

0.087 gm

87 mg

Station: Palo Alto *Macoma petalum*

Date: 10/24/2011

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
					Concentration (µg/ml) - Blank Corrected from ICP-AES							
Mp1	10.14	0.0557	0.0056	10	0.0379	0.0050	0.0372	0.5183	0.0523	0.0142	0.0291	2.2800
Mp2	13.35	0.0724	0.0145	10	0.0269	0.0047	0.0228	0.2620	0.0509	0.0117	0.0191	2.7750
Mp3	14.57	0.0871	0.0145	10	0.0382	0.0039	0.0216	0.4108	0.0456	~~0.0109~~	0.0183	4.3600
Mp4	15.64	0.1020	0.0204	10	0.0362	0.0049	0.0333	0.5124	0.0557	0.0149	0.0264	3.6520
Mp5	16.58	0.4994	0.0238	10	0.1663	0.0206	0.1176	2.3220	0.1996	0.0451	0.1248	12.2300
Mp6	17.60	0.3461	0.0266	10	0.1034	0.0137	0.0865	1.6450	0.1429	0.0351	0.0849	8.7140
Mp7	18.36	0.2387	0.0298	10	0.0918	0.0132	0.0807	1.1030	0.1284	0.0302	0.0828	7.6980
Mp8	19.63	0.2581	0.0369	10	0.0887	0.0106	0.0626	1.3560	0.1275	0.0271	0.0592	6.7450
Mp9	20.34	0.1746	0.0437	10	0.0654	0.0062	0.0373	0.9564	0.0852	0.0176	0.0356	3.9530
Mp10	21.82	0.1395	0.0698	10	0.0297	0.0036	0.0244	0.6034	0.0546	~~0.0116~~	0.0195	3.1570
Mp11	22.28	0.2659	0.0665	10	0.1178	0.0095	0.0578	1.1100	0.1033	0.0249	0.0569	5.2980
Mp12	23.36	0.2497	0.083	10	0.0645	0.0086	0.0625	0.7730	0.1032	0.0179	0.0628	7.9500
Mp13	24.57	0.1470	0.074	10	0.0550	0.0051	0.0444	0.6660	0.0724	0.0150	0.0392	1.4060

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
MDL	0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
MRL	0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052

Concentration (mg/kg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	6.8	0.90	6.7	93	9.4		5.2	410
Mp2	3.72	0.65	3.15	36.2	7.03		2.64	383
Mp3	4.39	0.45	2.48	47.2	5.24		2.10	501
Mp4	3.55	0.48	3.26	50.2	5.46	1.46	2.59	358
Mp5	3.33	0.41	2.35	46.5	4.00	0.903	2.50	245
Mp6	2.99	0.40	2.50	47.5	4.13	1.01	2.45	252
Mp7	3.85	0.55	3.38	46.2	5.38	1.27	3.47	322
Mp8	3.44	0.41	2.43	52.5	4.94	1.05	2.29	261
Mp9	3.75	0.36	2.14	54.8	4.88	1.01	2.04	226
Mp10	2.13	0.26	1.75	43.3	3.91		1.40	226
Mp11	4.43	0.36	2.17	41.7	3.88		2.14	199
Mp12	2.6	0.34	2.5	31	4.1		2.5	320
Mp13	3.7	0.35	3.0	45	4.9		2.7	96

Content (µg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	0.038	0.0050	0.037	0.52	0.052		0.029	2.3
Mp2	0.0538	0.0094	0.0456	0.524	0.102		0.0382	5.55
Mp3	0.0637	0.0065	0.0360	0.685	0.0760		0.0305	7.27
Mp4	0.0724	0.0098	0.0666	1.02	0.111	0.0298	0.0528	7.30
Mp5	0.0792	0.0098	0.0560	1.11	0.0950	0.0215	0.0594	5.82
Mp6	0.0795	0.011	0.0665	1.27	0.110	0.0270	0.0653	6.70
Mp7	0.115	0.017	0.101	1.38	0.161	0.0378	0.104	9.62
Mp8	0.127	0.015	0.0894	1.94	0.182	0.0387	0.0846	9.64
Mp9	0.164	0.016	0.0933	2.39	0.213	0.0440	0.0890	9.88
Mp10	0.149	0.018	0.122	3.02	0.273		0.0975	15.8
Mp11	0.295	0.024	0.145	2.78	0.258		0.142	13.2
Mp12	0.22	0.029	0.21	2.6	0.34		0.21	27
Mp13	0.28	0.026	0.22	3.3	0.36		0.20	7.0

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Station: Palo Alto			Statistical Summary					
Date: 12/5/2011								
Mean(mg/kg)	3.57	0.63	3.91	46.0	5.70	1.42	3.98	289
STD	1.42	0.17	1.01	15.5	1.27	0.33	1.06	70
SEM	0.41	0.05	0.29	4.5	0.37	0.11	0.31	20
CV%	39.8	27	25.9	33.7	22.3	23.5	26.6	24.1
n	12	12	12	12	12	9	12	12
r wt x [ ]	0.702	0.69	0.656	0.468	0.561	0.782	0.617	0.393
X 100mg	2.29	0.48	3.06	36.7	4.79	0.942	3.14	254
r l x [ ]	0.528	0.37	0.272	0.119	0.277	0.815	0.242	0.158
X 20mm	3.45	0.62	3.87	45.8	5.65	1.21	3.94	287
X 25mm	2.61	0.55	3.56	43.7	5.25	0.804	3.65	275

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.153	0.029	0.182	2.10	0.270	0.0629	0.185	13.6
25mm	0.244	0.051	0.326	3.81	0.494	0.108	0.333	25.4

Estimated weight for 15mm clam   Estimated weight for 20mm clam

0.021 gm   0.049 gm
21 mg   49 mg

Estimated weight for 25mm clam

0.097 gm
97 mg

Sample #-n	Average Length (mm)	Total Dry Wt (gm)	Average Dry Wt (gm)	Recon Amt (ml)	Concentration (µg/ml) - Blank Corrected from ICP-AES							
					Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	11.69	0.0799	0.0089	10	0.0558	0.0067	0.0356	0.5744	0.0626	0.0164	0.0350	3.3510
Mp2	14.54	0.2041	0.0186	10	0.0826	0.0162	0.1019	0.9577	0.1358	0.0353	0.1062	6.1890
Mp3	15.44	0.1415	0.0236	10	0.0553	0.0079	0.0533	0.6177	0.0771	0.0191	0.0508	4.5240
Mp4	16.47	0.2415	0.0242	10	0.0955	0.0168	0.1044	1.1670	0.1321	0.0374	0.1027	6.5060
Mp5	17.30	0.3065	0.0307	10	0.0882	0.0226	0.1391	1.1890	0.1676	0.0415	0.1459	6.5590
Mp6	18.43	0.3709	0.0371	10	0.1244	0.0201	0.1203	1.6420	0.1698	0.0417	0.1283	10.6200
Mp7	19.22	0.3083	0.0440	10	0.1033	0.0219	0.1327	1.2140	0.1735	0.0414	0.1397	7.9940
Mp8	21.50	0.3630	0.1210	10	0.0382	0.0137	0.0867	0.7785	0.1308	0.0325	0.0943	5.6320
Mp9	22.24	0.2006	0.0502	10	0.0786	0.0139	0.0913	1.1210	0.1513	0.0275	0.0927	5.6360
Mp10	23.16	0.2868	0.0956	10	0.0545	0.0098	0.0663	0.7666	0.1186	~~0.0251~~	0.0649	7.3410
Mp11	24.45	0.2011	0.1006	10	0.0688	0.0096	0.0548	0.8312	0.1117	0.0215	0.0528	6.5180
Mp12	26.98	0.1569	0.0785	10	0.0636	0.0131	0.0833	1.1600	0.1022	0.0283	0.0857	5.9410
				MDL	0.0007	0.0002	0.0009	0.0014	0.0003	0.0022	0.0002	0.0026
				MRL	0.0014	0.0003	0.0019	0.0029	0.0006	0.0043	0.0005	0.0052

	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Concentration (mg/kg) ==>	Mp1	7.0	0.84	4.5	72	7.8	2.1	4.4	420
	Mp2	4.05	0.79	4.99	46.9	6.65	1.73	5.20	303
	Mp3	3.91	0.56	3.77	43.7	5.45	1.35	3.59	320
	Mp4	3.95	0.70	4.32	48.3	5.47	1.55	4.25	269
	Mp5	2.88	0.74	4.54	38.8	5.47	1.35	4.76	214
	Mp6	3.35	0.54	3.24	44.3	4.58	1.12	3.46	286
	Mp7	3.35	0.71	4.30	39.4	5.63	1.34	4.53	259
	Mp8	1.05	0.38	2.39	21.4	3.60	0.895	2.60	155
	Mp9	3.92	0.69	4.55	55.9	7.54	1.37	4.62	281
	Mp10	1.90	0.34	2.31	26.7	4.14		2.26	256
	Mp11	3.42	0.48	2.73	41.3	5.55		2.63	324
	Mp12	4.05	0.83	5.31	73.9	6.51		5.46	379

	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Content (µg) ==>	Mp1	0.062	0.0074	0.040	0.64	0.070	0.018	0.039	3.7
	Mp2	0.0751	0.015	0.0926	0.871	0.123	0.0321	0.0965	5.63
	Mp3	0.0922	0.013	0.0888	1.03	0.129	0.0318	0.0847	7.54
	Mp4	0.0955	0.017	0.104	1.17	0.132	0.0374	0.103	6.51
	Mp5	0.0882	0.023	0.139	1.19	0.168	0.0415	0.146	6.56
	Mp6	0.124	0.020	0.120	1.64	0.170	0.0417	0.128	10.6
	Mp7	0.148	0.031	0.190	1.73	0.248	0.0591	0.200	11.4
	Mp8	0.127	0.046	0.289	2.60	0.436	0.108	0.314	18.8
	Mp9	0.197	0.035	0.228	2.80	0.378	0.0688	0.232	14.1
	Mp10	0.182	0.033	0.221	2.56	0.395		0.216	24.5
	Mp11	0.344	0.048	0.274	4.16	0.559		0.264	32.6
	Mp12	0.318	0.066	0.417	5.8	0.511		0.429	29.7

Appendix 4. **Mercury and selenium concentrations (mg/kg dry weight) determined in sample splits of surface sediments and *Macoma petalum* collected at Palo Alto, Calif., 2011.**

[One sediment sample and four clam tissue samples were split and analyzed for Se and Hg. The split results are shown here. *Macoma petalum* (clams) were divided according to size into three composite samples, and the numbers listed after the dates for clam tissue samples denote which composite sample was split.]

Date	Sediment		*M. petalum*	
	mercury	selenium	mercury	selenium
4/13/2011-1	--	--	--	4.4 \ 3.8
4/13/2011-2	--	--	0.27 \ 0.24	--
9/27/2011-2	--	--	--	4.3 \ 3.8
12/5/2011-1	--	--	0.37 \ 0.44	--
4/13/2011	0.30 \ 0.40	0.7 \ 0.5	--	--

Appendix 5. Results of the analyses of National Institute of Science and Technology (NIST) standard reference material 2709a (San Joaquin Soil) for elements, excluding selenium and mercury.

[Recoveries are reported as the observed concentrations (milligram per kilogram, dry weight (mg/kg)) 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						
1/25/2011	1	40,388	5	0.25	99	27	30,966	467	68	9	139	92
	2	40,988	5	0.25	101	28	32,044	488	70	9	140	94
2/23/2011	1	39,103	5	0.24	99	29	30,949	481	67	9	130	91
	2	46,041	6	0.27	112	32	33,736	527	71	9	150	98
3/22/2011	1	40,073	5	0.23	99	28	29,935	470	66	8	134	91
	2	35,983	5	0.24	90	25	27,520	429	61	8	121	84
4/13/2011	1	38,963	5	0.25	100	29	32,787	504	72	9	130	97
	2	37,477	5	0.24	97	28	31,692	484	68	9	125	93
5/22/2011	1	39,524	5	0.25	104	28	32,795	502	70	9	135	95
	2	39,953	5	0.25	105	28	33,463	513	71	9	137	97
6/21/2011	1	41,550	5	0.27	99	29	31,651	478	72	9	140	98
	2	42,717	6	0.25	104	29	33,061	496	76	9	144	101
9/27/2011	1	45,116	6	0.27	108	33	35,328	538	79	10	147	106
	2	40,297	5	0.26	98	30	31,623	483	71	9	133	96
10/24/2011	1	41,213	5	0.23	97	29	31,204	474	71	9	137	96
	2	41,782	6	0.27	100	30	31,939	485	73	9	140	98
12/5/2011	1	42,989	6	0.27	103	30	32,420	494	74	9	143	100
	2	42,584	5	0.25	104	30	32,884	498	74	9	141	100
						Certified concentration						
	Mean	73,700	11	0.371	130	34	33,600	529	85	17	110	103
	STD	1,600	0.3	0.002	9	1	700	18	2	0.1	11	4

Month	Rep	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
						Percent recovery						
1/25/2011	1	55	52	68	76	81	92	88	80	51	126	89
	2	56	52	68	78	83	95	92	82	51	127	91
2/23/2011	1	53	48	65	76	86	92	91	79	50	118	89
	2	62	53	74	86	94	100	100	84	52	137	95
3/22/2011	1	54	47	62	76	83	89	89	77	48	122	88
	2	49	44	64	69	73	82	81	72	44	110	82
4/13/2011	1	53	50	67	77	86	98	95	85	53	118	94
	2	51	46	66	75	83	94	92	80	51	114	90
5/22/2011	1	54	50	67	80	82	98	95	82	49	123	92
	2	54	49	68	81	83	100	97	83	51	125	94
6/21/2011	1	56	52	72	76	86	94	90	85	50	127	95
	2	58	55	69	80	85	98	94	89	54	131	98
9/27/2011	1	61	54	74	83	97	105	102	93	59	134	102
	2	55	48	70	75	87	94	91	84	50	121	93
10/24/2011	1	56	51	61	75	85	93	90	84	52	124	93
	2	57	52	73	77	88	95	92	86	52	127	95
12/5/2011	1	58	54	73	79	90	96	93	87	52	130	97
	2	58	51	68	80	88	98	94	87	53	129	97
	Mean	55	50	68	78	85	95	92	83	51	124	93
	STD	3	3	4	4	5	5	5	5	3	7	5

Appendix 6.   Observed and certified values for inorganic elements in NIST Standard Reference Material 2976 (mussel tissue) prepared in 2011.

[Observed Concentrations in NIST SRM 2976 in 2011. Concentration unit is mg/kg (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
1/25/2011	0.004 ± 0.003	0.59 ± 0.01	0.697 ± 0.030	3.52 ± 0.06	0.542 ± 0.008	0.777 ± 0.039	0.534 ± 0.009	125 ± 2
2/23/2011	0.005 ± 0.006	0.66 ± 0.02	0.933 ± 0.219	3.87 ± 0.06	0.615 ± 0.053	0.841 ± 0.031	0.573 ± 0.023	135 ± 3
3/22/2011	0.007 ± 0.006	0.67 ± 0.02	0.802 ± 0.067	3.81 ± 0.11	0.615 ± 0.027	0.865 ± 0.035	0.579 ± 0.017	138 ± 5
4/13/2011	<MRL	0.64 ± 0.005	0.746 ± 0.041	3.63 ± 0.08	0.583 ± 0.032	0.843 ± 0.014	0.550 ± 0.010	133 ± 2
5/22/2011	0.002 ± 0.010	0.66 ± 0.01	0.942 ± 0.230	3.76 ± 0.09	0.620 ± 0.034	0.856 ± 0.012	0.548 ± 0.011	132 ± 3
6/21/2011	<MRL	0.66 ± 0.02	0.711 ± 0.020	3.66 ± 0.04	0.588 ± 0.010	0.878 ± 0.046	0.532 ± 0.007	131 ± 2
9/27/2011	0.007 ± 0.002	0.65 ± 0.01	0.873 ± 0.149	3.83 ± 0.04	0.627 ± 0.022	0.877 ± 0.036	0.561 ± 0.007	129 ± 1
10/24/2011	0.004 ± 0.004	0.63 ± 0.01	0.816 ± 0.076	3.67 ± 0.03	0.578 ± 0.028	0.825 ± 0.022	0.521 ± 0.011	124 ± 1
12/5/2011	0.007 ± 0.003	0.62 ± 0.01	0.707 ± 0.051	3.55 ± 0.04	0.567 ± 0.010	0.835 ± 0.014	0.542 ± 0.009	126 ± 2
Mean	0.005	0.64	0.803	3.70	0.593	0.844	0.549	130
Median	0.005	0.65	0.802	3.67	0.588	0.843	0.548	131
Certified Concentrations								
	0.011 ± 0.005	0.82 ± 0.16	0.5 ± 0.2	4.02 ± 0.33	0.93 ± 0.12	1.19 ± 0.18	unknown	137 ± 13

Appendix 7.   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	0.0002	0.0033	0.0001	0.0014	0.0014	0.0060	0.0003	0.0004	0.0012	0.0002	0.0063
	MRL	0.0004	0.0066	0.0002	0.0029	0.0028	0.0120	0.0006	0.0008	0.0024	0.0003	0.0126
Tissue	MDL	0.0007	0.0039	0.0002	0.0009	0.0014	0.0035	0.0006	0.0003	0.0022	0.0002	0.0026
	MRL	0.0014	0.0078	0.0003	0.0019	0.0029	0.0071	0.0012	0.0006	0.0043	0.0005	0.0052

Appendix 8.   Observed and certified concentrations of mercury and selenium in standard reference materials (SRM) analyzed in 2011.

[Concentration is reported as parts per million (ppm). "nc" means non-certified.]

SRM	Mercury		Selenium	
	Observed	Certified	Observed	Certified
NIST 2976	0.06	0.06±0.01	2.0	1.8±0.2
NRCC DORM-2	4.51	4.5±0.3	1.3	1.4±0.1
NRCC TORT-2	0.23	0.27±0.06	4.9	5.6±0.7
NIST 1566b	0.05	0.04±0.01	2.0	2.1±0.2
NIST 2709a	0.80	0.9±0.2	1.3	1.5 (nc)
NIST 1646a	0.03	0.04 (nc)	0.3	0.2±0.1

Appendix 9.   Annual mean silver and annual mean copper in sediments and the clam *Macoma petalum*,

Palo Alto, Calif., 1977–2011.

[Mean, Median, Minimum, and Maximum are calculated from all data between 1977–2011. The 2011 column presents the current 2011 data. Values for the 2011 column are annual (grand) means for 8 to 13 separate samples and standard errors of those means, the rest of the columns are statistics from the grand means of 1977–2011. Samples were collected between January and December of each year. Units are milligrams per kilogram dry weight of soft tissue for the clam (Macoma petalum) and milligram per kilogram dry weight for sediment. HCl refers to hydrochloric acid extractable copper and silver.]

Type of Analysis	2011	Mean	Median	Minimum	Maximum
Copper					
Sediment - HCl	17±1	24	20	13	55
Sediment - Total	41±3	45	44	30	86
Clams	29±4	82	45	24	287
Silver					
Sediment - HCl	0.29±0.03	0.53	0.37	0.20	1.6
Clams	2.0±0.4	26	5.5	1.8	106

Appendix 10.   Complete list of benthic species found at Palo Alto in the year 2011.

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

TAXON	1/26/2011		2/24/2011		4/25/2011		5/24/2011		6/21/2011		7/19/2011		8/15/2011		9/26/2011		10/24/2011		12/19/2011	
	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	Mean	std dev
PHYLUM ANNELIDA																				
Class Oligochaeta																				
Naididae unid. 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	0.0	0.0
Oligochaeta unid. 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	0.0	0.0
Tubificidae unid. spp.	5.0	3.6	21.3	12.7	38.0	22.7	5.3	6.7	3.0	2.6	0.3	0.6	3.7	1.5	2.0	2.0	4.7	4.2	13.3	18.8
Class Polychaeta																				
Capitella capitata complex	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	0.7	1.2
Cirratulidae unid. spp.	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	0.0	0.0
Eteone lighti	3.0	2.0	4.7	3.1	1.7	1.2	6.0	3.6	7.3	3.5	8.0	2.0	3.7	1.5	0.7	1.2	2.7	0.6	5.7	5.5
Eteone unid. 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	0.0	0.0
Euchone limnicola	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.6	0.0	0.0	0.0	0.0
Euchone unid. 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	0.0	0.0
Glycera unid. 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	0.0	0.0
Glycinde armigera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glycinde picta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glycinde unid. sp. SF1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glycinde unid. spp.	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	0.0	0.0
Harmothoe imbricata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	1.0	0.0	2.3	3.2	4.0	3.6	2.3	1.5	2.0	1.0	1.0	1.0	3.0	2.0	0.3	0.6	4.7	0.6	5.0	5.3
Maldanidae unid. 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	0.0	0.0
Marphysa sanguinea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Neanthes succinea	0.7	0.6	0.0	0.0	0.7	0.6	0.0	0.0	0.7	1.2	0.0	0.0	0.3	0.6	0.3	0.6	0.3	0.6	0.0	0.0
Polychaeta unid. 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	0.0	0.0
Polydora cornuta	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	0.0	0.0	0.0	0.0	0.0	0.0
Polydora unid. 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	0.0	0.0
Pseudopolydora kempi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TAXON	1/26/2011		2/24/2011		4/25/2011		5/24/2011		6/21/2011		7/19/2011		8/15/2011		9/26/2011		10/24/2011		12/19/2011	
	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	Mean	std dev
Sabaco elongatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sphaerosyllis californiensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sphaerosyllis erinaceus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sphaerosyllis unid. sp. A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Streblospio benedicti	6.3	6.8	9.7	8.1	15.0	1.7	7.7	7.6	6.3	0.6	0.0	0.0	3.0	3.0	1.3	1.5	3.0	2.6	8.7	15.0
Spionidae unid. 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	0.0	0.0

PHYLUM ARTHROPODA

Class Arachnida

TAXON	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	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	0.0	0.0

Class Copepoda

TAXON	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	Mean	std dev
Calanoida unid. 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	0.0	0.0
Harpacticoida unid. 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	0.0	0.0

Class Insecta

TAXON	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	Mean	std dev
Chironomidae unid. 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	0.0	0.0

Class Malacostraca

TAXON	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	Mean	std dev
Americhelidium unid. 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	0.0	0.0
Ampelisca abdita	5.7	1.5	5.0	2.6	0.0	0.0	1.3	0.6	1.7	1.2	1.3	2.3	1.7	1.5	9.3	2.1	0.3	0.6	1.0	1.0
Ampithoe unid. 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	0.0	0.0
Callianassidae unid. 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	0.0	0.0
Caprella 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	0.0	0.0
Corophium alienense	0.0	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	0.3	0.6
Corophium heteroceratum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	3.5
Corophium spinicorne	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Corophium unid. 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	0.0	0.0
Corophiidae unid. spp.	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	0.0	0.0	0.0	0.0
Crangon nigricauda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cumella vulgaris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TAXON	1/26/2011		2/24/2011		4/25/2011		5/24/2011		6/21/2011		7/19/2011		8/15/2011		9/26/2011		10/24/2011		12/19/2011	
	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	Mean	std dev
Eogammarus confervicolus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gnorisphaeroma oregonensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grandidierella japonica	1.7	2.1	1.3	1.2	0.0	0.0	0.0	0.0	2.0	0.0	1.7	0.6	3.0	1.7	0.3	0.6	2.0	2.0	0.0	0.0
Hemigrapsus oregonensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita nitida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita unid. 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	0.0	0.0
Monocorophium acherusicum	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.2	0.0	0.0	0.0	0.0	0.3	0.6
Monocorophium insidiosum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monocorophium unid. spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	1.2	0.3	0.6	0.3	0.6
Mysidacea unid. 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	0.0	0.0
Nippoleucon hinumensis	15.0	4.6	34.7	34.8	88.0	21.7	79.7	49.2	153.3	17.2	66.0	37.7	66.0	31.6	33.7	6.4	6.7	5.5	41.7	25.5
Sinelobus unid. 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	0.3	0.6	0.0	0.0
Sphaeromatidae unid. 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	0.3	0.6	0.0	0.0	0.3	0.6	0.0	0.0
Synidotea laevidorsalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0
Synidotea unid. 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	0.3	0.6	0.3	0.6	0.0	0.0	0.0	0.0
Class Ostacoda																				
Eusarsiella zostericola	7.7	1.5	2.7	1.5	1.0	1.0	4.7	2.5	2.3	0.6	0.7	1.2	1.7	1.5	3.0	3.6	4.0	2.6	10.7	8.3
Cyprideis unid. 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	0.0	0.0
Class Thecostraca																				
Amphibalanus improvisus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.6	2.0	1.7	0.3	0.6	1.3	1.2
Balanomorpha unid. spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	1.7	1.2	1.3	1.5	1.0	1.0	0.3	0.6	1.0	0.0	1.3	2.3
Cirripedia unid. 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	0.0	0.0
PHYLUM CNIDARIA																				
Class Anthozoa																				
Actiniaria - attached	0.0	0.0	0.0	0.0	0.7	1.2	0.0	0.0	0.0	0.0	0.3	0.6	0.3	0.6	0.0	0.0	2.0	0.0	4.3	2.3
Actiniaria - burrowing	0.7	0.6	3.0	1.0	0.0	0.0	0.0	0.0	0.3	0.6	1.3	2.3	0.3	0.6	0.0	0.0	0.0	0.0	0.3	0.6
Actiniaria unid. 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	0.0	0.0

TAXON	1/26/2011		2/24/2011		4/25/2011		5/24/2011		6/21/2011		7/19/2011		8/15/2011		9/26/2011		10/24/2011		12/19/2011	
	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	Mean	std dev
PHYLUM MOLLUSCA																				
Class Bivalvia																				
Bivalvia unid. 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	0.0	0.0
Corbula amurensis	0.3	0.6	0.7	1.2	2.0	1.0	16.3	6.8	18.7	13.3	14.0	3.5	13.7	9.0	4.0	2.6	3.0	2.6	2.3	3.2
Gemma gemma	669.0	279.8	537.7	93.9	533.7	93.5	508.3	95.7	467.7	57.6	371.3	71.7	196.3	95.5	239.7	66.2	170.7	11.7	243.3	47.7
Macoma petalum	1.7	0.6	0.7	0.6	1.3	0.6	9.0	9.2	6.0	6.9	5.7	5.5	4.7	1.5	4.0	1.7	5.3	0.6	1.7	1.5
Macoma unid. spp.	0.0	0.0	0.7	0.6	12.0	5.6	6.3	2.1	1.0	1.0	0.3	0.6	0.7	0.6	0.0	0.0	0.0	0.0	0.3	0.6
Musculista senhousia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mya arenaria	0.0	0.0	0.0	0.0	0.7	1.2	1.0	1.0	1.0	1.0	0.7	0.6	0.3	0.6	0.7	1.2	1.0	0.0	0.7	1.2
Rochefortia grippi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rochefortia unid. 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	0.0	0.0
Tellinidae unid. 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	0.0	0.0
Class Gastropoda																				
Gastropoda unid. sp. B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ilyanassa obsoleta	0.7	0.6	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odetta bisuturalis	0.3	0.6	1.0	0.0	2.0	2.6	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.7	0.6	2.3	2.1	0.7	1.2
Philine unid. 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	0.0	0.0
Pyramidellidae unid. sp. A	1.0	1.0	0.0	0.0	0.3	0.6	0.3	0.6	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Urosalpinx cinerea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PHYLUM NEMATODA																				
Nematoda unid. spp.	6.0	6.9	3.3	2.9	1.7	2.1	1.0	1.7	1.3	2.3	1.0	1.0	0.3	0.6	4.0	0.0	6.7	5.9	0.7	0.6
PHYLUM PLATYHELMINTHES																				
Class Turbellaria																				
Turbellaria unid. sp. A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turbellaria unid. 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	0.0	0.0

Appendix 11.   Benthic species name changes as of 2011.

Current Species Name:	Formerly Documented As:
PHYLUM ANNELIDA	
Class Oligochaeta	
Naididae unid. spp.	Naididae
Oligochaeta unid. spp.	Oligochaeta, Unid. Oligochaeta family
Tubificidae unid. spp.	Tubificidae
Class Polychaeta	
Capitella capitata complex	Capitella "capitata"
Cirratulidae unid. spp.	Tharyx spp. ?, Cirratulidae
Eteone unid. spp.	Eteone spp., Eteone ?californica
Euchone unid. spp.	Euchone spp.
Glycera unid. spp.	Glycera spp.
Glycinde picta	Glycinde polygnatha
Glycinde unid. sp. SF1	Glycinde sp. SF1
Glycinde unid. spp.	Glycinde spp.
Maldanidae unid. spp.	Unid. Malanidae
Polychaeta unid. spp.	Unid. Polychaeta, Polychaeta
Polydora cornuta	Polydora lighti, Polydora ligni
Polydora unid. spp.	Polydora spp.
Sphaerosyllis unid. sp. A	Sphaerosyllis spp.
Spionidae unid. spp.	Unid. Spionidae, Spionidae Unidentified
PHYLUM ARTHROPODA	
Class Copepoda	
Calanoida unid. spp.	Calinoida
Harpacticoida unid. spp.	Harpacticoida
Class Insecta	
Chironomidae unid. spp.	Chironomidae
Class Malacostraca	
Americhelidium unid. spp.	Americhelidium spp., Synchelidium spp.
Ampithoe unid. spp.	Ampithoe spp.
Callianassidae unid. spp.	Callianassidae, Callianassidae unidentified
Corophium unid. spp.	Corophiidae - unidentified
Corophiidae unid. spp.	Corophium spp.
Eogammarus confervicolus	Anisogammarus confervicolus
Gnorisphaeroma oregonensis	Gnorisphaeroma oregonensis, Gnorimosphaeroma oregonensis
Melita unid. spp.	Melita spp.
Monocorophium acherusicum	Corophium acherusicum
Monocorophium insidiosum	Corophium insidiosum

Current Species Name:	Formerly Documented As:
Monocorophium unid. spp.	Corophium ?insidiosum, Corophium spp. (female & juvenile), Corophium spp. (male), Monocorophium spp.
Mysidacea unid. spp.	Mysidacea
Nippoleucon hinumensis	Hemileucon hinumensis
Sinelobus unid. spp.	Sinelobus stanfordi, Sinolobus spp., Sinolobus stanfordi, Tanais spp.
Sphaeromatidae unid. spp.	Sphaeromatidae (juv.), Sphaeromatidae unid., Dynamella spp.
Synidotea unid. spp.	Synidotea spp.
Class Ostacoda	
Eusarsiella zostericola	Sarsiella zostericola
Cyprideis unid. spp.	Cyprideis spp.
Class Thecostraca	
Amphibalanus improvisus	Balanus improvisus
Balanomorpha unid. spp.	Balanus ?aquila, Balanus spp., Unid. Balanomorpha, Balanomorpha - unidentified
Cirripedia unid. spp.	Cirripedia

Current Species Name:	Formerly Documented As:
PHYLUM CNIDARIA	
Class Anthozoa	
Actiniaria unid. spp.	Anthozoa, Unid. Actiniaria
PHYLUM MOLLUSCA	
Class Bivalvia	
Bivalvia unid. spp.	Unid. Bivalvia
Corbula amurensis	Potamocorbula amurensis
Macoma petalum	Macoma balthica
Macoma unid. spp.	Macoma spp.
Rochefortia unid. spp.	Rochefortia spp.
Tellinidae unid. spp.	Tellinidae
Class Gastropoda	
Gastropoda unid. sp. B	Unidentified Gastropoda B
Ilyanassa obsoleta	Nassarius obsoletus
Odetta bisuturalis	Boonea bisuturalis, Odostomia fetella
Philine unid. spp.	Philine spp.
Pyramidellidae unid. sp. A	Odostomia spp., Pyramidellidae, Unidentified Gastropod A
PHYLUM NEMATODA	
Nematoda unid. spp.	Nematoda
PHYLUM PLATYHELMINTHES	
Class Turbellaria	
Turbellaria unid. sp. A	Planariidae A
Turbellaria unid. spp.	Turbellaria