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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: 2010

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Conversion Factors

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

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

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: 2010

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

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 factors that could affect metal concentrations (body weight in animals, characteristics of sediment, salinity) and benthic community structure (exotic species invasions, pelagic food availability, and weather anomalies) have also been measured during this time.

These studies initially found exceptionally high concentrations of copper (Cu) and silver (Ag) in mud-dwelling animals in this area and strong seasonal variability in concentrations that confounded some interpretations. Additional studies associated elevated levels of metals in *Macoma petalum,* the clam being monitored for metals, with adverse physiological effects. The annual mean concentrations of Cu and Ag in *Macoma petalum* were 287 mg/kg and 105 mg/kg, respectively, in 1980. These levels were unprecedented in the literature for this species, and the levels were much greater than seen elsewhere in San Francisco Bay. During this period of enriched metal concentrations, reproductive activity in *M. petalum* was very low. USGS scientists believe Ag 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 particle size distribution, 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. Although Ag in sediments is only 27% of the concentrations observed during 1978-1980, concentrations remain greater than what may be considered the regional background (0.09 mg/kg). The concentrations of Cu and Ag in *M. petalum* have fluctuated by as much as four-fold. Concentration minima for Cu occurred in 1991, during 2000–2005, and more recently during 2008–2010. These Cu concentrations were comparable to what can be considered baseline concentrations for this species in San Francisco Bay (20–30 mg/kg). Annual variations in Ag and Cu in *M. petalum* were not correlated with discharge of Cu and Ag from PARWQCP. A concurrent study was conducted at San Jose, California, for a few years, and those results indicate that temporal patterns in the 1990s were driven by regional factors, not by changes at individual waste treatment facilities. Other metal contaminants have been monitored since the early 1990s (including selenium and mercury). In general, the concentrations of those metals have varied among years but have not exhibited any sustained temporal pattern. This further indicates that cycling of contaminants stored within South San Francisco Bay sediments and inputs from diffuse sources are now more important in determining metal concentrations at the sampling site than the effluent of the PARWQCP.

The percentage of individuals of *M. petalum* that were reproductively active increased as the concentrations of Ag and Cu in their bodies decreased. Frequency of reproductive activity during the year also increased. 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 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. 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.

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 pre-existing 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 for the period January 2010 to December 2010 and extends a critical long-term biogeochemical record that dates back to 1974. These data serve as the basis for the City of Palo Alto's Near-Field Receiving Water Monitoring Program initiated in 1994.

In 2010, metal concentrations in both sediments and clam tissue were among the lowest concentrations on record and consistent with results observed since 1991. Following significant reductions in the late 1980s, silver (Ag) and copper (Cu) concentrations appear to have stabilized. Annual mean concentrations have fluctuated modestly (2–4 fold) in a nondirectional manner. Data for other metals, including chromium, mercury, nickel, selenium, vanadium, and zinc, have been collected since 1994. Over this period, concentrations of these elements, which likely reflect regional inputs and systemwide processes, have remained relatively constant, aside from typical seasonal variation that is common to all elements. Within years, the winter months (January–March) generally exhibit maximum concentrations, with a decline to annual minima in spring through fall. Concentrations of chromium (Cr) and vanadium (V) in sediments have shown an upward trend since 2005. Chromium concentrations are approaching the record maximum levels observed in 2003, and concentrations of V in sediments in 2010 were the highest annual average concentrations on record. Mercury (Hg) concentrations in sediments and *M. petalum* in 2010 were comparable to concentrations observed in 2009 and were generally consistent with data from previous years. Selenium (Se) concentrations in sediment varied among years and showed no sustained temporal trend. During 2009–2010, sedimentary Se concentrations declined from the record high observed in 2008 to concentrations that were among the lowest on record. Selenium in *M. petalum* was slightly higher in 2010 than in 2009. Overall, Cu and Ag concentrations in sediments and soft tissues of the clam, *M. petalum*, remained representative of the concentrations observed since 1991 following significant reductions in the discharge of these elements from the PARWQCP. This indicates that, as with other elements of regulatory interest, regional-scale factors now largely affect sedimentary and bioavailable concentrations of Ag and Cu.

Analyses of the benthic community structure of a mudflat in South San Francisco Bay over a 37-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 (2010), with almost all animals initiating reproduction in the fall and spawning the following spring of most years. The community has shifted from being dominated by several opportunistic species to a community where the species are more similar in abundance, a pattern that 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 last several years prior to 2008, showed a stable population. An unidentified disturbance occurred on the mudflat in early 2008 that resulted in the loss of the benthic animals, except for those deep-dwelling animals like *Macoma petalum*. Animals immediately returned to the mudflat in 2008, which was the first indication that the disturbance was not due to a persistent toxin or to anoxia. The use of functional ecology was highlighted in the 2010 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 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

Environmental Monitoring

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. 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 (Hornberger and others, 2000a; Luoma and others, 1991, 1992, 1993, 1995a, 1996, 1997, 1998; Wellise and others, 1999; David and others, 2002; Moon and others, 2003, 2004, 2005; Shouse and others, 2003, 2004; Thompson and others, 2002; Cain and others, 2006; Lorenzi and others, 2007, 2008; Cain and others, 2009; Dyke and others, 2010) 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 2009, employing the methods described in the succeeding section.

Previous reports (Luoma and others, 1995a, 1996, 1997, 1998; Wellise and others, 1999) also included data for a site in South San Francisco Bay that was influenced by discharge from the San Jose/Santa Clara Water Pollution Control Plant. 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 2010. 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 (2010).

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 7 to 12 composites, with each composite consisting of 1 to 51 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 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), vanadium (V), 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 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 5 mm) were processed for reproductive activity concurrent with samples for metal analyses. Clams were immediately preserved in 10-percent formalin at the time of collection. The visceral mass of each clam was removed in the laboratory, stored in 70-percent ethyl alcohol, and then prepared using standard histological techniques. Tissues were dehydrated in a graded series of alcohol, cleared in toluene (twice for 1 hour each), and infiltrated in a saturated solution of toluene and Paraplast® for 1 hour, and two changes of melted Tissuemat® for 1 hour each. Samples were embedded in Paraplast® in a vacuum chamber and then thin sectioned (10 μm) using a microtome (Weesner, 1960). Sections were stained with Harris' hematoxylin and eosin and examined with a light microscope. Each individual was characterized by size (length in mm), sex, developmental stage, and condition of gonads, thus allowing each specimen to be placed in one of five qualitative classes of gonadal development (previously described by Parchaso, 1993).

Community Analysis

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

Benthic community samples were washed on a 500-μm screen, fixed in 10-percent formalin, and then later preserved in 70-percent ethanol. Samples were stained with rose bengal solution. All animals in all samples were sorted to species level where possible (some groups, such as the oligochaetes, are still not well defined in the bay), and individuals for each species were enumerated. Taxonomic work was performed in conjunction with a private contractor familiar with the taxonomy of San Francisco Bay invertebrates (Susan McCormick, Colfax, California) (appendix 9). McCormick also compared and verified her identifications with previously identified samples.

Results

Salinity

Surface-water salinity is related to the seasonal weather pattern in Northern California, which is characterized by a winter rainy season that has been defined as months with rainfall amounts greater than 0.25 inches (November through April) and a summer dry season (May through October) (fig. 2). The average annual rainfall during the record (1994–2010) is 23.5 inches. Rainfall during 2010 was 28.1 inches, a marked increase from the previous 3 years of below average rainfall. The maximum monthly rainfall in 2010 occurred in January (6.7 inches). Rainfall during November–December 2010 was also high, with a cumulative total of 8.8 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 2010; however, the winter-spring decline in salinity was minimal. The range of salinity in 2010 was small. It was lowest in March at 21 ppt and highest at 30 ppt during September–October. In contrast, during the spring decline in salinity, salinity minimums for the period of 1995–2000 and again in 2006 were 10 ppt or less.

Sediments

Metal concentrations in surface sediments from Palo Alto typically display an annual periodicity of seasonal patterns. 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 of fine-grained particles are typically higher on a weight basis than larger particles. Thomson-Becker and Luoma (1985) showed that the composition of surface sediments was dominated by fine-grained particles, accompanied by high Al and Fe concentrations, during the period of freshwater input (low salinities through April), reflecting annual terrigenous sediment inputs from runoff. Coarser sediments dominated later in the year because the seasonal diurnal winds progressively winnow the fine sediments into suspension through the summer. This typical seasonal pattern of variation in sediment properties was repeated in 2010 (fig. 4, appendix 1).

The percentage of silt/clay in the sediment increased from 41 percent in the fall of 2009 to values of greater than 90 percent following the onset of winter rains. Values were at their maximum in March (96 percent) and, thereafter, declined to a seasonal minimum (46 percent) in October. The concentrations of Al and Fe changed directly in response to the proportion of silt/clay size particles (maximum concentrations occurred during March–April) (fig. 4, table 1), as described above, reflecting the contribution of clays rich in Al and Fe.

Surface sediments from Palo Alto in 2010 contained about 1.2 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 1.04 to 1.67 percent during January to April, declined to a minimum of 0.73 percent in June, and increased to 1.21 percent in December.

The metals Cr, Ni, and V are highly enriched in some geologic formations within the watershed. In North San Francisco Bay, studies of sediment cores indicated that concentrations of these elements similar to those reported here were derived from natural geologic inputs (Hornberger and others, 1999; Topping and Kuwabara, 2003). Inputs of minerals bearing Cr, Ni, and V appear to vary seasonally as indicated by the varying concentrations of these metals in surface sediments. Typically, maximum concentrations coincide with winter/spring maximums in fine sediments, whereas minimum concentrations occur during the late summer/fall (fig. 5, table 1). The minimum Ni concentration occurred in the summer of 2010 (57 mg/kg in June) and the maximum in early spring (94 mg/kg in April). The concentration range and timing of variation is typical of the record (1994–2010). Concentrations of Cr and V also declined from their maximum concentrations in April to their minima in summer/fall. Average concentrations of Cr tended to increase during 2006–2010, approaching the record high Cr concentrations in 2003. Average concentrations of V have increased during 2006–2010 to levels roughly comparable to record high concentrations in 2003. High percent recoveries for V in both 2008 and 2010 (124% and 128%, respectively) (appendix 5), however, may overestimate this upward trend.

Copper concentrations in sediments are shown with sediment guidelines set by the National Oceanic and Atmospheric Administration (Long and others, 1995) in figure 6 and table 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 (21–47 percent of the time for different metals). Values greater than the ERM were frequently associated with adverse effects (42–93 percent of the time for different metals). It 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 2008–2010, Cu concentrations were lower, roughly comparable to 2003 values, yet remained above the ERL (34 mg/kg) for much of the time. The typical seasonal pattern was evident, as Cu concentrations peaked in April (51 mg/kg) and fell below the ERL in June (27 mg/kg) and October (32 mg/kg) (fig. 6, table 1). The partially extractable concentrations have shown a downward trend since 2006. Near-total and partially extractable Zn concentrations were below the Zn ERL (150 mg/kg) for all of 2010 (fig. 7, 1). Zn concentrations have shown a slight decreasing trend over the past 3 years (2008–2010).

Silver extracted from sediments averaged 0.27 mg/kg in 2010, a slight increase from the previous two years (0.20 mg/kg for both 2008 and 2009, the lowest annual averages recorded) (appendix 10). A deviation from the typical seasonal pattern was observed in 2010 (fig. 8, table 1). As with other elements, concentrations were relatively high during the late winter-early spring (March–April); however, the annual minimum in June (0.15 mg/kg) was followed by the annual maximum in September (0.41 mg/kg).

Mercury concentrations throughout all of 2010 were within the range usually observed in San Francisco Bay (0.2–0.4 mg/kg). Concentrations in sediment followed the typical seasonal pattern of highest concentration in late winter-early spring (0.30 mg/kg in April) and lowest concentration in June (0.22 mg/kg) (fig. 9, 1).

Selenium concentrations remained relatively stable (0.2–0.3 mg/kg in 2010 and were the lowest of the record (fig. 9, table 1). Concentrations were substantially lower than in 2008, the highest annual average concentration on record (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, and 2008) to relatively low concentrations (2005, 2007, and 2009–2010).

Clam Tissue

Metal concentrations in the soft tissues of *Macoma petalum* reflect the combined metal exposures from water and food. Exposures to Cu and Ag at Palo Alto are of special interest because of the high tissue concentrations observed at this site in the past (figs. 10 and 11, appendixes 10 and 11). 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 2010 were 29±2 and 2.1±0.3 mg/kg, respectively; these are within the range of concentrations observed since 2008. Concentrations of Ag for 2008–2010, along with the concentrations observed in 2003–2005, are the lowest concentrations observed at the site. Copper concentrations for 2008–2010 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 the 2007 water year 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 2010, Ag and Cu concentrations were highest in February (3.4 mg/kg and 39 mg/kg, respectively), then declined and reached their annual minima of 0.9 mg/kg Ag and 20 mg/kg Cu in April (table 2). Concentrations increased through the fall and early winter and in December were 2.7 mg/kg (Ag) and 34 mg/kg (Cu).

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 (1994–2010). Maximum concentrations occurred in the winter of 1996–1997, 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 2010 were similar in magnitude and timing to the previous year. In addition to the typical seasonal pattern, Zn concentrations exhibited a slight long-term decline through 2005. 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 2007–2010. Concentrations of Zn over the past 3 years (2008–2010) are similar to those observed from 2000–2005. In 2010, maximum Zn concentrations occurred in February (341 mg/kg) and decreased to their lowest concentration in September (202 mg/kg). Wellise and others (1999) observed that seasonal and interannual patterns of Cr, Ni, and Zn in *M. petalum* at Palo Alto were generally similar to those from the San Jose site, indicating that regional-scale processes may be more important than treatment plant inputs in controlling the bioavailability of these elements.

Although average Hg concentration in *M. petalum* for 2010 was typical of the record at 0.35 mg/kg, the seasonal maximum concentration of 0.66 mg/kg (observed in February) was the highest concentration observed throughout the entire record. Seasonal variation for 2010 was typical of the record, with a minimum of 0.20 mg/kg in April. A long-term trend in Hg concentration is not evident (fig. 17).

Selenium concentrations in *M. petalum* in 2010 varied seasonally like those of other elements (fig. 18, table 2). The annual maximum concentration of 6.3 mg/kg in February was followed by the annual minimum of 4.1 mg/kg in June. By December 2010, Se concentrations were back at 6.3 mg/kg. Average Se concentrations were typical of the record, and 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. For example, the maximum value of the CI during 1994–1999 was generally less than in preceding or succeeding years. In 2006, the maximum CI was one of the lowest observed (125 mg) since 1999, but in 2010 the maximum CI (238 mg in April) was the third highest of the entire record.

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.

Data for 2010 show that *M. petalum* continues to be highly reproductive relative to the 1970s, with a high percentage of the animals being reproductively active at any time during the normal seasonal cycle of reproduction. That cycle begins in fall, with spawning occurring the following spring (see table 3 for detailed reproduction data for 2010 and figures 20 and 21 for short-term history of reproduction).

Benthic Community

Estimates of species diversity and total animal abundance are simple metrics that are used in assessing environmental stress on biological communities. Species diversity at the Palo Alto site, as estimated by a time series of number of species, has shown an upward trend (with one exception) since the last very wet year in 1998 (fig. 22). Total animal abundance has varied significantly during the sampling period, with the last 2 years being similar (fig. 23). The difficulty with these types of metrics is that they do not consider the possibility that one species can take the place of another or that high abundance is based on one species. Depending on the characteristics of a species new to the community or newly dominant in the community, the community structure and function may change as a result of this change in species composition or dominance. The details of changes in species composition are important because they may reflect the relative ability of species to accommodate environmental stress and redistribute site resources. In general, the species composition has changed little since 1998, although there have been seasonal eruptions of several species in some years.

Three common bivalves (*Macoma petalum*, *Mya arenaria*, and *Gemma gemma*) have not shown any consistent trend over the 37-year period from 1974–2010 (figs. 24, 25, and 26). There was significant seasonal and interannual variability in species abundances for all species, and that is well illustrated in these three bivalves—*Gemma gemma* has been particularly volatile since 2005. *Gemma gemma* abundance dropped to near zero in late fall 2007 and has not regained its previous high density, although the abundance rebounded in 2009 and into 2010 relative to the dip in 2008. There were six species that did show trends in their abundance since the 1970s, and these trends continued through 2008. The first species with trends, *Ampelisca abdita*, is a small crustacean that lives above the surface of the mudflat in a tube built from selected sediment particles. *A. abdita* showed a general decline in both the annual average abundances and annual maximum abundances (seasonal peaks in abundance; fig. 27) from before 1990 and after 1998. That pattern mostly continues through today; there was a small increase in population size in 2008 and 2009 followed by an decrease in 2010. 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* annual maximum abundances and annual average abundances have declined and, over the past 3 years, the data have settled into a seasonal pattern of fall increases in abundances followed by a winter decline (fig. 28). The maximum seasonal abundance of the small burrowing crustacean *Grandiderella japonica*, a deposit feeder, declined through the 1980s, but it has since become more abundant (fig. 29) and has shown a consistent peak in abundance in the fall since 1999. *Neanthes succinea*, a burrowing polychaete that feeds on surface deposits and scavenges for detrital food, similarly showed large seasonal fluctuations in abundance through the 1980s. *N. succinea* abundance had increased by the late 1990s, and the annual average abundances and annual maximum abundances (fig. 30) remained relatively stable until 2005, when the abundance decreased. *N. succinea* showed a small resurgence in 2008, a larger one in 2009, and settled to 2008 levels in 2010. Two species showed an increase in abundance within the time series. The first was the polychaete worm *Heteromastus filiformis* (fig. 31), a deposit feeding, burrowing species that lives deep in the sediment (usually 5–20 cm below the surface of the mudflat). Abundance increased sharply in 1985 and then partially receded in the late 1980s. Abundances remained higher than in the late 1970s until 2008, when a large drop in the population abundance occurred. The second species showing an increase was *Nippoleucon hinumensis*, a small burrowing crustacean, which appeared in the dataset in 1988 (fig. 32) following its introduction into the bay in 1986 (Cohen and Carlton, 1995). Another nonindigenous species, *Corbula amurensis*, a filter-feeding bivalve that first appeared in the benthic community in significant numbers in April 2005 and persisted into 2006 with peaks in abundance occurring in spring and fall, has shown another small peak in summer 2010 (appendix 9).

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 2010 when brooders and oviparous species were 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. Comparison of metal concentration and benthic species abundance can be made by plotting the metals and individual species together over the period of the study. The worm *H. filiformis* increased in abundance with the decrease in Ag and Cu until 2008 (fig. 33). Because the natural spatial variability (that is, the large standard deviations around the monthly means) and seasonal variability of invertebrate abundance and metal concentration can be quite large, the annual average abundances for *H. filiformis* and annual average metal concentrations are shown in figures 34 and 35. To interpret these plots, life history characteristics of this species must first be examined to determine if there is some mechanism by which this organism could be responding to a decrease in Ag or Cu in the environment. *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 speed of expansion into new areas. The authors hypothesize that once a few individuals successfully arrived at the study site, *H. filiformis* increased in abundance because either the adult worms or the eggs were less stressed in the current environment than they were in the previous environment. Because of its mode of reproduction and short planktonic larval period, this species is not likely to move into an area quickly after an environmental stressor. A large spike in *H. filiformis* abundance was observed in January 2008 because of the settling of larvae, but these larvae did not survive the event that occurred before the February sampling. So far, the species has not returned in high numbers to the study site. The dynamics of recovery for this species will continue to be monitored closely.

The authors hypothesize that Ag, but probably not Cu, adversely affected reproduction in *H. filiformis* (Ahn and others, 1995) in the early years of the study, and that the gradual increase in *H. filiformis* abundance through 1984 was a response to the gradual reduction of metals in the environment. In the present environment of much lower metal concentrations, the authors predict that *H. filiformis* will gradually invade and then explosively increase once there are sufficient adults to support a large reproductive effort. *H. filiformis* could then experience “boom and bust” population behavior, whereby a species rises to levels too high for the habitat to support, then declines in abundance until it levels out to a habitat-supportable abundance (Begon and others, 1986). For this to occur, a reproducing population must first settle, and that did not happen in 2009 and 2010.

Two species that have declined in abundance coincident with the decline in metals—the crustacean *A. abdita* (figs. 36, 37, and 38) and the worm *S. benedicti* (figs. 39, 40, and 41)—have very similar life-history characteristics. Both species live on the surface of the sediment in tubes that are built from sediment particles, brood their young, and produce young that are capable of either swimming or settling upon hatching. The authors hypothesize that these opportunistic characteristics make these species ideal for invading a disturbed or stressed environment; thus they are capable of rapid increase in population size and distribution. It is not surprising that both species immediately responded to the near-empty community in February 2008 and have subsequently declined. This abundance pattern is consistent with the proposed hypothesis. The abundance of *G. gemma* has also changed dramatically since the 1970s and 1980s; episodic peaks and protracted declines in abundance have been observed in the last decade (figs. 42, 43, and 44). This small clam reproduces by brooding its young and lives on the sediment surface, which makes them fairly resistant to sediment-borne stresses. *G. gemma* abundance has been variable throughout the study. As with *H. filiformis*, the authors hypothesize that the nonpelagic larvae of *G. gemma* will limit the speed of its reintroduction to the benthic community at Palo Alto, and its increase in 2010 relative to 2008–2009 is consistent with that hypothesis.

The change in function of the benthic community over time can be examined by ranking the top 10 species by abundance and plotting the ln (abundance +1) against the rank of each species (fig. 45). The plot for 2010 (fig. 45) is indicative of a healthy benthic community, with species dominance, as revealed by abundance, not showing large differences among the top 10 species. An examination of similar plots for August of 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 has rebounded to what was observed in earlier years, reflecting the establishment of opportunistic species after the defaunation event in 2008. Even with those changes, the 2010 curve is considerably less severe than that seen in 1977 and 1989 (fig. 46). The series of lines shows a community that was heavily dominated by three species in 1977 and 1989, and a community with one dominant species in 2002. The 1977 community plot is the most extreme and reflects a bimodal species distribution, with three species dominating the community and the remainder having similar but relatively low abundances. The 1977 community was dominated by opportunistic species, but the community was also continuously stressed by metal contaminants. In contrast, the 2010 community plot is dissimilar because the opportunists are present but display less dominance in the community (the curve is less steep).

It is informative to examine the rank-abundance plots within the context of the life-history characteristics of each species to determine if shifts in plot shape coincide with a shift in community structure and function that might be indicative of a healthier environment. Two critical life history characteristics are shown: feeding mode in fig. 46 and reproductive mode in fig. 47. The 1977 community was dominated by filter-feeding species (species that consume particles in the water column), species that have the option of either filter-feeding or feeding on the sediment surface (mixed feeders), and one species that feeds on food particles on the sediment surface. In 1989, the species composition had shifted such that filter-feeding species and subsurface deposit feeding species (those that ingest sediment and strip the food off of the sediment in their gut) dominated the community. In 2002, a shift was observed towards species that could either filter feed or deposit feed (mixed feeders) and those species that feed on subsurface sediment. The most recent data shows the community to be mostly composed of a mix of surface and subsurface 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. 47). The dominant species in 1977 were species that brood their young and release fully functional juveniles into the environment. In 1989, there were still several brooders, but there were also two species that lay their eggs in the sediment. Although brooding species remain in the 10 most abundant species, species that spawn their gametes into the water column and those that lay eggs in the sediment (oviparous) have 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 2010 is reflective of the species that were available either as pelagic larvae or as mobile adults. Although egg layers were lower in number in this group, the authors hypothesize that these species will return slowly as more species move back into the area.

Summary

Long-Term Observations

Since 1974, USGS personnel have monitored and conducted basic research on the benthic sediments and biological community in the vicinity of the discharge of the Palo Alto Regional Water Quality Control Plant (PARWQCP). The time series presented here update previous findings (Luoma and others, 1991, 1992, 1993, 1995a, 1996, 1997, 1998; Wellise and others, 1999; David and others, 2002; Moon and others, 2003, 2004, 2005; Shouse and others, 2003, 2004; Thompson and others, 2002; Cain and others, 2006; Lorenzi and others, 2007, 2008; Cain and others, 2009; Dyke and others, 2010) with additional data from January 2010 through December 2010 to create a record spanning 37 years. This long-term dataset includes sediment chemistry and tissue concentrations of metals (1977–2010 for Cu and Ag, 1994–2010 for other metals), condition index (1988–2010), and reproductive activity in *M. petalum* and population dynamics of benthic invertebrate species (1974–2010). 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 are highly correlated with Cu loadings from PARWQCP. Metal levels in sediments and clams respond relatively quickly to changes in metal loading; the reduction in metal loadings by the PARWQCP resulted in a reduction in metal concentrations in both the sediment and *M. petalum* within a year (Hornberger and others, 2000b).

Biological responses to metal inputs to South 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.

2010 Observations

Throughout 2010, 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. Sedimentary Se concentrations were 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 1997–2005, increased notably in 2006–2007, and have since returned to 1997–2005 levels in the past 3 consecutive years (2008–2010). The most recent results (2010) 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 2010 were 17 percent and 47 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, V, 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 2010. The benthic community declined, with few animals present in February 2008. 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 data revealed a community that had a short-term physical stressor but not one that was subject to unhealthy sediment. In 2010, 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 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. Nanotechnologies, many of which include metal-based products in forms for which environmental researchers have little or no experience, are beginning to take hold in consumer products. The long-term, detailed, integrated ecological baseline that has been established at this sampling site will be uniquely valuable in assessing the response of the environment as human activities in the watershed continue to change.

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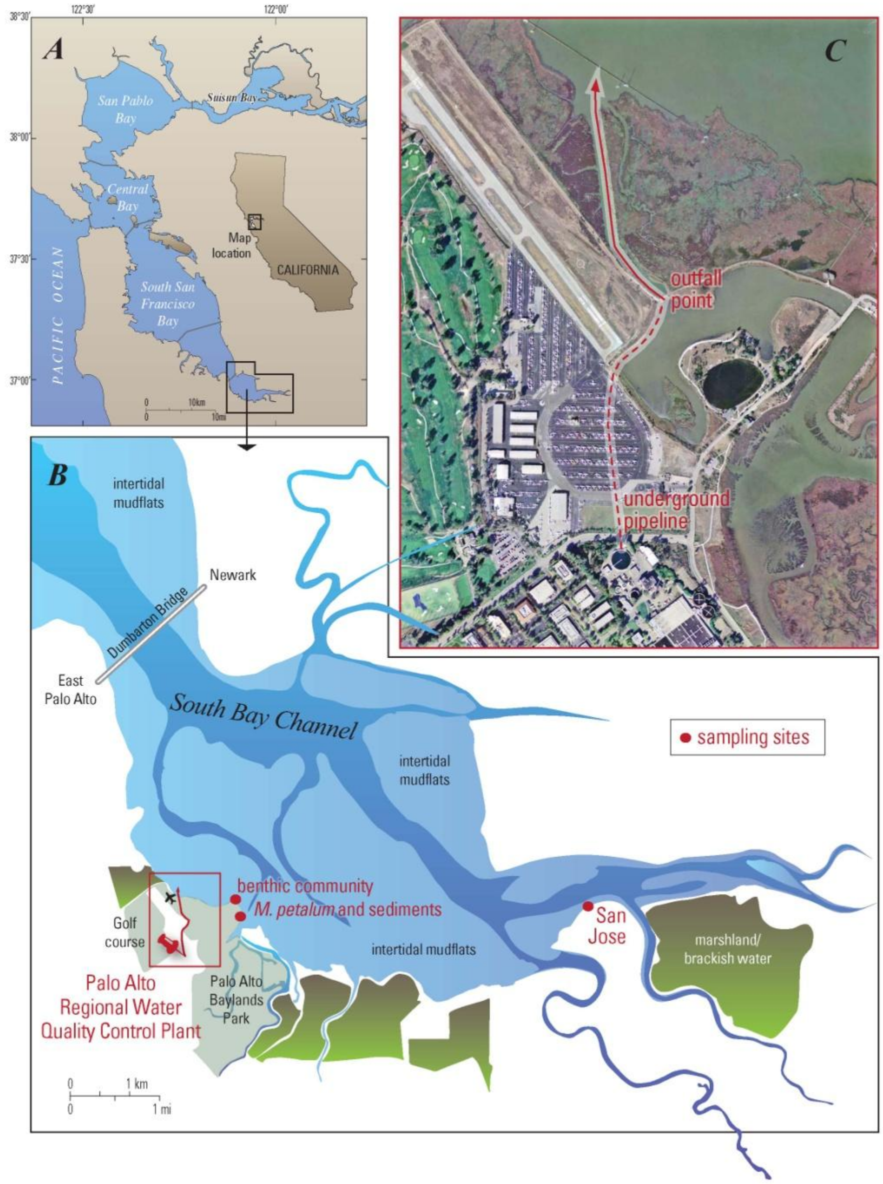


Figure 1. Location of the Palo Alto sampling site in South San Francisco Bay, Calif.

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.

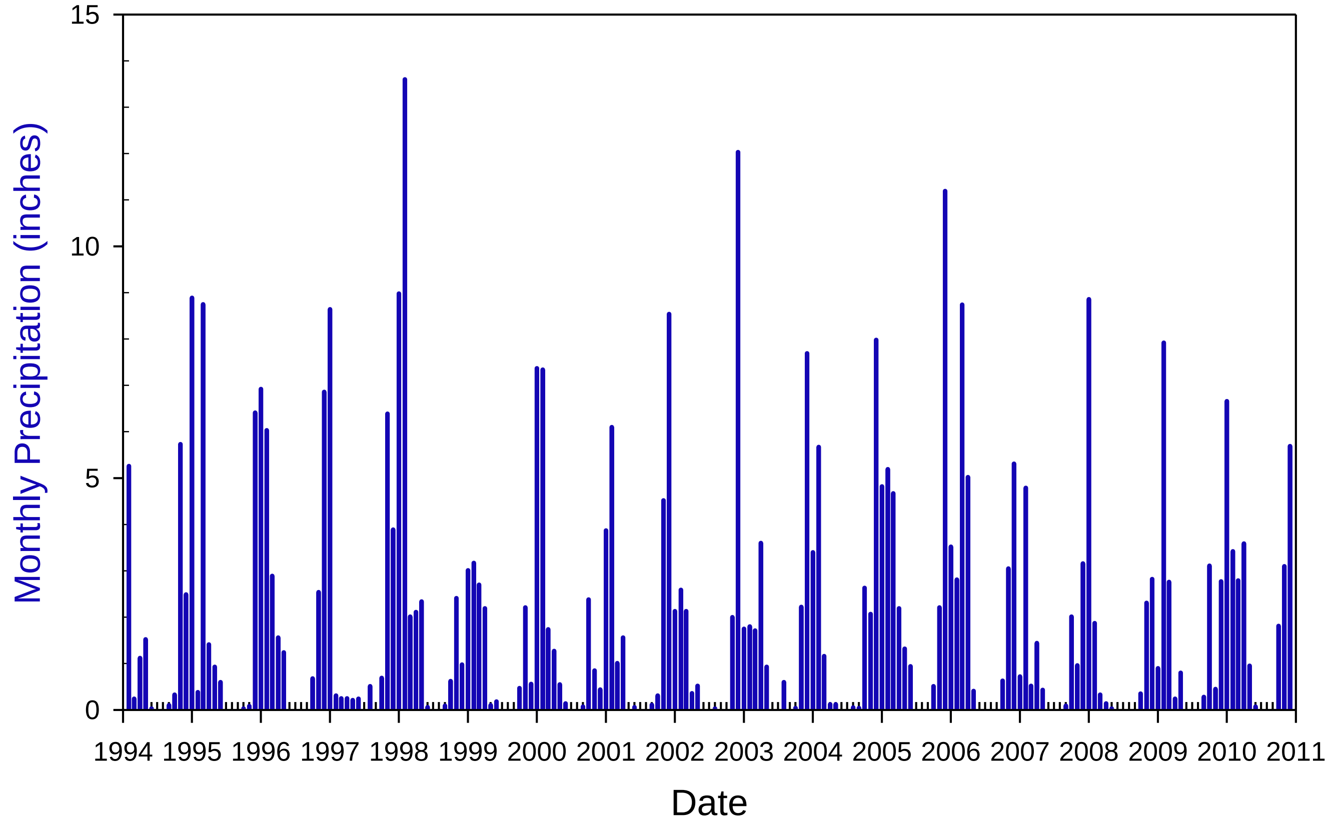


Figure 2. Total monthly rainfall recorded at San Francisco WB AP in San Mateo County, Calif., 1994–2010. The station (identification SFF) is operated by the National Weather Service.

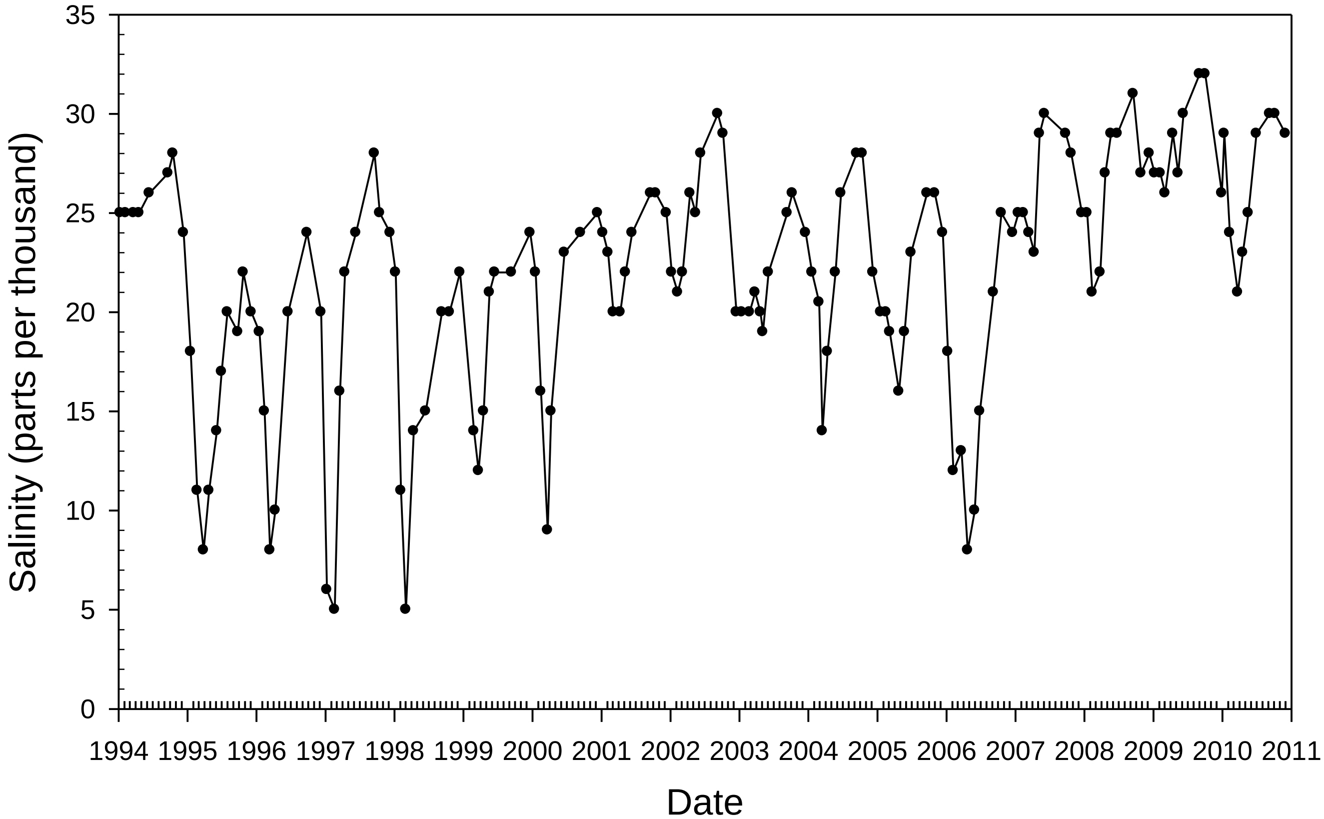


Figure 3. Surface-water salinity at the Palo Alto site, Calif.,1994–2010.

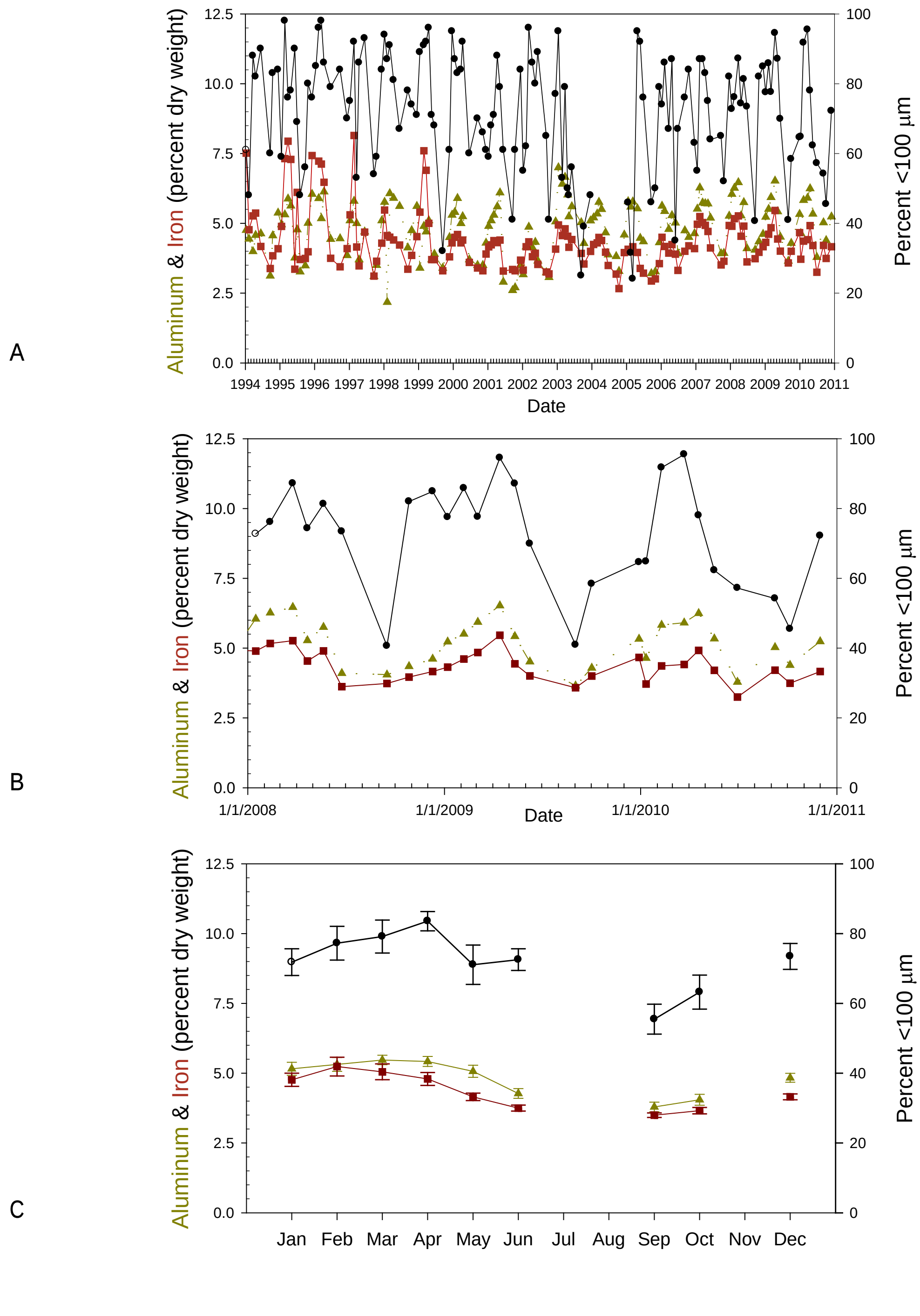


Figure 4. Aluminum, iron, and silt/clay in sediments, Palo Alto, Calif.,1994–2010.

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 (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, 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).

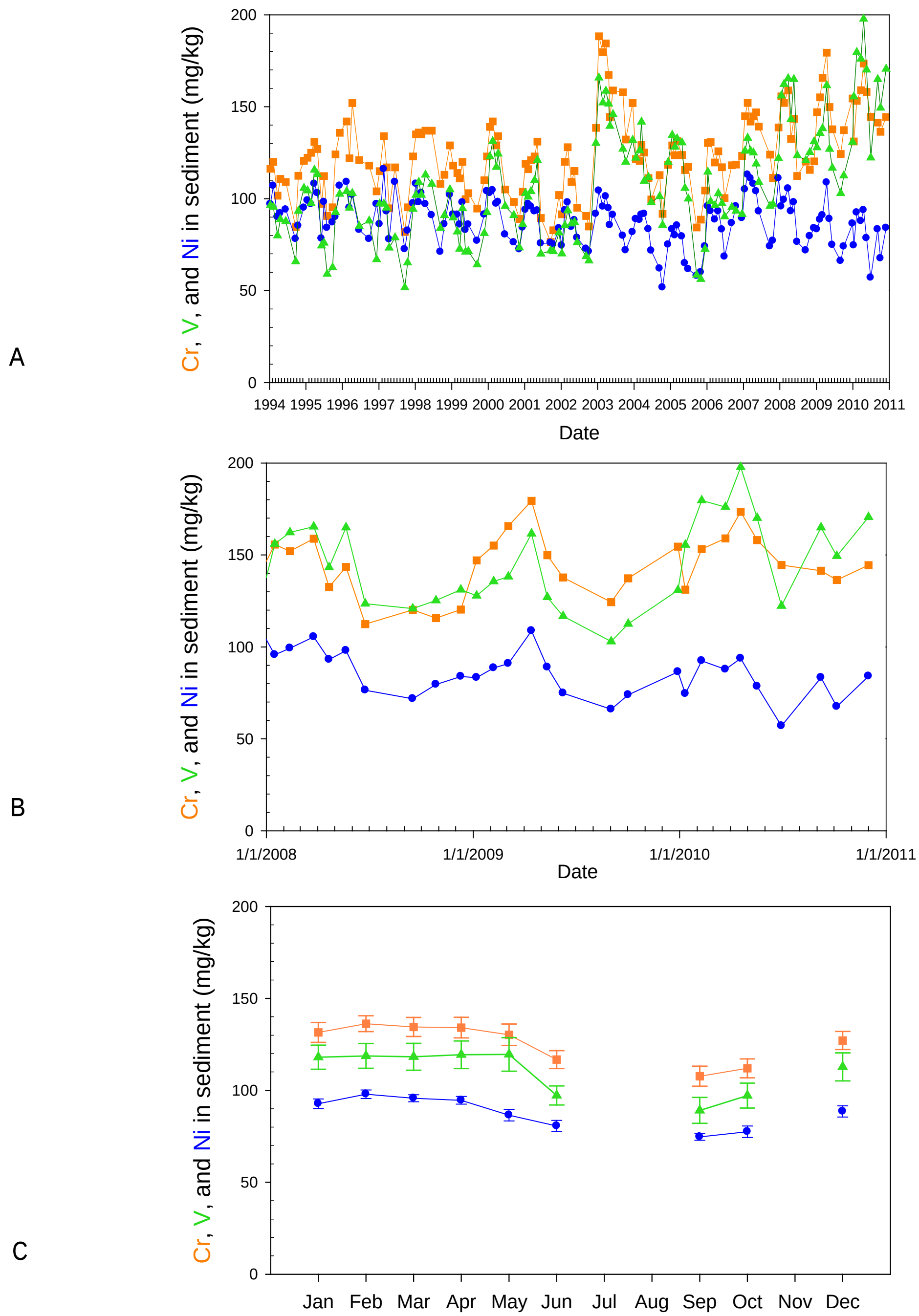


Figure 5. Chromium, nickel, and vanadium in sediments, Palo Alto, Calif., 1994–2010.

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

B. Data for the past 3 years (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, illustrating the general seasonal variation in Cr, Ni, and V. Collections are not made in July, August, and November. The error bar is the standard error of the mean (SEM).

A

B

C

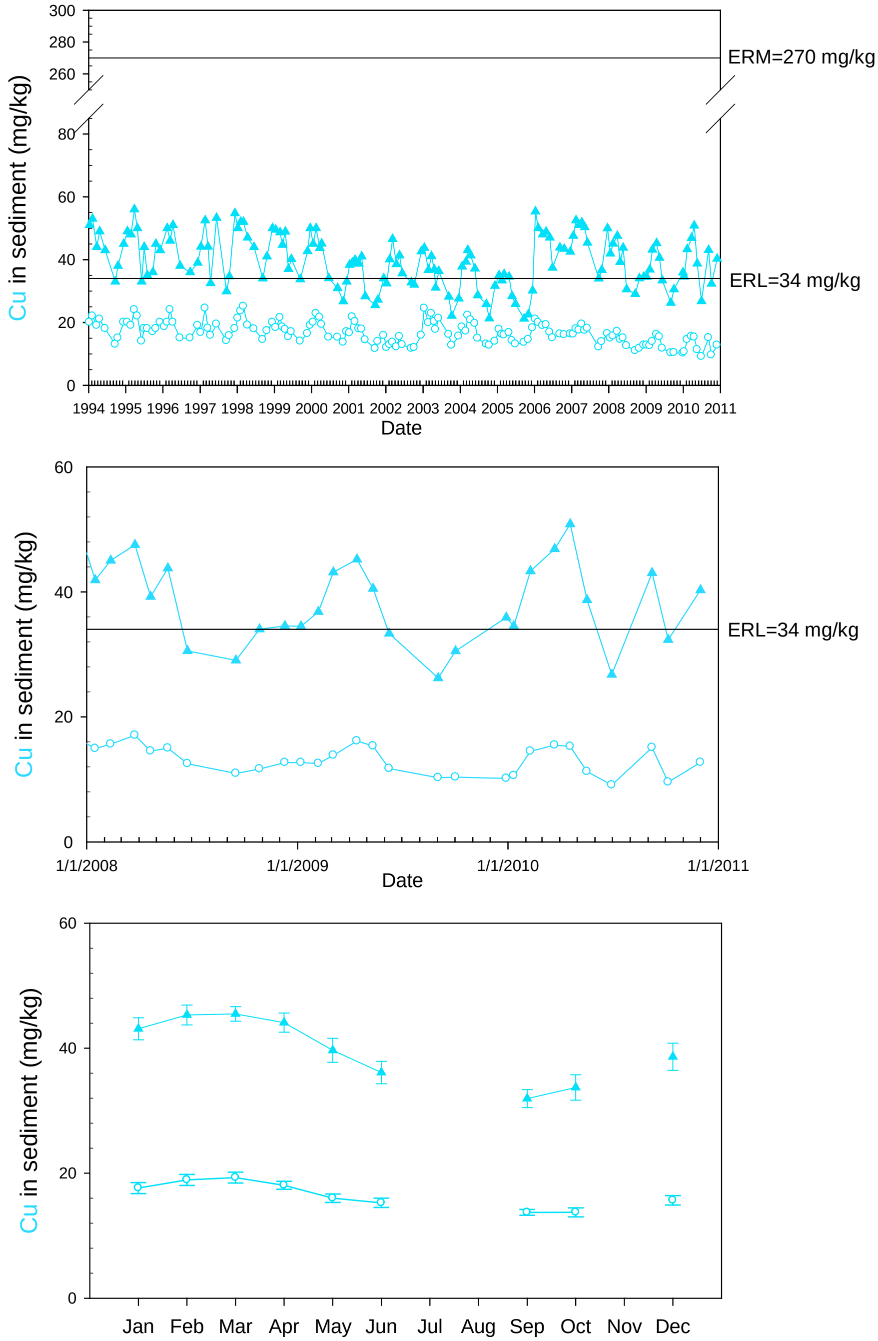


Figure 6. Copper in sediments, Palo Alto, Calif., 1994–2010.

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

B. Data for the past 3 years (2009–2010).

C. The monthly mean of all samples collected from 1994–2010, 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).

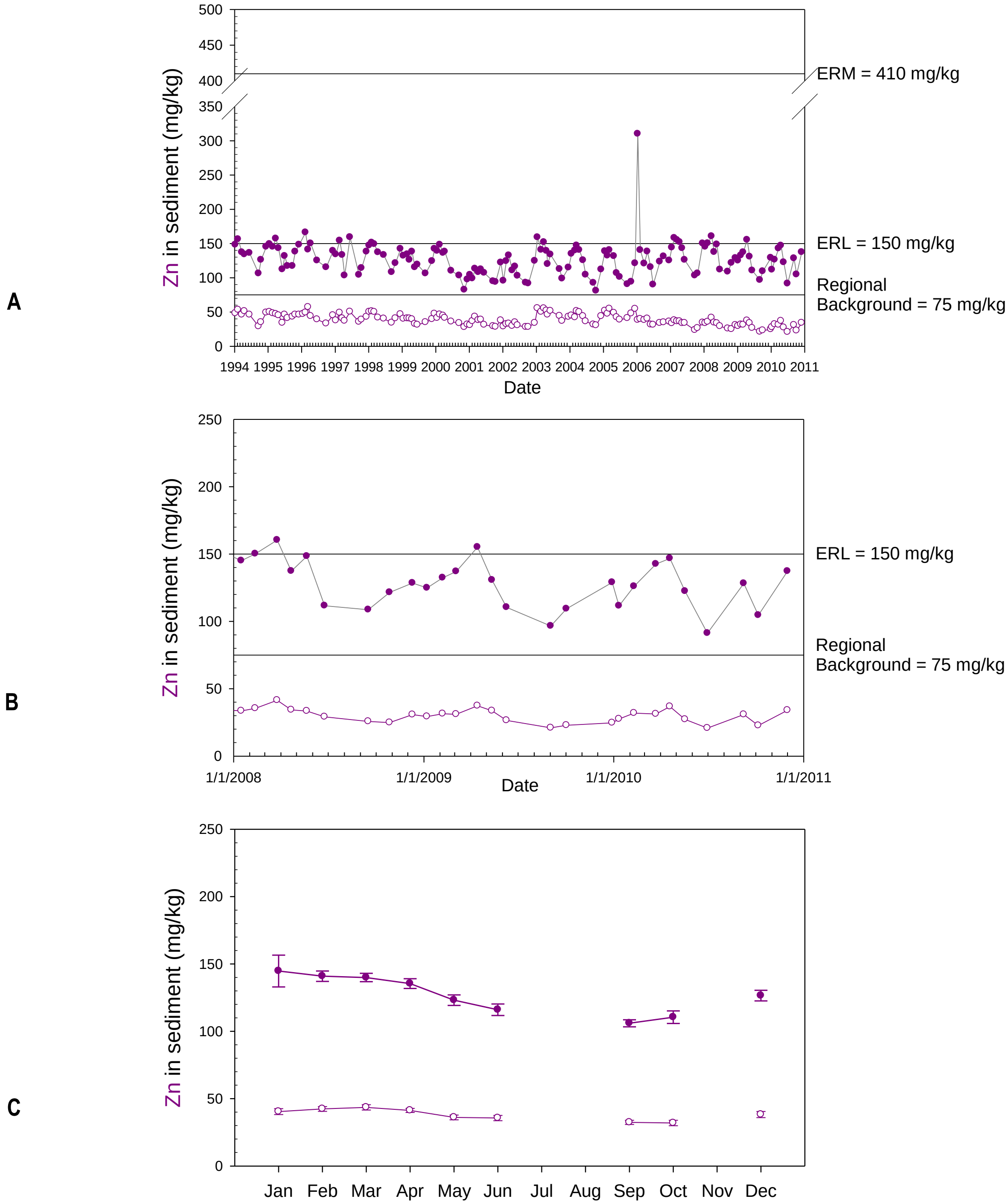


Figure 7. Zinc in sediments, Palo Alto, Calif., 1994–2010.

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

B. Data for the past 3 years (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, 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).

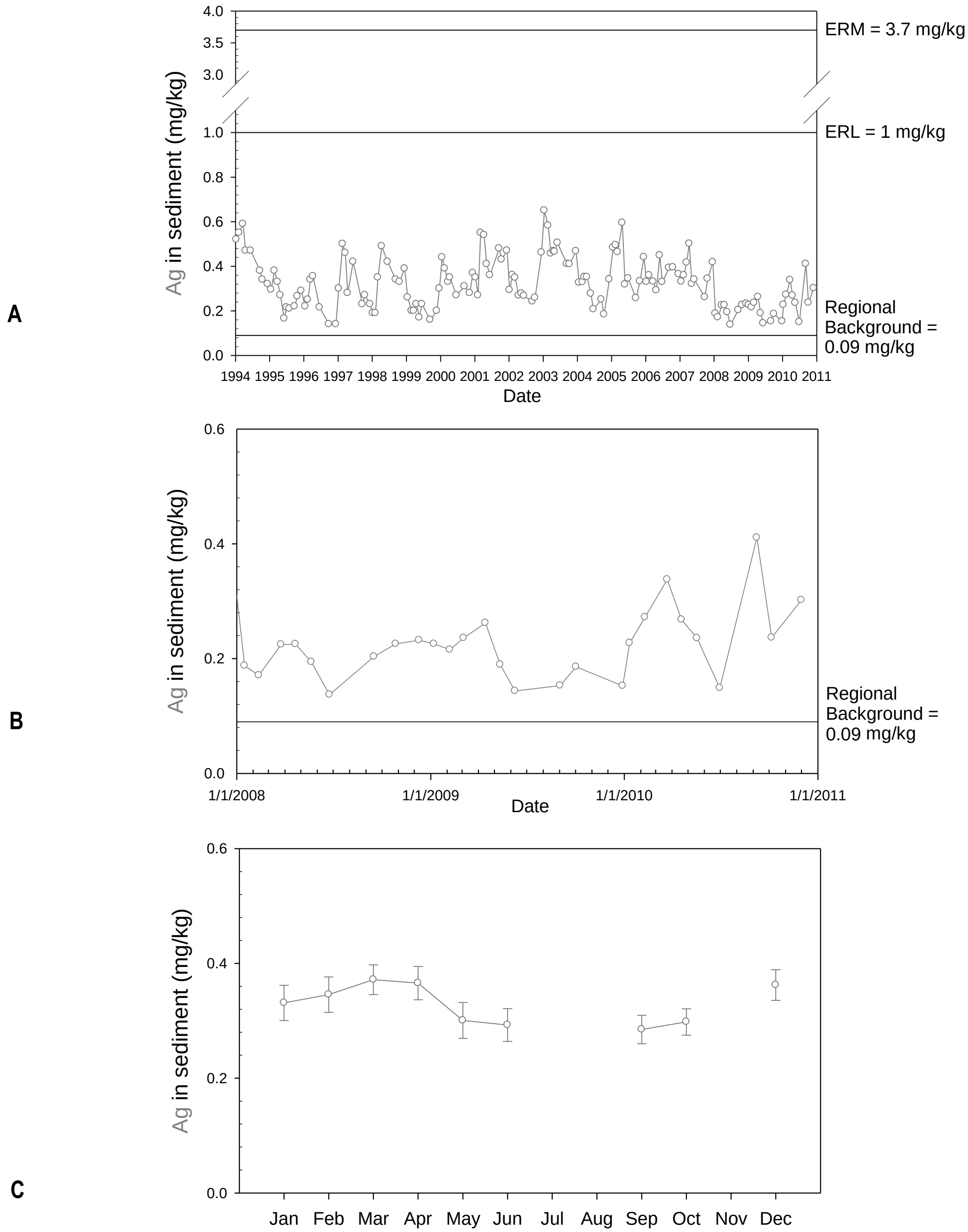


Figure 8. Silver in sediments, Palo Alto, Calif., 1994–2010.

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

B. Data for the past 3 years (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, 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).

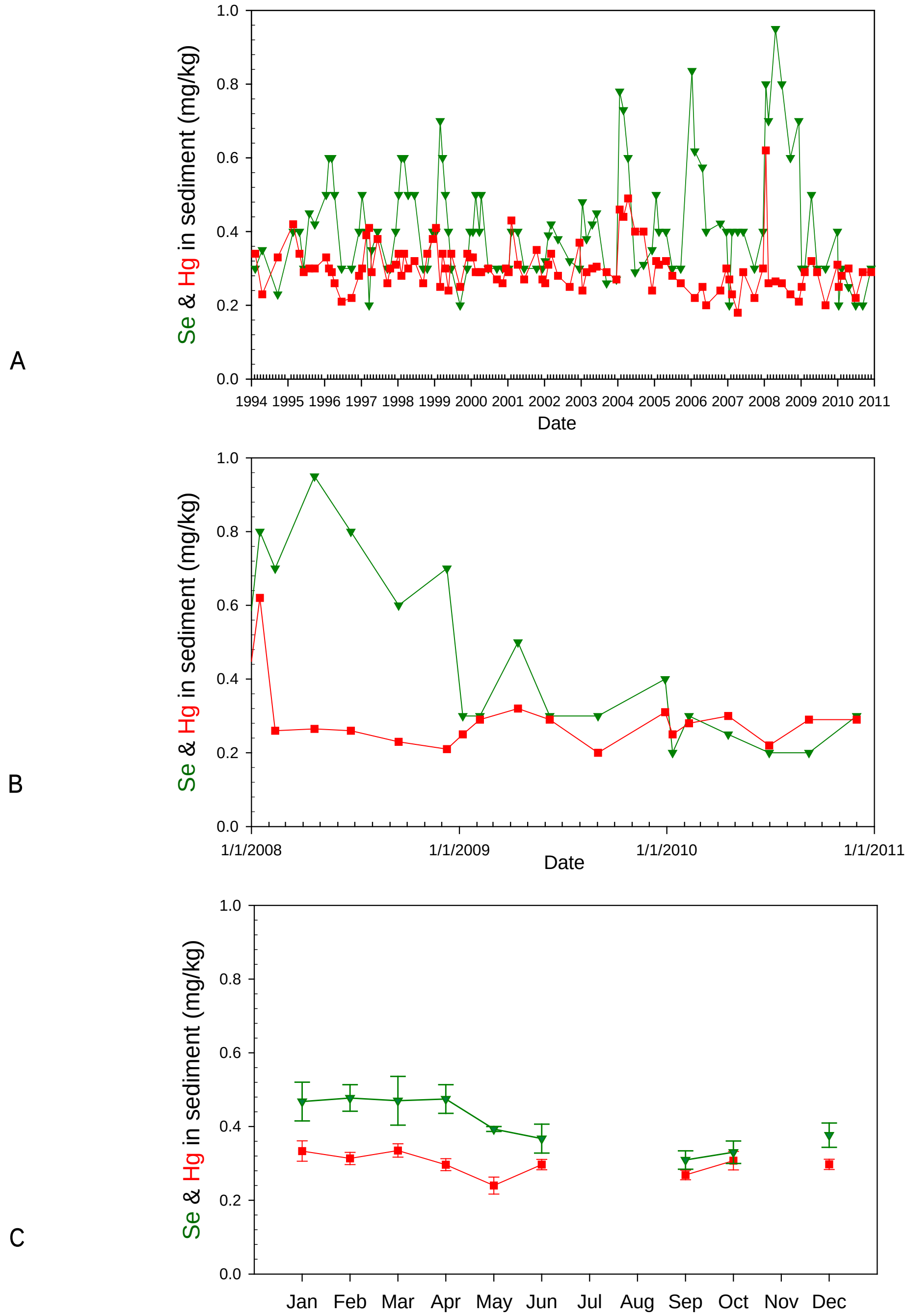


Figure 9. Selenium and mercury in sediments, Palo Alto, Calif., 1994–2010.

A. Selenium (▼); mercury (■).

B. Data for the past 3 years (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, 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).

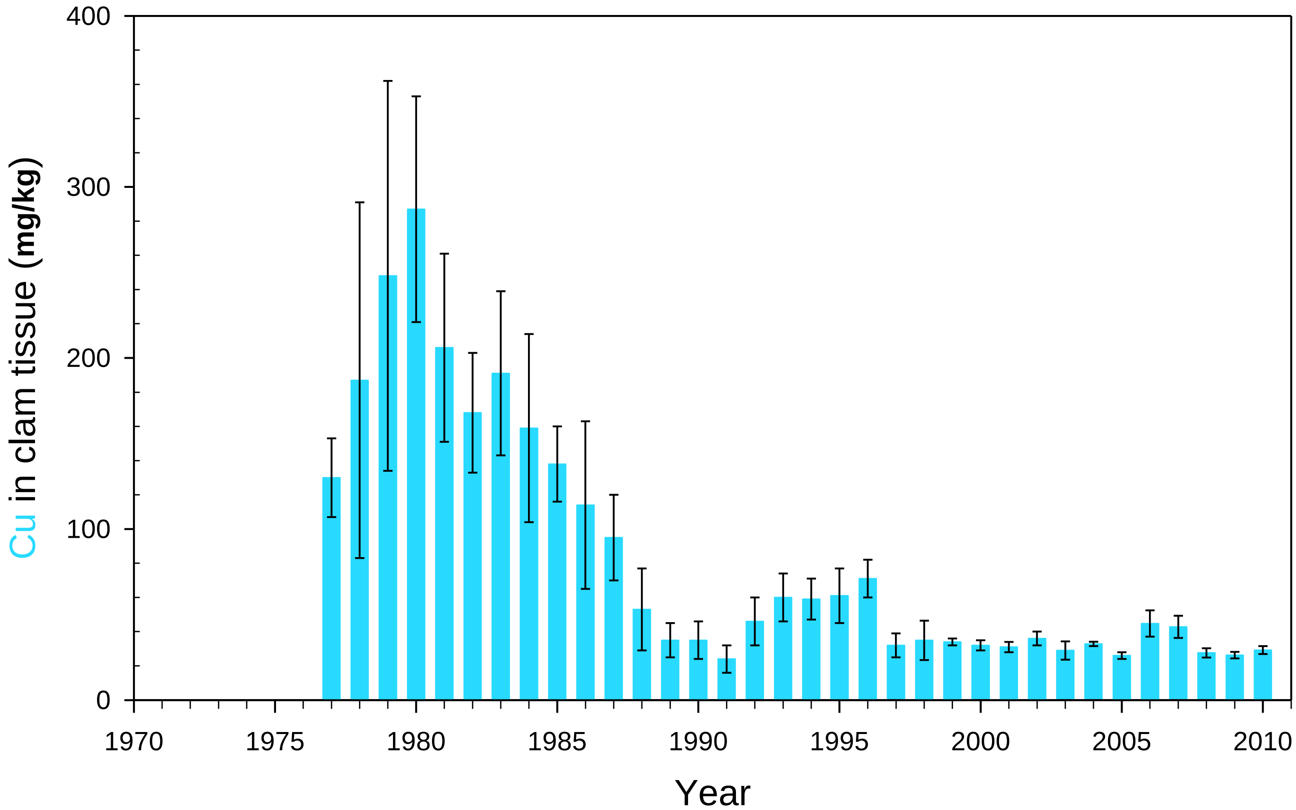


Figure 10. Annual mean copper concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1977–2010.

Values are the annual (grand) means for 7 to 12 separate samples per year and error bars are standard errors of those means (SEM).

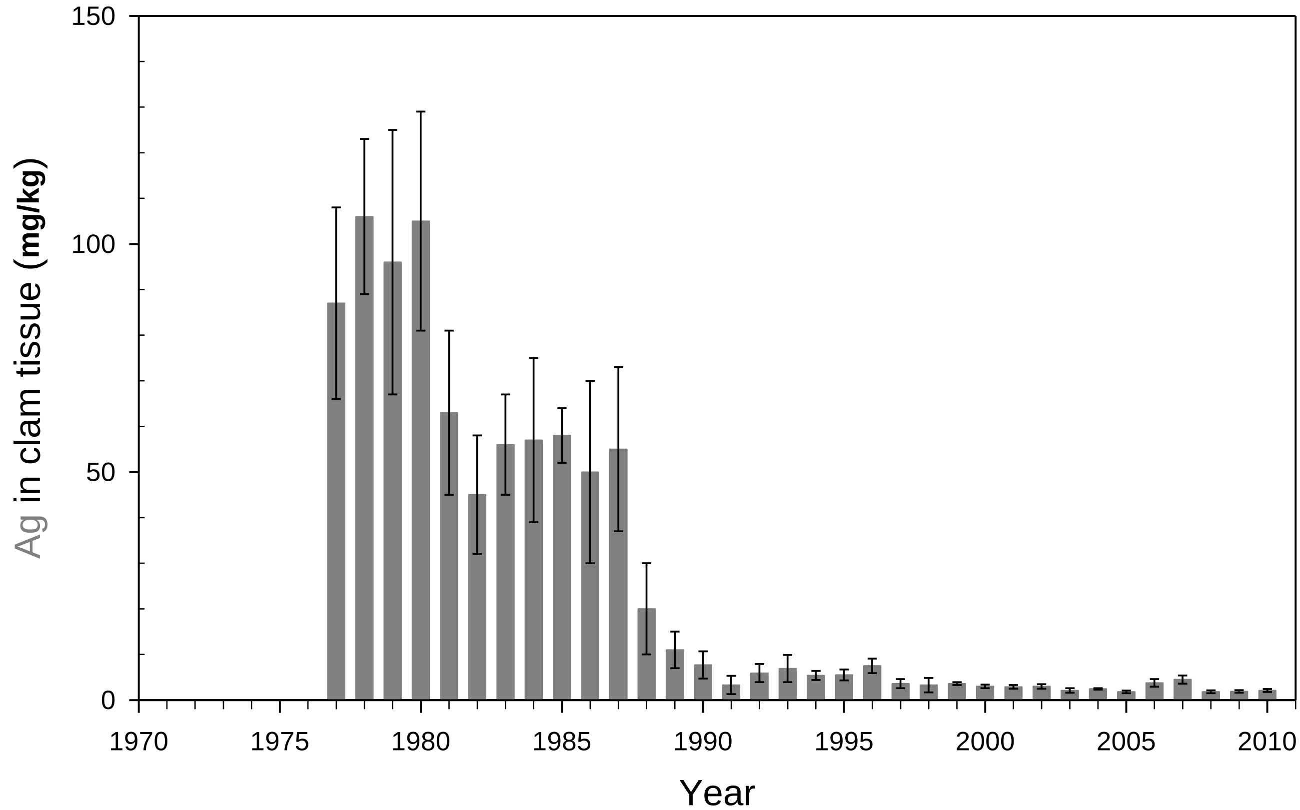


Figure 11. Annual mean silver concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1977–2010.

Values are the annual (grand) means for 7 to 12 separate samples per year and error bars are standard errors of those means (SEM).

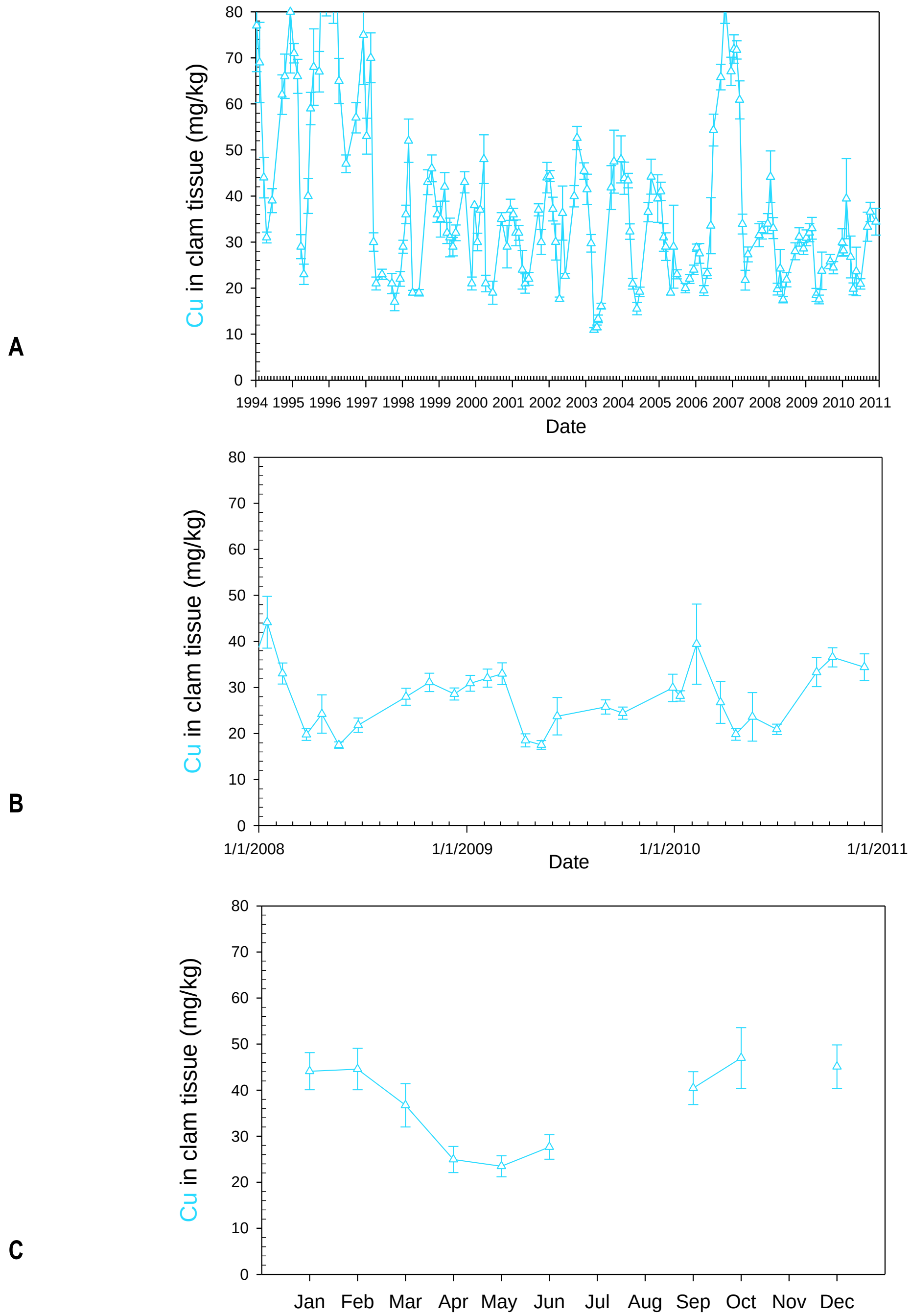


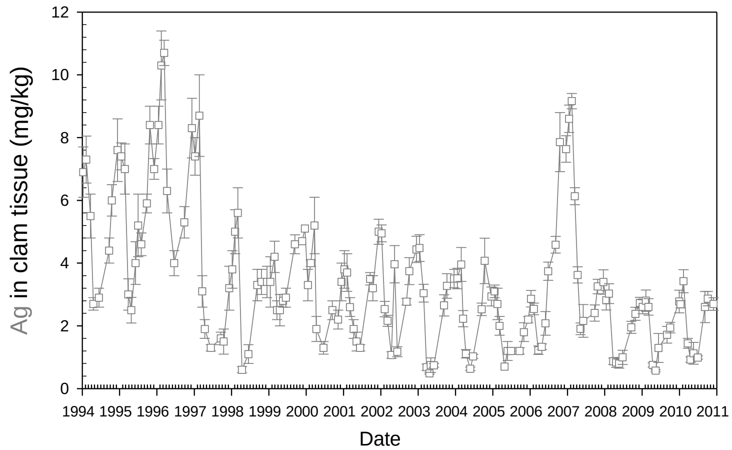
Figure 12. Copper concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2010.

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).

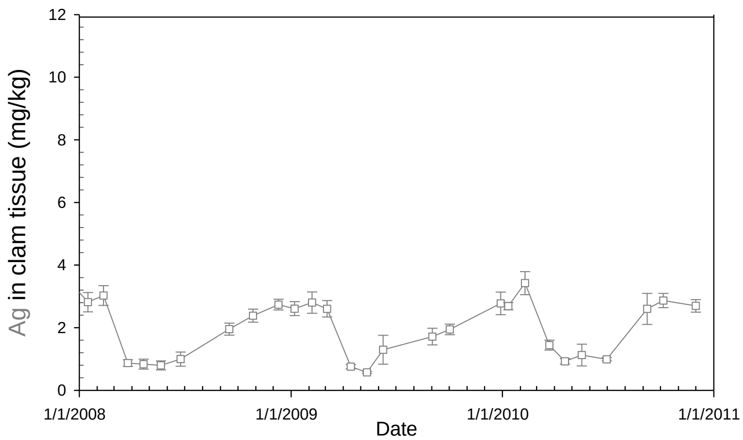
B. Data for the past 3 years (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, illustrating the general seasonal variation in Cu. Collections are not made in July, August, and November. The error bar is the SEM.

A



B



C

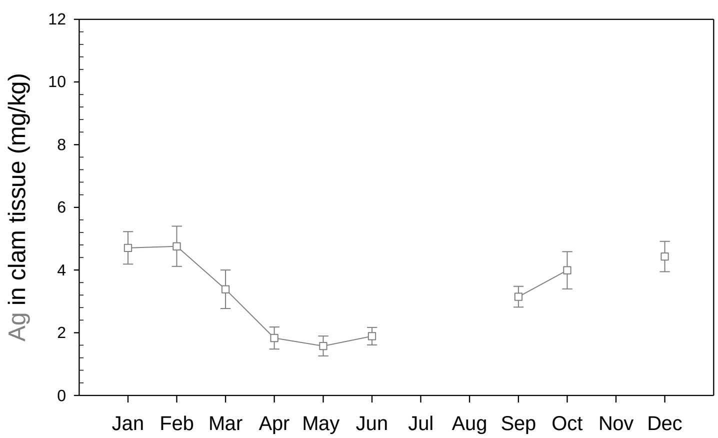


Figure 13. Silver concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2010.

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 (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, illustrating the general seasonal variation in Ag. Collections are not made in July, August, and November. The error bar is the SEM.

A

B

C

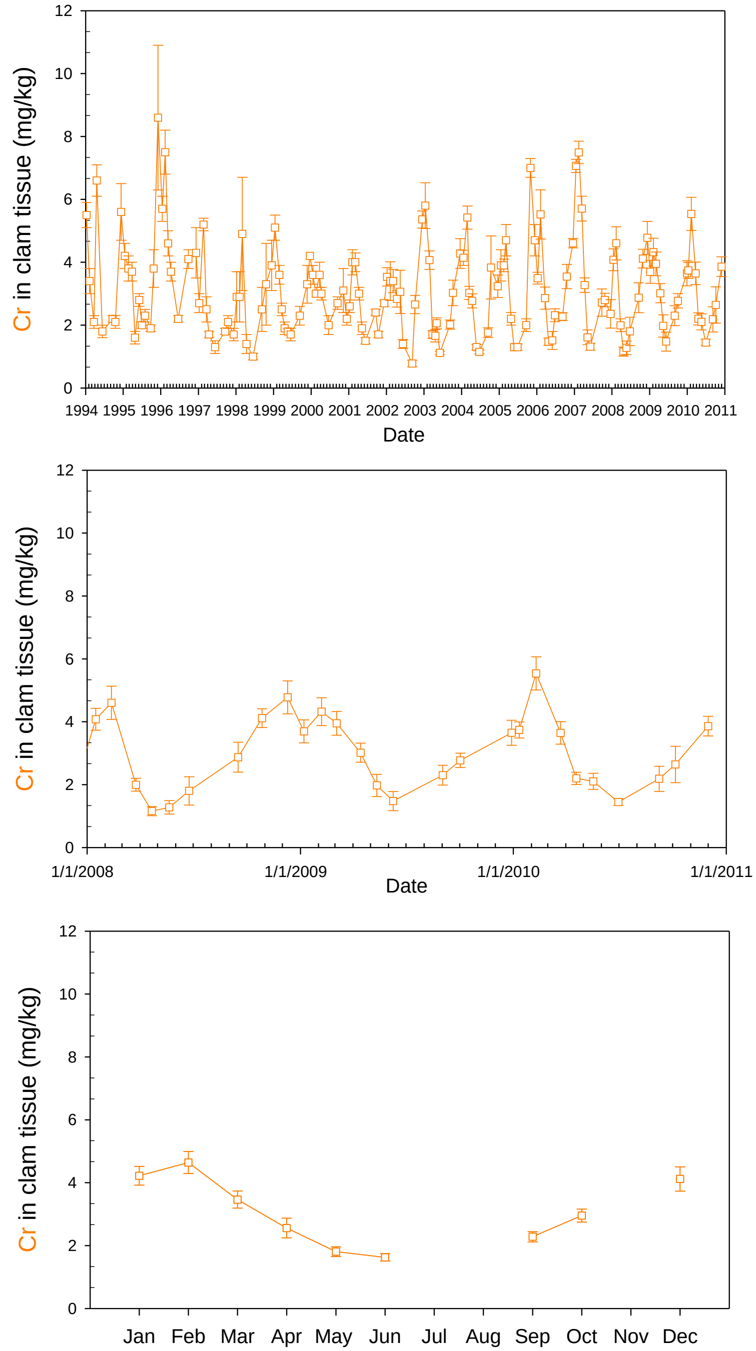


Figure 14. Chromium concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2010.

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 (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, illustrating the general seasonal variation in Cr. Collections are not made in July, August, and November. The error bar is the SEM.

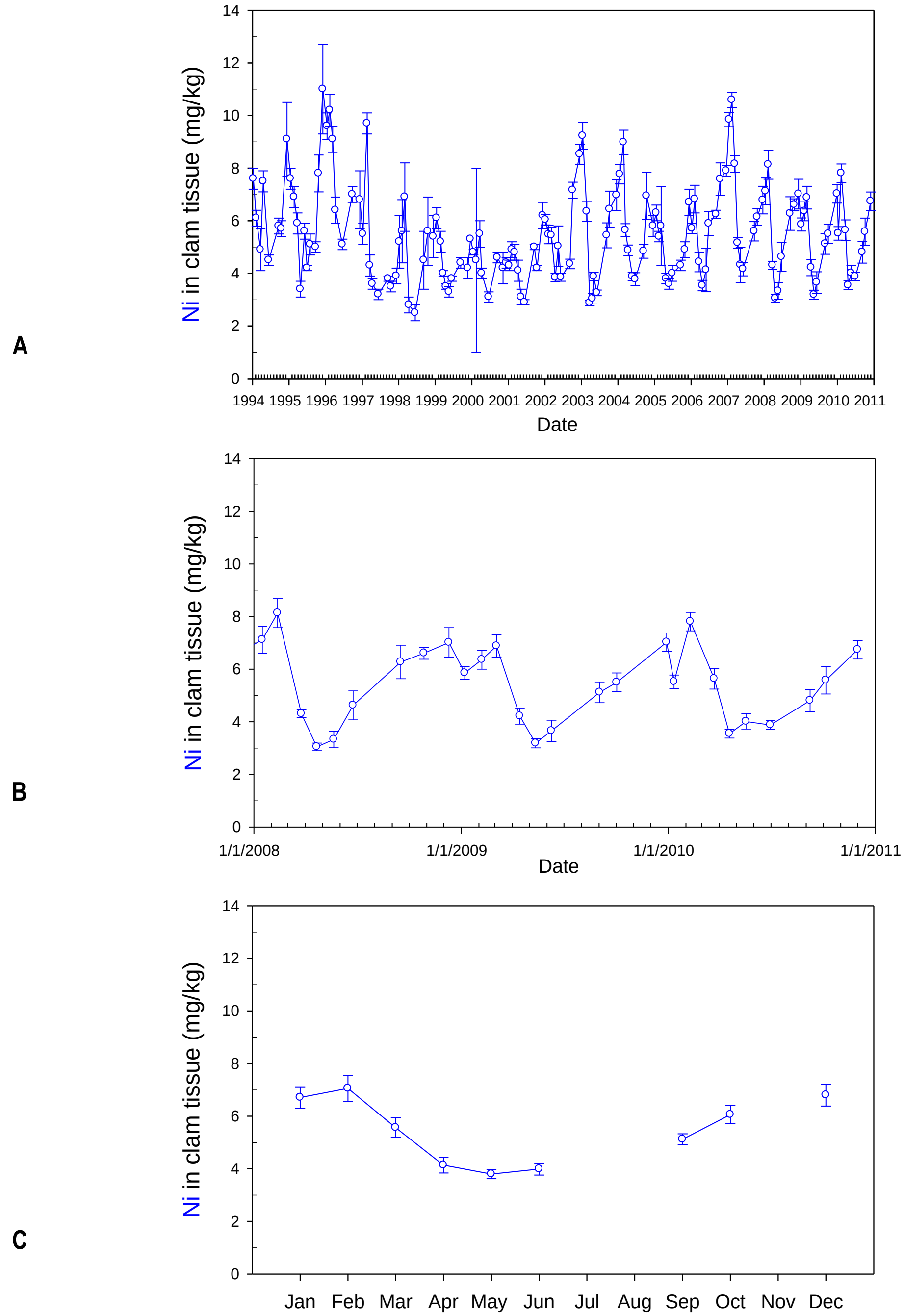


Figure 15. Nickel concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2010.

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 (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, illustrating the general seasonal variation in Ni. Collections are not made in July, August, and November. The error bar is the SEM.

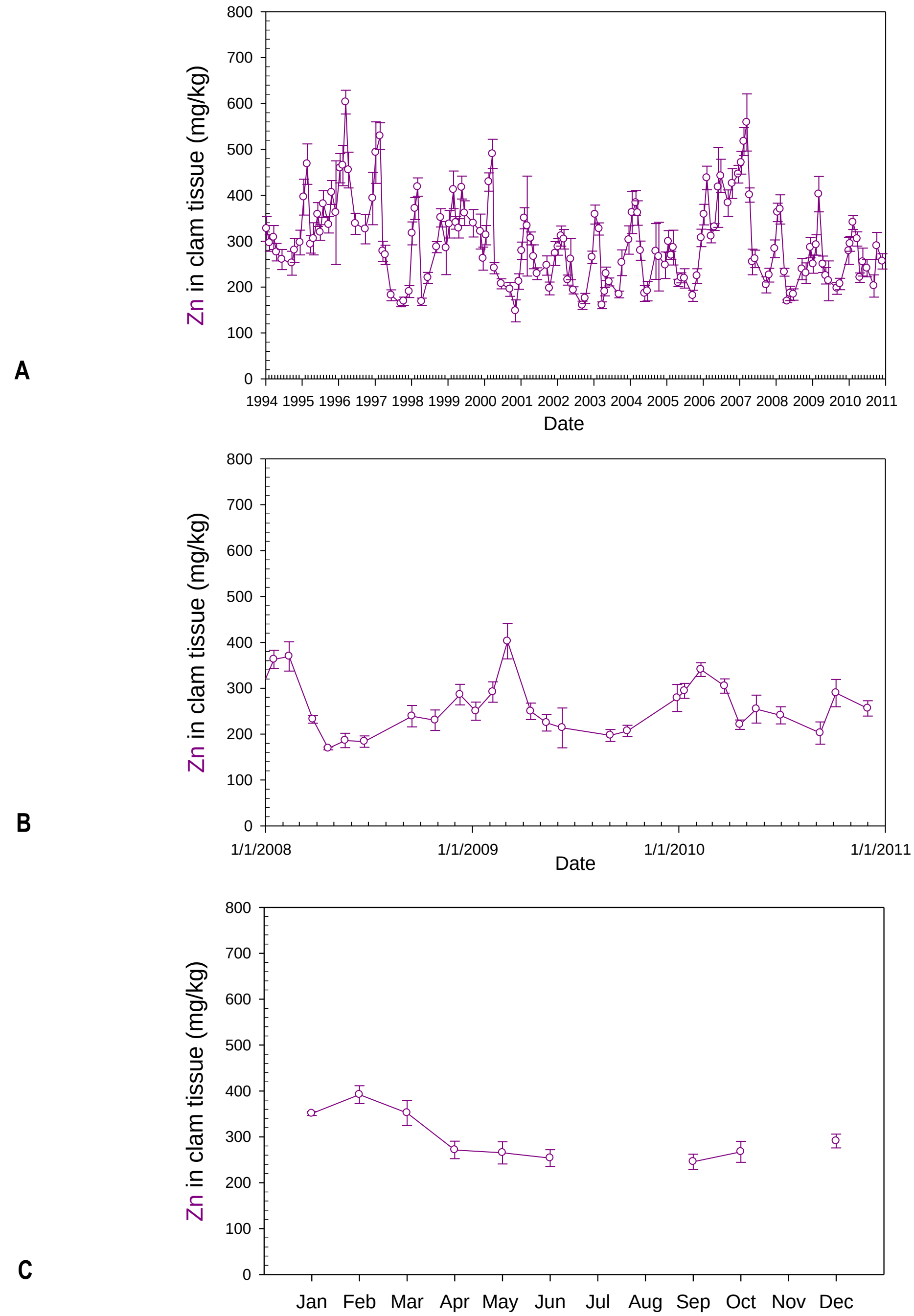


Figure 16. Zinc concentrations in the clam *Macoma petalum,* Palo Alto, Calif., 1994–2010.

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 (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, illustrating the general seasonal variation in Zn. Collections are not made in July, August, and November. The error bar is the SEM.

A

B

C

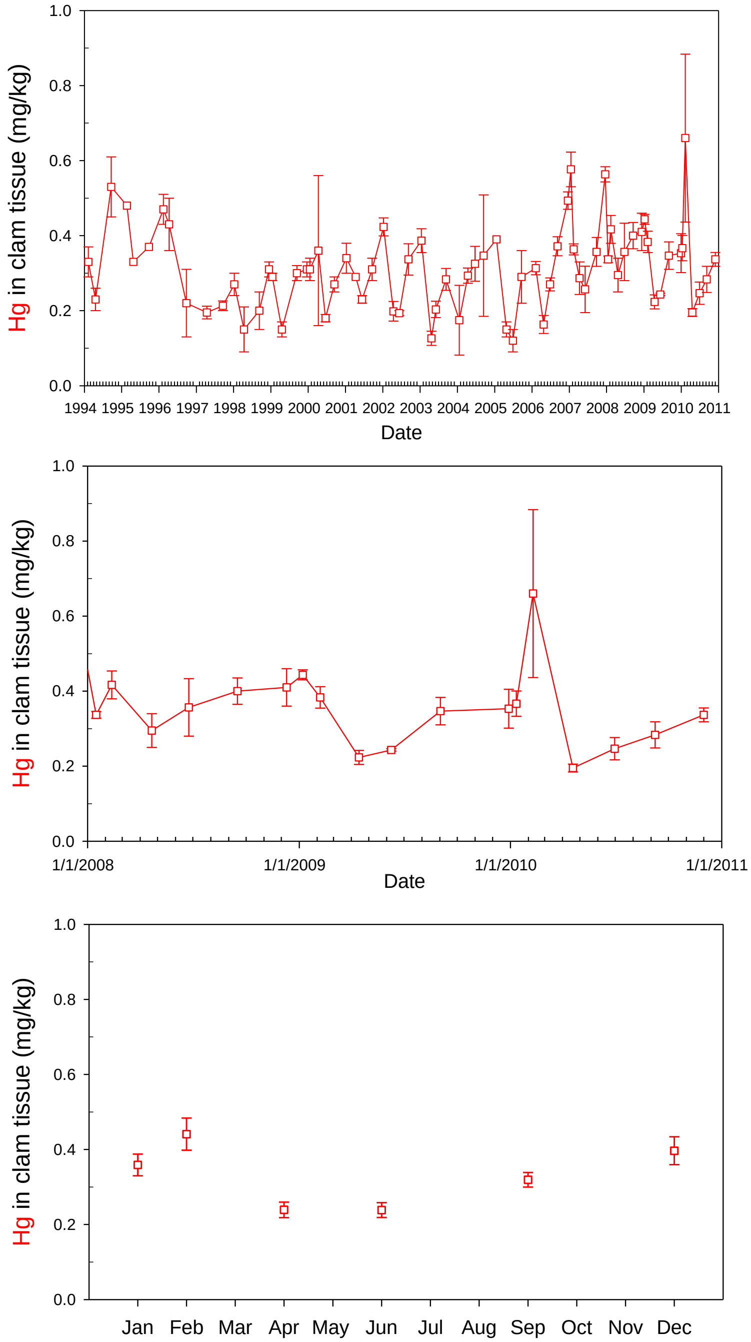


Figure 17. Mercury concentrations in the clam *Macoma petalum,* Palo Alto, Calif., 1994–2010.

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 (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, illustrating the general seasonal variation in Hg. Collections are not made in March, May, July, August, October, and November. The error bar is the SEM.

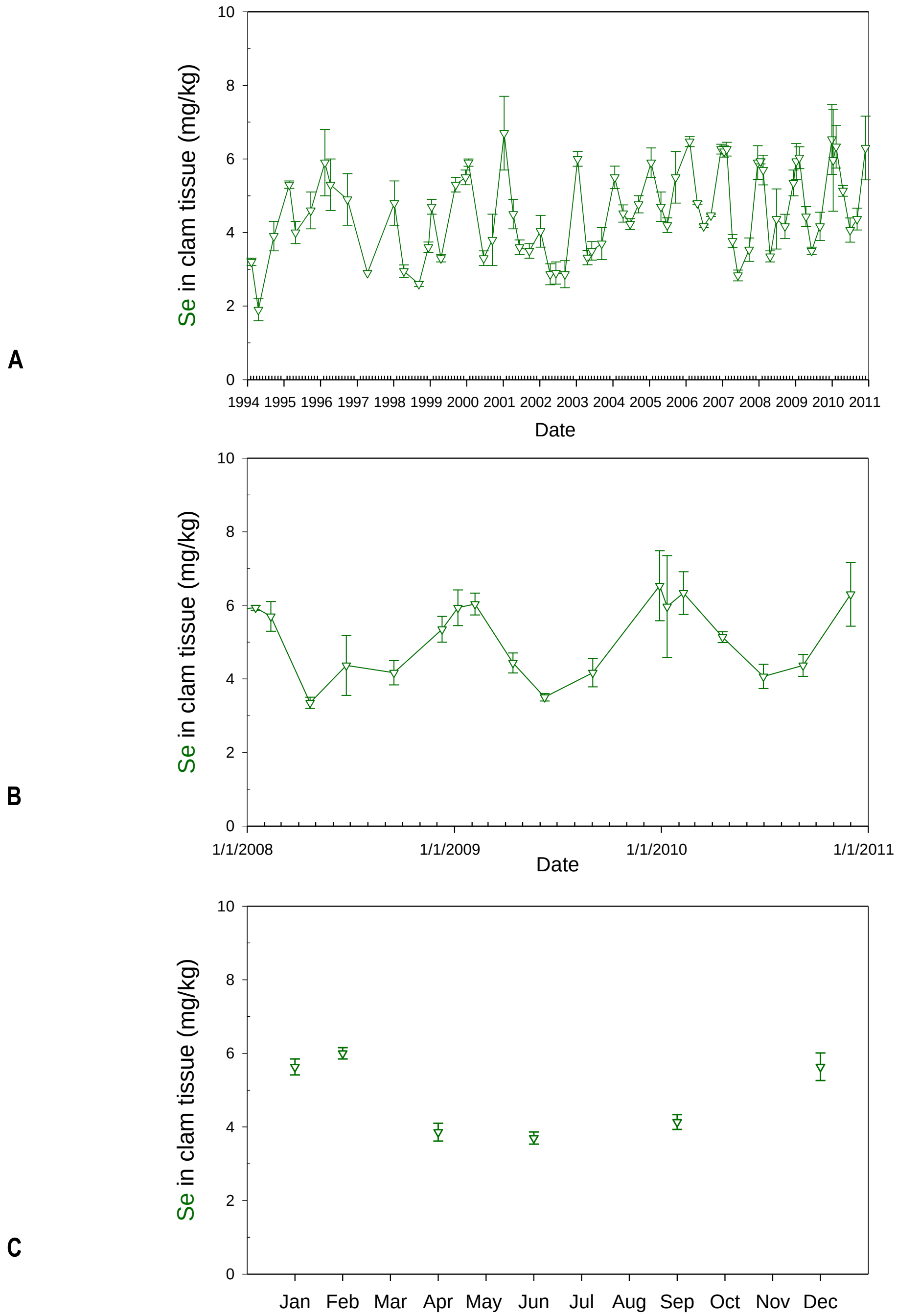


Figure 18. Selenium concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1994–2010.

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 (2008–2010).

C. The monthly mean of all samples collected from 1994–2010, illustrating the general seasonal variation in Se. Collections are not made in March, May, July, August, October, and November. The error bar is the SEM.

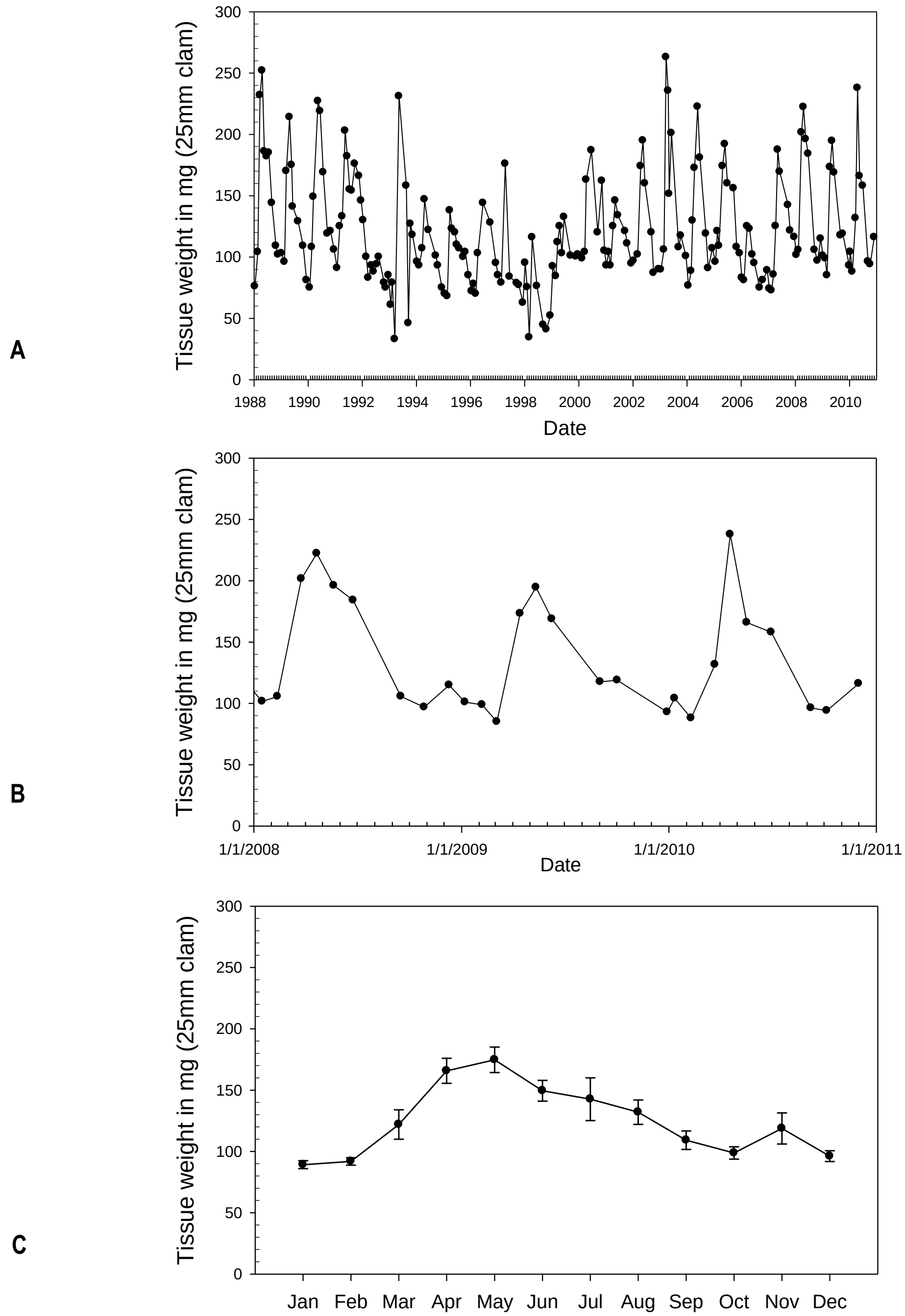


Figure 19. Condition index of the clam *Macoma petalum*, Palo Alto, Calif., 1988–2010.

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 (2008–2010).

C. The monthly mean of all samples collected from 1988–2010, illustrating the general seasonal variation in condition index. The error bar is the SEM.

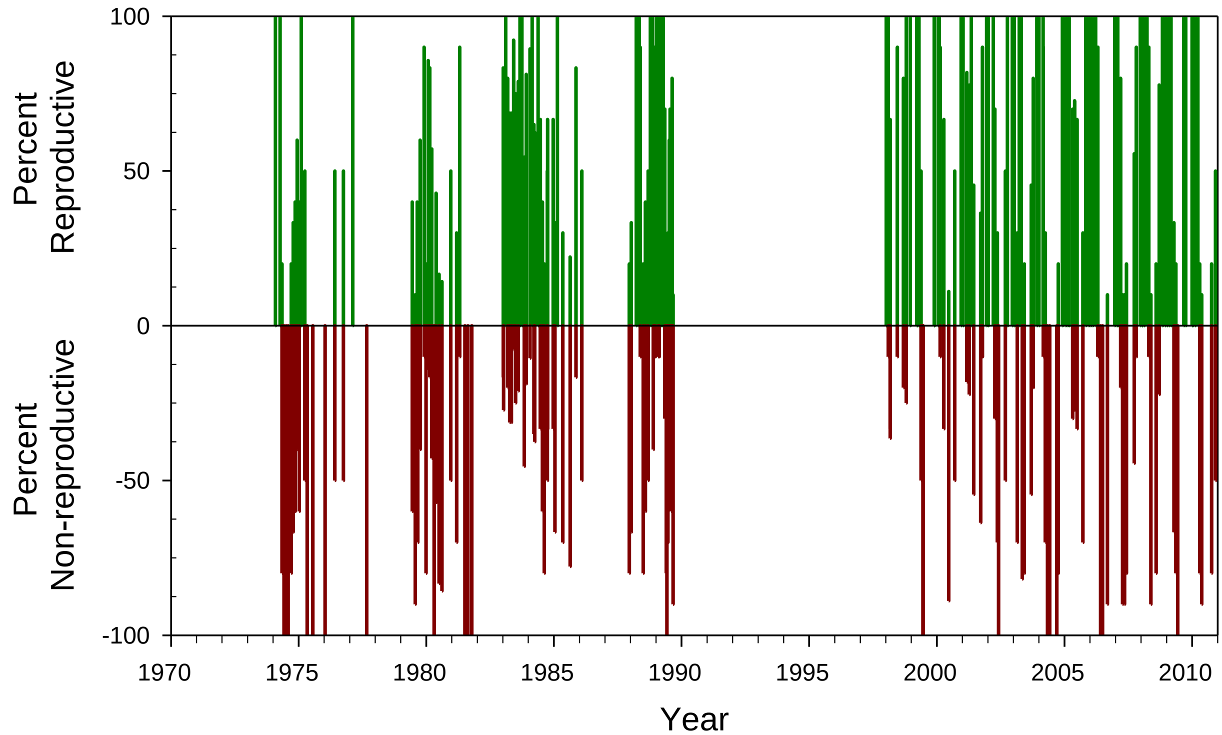


Figure 20. Reproductive activity of the clam *Macoma petalum*, Palo Alto, Calif., 1974–2010.

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.

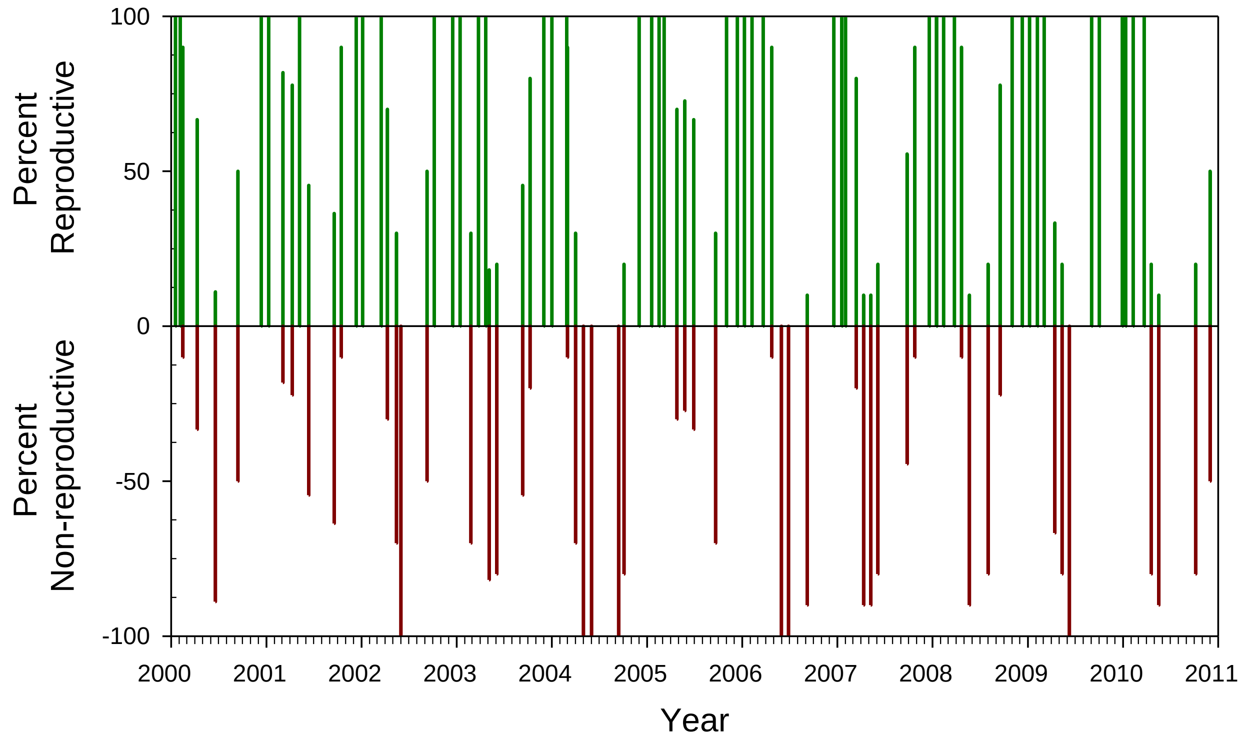


Figure 21. Reproductive activity of the clam *Macoma petalum*, Palo Alto, Calif., 2000–2010.

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.

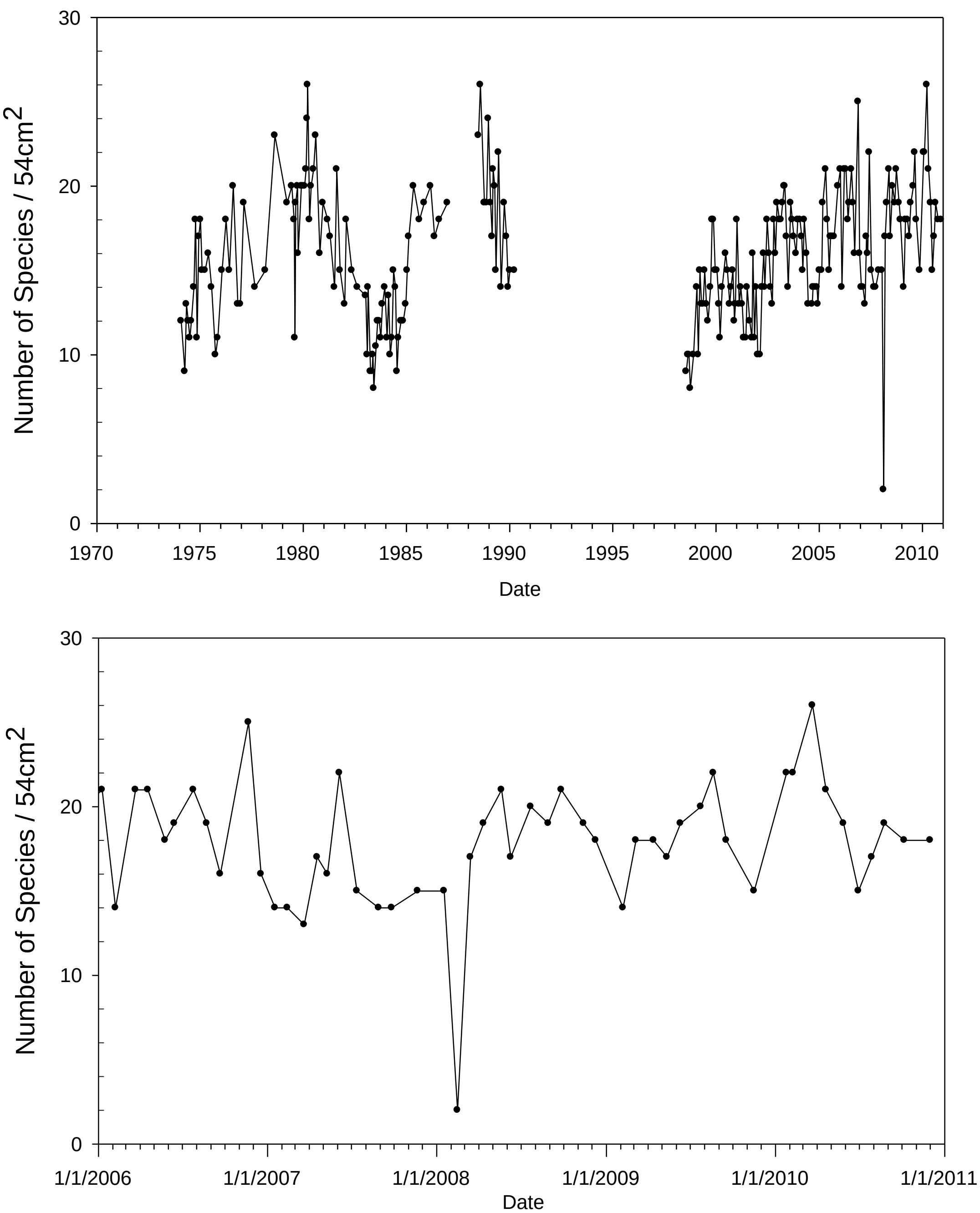


Figure 22. Total number of species present at the Palo Alto site, Calif., 1974–2010.

Collections were not made between 1991 and 1998.

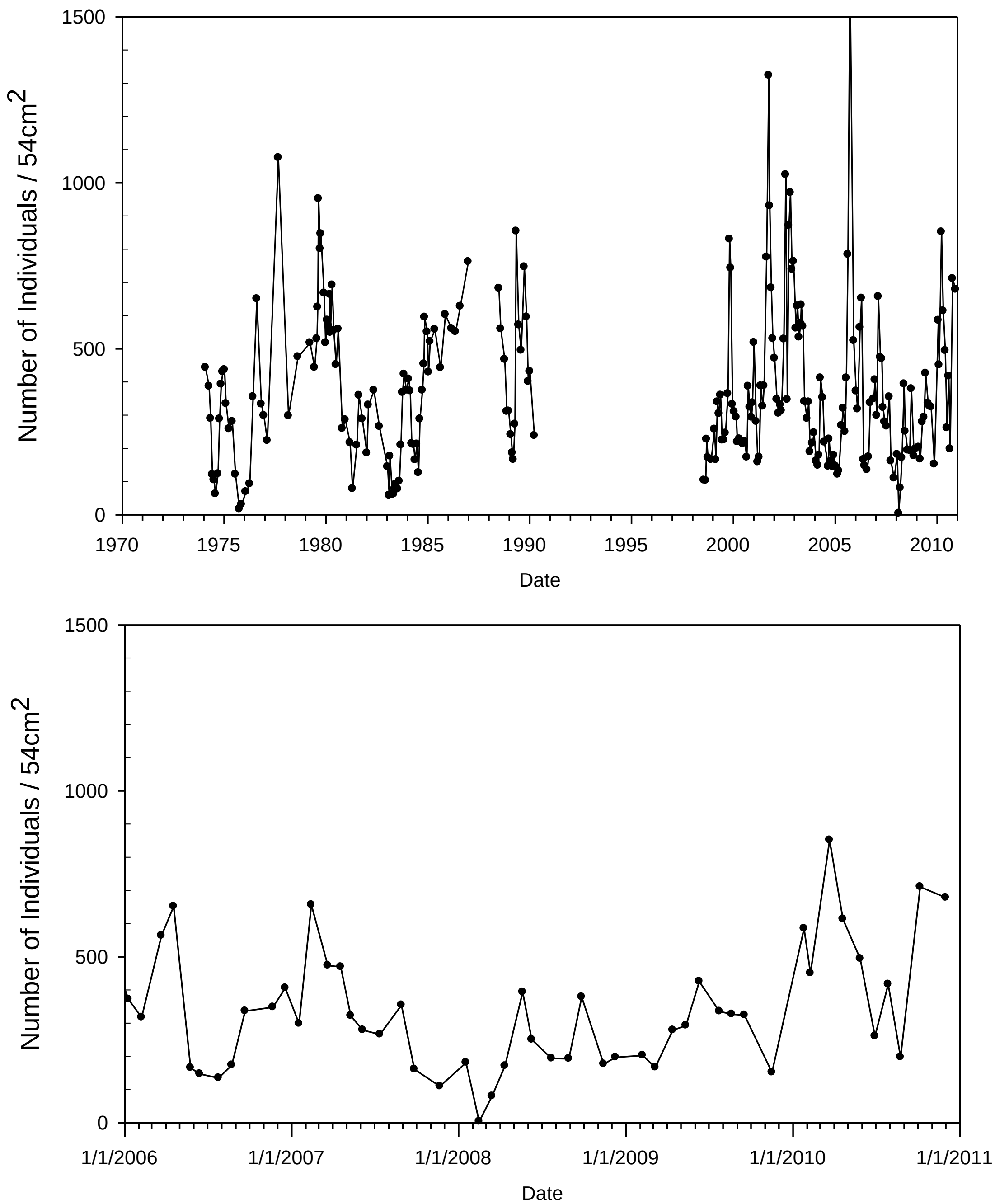


Figure 23. Total average number of individuals present at the Palo Alto site, Calif., 1974–2010.

Collections were not made between 1991 and 1998.

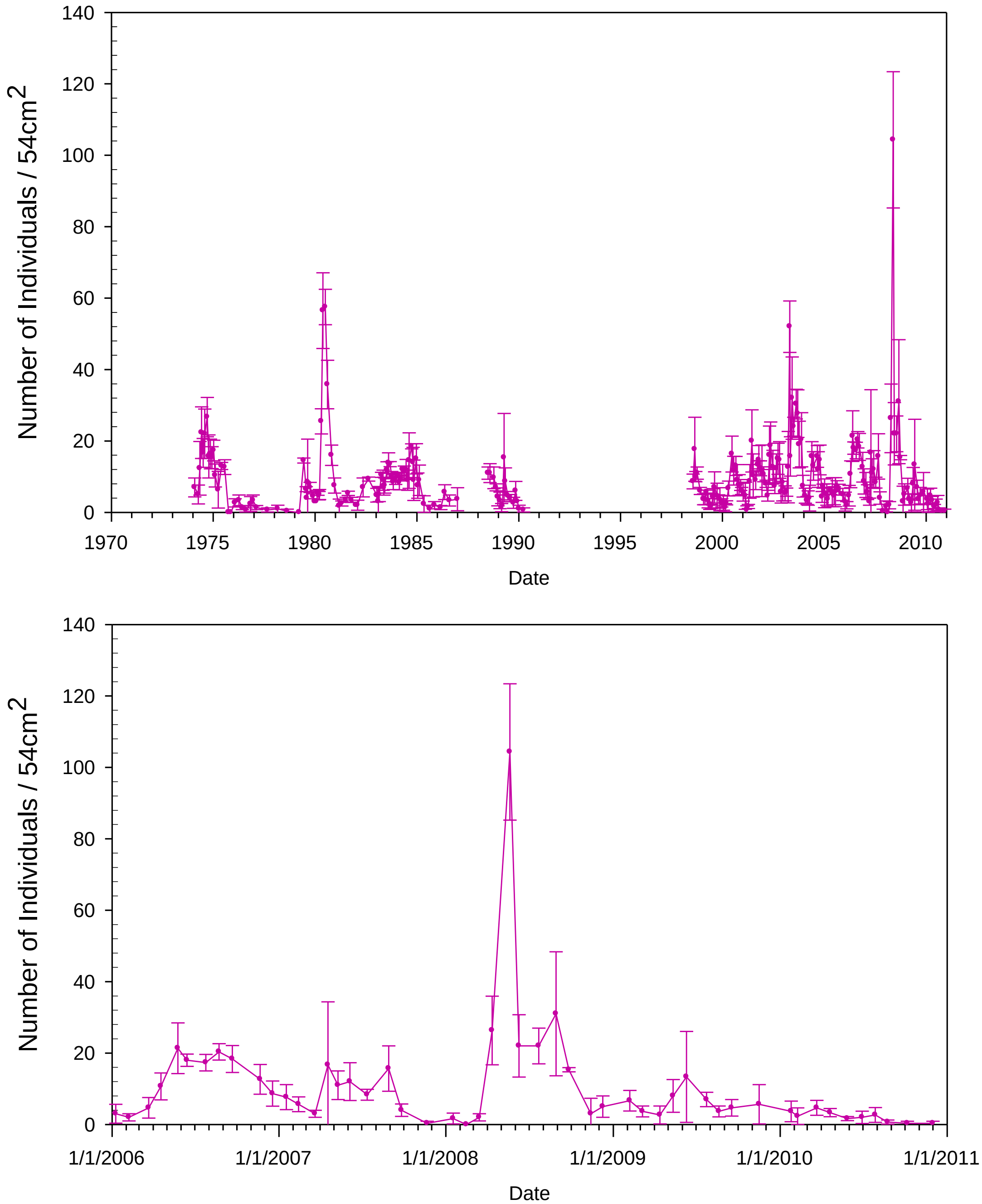


Figure 24. Monthly average abundance of *Macoma petalum*, Palo Alto, Calif., 1974–2010.

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

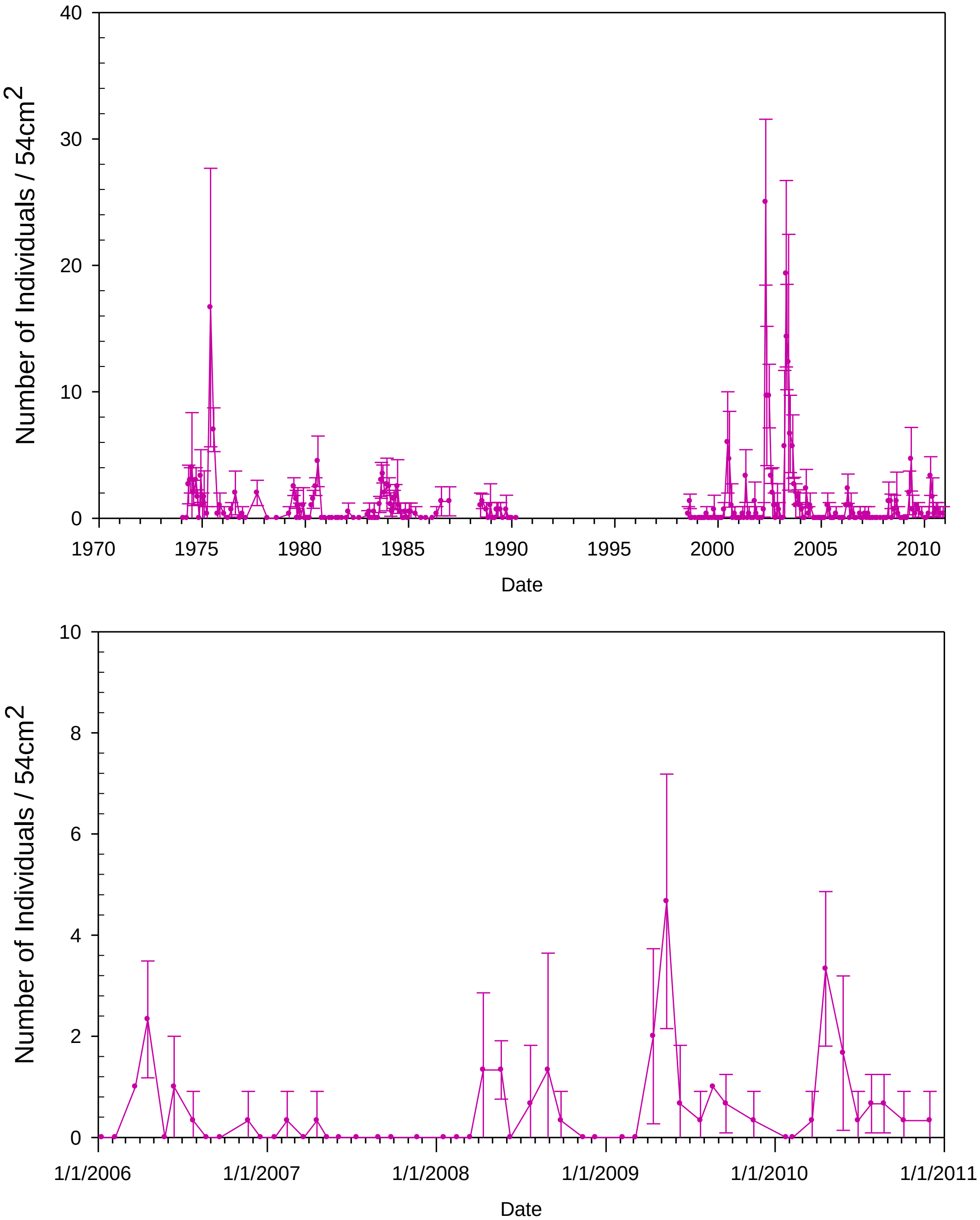


Figure 25. Monthly average abundance of *Mya arenaria*, Palo Alto, Calif., 1974–2010.

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

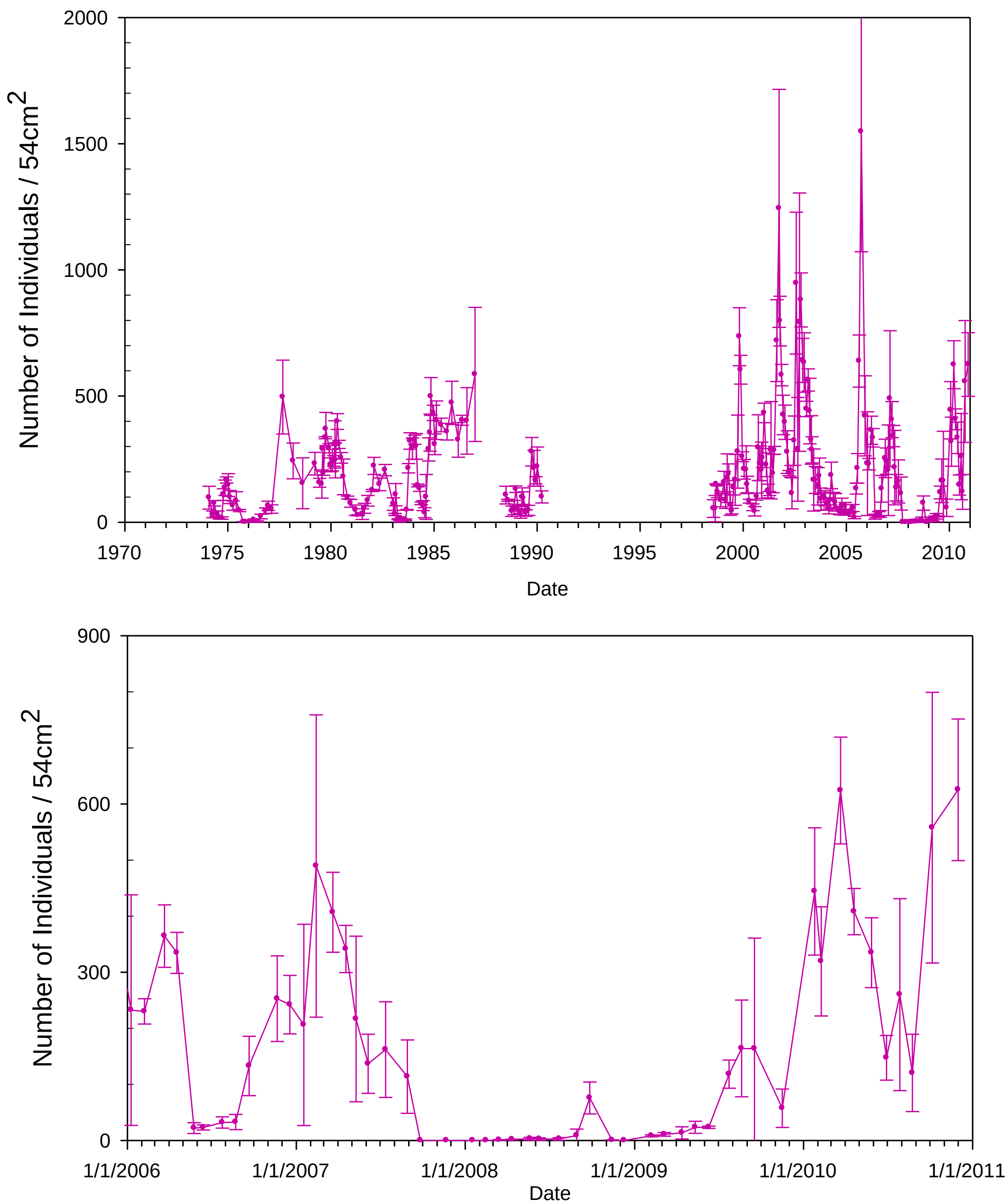


Figure 26. Monthly average abundance of *Gemma gemma*, Palo Alto, Calif., 1974–2010.

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

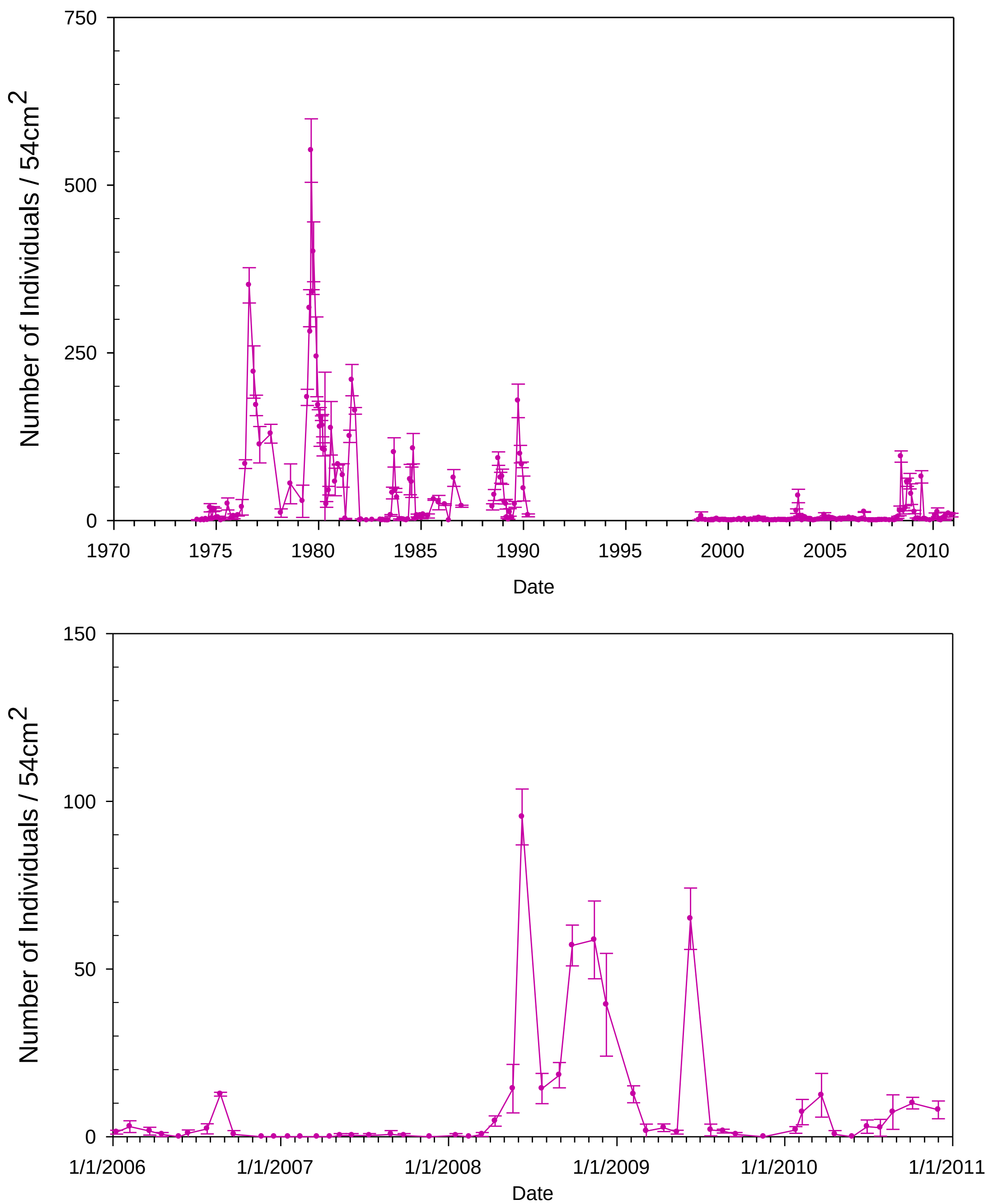


Figure 27. Monthly average abundance of *Ampelisca abdita*, Palo Alto, Calif., 1974–2010.

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

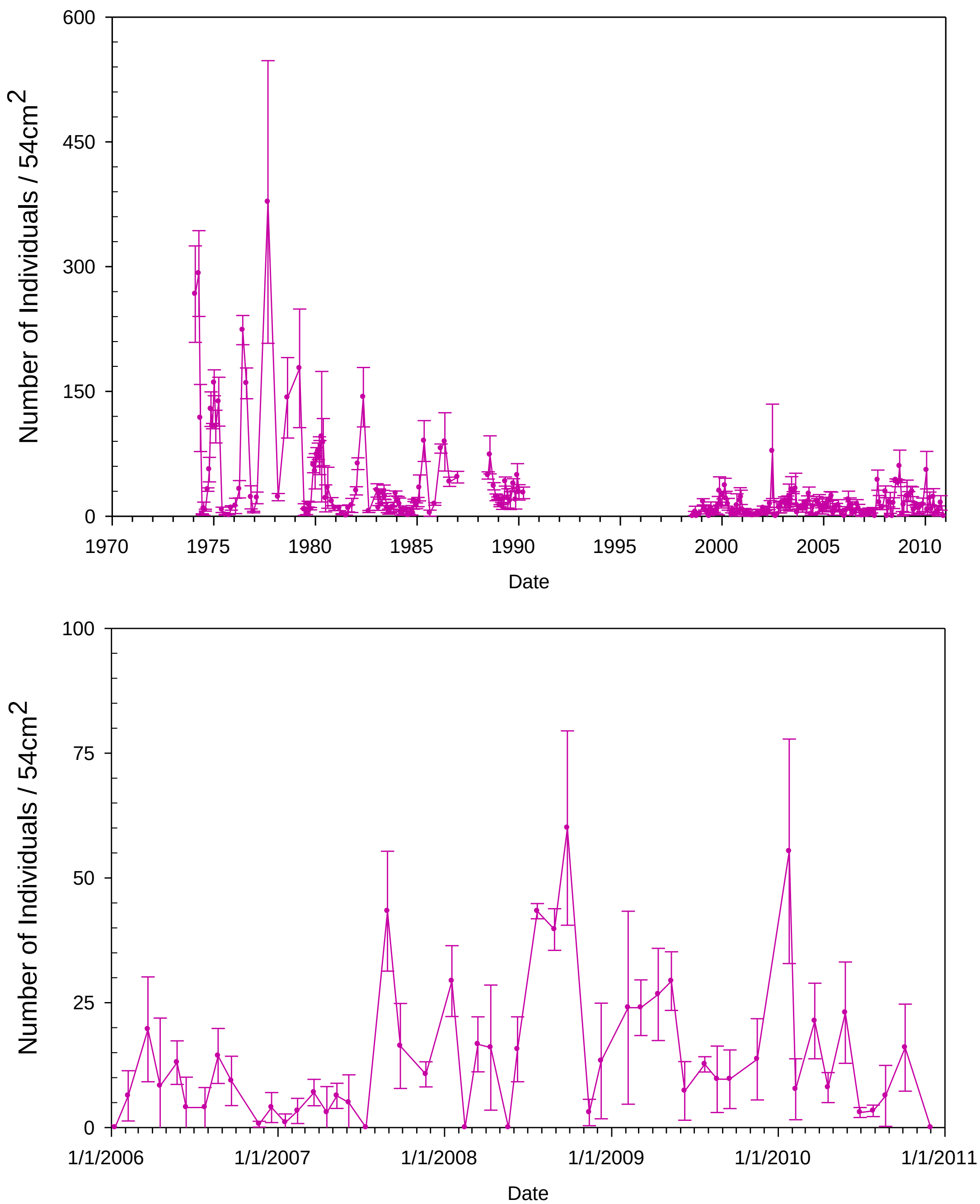


Figure 28. Monthly average abundance of *Streblospio benedicti*, Palo Alto, Calif., 1974–2010.

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

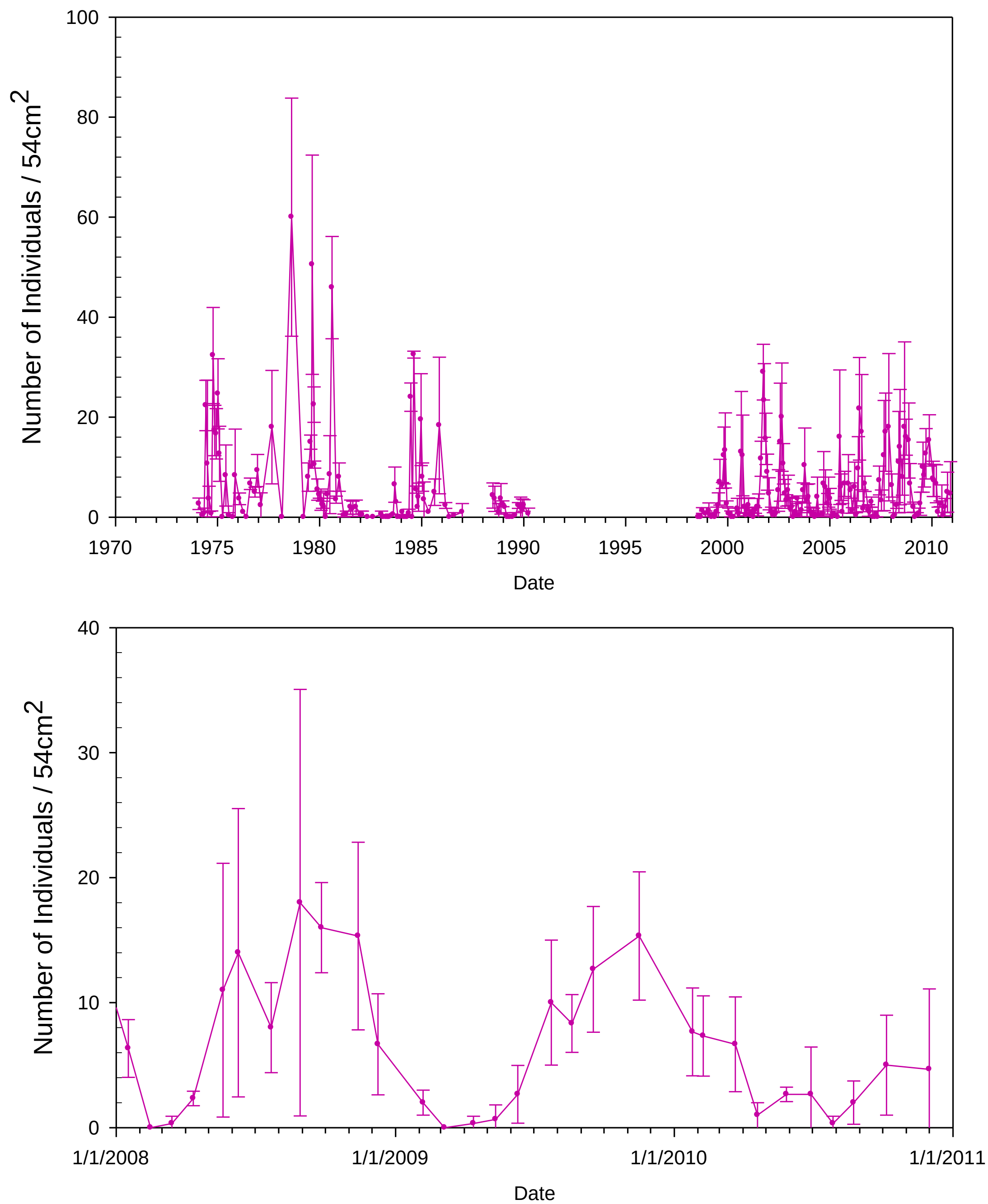


Figure 29. Monthly average abundance of *Grandiderella japonica*, Palo Alto, Calif., 1974–2010.

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

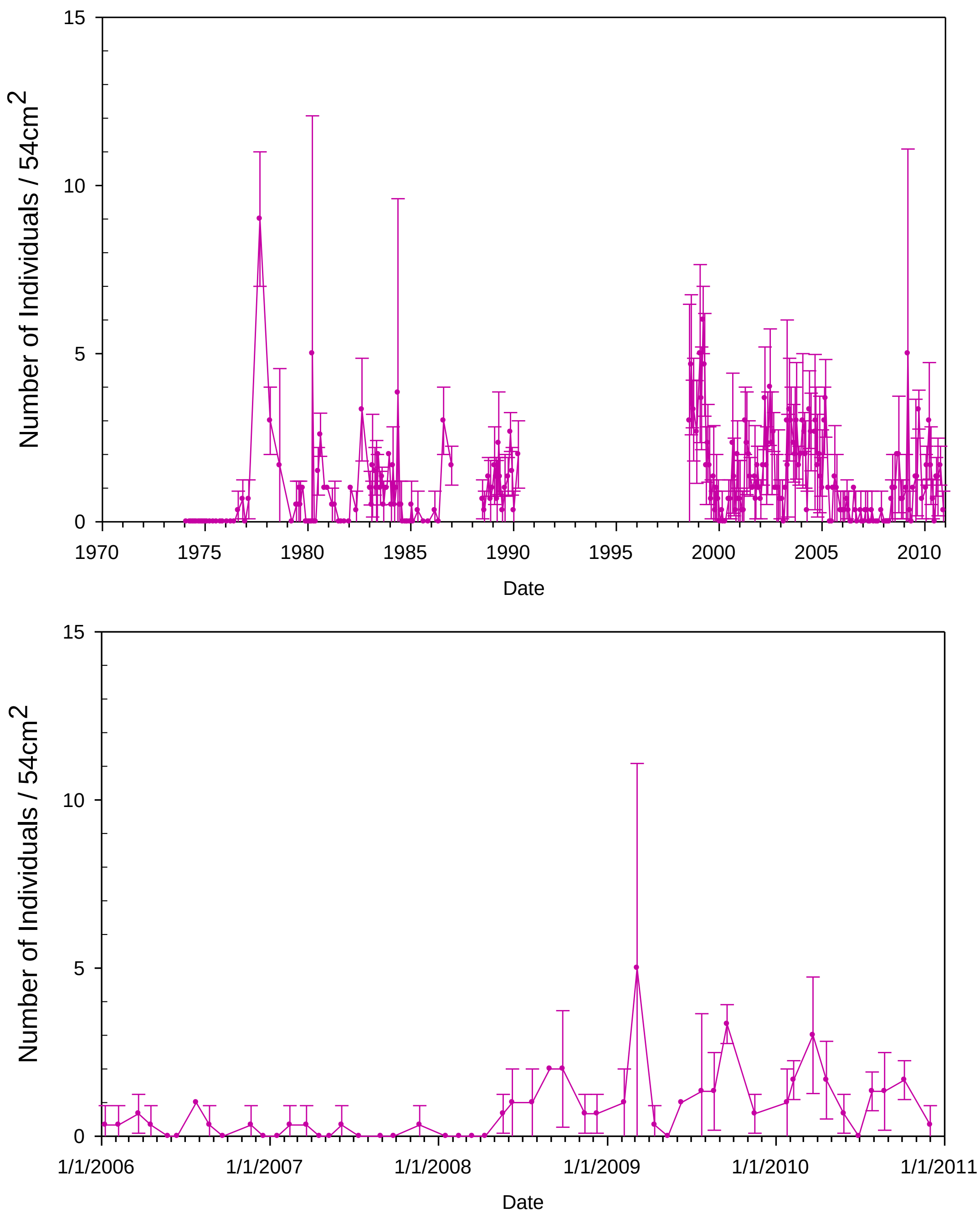


Figure 30. Monthly average abundance of *Neanthes succinea*, Palo Alto, Calif., 1974–2010.

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

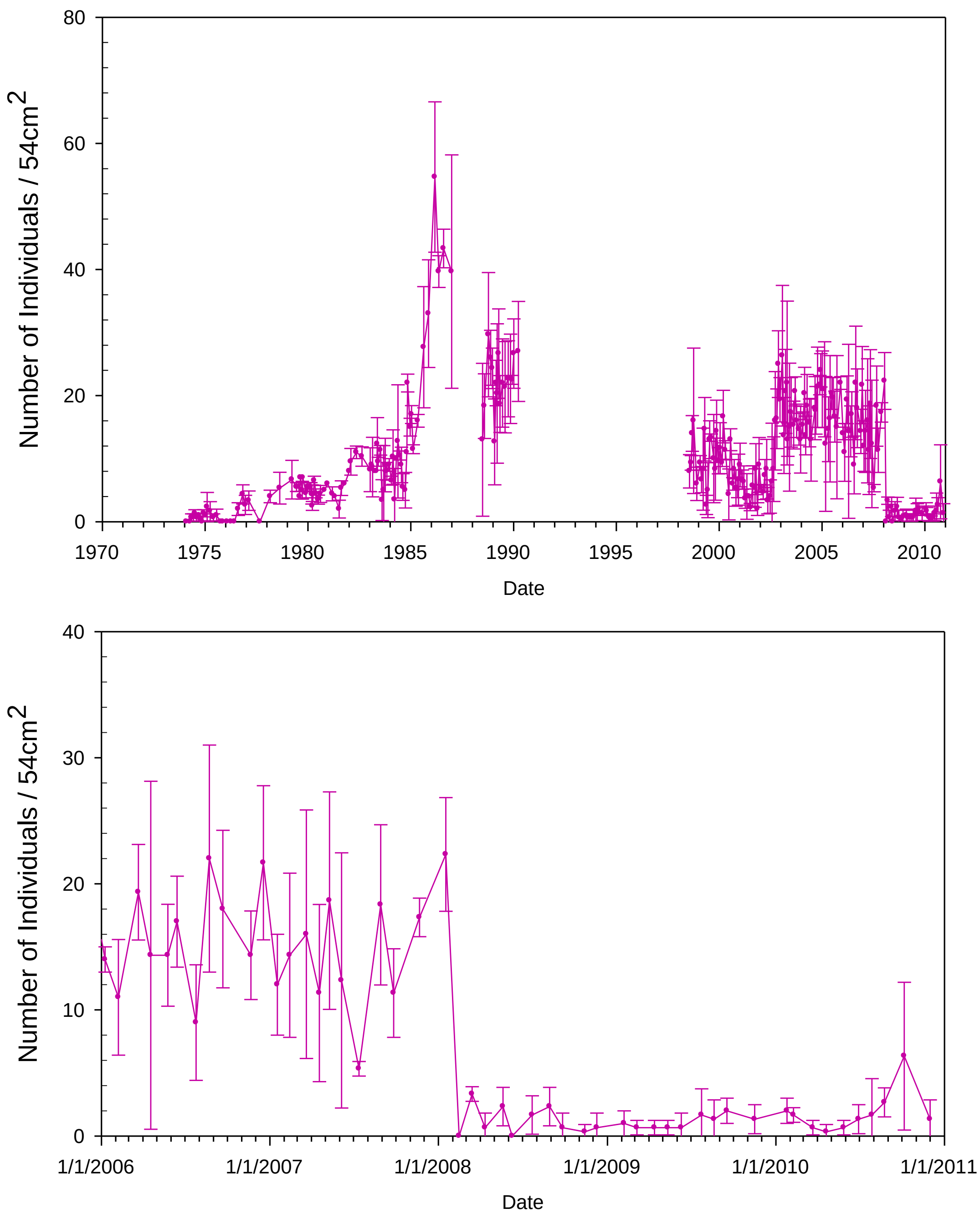


Figure 31. Monthly average abundance of *Heteromastus filiformis*, Palo Alto, Calif., 1974–2010.

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

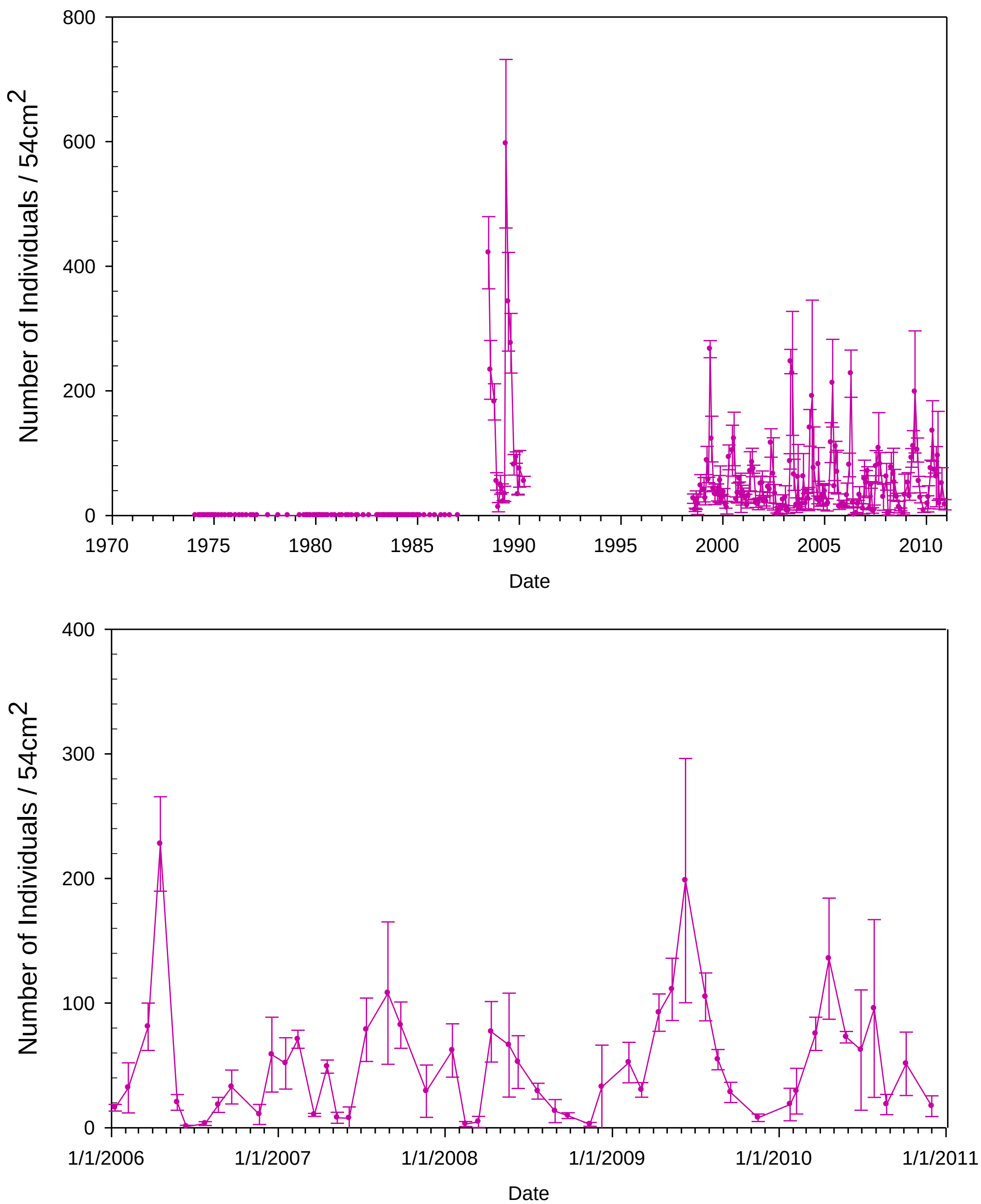


Figure 32. Monthly average abundance of *Nippoleucon hinumensis*, Palo Alto, Calif., 1974–2010.

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

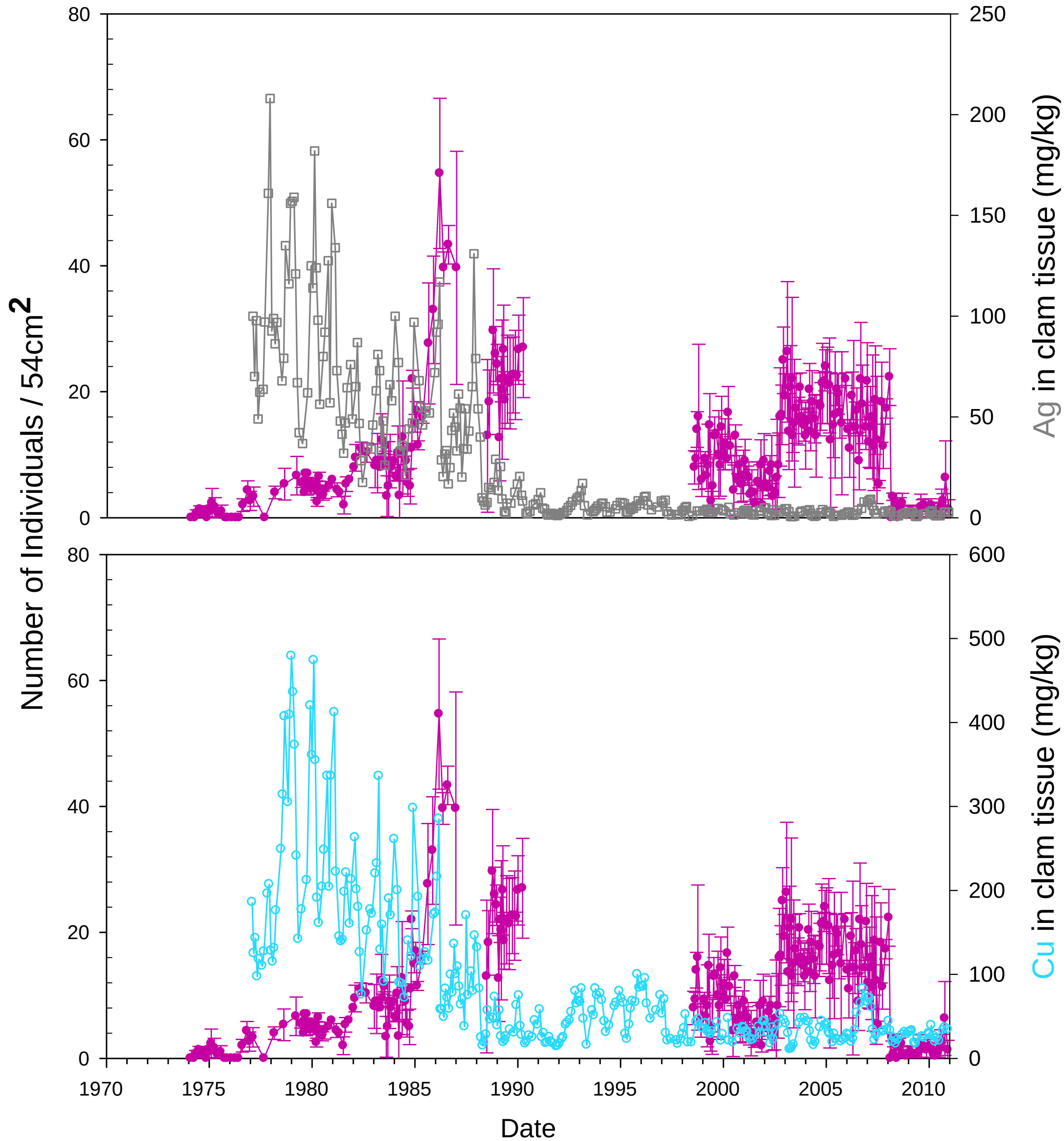


Figure 33. *Heteromastus filiformis* abundance with silver and copper concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1974–2010.

Error bars represent standard deviation from three replicate samplings.

The number of individuals (●); tissue concentration of silver (□) and copper (○) in *M. petalum.*

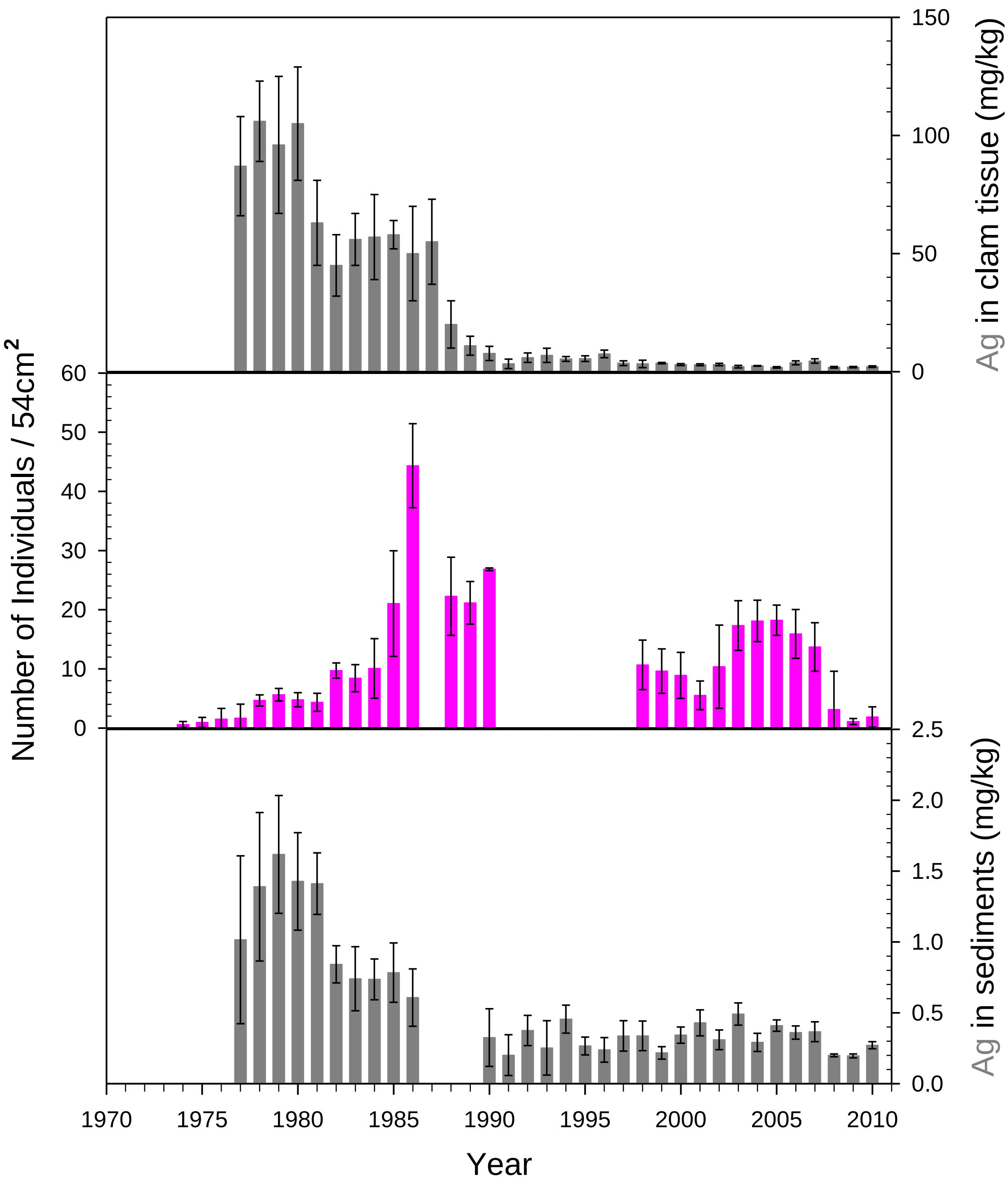


Figure 34. *Heteromastus filiformis* annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2010.

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

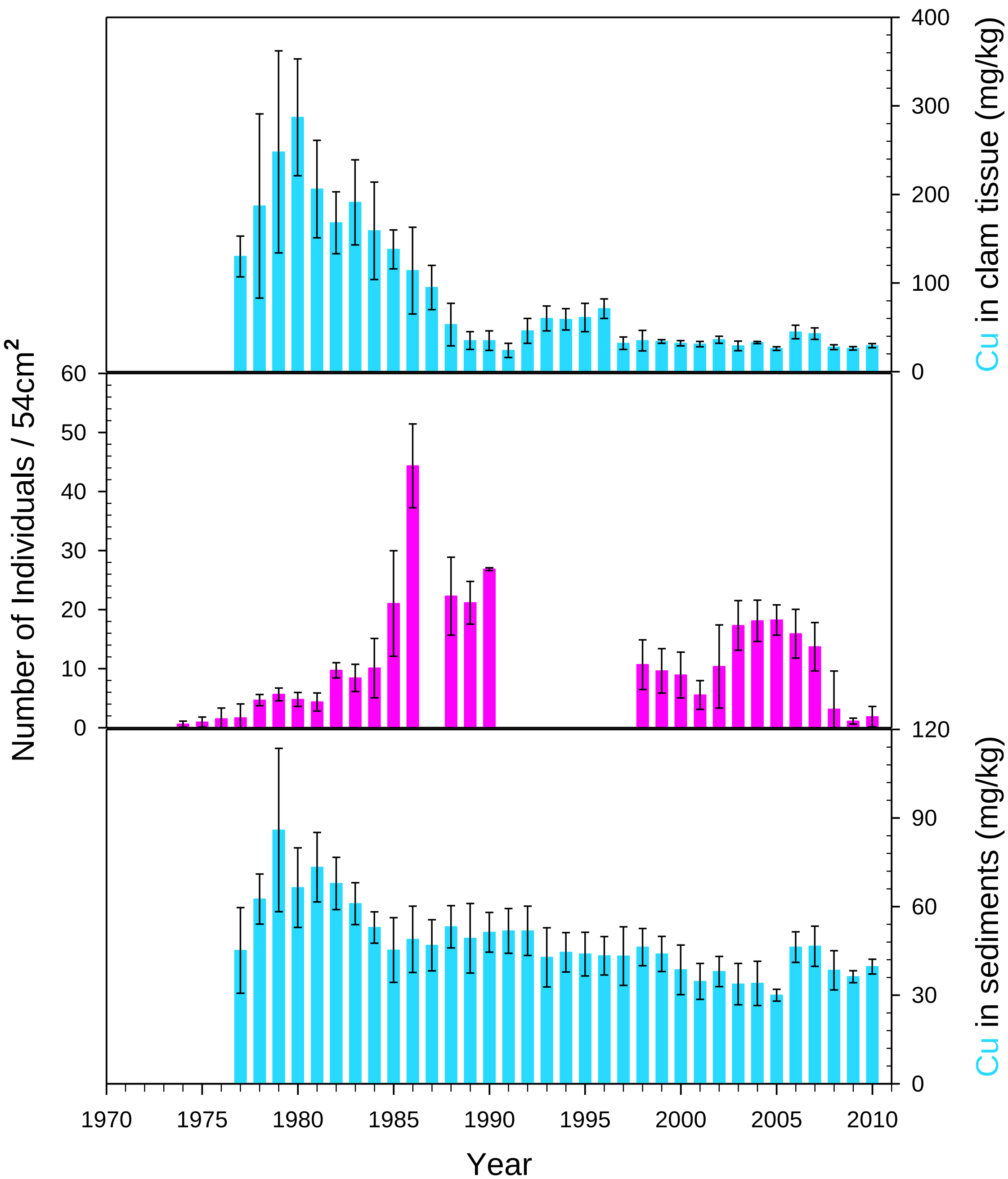


Figure 35. *Heteromastus filiformis* annual abundance with copper concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2010.

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

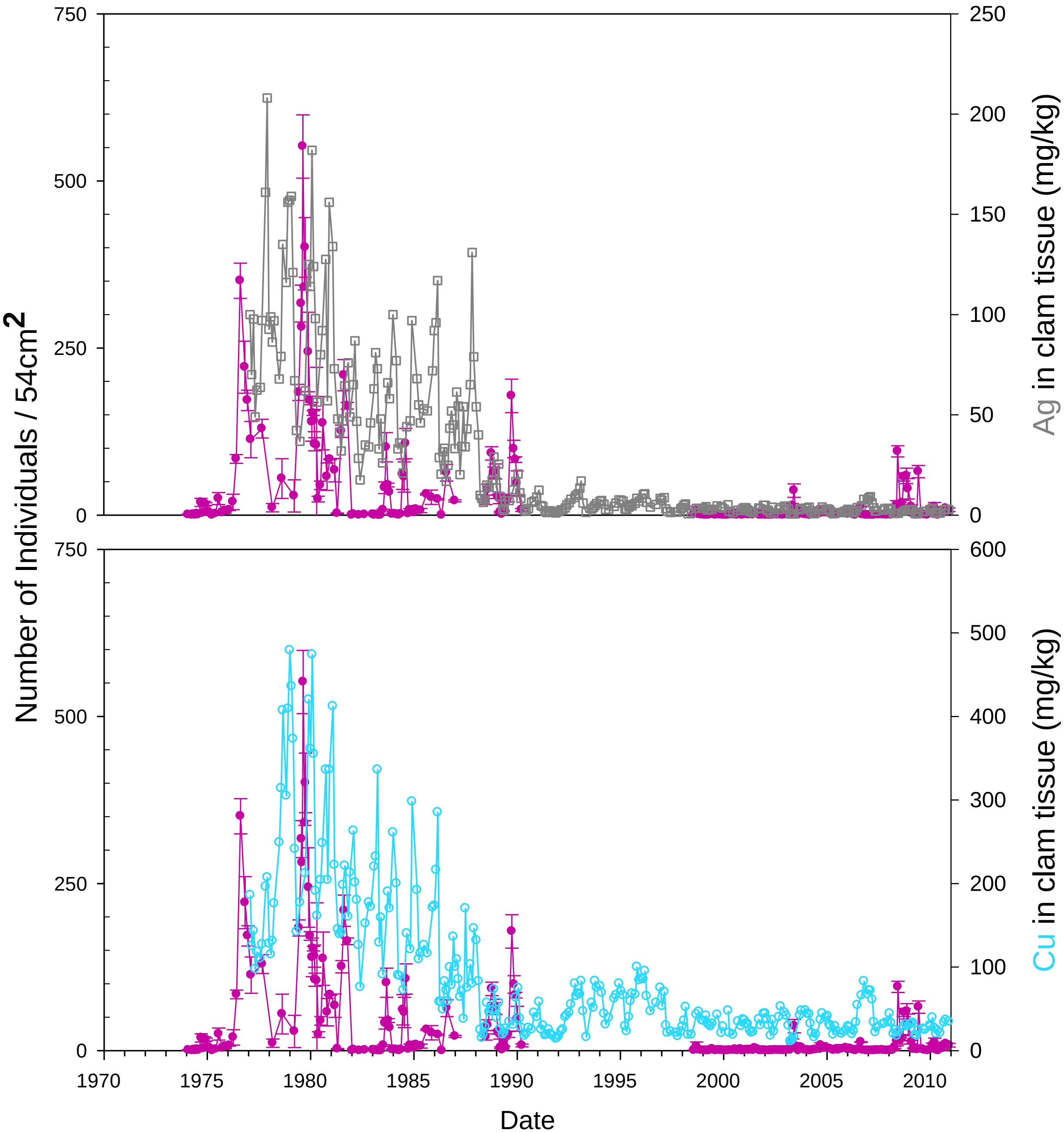


Figure 36. *Ampelisca abdita* abundance with silver and copper concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1974–2010.

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

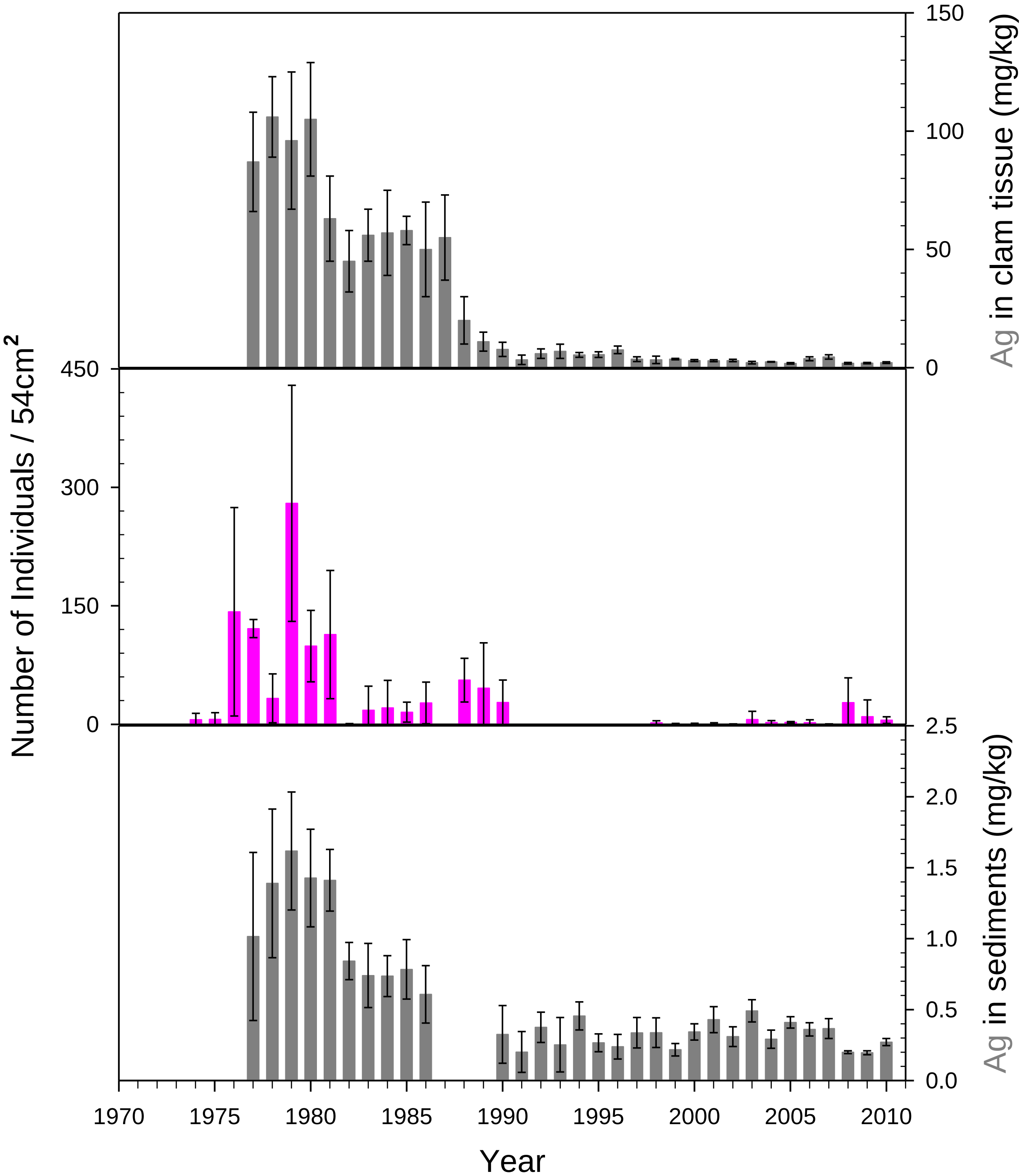


Figure 37. *Ampelisca abdita* annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2010.

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

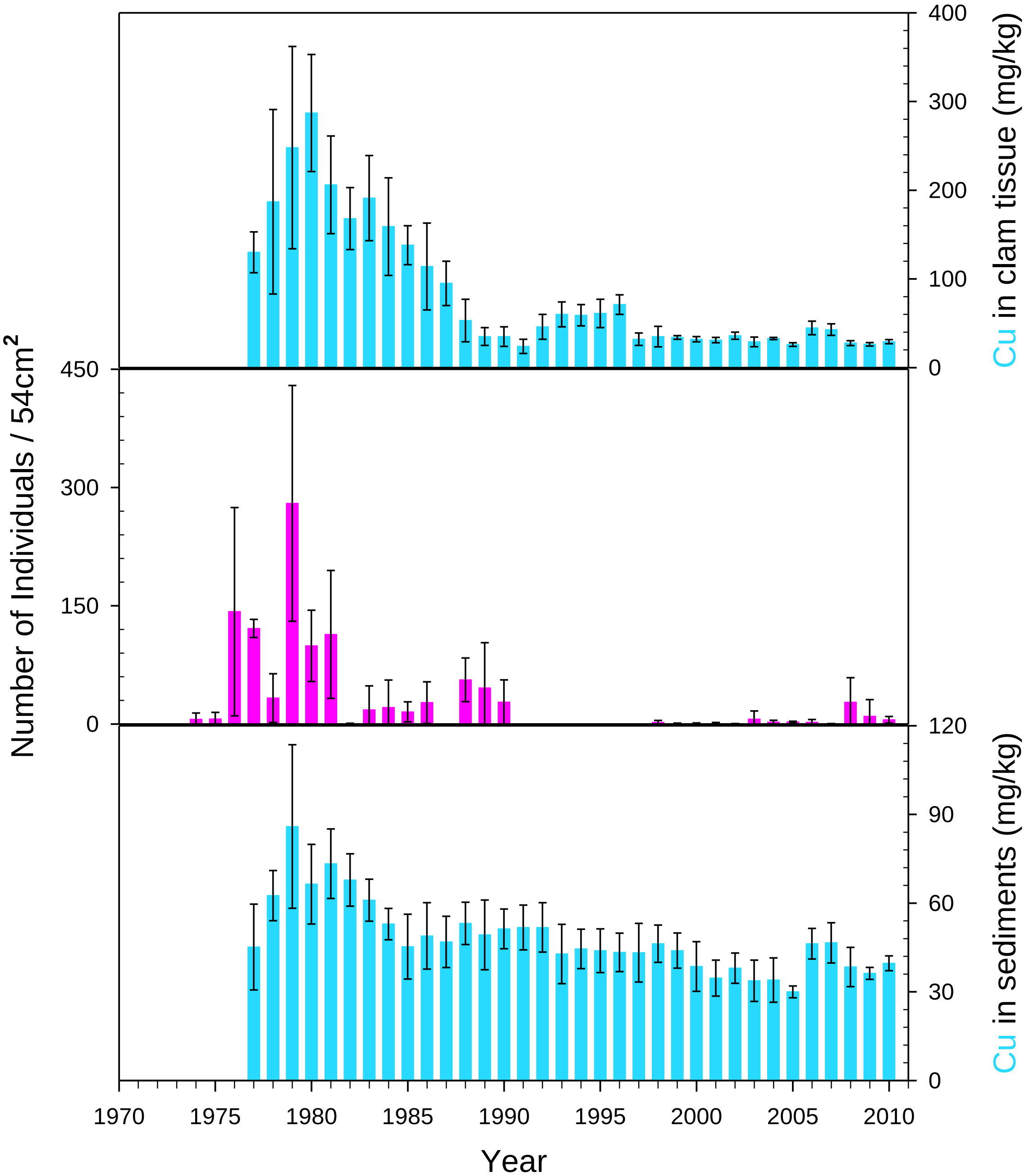


Figure 38. *Ampelisca abdita* annual abundance with copper concentrations in the clam *Macoma petalum* and sediment, Palo Alto, Calif., 1974–2010.

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

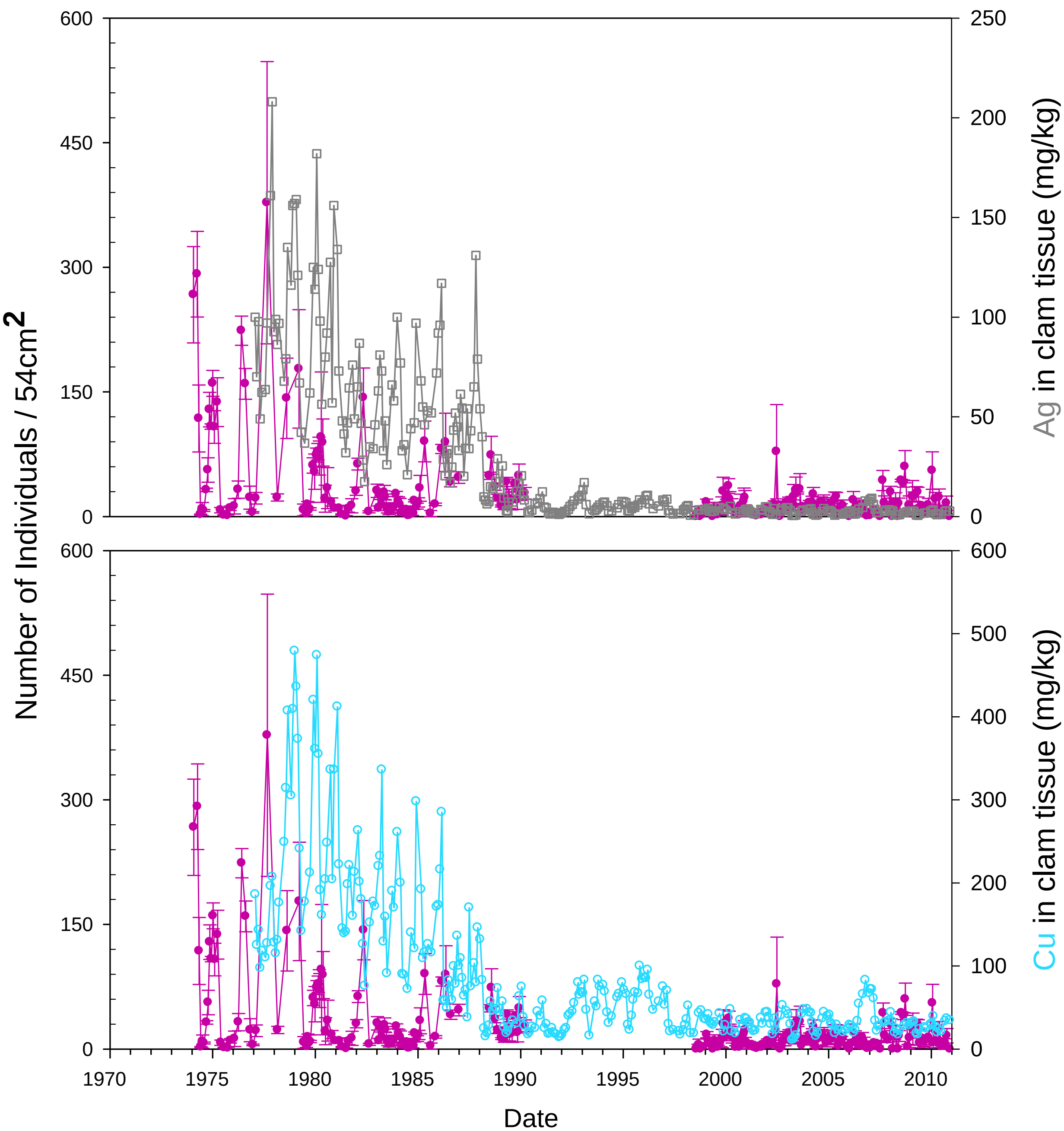


Figure 39. *Streblospio benedicti* abundance with silver and copper concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1974–2010.

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

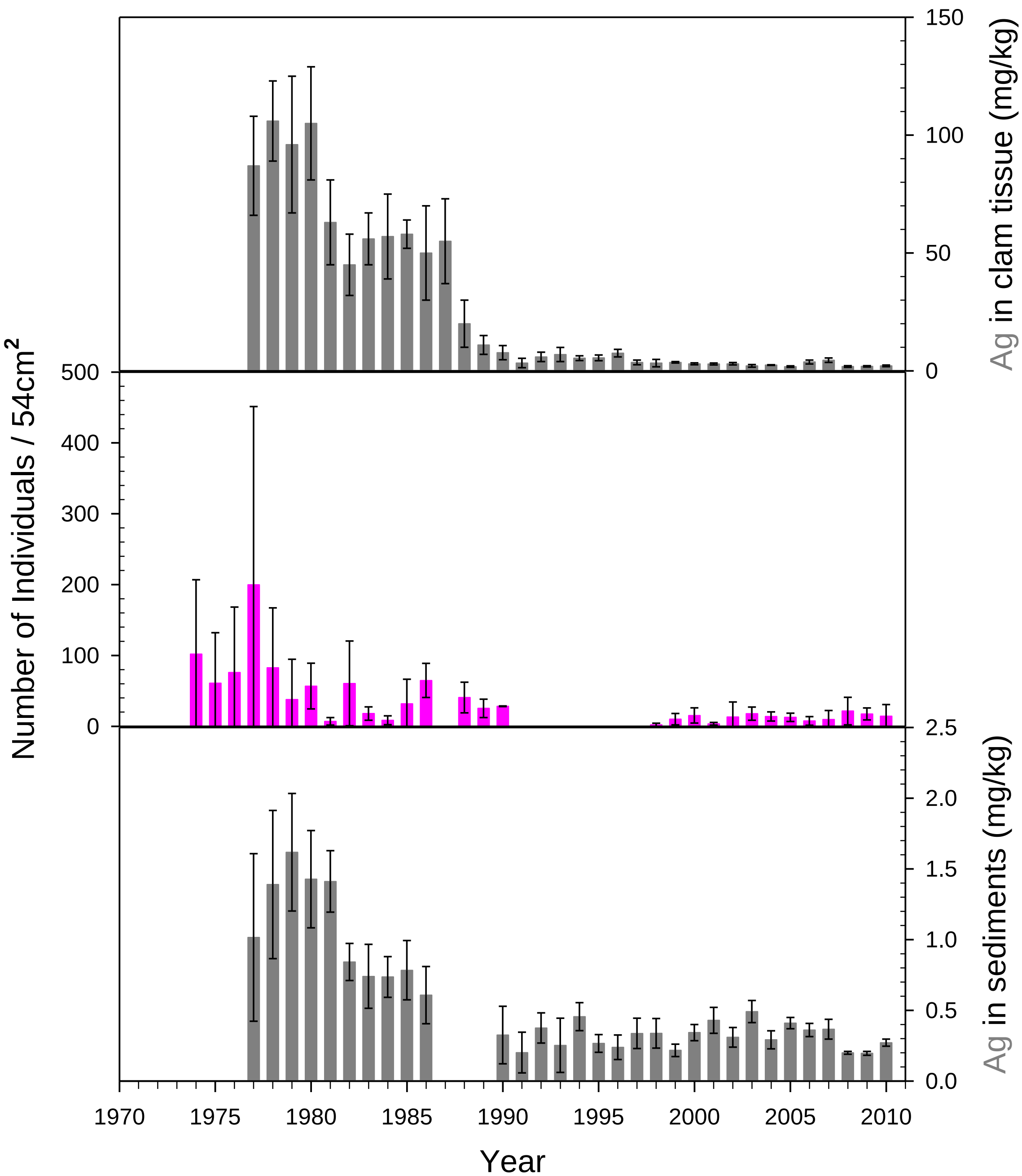


Figure 40. *Streblospio benedicti* annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2010.

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

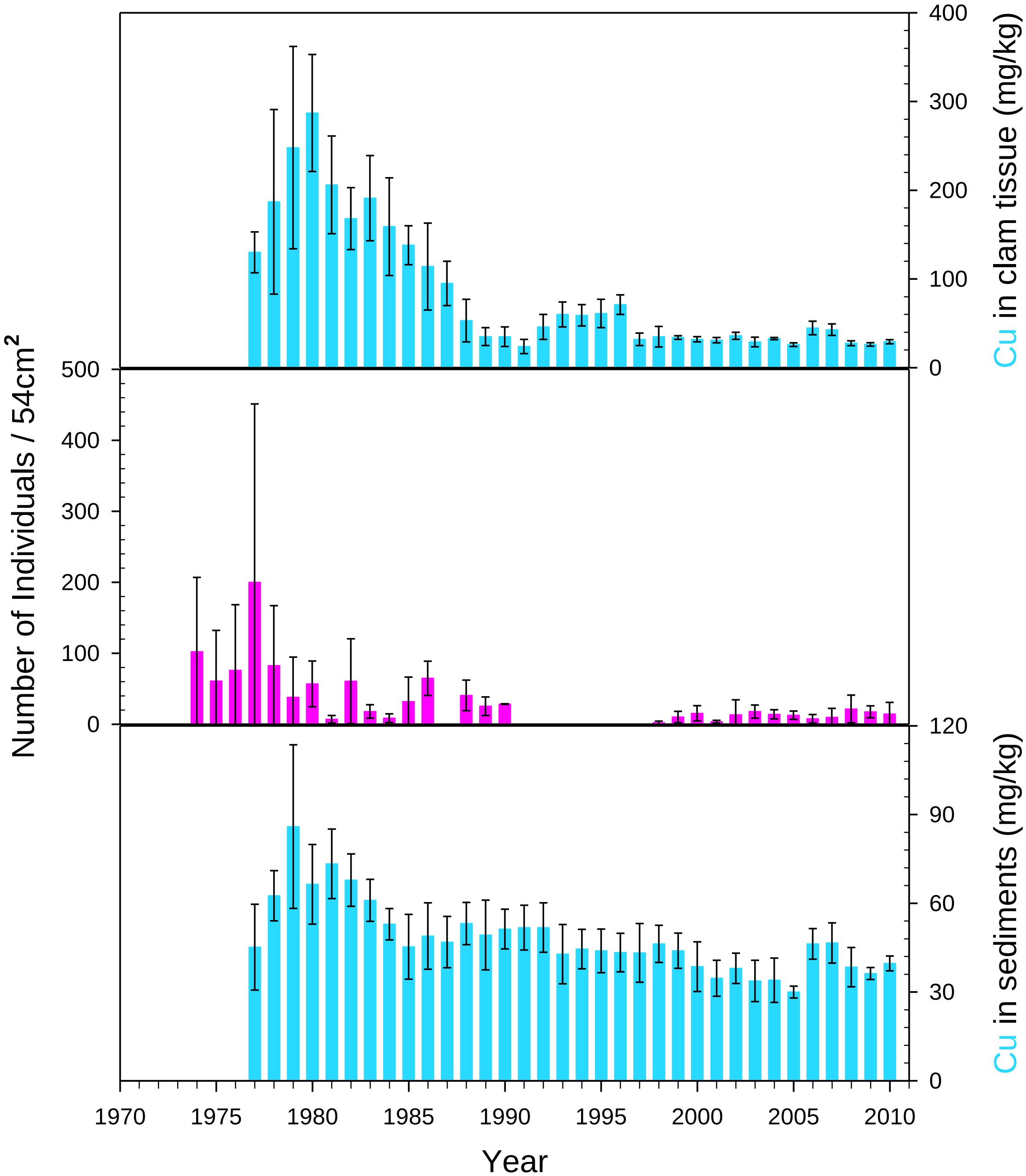


Figure 41. *Streblospio benedicti* annual abundance with copper concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2010.

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

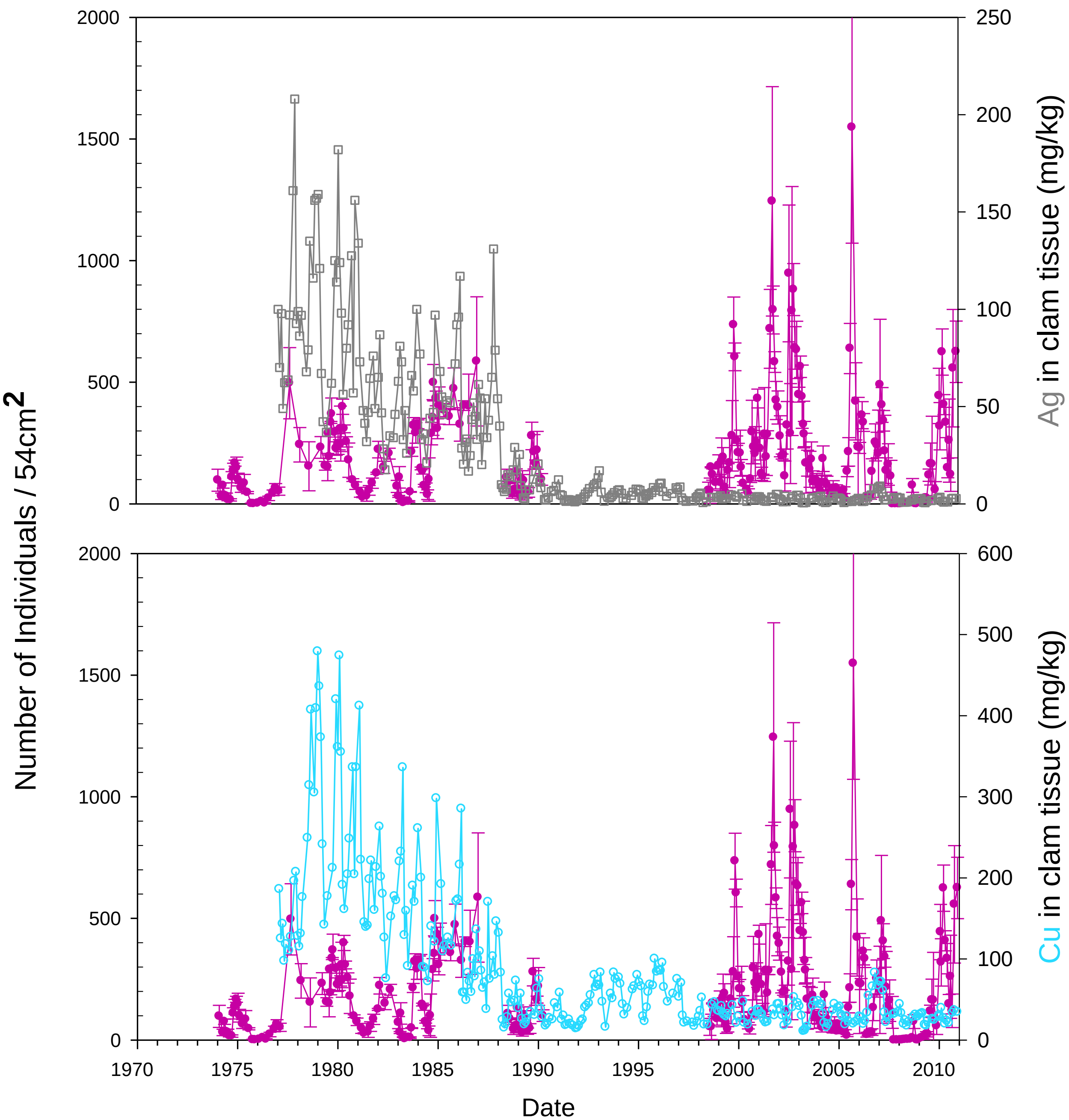


Figure 42. *Gemma gemma* abundance with silver and copper concentrations in the clam *Macoma petalum*, Palo Alto, Calif., 1974–2010.

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

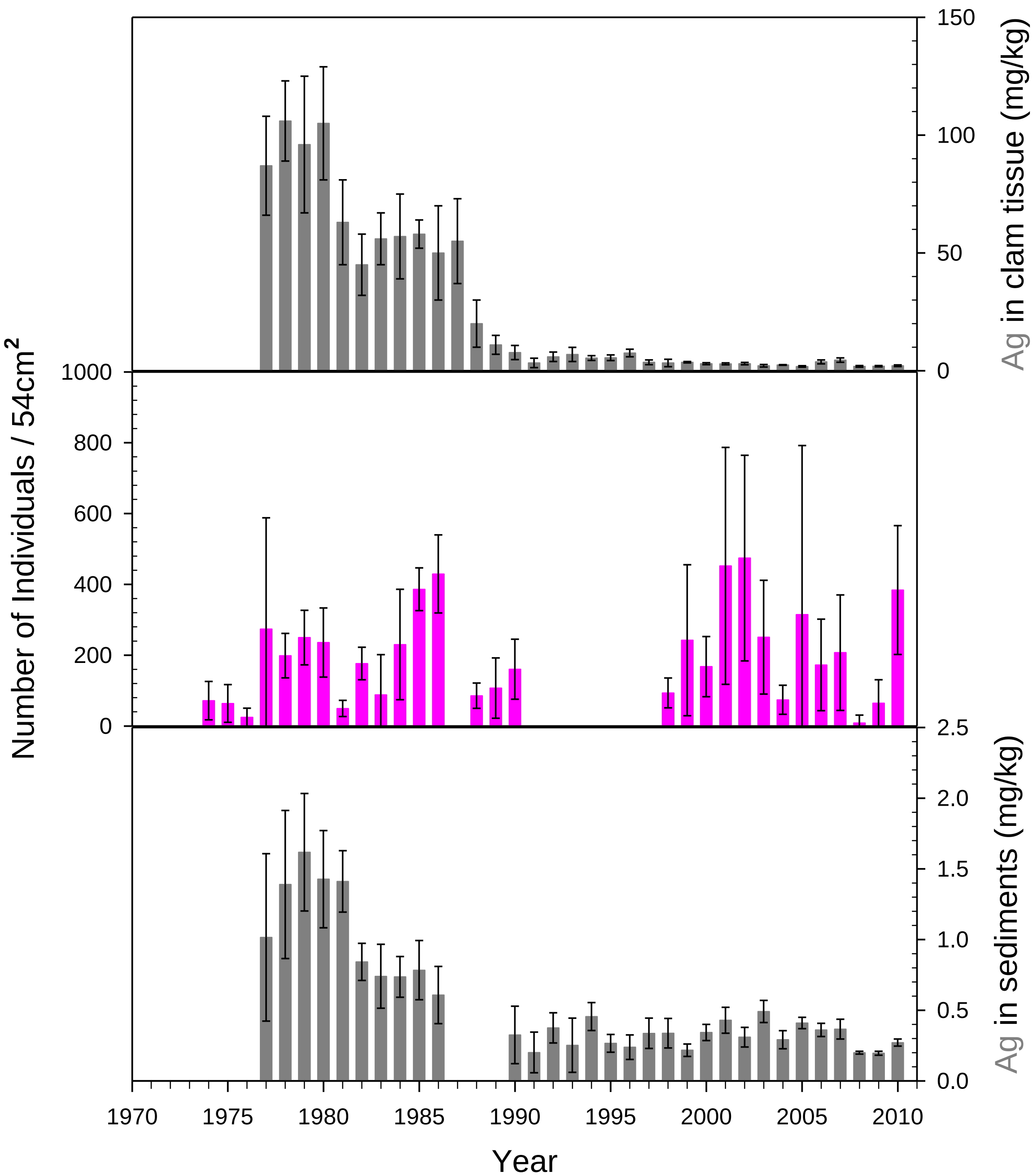


Figure 43. *Gemma gemma* annual abundance with silver concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2010.

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

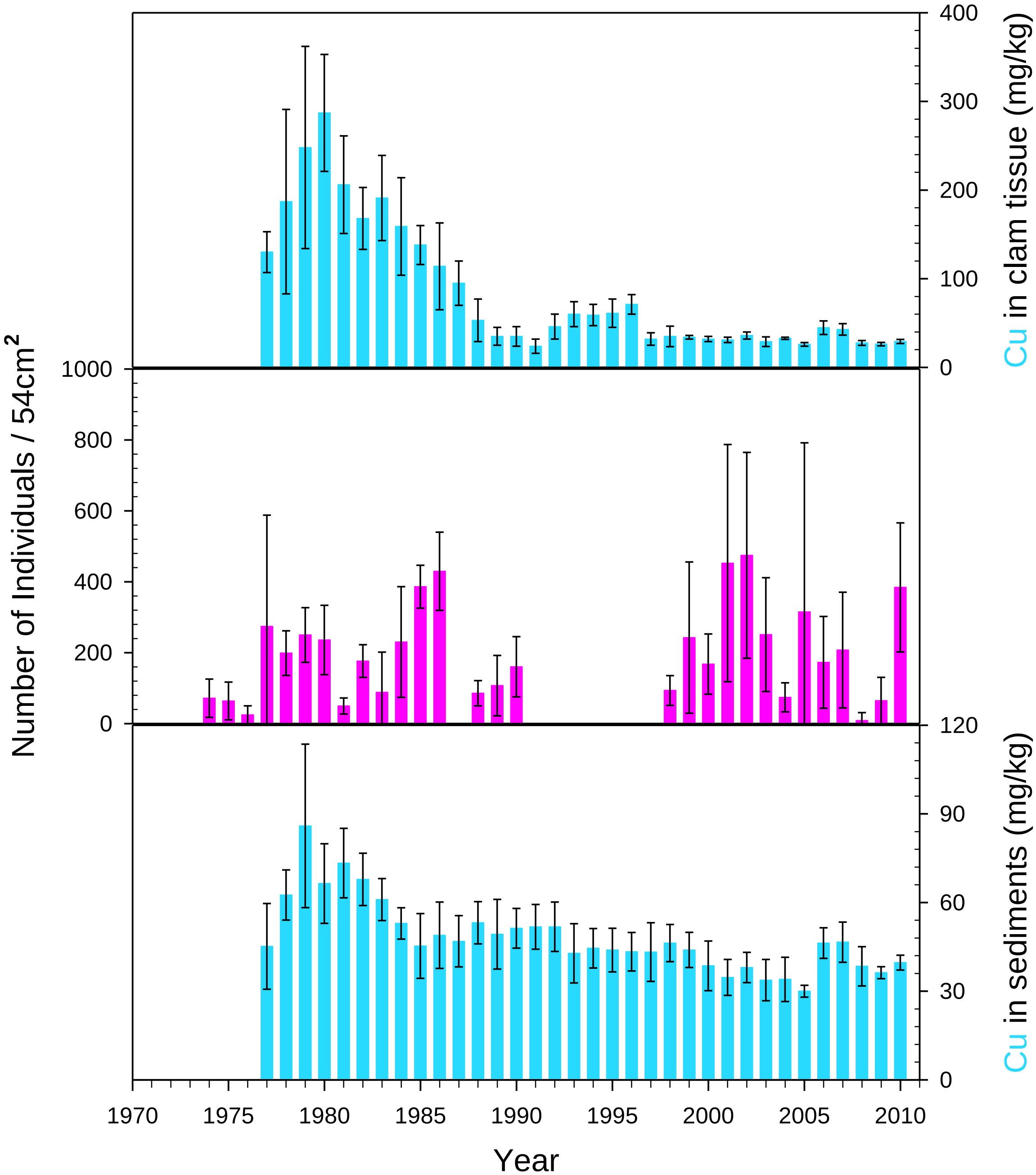


Figure 44. *Gemma gemma* annual abundance with copper concentrations in the clam *Macoma petalum* and in sediment, Palo Alto, Calif., 1974–2010.

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

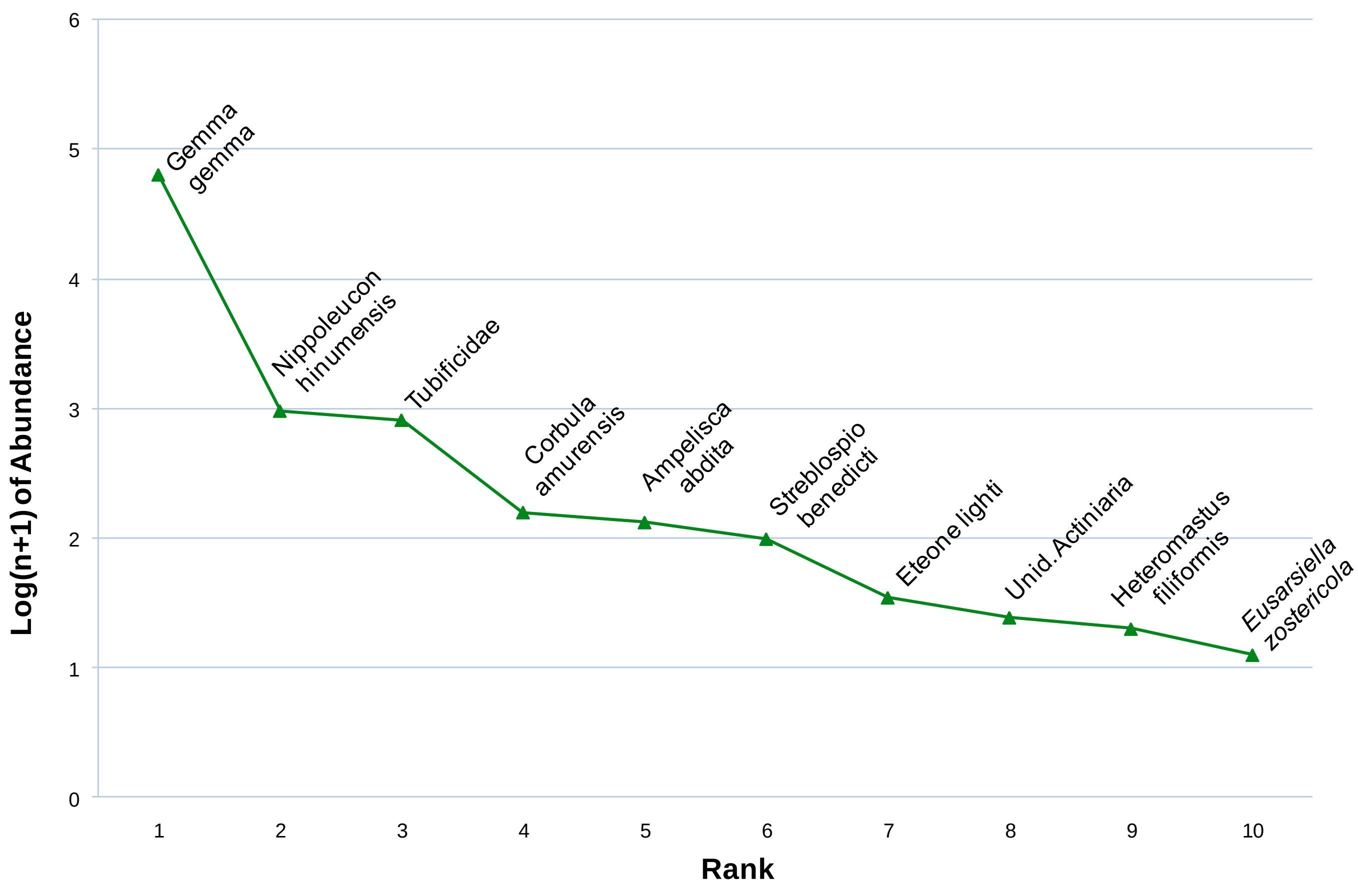


Figure 45. Species rank-abundance for the benthic community, Palo Alto, Calif., 2010.

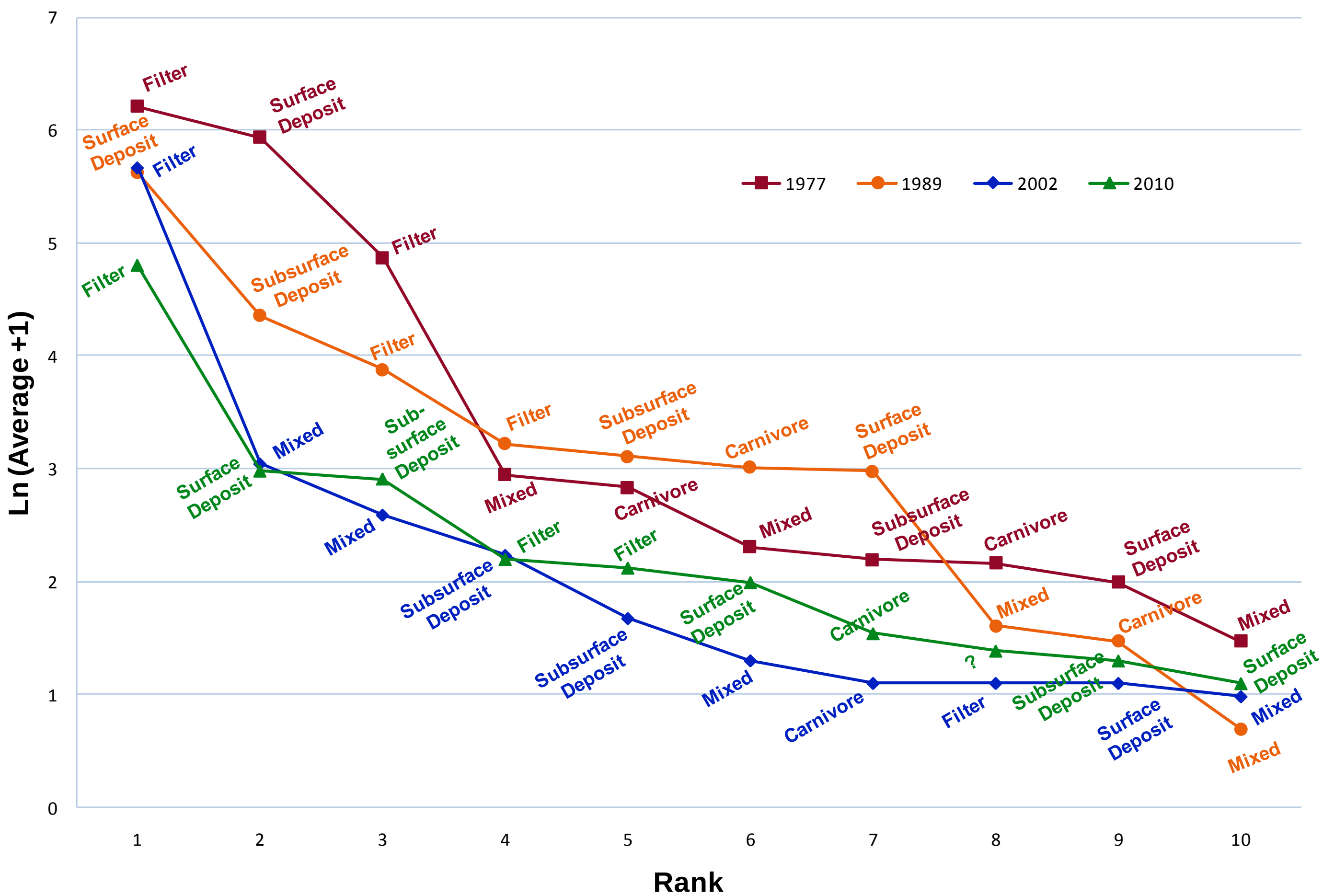


Figure 46. Species rank-abundance identified by feeding mode, Palo Alto, Calif., for 1977, 1989, 2002, and 2010.

The feeding mode for each species at each rank is shown:

Filter: filters food particles from water column; **Subsurface Deposit**: ingests subsurface sediment and removes food from sediment in gut;

Surface Deposit: ingests food particles on surface sediment; **Mixed**: capable of filter feeding and surface deposit feeding; **Carnivore**: predator on other fauna.

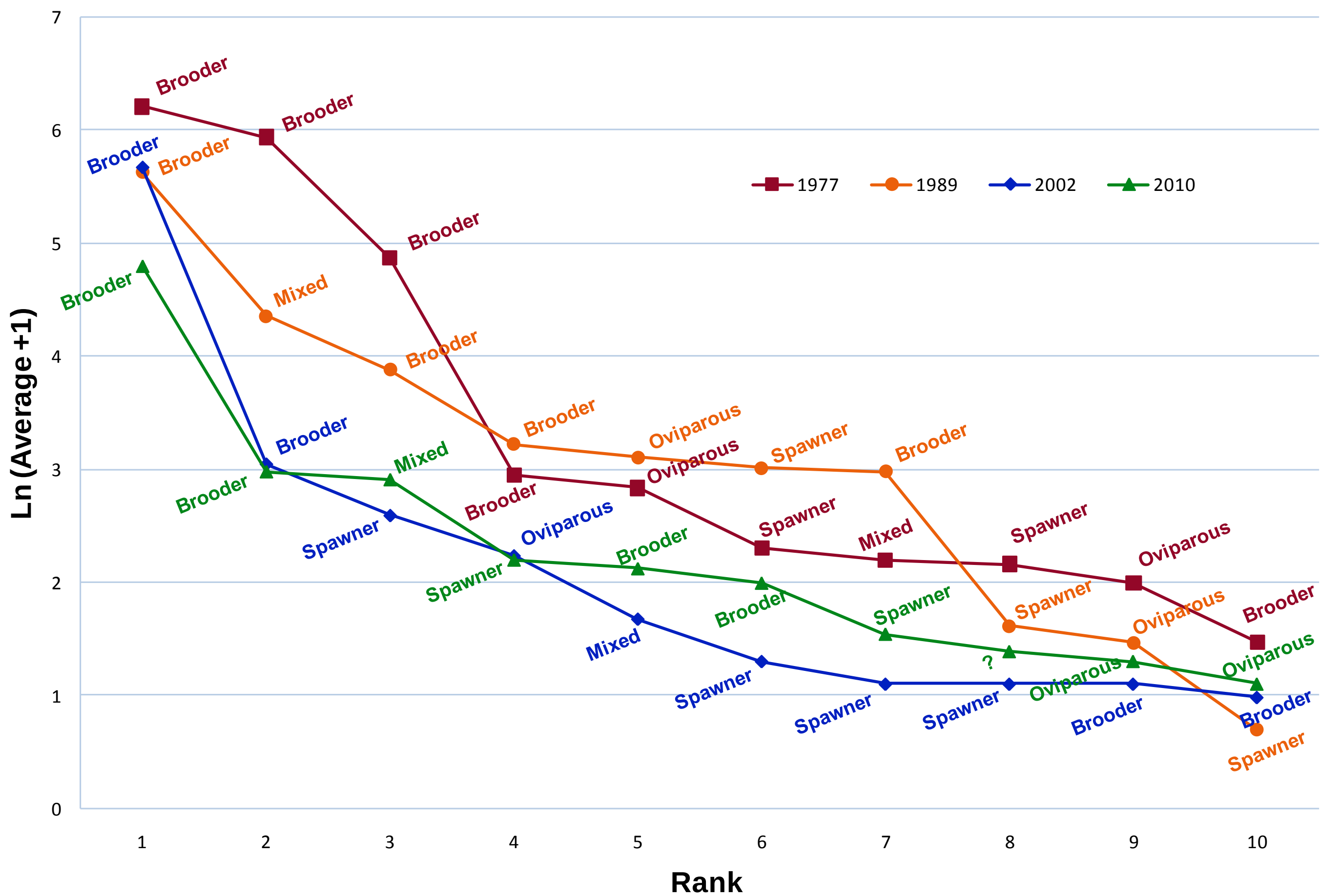


Figure 47. Species rank-abundance data identified by reproductive mode, Palo Alto, Calif., for 1977, 1989, 2002, and 2010.

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., 2010.**

[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). 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	V	Zn	Al (%)	Fe (%)	TOC (%)	Silt/ Clay (%)	Salinity (ppt)
1/11/2010	0.23 ± 0.001	131 ± 4	34.5 ± 1.4	0.25	74.5 ± 0.6	0.2	156 ± 2	112 ± 0.3	4.6 ± 0.1	3.7 ± 0.1	1.04	65	29
2/9/2010	0.27 ± 0.002	153 ± 1	43.3 ± 1.5	0.28	92.5 ± 3.5	0.3	180 ± 3	126 ± 7	5.8 ± 0.1	4.4 ± 0.1	1.45	92	24
3/23/2010	0.34 ± 0.001	159 ± 5	46.9 ± 1.3	ND	87.8 ± 2.7	ND	176 ± 2	143 ± 4	5.9 ± 0.2	4.4 ± 0.1	1.67	96	21
4/19/2010	0.27 ± 0.008	173 ± 2	50.8 ± 5.4	0.30	93.7 ± 0.2	0.3	198 ± 20	147 ± 4	6.2 ± 0.02	4.9 ± 0.01	1.41	78	23
5/18/2010	0.24 ± 0.000	158 ± 1	38.7 ± 0.2	ND	78.5 ± 2.1	ND	170 ± 9	122 ± 2	5.3 ± 0.04	4.2 ± 0.1	1.14	62	25
6/30/2010	0.15 ± 0.010	145 ± 6	26.8 ± 1.0	0.22	57.0 ± 0.3	0.2	122 ± 6	91.3 ± 3.7	3.8 ± 0.02	3.2 ± 0.01	0.73	57	29
9/8/2010	0.41 ± 0.003	141 ± 7	43.0 ± 0.2	0.29	83.3 ± 0.1	0.2	165 ± 10	128 ± 0.4	5.0 ± 0.4	4.2 ± 0.1	1.20	54	30
10/6/2010	0.24 ± 0.002	136 ± 1	32.3 ± 0.4	ND	67.5 ± 2.2	ND	149 ± 4	105 ± 3	4.4 ± 0.05	3.7 ± 0.02	0.84	46	30
12/1/2010	0.30 ± 0.005	144 ± 2	40.3 ± 0.4	0.29	84.1 ± 0.5	0.3	171 ± 4	137 ± 1	5.2 ± 0.04	4.2 ± 0.02	1.21	72	29
Annual Mean:	0.27	149	39.6	0.27	79.9	0.2	165	123	5.2	4.1	1.19	69	27
SEM:	0.02	4	2.5	0.01	4.0	0.02	7	6	0.3	0.2	0.10	6	1

Table 2. **Concentrations of trace metals in the clam *Macoma petalum*, Palo Alto, Calif., 2010.**

[Monthly data are the mean and standard deviation for replicate composites (n=7–12). 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
1/11/2010	2.69 ± 0.39	3.74 ± 0.81	28.2 ± 3.7	0.37 ± 0.06	5.52 ± 0.85	6.0 ± 2.4	294 ± 54	104
2/9/2010	3.42 ± 1.28	5.54 ± 1.82	39.4 ± 30.1	0.66 ± 0.39	7.81 ± 1.21	6.3 ± 1.0	341 ± 52	88
3/23/2010	1.44 ± 0.55	3.65 ± 1.19	26.8 ± 15.7	ND	5.64 ± 1.37	ND	305 ± 54	132
4/19/2010	0.925 ± 0.290	2.07 ± 0.72	19.8 ± 4.3	0.20 ± 0.02	3.55 ± 0.56	5.1 ± 0.3	221 ± 34	238
5/18/2010	1.13 ± 1.10	2.11 ± 0.77	23.6 ± 16.6	ND	4.01 ± 0.92	ND	255 ± 96	166
6/30/2010	0.990 ± 0.164	1.45 ± 0.33	20.9 ± 3.5	0.25 ± 0.05	3.88 ± 0.52	4.1 ± 0.6	241 ± 59	158
9/8/2010	2.60 ± 1.31	2.18 ± 0.89	33.3 ± 8.4	0.28 ± 0.06	4.80 ± 1.10	4.4 ± 0.5	202 ± 64	96
10/6/2010	2.87 ± 0.69	2.59 ± 1.04	36.6 ± 6.2	ND	5.58 ± 1.57	ND	290 ± 89	94
12/1/2010	2.70 ± 0.62	3.86 ± 0.99	34.4 ± 9.1	0.34 ± 0.03	6.74 ± 1.12	6.3 ± 1.5	256 ± 53	116
Annual Mean:	2.08	3.02	29.2	0.35	5.28	5.4	267	132
SEM:	0.32	0.43	2.3	0.07	0.47	0.4	15	16

Table 3. Reproduction data for *Macoma petalum*, Palo Alto, Calif., 2010.

[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
1/11/2010	0	0	100	0	0	10	100	0
2/9/2010	0	0	100	0	0	10	100	0
3/23/2010	0	0	90	10	0	10	100	0
4/19/2010	0	0	0	20	80	10	20	80
5/18/2010	50	0	0	10	40	10	10	90
6/30/2010	ND	ND	ND	ND	ND	ND	ND	ND
9/8/2010	ND	ND	ND	ND	ND	ND	ND	ND
10/6/2010	80	20	0	0	0	10	20	80
12/1/2010	50	50	0	0	0	10	50	50

Appendixes 1–11

Appendix 1. Statistical summary of percentage of sediment in samples composed of clay- and silt-sized particles, collected from Palo Alto, Calif., 1994–2010.

[Statistical results are for percent fine-grained particles (silt and clay, ≤100 micrometer) observed each month from 1994–2010. Data for percent fines for 2004 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	15	95	46	73	74
February	15	98	32	79	86
March	15	98	24	79	84
April	15	96	50	84	86
May	10	92	35	71	77
June	15	93	56	71	68
July	1	-	-	-	69
August	1	-	-	-	48
September	15	84	25	55	54
October	11	84	39	61	59
November	3	66	50	59	61
December	15	95	48	74	76

Appendix 2. Trace-metal concentrations in sediment samples collected at the Palo Alto, Calif., mudflat, 2010.

[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

1/11/2010: 64.8% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.4947	10	10	228	0.635	0.166	182	4.83	0.371	0.0806	0.776	0.551
Tot2	0.5265	10	10	246	0.706	0.187	198	5.28	0.390	0.0976	0.812	0.588
				Concentration, mg/kg								
Tot1				46,089	128.30	33.5	36,790	975	74.9	16.3	157	111
Tot2				46,800	134.00	35.6	37,512	1,003	74.1	18.5	154	112
			Average	46,400	131	34.5	37,200	989	74.5	17.4	156	112
			Std	503	4	1.4	510	20	0.6	1.6	2	0.3

2/9/2010: 91.7% < 100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.3297	10	10	190	0.507	0.139	142	3.73	0.297	0.0789	0.586	0.399
Tot2	0.3523	10	10	207	0.538	0.156	156	4.13	0.334	0.0874	0.639	0.461
				Concentration, mg/kg								
Tot1				57,689	154	42.3	42,918	1,133	90.0	23.9	178	121
Tot2				58,842	153	44.4	44,309	1,171	94.9	24.8	181	131
			Average	58,300	153	43.3	43,600	1,150	92.5	24.4	180	126
			Std	815	1	1.5	984	27	3.5	0.6	3	7

3/23/2010: 95.5% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5485	10	10	316	0.852	0.252	238	7.67	0.471	0.115	0.975	0.765
Tot2	0.5607	10	10	340	0.913	0.268	252	8.20	0.503	0.109	0.978	0.817
				Concentration, mg/kg								
Tot1				57,575	155	46.0	43,336	1,398	85.8	20.9	178	139
Tot2				60,603	163	47.8	44,997	1,463	89.7	19.5	174	146
			Average	59,100	159	46.9	44,200	1,430	87.8	20.2	176	143
			Std	2,140	5	1.3	1,170	46	2.7	1.0	2	4

Near-total metal extractions, continued

4/19/2010: 78.0% <100 µm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
				Concentration, µg/mL								
Tot1	0.3139	10	10	197	0.549	0.172	154	3.01	0.295	0.0816	0.665	0.470
Tot2	0.3005	10	10	187	0.517	0.141	148	2.89	0.281	0.0703	0.552	0.433
				Concentration, mg/kg								
Tot1				62,663	175	54.6	49,092	958	93.8	26.0	212	150
Tot2				62,329	172	47.1	49,285	961	93.6	23.4	184	144
			Average	62,500	173	50.8	49,200	960	93.7	24.7	198	147
			Std	236	2	5.4	136	2	0.2	1.8	20	4

5/18/2010: 62.3% < 100 µm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
				Concentration, µg/mL								
Tot1	0.5078	10	10	270	0.806	0.196	211	4.02	0.391	0.0913	0.831	0.613
Tot2	0.4189	10	10	225	0.659	0.163	178	3.38	0.335	0.0771	0.739	0.520
				Concentration, mg/kg								
Tot1				53,092	159	38.6	41,552	792	77.0	18.0	164	121
Tot2				53,688	157	38.9	42,540	807	79.9	18.4	176	124
			Average	53,400	158	38.7	42,000	800	78.5	18.2	170	122
			Std	422	1	0.2	699	11	2.1	0.3	9	2

6/30/2010: 57.2% <100 µm

Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
				Concentration, µg/mL								
Tot1	0.5246	10	10	199	0.737	0.144	171	2.83	0.300	0.0694	0.619	0.493
Tot2	0.5302	10	10	200	0.788	0.138	172	2.86	0.301	0.0657	0.672	0.470
				Concentration, mg/kg								
Tot1				37,972	140	27.5	32,558	539	57.2	13.2	118	94
Tot2				37,740	149	26.1	32,441	540	56.8	12.4	127	89
			Average	37,900	145	26.8	32,500	539	57.0	12.8	122	91
			Std	164	6	1.0	83	1	0.3	0.6	6	4

Near-total metal extractions, continued

9/8/2010: 54.2% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.3444	10	10	165	0.469	0.148	143	3.97	0.287	0.0758	0.544	0.440
Tot2	0.3077	10	10	162	0.451	0.133	131	3.60	0.257	0.0650	0.529	0.395
				Concentration, mg/kg								
Tot1				47,793	136	42.9	41,492	1,153	83.2	22.0	158	128
Tot2				52,746	147	43.2	42,671	1,168	83.4	21.1	172	128
			Average	50,300	141	43.0	42,100	1,160	83.3	21.6	165	128
			Std	3,500	7	0.2	834	11	0.1	0.6	10	0.4

10/6/2010: 45.5% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.4789	10	10	209	0.656	0.154	179	5.05	0.316	0.0805	0.703	0.491
Tot2	0.4685	10	10	207	0.636	0.153	176	5.01	0.324	0.0760	0.713	0.500
				Concentration, mg/kg								
Tot1				43,558	137	32.1	37,273	1,055	65.9	16.8	147	102
Tot2				44,248	136	32.6	37,588	1,070	69.1	16.2	152	107
			Average	43,900	136	32.3	37,400	1,060	67.5	16.5	149	105
			Std	488	1	0.4	223	11	2.2	0.4	4	3

12/1/2010: 72.2% <100 µm				Concentration, µg/mL								
Sample	Weight (g)	Recon. (mL)	Dil. Factor	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Tot1	0.5239	10	10	276	0.764	0.210	217	6.33	0.438	0.117	0.910	0.716
Tot2	0.4867	10	10	253	0.696	0.197	203	5.92	0.411	0.110	0.815	0.671
				Concentration, mg/kg								
Tot1				52,682	146	40.0	41,477	1,208	83.7	22.3	174	137
Tot2				52,065	143	40.6	41,751	1,217	84.4	22.6	167	138
			Average	52,400	144	40.3	41,600	1,210	84.1	22.5	171	137
			Std	436	2	0.4	193	6	0.5	0.2	4	1

Partial metal extraction

1/11/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.4865	10		0.011	63.7	0.207	0.520	157	24.6	0.188	0.633	0.372	1.34
HCL2	0.4864	10		0.011	63.7	0.208	0.511	156	24.3	0.187	0.636	0.369	1.34
				Concentration, mg/kg									
HCl1				0.23	1,309	4.26	10.7	3,229	505	3.87	13.0	7.65	27.6
HCl2				0.23	1,309	4.27	10.5	3,211	499	3.83	13.1	7.58	27.5
			Average	0.23	1,310	4.27	10.6	3,220	502	3.85	13.0	7.62	27.6
			Std	0.001	0.03	0.01	0.1	9	3	0.02	0.03	0.04	0.01

2/9/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.2006	10		0.0055	32.6	0.104	0.294	73.3	12.1	0.111	0.345	0.185	0.648
HCL2	0.2149	10		0.0058	34.1	0.111	0.309	76.4	12.7	0.116	0.359	0.196	0.680
				Concentration, mg/kg									
HCl1				0.27	1,625	5.18	14.6	3,653	603	5.51	17.2	9.24	32.3
HCl2				0.27	1,589	5.18	14.4	3,554	589	5.40	16.7	9.13	31.6
			Average	0.27	1,610	5.18	14.5	3,600	596	5.46	16.9	9.19	32.0
			Std	0.002	18	0.0002	0.1	50	7	0.06	0.3	0.05	0.3

3/23/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.5486	10		0.0186	85.5	0.261	0.851	164	38.3	0.278	0.833	0.475	1.72
HCL2	0.5463	10		0.0184	85.1	0.260	0.844	163	37.7	0.277	0.826	0.468	1.70
				Concentration, mg/kg									
HCl1				0.34	1,558	4.75	15.5	2,991	698	5.06	15.2	8.65	31.4
HCl2				0.34	1,558	4.76	15.5	2,982	689	5.08	15.1	8.56	31.1
			Average	0.34	1,560	4.76	15.5	2,990	694	5.07	15.2	8.61	31.3
			Std	0.001	0.1	0.01	0.03	5	4	0.01	0.03	0.04	0.2

Partial metal extraction, continued

4/19/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.2612	10		0.0068	45.3	0.145	0.398	102.1	10.4	0.173	0.435	0.236	0.971
HCL2	0.2433	10		0.0067	42.2	0.133	0.373	96.1	9.7	0.164	0.406	0.220	0.888
				Concentration, mg/kg									
HCl1				0.26	1,734	5.54	15.2	3,909	400	6.62	16.7	9.02	37.2
HCl2				0.28	1,735	5.47	15.3	3,951	400	6.74	16.7	9.04	36.5
			Average	0.27	1,730	5.51	15.3	3,930	400	6.68	16.7	9.03	36.8
			Std	0.01	1	0.03	0.03	21	0.1	0.06	0.01	0.01	0.4

5/18/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.4035	10		0.0095	55.1	0.173	0.448	130	12.6	0.192	0.550	0.291	1.10
HCL2	0.3180	10		0.0075	43.9	0.133	0.362	106	10.1	0.156	0.441	0.229	0.87
				Concentration, mg/kg									
HCl1				0.24	1,365	4.30	11.1	3,219	313	4.75	13.6	7.20	27.3
HCl2				0.24	1,381	4.19	11.4	3,333	317	4.91	13.9	7.20	27.3
			Average	0.24	1,370	4.25	11.2	3,280	315	4.83	13.7	7.20	27.3
			Std	0.0002	8	0.05	0.1	57	2	0.08	0.1	0.001	0.003

6/30/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.5340	10		0.0085	57.8	0.173	0.498	136	9.92	0.202	0.495	0.274	1.11
HCl2	0.5118	10		0.0071	54.4	0.169	0.454	129	9.27	0.195	0.496	0.261	1.06
				Concentration, mg/kg									
HCl1				0.16	1,082	3.24	9.33	2,543	186	3.78	9.26	5.14	20.8
HCl2				0.14	1,062	3.30	8.86	2,522	181	3.80	9.69	5.10	20.7
			Average	0.15	1,070	3.27	9.09	2,530	183	3.79	9.47	5.12	20.8
			Std	0.01	10	0.03	0.23	10	2	0.01	0.21	0.02	0.05

Partial metal extraction, continued

9/8/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.2390	10		0.0099	34.5	0.127	0.358	88.8	14.7	0.144	0.392	0.189	0.721
HCl2	0.1817	10		0.0074	26.9	0.104	0.276	70.3	11.1	0.110	0.309	0.147	0.574
				Concentration, mg/kg									
HCl1				0.41	1,445	5.29	15.0	3,716	615	6.03	16.4	7.89	30.2
HCl2				0.41	1,480	5.71	15.2	3,868	609	6.04	17.0	8.10	31.6
			Average	0.41	1,460	5.50	15.1	3,790	612	6.03	16.7	7.99	30.9
			Std	0.003	18	0.21	0.1	76	3	0.004	0.3	0.11	0.7

10/6/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.4826	10		0.0115	57.5	0.193	0.461	151	23.0	0.192	0.559	0.300	1.10
HCl2	0.4771	10		0.0112	56.7	0.187	0.457	148	22.8	0.189	0.544	0.295	1.08
				Concentration, mg/kg									
HCl1				0.24	1,192	4.00	9.55	3,131	476	3.98	11.6	6.21	22.7
HCl2				0.23	1,187	3.92	9.58	3,110	479	3.96	11.4	6.18	22.7
			Average	0.24	1,190	3.96	9.57	3,120	477	3.97	11.5	6.20	22.7
			Std	0.002	2	0.04	0.02	10	1	0.01	0.1	0.01	0.02

12/1/2010				Concentration, µg/mL									
Sample	Weight (g)	Recon. (mL)		Ag	Al	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
HCl1	0.4248	10		0.0126	68.8	0.222	0.543	162	26.3	0.215	0.616	0.361	1.46
HCl2	0.4494	10		0.0138	71.8	0.232	0.569	168	27.7	0.221	0.650	0.379	1.52
				Concentration, mg/kg									
HCl1				0.30	1,620	5.23	12.8	3,823	618	5.05	14.5	8.51	34.3
HCl2				0.31	1,597	5.17	12.7	3,736	617	4.92	14.5	8.44	33.7
			Average	0.30	1,610	5.20	12.7	3,780	617	4.98	14.5	8.47	34.0
			Std	0.01	12	0.03	0.1	43	0.4	0.07	0.02	0.04	0.3

Appendix 3. Trace-metal concentrations in the clam *Macoma petalum* collected at the Palo Alto, Calif., mudflat, 2010.

[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

Date: 1/11/2010

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	2.69	0.22	3.74	28.2	5.52	1.18	3.32	294
STD	0.39	0.03	0.81	3.7	0.85	0.25	1.02	54
SEM	0.12	0.01	0.26	1.1	0.26	0.07	0.31	16
CV%	14.4	14	21.6	13.3	15.4	20.8	30.6	18.4
n	11	11	10	11	11	11	11	11
r wt x [ ]	0.360	0.91	0.742	0.169	0.423	0.243	0.0175	0.359
X 100mg	3.21	0.12	6.74	30.5	4.19	1.41	3.39	366
r l x [ ]	0.185	0.89	0.696	0.305	0.314	0.365	0.167	0.238
X 20mm	2.78	0.19	4.66	29.7	5.17	1.30	3.55	311
X 25mm	2.87	0.15	5.41	31.1	4.85	1.41	3.75	327

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.149	0.011	0.243	1.63	0.285	0.0705	0.176	16.5
25mm	0.283	0.018	0.504	3.16	0.515	0.140	0.331	31.5

Estimated weight for 15mm clam

0.025 gm
25 mg

Estimated weight for 20mm clam

0.055 gm
55 mg

Estimated weight for 25mm clam

0.104 gm
104 mg

Station: Palo Alto

Date: 1/11/2010

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	8.57	0.2398	0.0050	10	0.0625	0.0066	0.0792	0.6372	0.1402	0.0268	0.0701	7.3160
Mp2	9.55	0.3207	0.0071	10	0.0949	0.0078	0.0963	0.8672	0.1716	0.0309	0.0928	8.7800
Mp3	10.52	0.2716	0.0091	10	0.0680	0.0068	0.0870	0.6609	0.1509	0.0269	0.0824	7.6950
Mp4	11.44	0.2593	0.0113	10	0.0736	0.0059	0.0762	0.6481	0.1338	0.0240	0.0728	6.7410
Mp5	12.20	0.0942	0.0135	10	0.0248	0.0023	0.0411	0.2594	0.0660	0.0130	0.0347	3.2120
Mp6	14.12	0.1096	0.0219	10	0.0285	0.0025	0.0370	0.3664	0.0576	0.0139	0.0346	3.0850
Mp7	16.54	0.1477	0.0295	10	0.0341	0.0034	0.0515	0.4171	0.0925	0.0188	0.0507	4.5390
Mp8	17.42	0.3026	0.0378	10	0.0746	0.0057	0.1078	0.9698	0.1293	0.0315	0.1050	6.1740
Mp9	18.44	0.1825	0.0456	10	0.0425	0.0035	0.0952	0.4763	0.1060	0.0283	0.0887	4.8630
Mp10	18.65	0.1289	0.0430	10	0.0340	0.0028	0.0636	0.4538	0.0790	0.0206	0.0648	3.7790
Mp11	20.90	0.0665	0.0665	10	0.0246	0.0011	~~0.0137~~	0.1623	0.0271	0.0061	0.0085	2.7990

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

Concentration (mg/kg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	2.61	0.28	3.30	26.6	5.85	1.12	2.92	305
Mp2	2.96	0.24	3.00	27.0	5.35	0.964	2.89	274
Mp3	2.50	0.25	3.20	24.3	5.56	0.990	3.03	283
Mp4	2.84	0.23	2.94	25.0	5.16	0.926	2.81	260
Mp5	2.63	0.24	4.36	27.5	7.01	1.38	3.68	341
Mp6	2.60	0.23	3.38	33.4	5.26	1.27	3.16	281
Mp7	2.31	0.23	3.49	28.2	6.26	1.27	3.43	307
Mp8	2.47	0.19	3.56	32.0	4.27	1.04	3.47	204
Mp9	2.33	0.19	5.22	26.1	5.81	1.55	4.86	266
Mp10	2.64	0.22	4.93	35.2	6.13	1.60	5.03	293
Mp11	3.70	0.17		24.4	4.08	0.917	1.28	421

Content (µg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	0.013	0.0014	0.017	0.13	0.029	0.0056	0.015	1.5
Mp2	0.021	0.0017	0.021	0.19	0.038	0.0069	0.021	2.0
Mp3	0.023	0.0023	0.029	0.22	0.050	0.0090	0.027	2.6
Mp4	0.0320	0.0026	0.0331	0.282	0.0582	0.0104	0.0317	2.93
Mp5	0.0354	0.0033	0.0587	0.371	0.0943	0.0186	0.0496	4.59
Mp6	0.0570	0.0050	0.0740	0.733	0.115	0.0278	0.0692	6.17
Mp7	0.0682	0.0068	0.103	0.834	0.185	0.0376	0.101	9.08
Mp8	0.0933	0.0071	0.135	1.21	0.162	0.0394	0.131	7.72
Mp9	0.106	0.0088	0.238	1.19	0.265	0.0708	0.222	12.2
Mp10	0.113	0.0093	0.212	1.51	0.263	0.0687	0.216	12.6
Mp11	0.246	0.011		1.62	0.271	0.0610	0.0850	28.0

Station: Palo Alto

Date: 2/9/2010

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	3.42	0.23	5.54	39.4	7.81	1.85	5.53	341
STD	1.28	0.03	1.82	30.1	1.21	0.55	1.92	52
SEM	0.37	0.01	0.53	8.7	0.35	0.16	0.55	15
CV%	37.3	11	32.9	76.4	15.6	29.9	34.7	15.4
n	12	12	12	12	12	12	12	12
r wt x [ ]	0.454	0.67	0.546	0.513	0.624	0.640	0.539	0.228
X 100mg	5.25	0.18	8.67	88.2	10.2	2.96	8.78	303
r l x [ ]	0.502	0.64	0.611	0.530	0.710	0.756	0.609	0.143
X 20mm	4.01	0.22	6.55	54.0	8.59	2.23	6.60	334
X 25mm	4.68	0.20	7.72	70.7	9.49	2.67	7.82	326

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.182	0.011	0.319	2.23	0.429	0.111	0.319	16.5
25mm	0.356	0.018	0.653	4.84	0.824	0.235	0.656	28.7

Estimated weight for 15mm clam	Estimated weight for 20mm clam
0.024 gm	0.050 gm
24 mg	50 mg

Estimated weight for 25mm clam

0.088 gm
88 mg

Station: Palo Alto

Date: 2/9/2010

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	8.57	0.1655	0.0055	10	0.0469	0.0043	0.0669	0.3888	0.1136	0.0219	0.0653	5.5550
Mp2	9.49	0.3710	0.0074	10	0.1017	0.0086	0.1327	0.8927	0.2032	0.0366	0.1398	10.8100
Mp3	11.36	0.2244	0.0118	10	0.0598	0.0056	0.1036	0.6088	0.1559	0.0289	0.1064	7.0200
Mp4	12.15	0.0886	0.0148	10	0.0210	0.0020	0.0329	0.2040	0.0569	0.0116	0.0305	3.4090
Mp5	13.37	0.0507	0.0169	10	0.0136	0.0012	0.0230	0.1328	0.0452	0.0093	0.0219	2.0060
Mp6	14.76	0.0670	0.0223	10	0.0242	0.0017	0.0270	0.2758	0.0493	0.0114	0.0249	2.5040
Mp7	15.46	0.0868	0.0289	10	0.0418	0.0022	0.0703	0.3096	0.0746	0.0214	0.0690	3.2960
Mp8	18.42	0.0842	0.0421	10	0.0115	0.0018	0.0660	0.2566	0.0775	0.0186	0.0680	2.4660
Mp9	19.68	0.0783	0.0392	10	0.0364	0.0018	0.0598	0.3246	0.0719	0.0221	0.0628	2.9400
Mp10	20.20	0.1053	0.0527	10	0.0433	0.0025	0.0810	0.3908	0.0812	0.0240	0.0823	4.0410
Mp11	21.86	0.0606	0.0606	10	0.0364	0.0010	0.0263	0.8049	0.0489	0.0113	0.0273	1.3460
Mp12	22.27	0.0712	0.0712	10	0.0230	0.0015	0.0451	0.2175	0.0636	0.0149	0.0433	2.4220
				MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
				MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

Concentration (mg/kg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	2.83	0.26	4.04	23.5	6.86	1.32	3.95	336
Mp2	2.74	0.23	3.58	24.1	5.48	0.987	3.77	291
Mp3	2.66	0.25	4.62	27.1	6.95	1.29	4.74	313
Mp4	2.37	0.23	3.71	23.0	6.42	1.31	3.44	385
Mp5	2.68	0.24	4.54	26.2	8.92	1.83	4.32	396
Mp6	3.61	0.25	4.03	41.2	7.36	1.70	3.72	374
Mp7	4.82	0.25	8.10	35.7	8.59	2.47	7.95	380
Mp8	1.37	0.21	7.84	30.5	9.20	2.21	8.08	293
Mp9	4.65	0.23	7.64	41.5	9.18	2.82	8.02	375
Mp10	4.11	0.24	7.69	37.1	7.71	2.28	7.82	384
Mp11	6.01	0.17	4.34	133	8.07	1.86	4.50	222
Mp12	3.23	0.21	6.33	30.5	8.93	2.09	6.08	340

Content (µg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	0.016	0.0014	0.022	0.13	0.038	0.0073	0.022	1.9
Mp2	0.020	0.0017	0.027	0.18	0.041	0.0073	0.028	2.2
Mp3	0.0315	0.0029	0.0545	0.320	0.0821	0.0152	0.0560	3.69
Mp4	0.0350	0.0033	0.0548	0.340	0.0948	0.0193	0.0508	5.68
Mp5	0.0453	0.0040	0.0767	0.443	0.151	0.0310	0.0730	6.69
Mp6	0.0807	0.0057	0.0900	0.919	0.164	0.0380	0.0830	8.35
Mp7	0.139	0.0073	0.234	1.03	0.249	0.0713	0.230	11.0
Mp8	0.0575	0.0090	0.330	1.28	0.388	0.0930	0.340	12.3
Mp9	0.182	0.0090	0.299	1.62	0.360	0.111	0.314	14.7
Mp10	0.217	0.013	0.405	1.95	0.406	0.120	0.412	20.2
Mp11	0.364	0.010	0.263	8.05	0.489	0.113	0.273	13.5
Mp12	0.230	0.015	0.451	2.18	0.636	0.149	0.433	24.2

Station: Palo Alto

Date: 3/23/2010

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	1.44	0.20	3.65	26.8	5.64	1.14	3.29	305
STD	0.55	0.03	1.19	15.7	1.37	0.38	1.18	54
SEM	0.16	0.01	0.36	4.5	0.39	0.11	0.34	16
CV%	38.1	15	32.7	58.6	24.3	33.4	35.8	17.6
n	12	12	11	12	12	12	12	12
r wt x [ ]	0.126	0.58	0.0360	0.735	0.703	0.355	0.0700	0.258
X 100mg	1.62	0.16	3.54	56.2	8.10	1.49	3.51	269
r l x [ ]	0.0411	0.65	0.0421	0.637	0.637	0.465	0.163	0.260
X 20mm	1.42	0.18	3.71	39.3	6.73	1.36	3.54	287
X 25mm	1.39	0.16	3.77	51.0	7.75	1.57	3.76	271

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0858	0.013	0.242	2.28	0.448	0.0905	0.233	19.8
25mm	0.150	0.022	0.447	5.10	0.921	0.188	0.455	35.6

Estimated weight for 15mm clam	Estimated weight for 20mm clam
0.031 gm	0.070 gm
31 mg	70 mg

Estimated weight for 25mm clam

0.132 gm
132 mg

Station: Palo Alto

Date: 3/23/2010

Macoma petalum

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	8.56	0.0425	0.0061	10	0.0085	0.0011	~~0.0110~~	0.0894	0.0216	0.0047	0.0086	1.5950
Mp2	9.62	0.0776	0.0086	10	0.0099	0.0019	0.0332	0.1534	0.0448	0.0084	0.0293	2.6430
Mp3	10.66	0.2842	0.0114	10	0.0445	0.0059	0.0740	0.6254	0.1278	0.0209	0.0714	8.0560
Mp4	11.59	0.3499	0.0159	10	0.0450	0.0064	0.1026	0.6832	0.1423	0.0247	0.0984	9.0220
Mp5	12.58	0.2888	0.0206	10	0.0394	0.0053	0.1045	0.5578	0.1368	0.0264	0.1036	8.1680
Mp6	13.62	0.1453	0.0242	10	0.0197	0.0031	0.0385	0.3008	0.0751	0.0126	0.0384	4.4760
Mp7	14.66	0.1021	0.0340	10	0.0211	0.0025	0.0578	0.2366	0.0688	0.0155	0.0552	3.4490
Mp8	16.82	0.0893	0.0447	10	0.0081	0.0018	0.0261	0.1840	0.0459	0.0096	0.0229	3.5260
Mp9	18.21	0.0492	0.0492	10	0.0043	0.0008	0.0188	0.1310	0.0292	0.0086	0.0153	1.2250
Mp10	18.59	0.2636	0.0659	10	0.0338	0.0047	0.1096	0.6460	0.1347	0.0287	0.1072	5.4050
Mp11	19.37	0.0539	0.0539	10	0.0039	0.0010	0.0297	0.1519	0.0329	0.0102	0.0286	1.6770
Mp12	21.83	0.0870	0.0870	10	0.0228	0.0016	0.0170	0.6591	0.0809	0.0084	0.0150	2.7110
				MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
				MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Concentration (mg/kg) ==>	Mp1	2.0	0.26		21.0	5.08	1.11	2.02	375
	Mp2	1.3	0.24	4.28	19.8	5.77	1.08	3.78	341
	Mp3	1.57	0.21	2.60	22.0	4.50	0.735	2.51	283
	Mp4	1.29	0.18	2.93	19.5	4.07	0.706	2.81	258
	Mp5	1.36	0.18	3.62	19.3	4.74	0.914	3.59	283
	Mp6	1.36	0.21	2.65	20.7	5.17	0.867	2.64	308
	Mp7	2.07	0.24	5.66	23.2	6.74	1.52	5.41	338
	Mp8	0.91	0.20	2.92	20.6	5.14	1.08	2.56	395
	Mp9	0.87	0.16	3.82	26.6	5.93	1.75	3.11	249
	Mp10	1.28	0.18	4.16	24.5	5.11	1.09	4.07	205
	Mp11	0.72	0.19	5.51	28.2	6.10	1.89	5.31	311
	Mp12	2.62	0.18	1.95	75.8	9.30	0.966	1.72	312

	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Content (μg) ==>	Mp1	0.012	0.0016		0.13	0.031	0.0067	0.012	2.3
	Mp2	0.011	0.0021	0.037	0.17	0.050	0.0093	0.033	2.9
	Mp3	0.0178	0.0024	0.0296	0.250	0.0511	0.00836	0.0286	3.22
	Mp4	0.0205	0.0029	0.0466	0.311	0.0647	0.0112	0.0447	4.10
	Mp5	0.0281	0.0038	0.0746	0.398	0.0977	0.0189	0.0740	5.83
	Mp6	0.0328	0.0052	0.0642	0.501	0.125	0.0210	0.0640	7.46
	Mp7	0.0703	0.0083	0.193	0.789	0.229	0.0517	0.184	11.5
	Mp8	0.041	0.0090	0.131	0.920	0.230	0.0480	0.115	17.6
	Mp9	0.043	0.0080	0.188	1.31	0.292	0.0860	0.153	12.3
	Mp10	0.0845	0.012	0.274	1.62	0.337	0.0718	0.268	13.5
	Mp11	0.039	0.010	0.297	1.52	0.329	0.102	0.286	16.8
	Mp12	0.228	0.016	0.170	6.59	0.809	0.0840	0.150	27.1

Station: Palo Alto — Statistical Summary

Date: 4/19/2010

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	0.925	0.15	2.07	19.8	3.55	0.719	2.09	221
STD	0.290	0.02	0.72	4.3	0.56	0.189	0.71	34
SEM	0.087	0.01	0.22	1.3	0.17	0.057	0.21	10
CV%	31.3	14	34.7	21.6	15.8	26.2	34.0	15.4
n	11	11	11	11	11	11	11	11
r wt x [ ]	0.582	0.77	0.114	0.858	0.423	0.0572	0.0195	0.190
X 100mg	1.11	0.13	1.98	24.0	3.28	0.707	2.11	213
r l x [ ]	0.636	0.85	0.111	0.782	0.498	0.172	0.0432	0.324
X 20mm	1.19	0.12	1.96	24.7	3.15	0.673	2.14	205
X 25mm	1.45	0.099	1.85	29.3	2.76	0.628	2.18	190

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.134	0.015	0.206	2.84	0.373	0.0758	0.228	24.2
25mm	0.316	0.027	0.382	6.54	0.691	0.143	0.446	46.0

Estimated weight for 15mm clam	Estimated weight for 20mm clam
0.049 gm	0.119 gm
49 mg	119 mg

Estimated weight for 25mm clam

0.238 gm
238 mg

Station: Palo Alto

Date: 4/19/2010

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	9.71	0.0986	0.0141	10	0.0056	0.0018	0.0235	0.1550	0.0430	0.0101	0.0208	2.9490
Mp2	10.48	0.1553	0.0155	10	0.0139	0.0029	0.0385	0.2987	0.0664	0.0135	0.0373	3.7170
Mp3	11.55	0.2831	0.0202	10	0.0246	0.0044	0.0436	0.4541	0.0931	0.0171	0.0438	6.1660
Mp4	12.58	0.3229	0.0269	10	0.0264	0.0051	0.0674	0.5365	0.1262	0.0223	0.0658	7.3450
Mp5	13.45	0.5988	0.0352	10	0.0448	0.0086	0.1384	1.0590	0.1924	0.0367	0.1363	10.3700
Mp6	14.47	0.3186	0.0455	10	0.0273	0.0045	0.0591	0.5710	0.1094	0.0185	0.0566	6.4410
Mp7	15.42	0.4323	0.0480	10	0.0274	0.0059	0.1412	0.6973	0.1660	0.0355	0.1490	8.1660
Mp8	16.60	0.1987	0.0662	10	0.0263	0.0027	0.0160	0.4600	0.0536	0.0088	0.0192	4.1930
Mp9	18.72	0.2011	0.1006	10	0.0223	0.0026	0.0224	0.5427	0.0552	0.0102	0.0254	4.2630
Mp10	19.38	0.1235	0.1235	10	0.0101	0.0015	0.0263	0.3358	0.0417	0.0099	0.0277	2.5260
Mp11	20.16	0.2241	0.1121	10	0.0344	0.0032	0.0633	0.4828	0.0877	0.0215	0.0658	5.6290
				MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
				MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Concentration (mg/kg) ==>	Mp1	0.57	0.18	2.38	15.7	4.36	1.02	2.11	299
	Mp2	0.895	0.19	2.48	19.2	4.28	0.869	2.40	239
	Mp3	0.869	0.16	1.54	16.0	3.29	0.604	1.55	218
	Mp4	0.818	0.16	2.09	16.6	3.91	0.691	2.04	227
	Mp5	0.748	0.14	2.31	17.7	3.21	0.613	2.28	173
	Mp6	0.857	0.14	1.85	17.9	3.43	0.581	1.78	202
	Mp7	0.634	0.14	3.27	16.1	3.84	0.821	3.45	189
	Mp8	1.32	0.14	0.805	23.2	2.70	0.443	0.966	211
	Mp9	1.11	0.13	1.11	27.0	2.74	0.507	1.26	212
	Mp10	0.818	0.12	2.13	27.2	3.38	0.802	2.24	205
	Mp11	1.54	0.14	2.82	21.5	3.91	0.959	2.94	251

	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Content (µg) ==>	Mp1	0.0080	0.0026	0.0336	0.221	0.0614	0.0144	0.0297	4.21
	Mp2	0.0139	0.0029	0.0385	0.299	0.0664	0.0135	0.0373	3.72
	Mp3	0.0176	0.0031	0.0311	0.324	0.0665	0.0122	0.0313	4.40
	Mp4	0.0220	0.0043	0.0562	0.447	0.105	0.0186	0.0548	6.12
	Mp5	0.0264	0.0051	0.0814	0.623	0.113	0.0216	0.0802	6.10
	Mp6	0.0390	0.0064	0.0844	0.816	0.156	0.0264	0.0809	9.20
	Mp7	0.0304	0.0066	0.157	0.775	0.184	0.0394	0.166	9.07
	Mp8	0.0877	0.0090	0.0533	1.53	0.179	0.0293	0.0640	14.0
	Mp9	0.112	0.013	0.112	2.71	0.276	0.0510	0.127	21.3
	Mp10	0.101	0.015	0.263	3.36	0.417	0.0990	0.277	25.3
	Mp11	0.172	0.016	0.317	2.41	0.439	0.108	0.329	28.1

Station: Palo Alto — Statistical Summary

Date: 5/18/2010

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	1.13	0.16	2.11	23.6	4.01	1.05	1.95	255
STD	1.10	0.02	0.77	16.6	0.92	0.27	0.67	96
SEM	0.35	0.01	0.26	5.3	0.29	0.09	0.21	30
CV%	98.0	15	36.5	70.4	22.9	25.8	34.7	37.7
n	10	10	9	10	10	10	10	10
r wt x [ ]	0.686	0.25	0.794	0.751	0.343	0.464	0.676	0.649
X 100mg	2.34	0.16	3.02	43.6	4.52	1.25	2.67	354
r l x [ ]	0.727	0.23	0.806	0.764	0.298	0.397	0.651	0.676
X 20mm	2.11	0.16	2.82	39.3	4.35	1.18	2.49	335
X 25mm	3.17	0.17	3.69	56.0	4.71	1.32	3.06	420

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.116	0.014	0.228	2.67	0.357	0.0978	0.196	25.8
25mm	0.298	0.026	0.534	6.68	0.690	0.196	0.422	56.0

Estimated weight for 15mm clam

0.039 gm
39 mg

Estimated weight for 20mm clam

0.088 gm
88 mg

Estimated weight for 25mm clam

0.166 gm
166 mg

Station: Palo Alto

Date: 5/18/2010

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	10.25	0.0623	0.0125	10	0.0038	0.0011	~~0.0131~~	0.0957	0.0280	0.0073	0.0114	1.6090
Mp2	11.65	0.1854	0.0185	10	0.0185	0.0032	0.0319	0.4354	0.0779	0.0177	0.0318	4.0990
Mp3	12.69	0.4233	0.0249	10	0.0335	0.0068	0.0632	0.6894	0.1534	0.0347	0.0631	8.0160
Mp4	13.47	0.2606	0.0290	10	0.0170	0.0030	0.0640	0.4830	0.1310	0.0370	0.0630	6.8940
Mp5	14.54	0.3436	0.0344	10	0.0367	0.0051	0.0608	0.5847	0.1123	0.0281	0.0600	7.6380
Mp6	15.44	0.3740	0.0416	10	0.0272	0.0052	0.0605	0.6970	0.1194	0.0272	0.0586	7.2410
Mp7	16.20	0.0902	0.0451	10	0.0049	0.0014	0.0166	0.1230	0.0262	0.0093	0.0132	2.2320
Mp8	17.14	0.1244	0.0622	10	0.0161	0.0018	0.0219	0.2991	0.0497	0.0104	0.0181	2.8340
Mp9	18.30	0.1777	0.0889	10	0.0072	0.0025	0.0412	0.3421	0.0631	0.0215	0.0376	3.6090
Mp10	23.51	0.1161	0.1161	10	0.0485	0.0023	0.0461	0.8135	0.0682	0.0176	0.0424	6.0130
				MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
				MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

Concentration (mg/kg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	0.61	0.18		15.4	4.49	1.17	1.83	258
Mp2	0.998	0.17	1.72	23.5	4.20	0.955	1.72	221
Mp3	0.791	0.16	1.49	16.3	3.62	0.820	1.49	189
Mp4	0.652	0.12	2.46	18.5	5.03	1.42	2.42	265
Mp5	1.07	0.15	1.77	17.0	3.27	0.818	1.75	222
Mp6	0.727	0.14	1.62	18.6	3.19	0.727	1.57	194
Mp7	0.54	0.16	1.84	13.6	2.90	1.03	1.46	247
Mp8	1.29	0.14	1.76	24.0	4.00	0.836	1.45	228
Mp9	0.41	0.14	2.32	19.3	3.55	1.21	2.12	203
Mp10	4.18	0.20	3.97	70.1	5.87	1.52	3.65	518

Content (µg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	0.0076	0.0022		0.191	0.0560	0.0146	0.0228	3.22
Mp2	0.0185	0.0032	0.0319	0.435	0.0779	0.0177	0.0318	4.10
Mp3	0.0197	0.0040	0.0372	0.406	0.0902	0.0204	0.0371	4.72
Mp4	0.0189	0.0033	0.0711	0.537	0.146	0.0411	0.0700	7.66
Mp5	0.0367	0.0051	0.0608	0.585	0.112	0.0281	0.0600	7.64
Mp6	0.0302	0.0058	0.0672	0.774	0.133	0.0302	0.0651	8.05
Mp7	0.025	0.0070	0.0830	0.615	0.131	0.0465	0.0660	11.2
Mp8	0.0805	0.0090	0.110	1.50	0.249	0.0520	0.0905	14.2
Mp9	0.036	0.013	0.206	1.71	0.316	0.108	0.188	18.0
Mp10	0.4850	0.023	0.461	8.14	0.682	0.176	0.424	60.1

Station: Palo Alto   Statistical Summary

Date: 6/30/2010

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	0.990	0.17	1.45	20.9	3.88	0.835	1.38	241
STD	0.164	0.02	0.33	3.5	0.52	0.213	0.23	59
SEM	0.052	0.01	0.10	1.1	0.17	0.067	0.07	19
CV%	16.6	11	22.6	16.9	13.5	25.5	17.0	24.6
n	10	10	10	10	10	10	10	10
r wt x [ ]	0.447	0.28	0.283	0.646	0.519	0.377	0.196	0.683
X 100mg	0.971	0.17	1.42	20.3	3.95	0.814	1.37	251
r l x [ ]	0.450	0.28	0.409	0.704	0.425	0.479	0.325	0.653
X 20mm	0.978	0.17	1.43	20.5	3.91	0.818	1.37	247
X 25mm	0.903	0.16	1.29	18.0	4.14	0.715	1.29	286

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.0710	0.012	0.102	1.48	0.289	0.0583	0.0991	18.1
25mm	0.142	0.026	0.198	2.81	0.644	0.111	0.199	43.1

Estimated weight for 15mm clam	Estimated weight for 20mm clam
0.028 gm	0.074 gm
28 mg	74 mg

Estimated weight for 25mm clam

0.158 gm
158 mg

Station: Palo Alto

Date: 6/30/2010

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	12.67	0.2910	0.0162	10	0.0373	0.0056	0.0444	0.7791	0.1094	0.0273	0.0417	6.1260
Mp2	14.46	0.1023	0.0256	10	0.0083	0.0018	0.0217	0.2093	0.0470	0.0137	0.0167	2.4950
Mp3	15.54	0.4174	0.0321	10	0.0418	0.0077	0.0621	0.9578	0.1608	0.0362	0.0618	9.4580
Mp4	16.51	0.6250	0.0391	15	0.0463	0.0064	0.0589	0.8292	0.1301	0.0290	0.0599	8.7460
Mp5	17.52	0.6858	0.0457	15	0.0499	0.0070	0.0625	0.9296	0.1440	0.0323	0.0616	8.4080
Mp6	18.57	0.3542	0.0506	10	0.0358	0.0066	0.0480	0.8114	0.1356	0.0274	0.0510	7.8270
Mp7	19.53	0.2743	0.0686	10	0.0232	0.0044	0.0301	0.6291	0.0960	0.0208	0.0279	6.0550
Mp8	24.73	0.1574	0.1574	10	0.0172	0.0027	0.0245	0.2929	0.0652	0.0145	0.0211	3.4480
Mp9	25.69	0.1967	0.1967	10	0.0145	0.0027	0.0326	0.4149	0.0844	0.0159	0.0336	5.4860
Mp10	26.86	0.1855	0.1855	10	0.0170	0.0035	0.0166	0.2455	0.0843	0.0100	0.0180	7.3180
				MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
				MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Concentration (mg/kg) ==>	Mp1	1.28	0.19	1.53	26.8	3.76	0.938	1.43	211
	Mp2	0.81	0.18	2.12	20.5	4.59	1.34	1.63	244
	Mp3	1.00	0.18	1.49	22.9	3.85	0.867	1.48	227
	Mp4	1.11	0.15	1.41	19.9	3.12	0.696	1.44	210
	Mp5	1.09	0.15	1.37	20.3	3.15	0.706	1.35	184
	Mp6	1.01	0.19	1.36	22.9	3.83	0.774	1.44	221
	Mp7	0.846	0.16	1.10	22.9	3.50	0.758	1.02	221
	Mp8	1.09	0.17	1.56	18.6	4.14	0.921	1.34	219
	Mp9	0.737	0.14	1.66	21.1	4.29	0.808	1.71	279
	Mp10	0.916	0.19	0.895	13.2	4.54	0.539	0.970	395

	Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Content (µg) ==>	Mp1	0.0207	0.0031	0.0247	0.433	0.0608	0.0152	0.0232	3.40
	Mp2	0.021	0.0045	0.0543	0.523	0.118	0.0343	0.0418	6.24
	Mp3	0.0322	0.0059	0.0478	0.737	0.124	0.0278	0.0475	7.28
	Mp4	0.0434	0.0060	0.0552	0.777	0.122	0.0272	0.0562	8.20
	Mp5	0.0499	0.0070	0.0625	0.930	0.144	0.0323	0.0616	8.41
	Mp6	0.0511	0.0094	0.0686	1.16	0.194	0.0391	0.0729	11.2
	Mp7	0.0580	0.011	0.0753	1.57	0.240	0.0520	0.0698	15.1
	Mp8	0.172	0.027	0.245	2.93	0.652	0.145	0.211	34.5
	Mp9	0.145	0.027	0.326	4.15	0.844	0.159	0.336	54.9
	Mp10	0.170	0.035	0.166	2.46	0.843	0.100	0.180	73.2

Station: Palo Alto

Date: 9/8/2010

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	2.60	0.23	2.18	33.3	4.80	1.11	1.98	202
STD	1.31	0.05	0.89	8.4	1.10	0.31	0.84	64
SEM	0.49	0.02	0.40	3.2	0.42	0.12	0.32	24
CV%	50.3	22	40.9	25.1	22.9	28.3	42.4	31.8
n	7	7	5	7	7	7	7	7
r wt x [ ]	0.503	0.71	0.977	0.176	0.712	0.507	0.733	0.447
X 100mg	4.04	0.15	-3.90	36.5	3.10	0.764	0.639	140
r l x [ ]	0.453	0.88	0.999	0.180	0.854	0.800	0.912	0.596
X 20mm	2.95	0.20	1.13	34.2	4.25	0.962	1.53	180
X 25mm	3.62	0.15	-0.0711	35.9	3.18	0.677	0.658	136

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.127	0.0099	0.0679	1.63	0.211	0.0477	0.0761	8.59
25mm	0.263	0.017	0.0949	3.13	0.353	0.0783	0.113	14.2

Estimated weight for 15mm clam	Estimated weight for 20mm clam
0.022 gm	0.050 gm
22 mg	50 mg

Estimated weight for 25mm clam

0.096 gm
96 mg

Station: Palo Alto

Date: 9/8/2010

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	9.34	0.1077	0.0057	10	0.0274	0.0034	0.0396	0.4030	0.0756	0.0189	0.0401	3.0030
Mp2	15.61	0.1629	0.0233	10	0.0394	0.0041	0.0362	0.5243	0.0868	0.0196	0.0358	2.6350
Mp3	16.49	0.1772	0.0295	10	0.0391	0.0038	0.0351	0.5183	0.0809	0.0183	0.0349	3.9440
Mp4	17.66	0.1113	0.0278	10	0.0138	0.0020	0.0184	0.3447	0.0478	0.0113	0.0210	1.7330
Mp5	18.42	0.1033	0.0344	10	0.0202	0.0025	~~0.0124~~	0.2701	0.0434	0.0077	0.0134	2.9140
Mp6	21.03	0.0838	0.0838	10	0.0205	0.0016	~~0.0101~~	0.2266	0.0305	0.0087	0.0108	1.7150
Mp7	23.17	0.1426	0.0713	10	0.0769	0.0026	0.0198	0.7169	0.0653	0.0141	0.0217	1.5780

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

Concentration (mg/kg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	2.54	0.32	3.68	37.4	7.02	1.75	3.72	279
Mp2	2.42	0.25	2.22	32.2	5.33	1.20	2.20	162
Mp3	2.21	0.21	1.98	29.2	4.57	1.03	1.97	223
Mp4	1.24	0.18	1.65	31.0	4.29	1.02	1.89	156
Mp5	1.96	0.24		26.1	4.20	0.75	1.30	282
Mp6	2.45	0.19		27.0	3.64	1.04	1.29	205
Mp7	5.39	0.18	1.39	50.3	4.58	0.99	1.52	111

Content (μg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	0.015	0.0018	0.021	0.21	0.040	0.010	0.021	1.6
Mp2	0.0564	0.0059	0.0518	0.750	0.124	0.0280	0.0512	3.77
Mp3	0.0651	0.0063	0.0584	0.863	0.135	0.0305	0.0581	6.57
Mp4	0.0345	0.0050	0.0460	0.861	0.119	0.0282	0.0525	4.33
Mp5	0.0673	0.0083		0.899	0.145	0.0256	0.0446	9.70
Mp6	0.205	0.0160		2.27	0.305	0.0870	0.108	17.2
Mp7	0.385	0.0130	0.0990	3.58	0.327	0.0705	0.109	7.89

Station: Palo Alto   Statistical Summary

Date: 10/6/2010

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	2.87	0.36	2.59	36.6	5.58	1.33	2.08	290
STD	0.69	0.09	1.04	6.2	1.57	0.37	0.95	89
SEM	0.23	0.03	0.42	2.1	0.52	0.12	0.32	30
CV%	24.0	25	40.0	17.0	28.1	28.1	45.9	30.8
n	9	9	6	9	9	9	9	9
r wt x [ ]	0.612	0.68	0.903	0.821	0.666	0.814	0.699	0.482
X 100mg	2.13	0.25	8.98	27.6	3.75	0.798	0.913	365
r l x [ ]	0.752	0.86	0.903	0.915	0.816	0.874	0.749	0.245
X 20mm	2.54	0.31	4.56	32.9	4.76	1.12	1.62	304
X 25mm	2.11	0.24	5.30	28.2	3.71	0.854	1.04	321

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.116	0.014	0.181	1.56	0.220	0.0517	0.0703	13.5
25mm	0.201	0.025	0.373	2.77	0.375	0.0871	0.111	26.4

Estimated weight for 15mm clam

0.021 gm
21 mg

Estimated weight for 20mm clam

0.048 gm
48 mg

Estimated weight for 25mm clam

0.094 gm
94 mg

Station: Palo Alto

Date: 10/6/2010

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	8.51	0.1325	0.0041	10	0.0463	0.0063	0.0398	0.6009	0.1026	0.0218	0.0365	4.3640
Mp2	9.44	0.1828	0.0051	10	0.0694	0.0086	0.0502	0.8258	0.1150	0.0277	0.0484	5.9700
Mp3	10.47	0.0483	0.0069	10	0.0153	0.0023	0.0160	0.1824	0.0389	0.0095	0.0146	1.3460
Mp4	14.71	0.0894	0.0179	10	0.0250	0.0029	0.0338	0.3374	0.0535	0.0138	0.0330	1.5910
Mp5	15.66	0.0910	0.0228	10	0.0283	0.0030	~~0.0115~~	0.3590	0.0493	0.0110	0.0136	3.0220
Mp6	17.28	0.0939	0.0313	10	0.0264	0.0027	0.0157	0.3248	0.0378	0.0101	0.0135	1.5460
Mp7	19.34	0.0952	0.0476	10	0.0244	0.0026	~~0.0120~~	0.2881	0.0367	0.0124	0.0123	2.5440
Mp8	22.75	0.2739	0.0685	10	0.0373	0.0077	0.0285	0.8008	0.1185	0.0239	0.0331	7.3330
Mp9	26.48	0.1156	0.1156	10	0.0313	0.0034	~~0.0120~~	0.3406	0.0520	0.0097	0.0133	5.3360
				MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
				MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

Concentration (mg/kg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	3.49	0.48	3.00	45.4	7.74	1.65	2.75	329
Mp2	3.80	0.47	2.75	45.2	6.29	1.52	2.65	327
Mp3	3.17	0.48	3.31	37.8	8.05	1.97	3.02	279
Mp4	2.80	0.32	3.78	37.7	5.98	1.54	3.69	178
Mp5	3.11	0.33		39.5	5.42	1.21	1.49	332
Mp6	2.81	0.29	1.67	34.6	4.03	1.08	1.44	165
Mp7	2.56	0.27		30.3	3.86	1.30	1.29	267
Mp8	1.36	0.28	1.04	29.2	4.33	0.873	1.21	268
Mp9	2.71	0.29		29.5	4.50	0.839	1.15	462

Content (µg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	0.014	0.0019	0.012	0.19	0.032	0.0067	0.011	1.4
Mp2	0.019	0.0024	0.014	0.23	0.032	0.0077	0.014	1.7
Mp3	0.022	0.0033	0.023	0.26	0.056	0.014	0.021	1.9
Mp4	0.0501	0.0058	0.0677	0.6756	0.1071	0.0276	0.0661	3.19
Mp5	0.0709	0.0075		0.8995	0.1235	0.0276	0.0341	7.57
Mp6	0.0880	0.0090	0.0523	1.0827	0.1260	0.0337	0.0450	5.15
Mp7	0.1220	0.0130		1.4405	0.1835	0.0620	0.0615	12.7
Mp8	0.0933	0.0193	0.0713	2.0027	0.2964	0.0598	0.0828	18.3
Mp9	0.3130	0.0340		3.4060	0.5200	0.0970	0.133	53.4

Station: Palo Alto

Date: 12/1/2010

Statistical Summary

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mean(mg/kg)	2.70	0.23	3.86	34.4	6.74	1.39	3.84	256
STD	0.62	0.04	0.99	9.1	1.12	0.35	0.98	53
SEM	0.20	0.01	0.31	2.9	0.35	0.11	0.31	17
CV%	23.1	17	25.5	26.5	16.6	25.0	25.4	20.8
n	10	10	10	10	10	10	10	10
r wt x [ ]	0.643	0.81	0.641	0.232	0.140	0.457	0.581	0.385
X 100mg	2.22	0.19	3.10	36.9	6.55	1.20	3.16	231
r l x [ ]	0.637	0.81	0.528	0.120	0.0745	0.419	0.443	0.403
X 20mm	2.52	0.22	3.64	34.9	6.70	1.33	3.65	247
X 25mm	2.16	0.19	3.15	35.9	6.63	1.19	3.25	227

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

	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
20mm	0.145	0.013	0.204	1.99	0.389	0.0747	0.205	14.2
25mm	0.257	0.023	0.362	3.90	0.749	0.136	0.369	26.1

Estimated weight for 15mm clam

0.025 gm
25 mg

Estimated weight for 20mm clam

0.059 gm
59 mg

Estimated weight for 25mm clam

0.116 gm
116 mg

Station: Palo Alto

Date: 12/1/2010

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	9.09	0.2033	0.0060	10	0.0620	0.0057	0.0770	0.6848	0.1305	0.0284	0.0738	5.9030
Mp2	10.45	0.1305	0.0082	10	0.0449	0.0037	0.0634	0.4726	0.0940	0.0219	0.0599	4.1760
Mp3	13.88	0.0955	0.0191	10	0.0343	0.0025	0.0447	0.3224	0.0694	0.0172	0.0429	3.0010
Mp4	15.69	0.1033	0.0258	10	0.0323	0.0027	0.0517	0.3526	0.0747	0.0181	0.0532	2.1660
Mp5	16.58	0.1492	0.0373	10	0.0298	0.0030	0.0580	0.4394	0.1007	0.0180	0.0593	3.0050
Mp7	19.61	0.1745	0.0436	10	0.0453	0.0042	0.0657	0.5506	0.1218	0.0208	0.0657	4.8060
Mp8	21.33	0.1995	0.0665	10	0.0485	0.0041	0.0789	0.5689	0.1229	0.0264	0.0820	5.0440
Mp9	21.95	0.1907	0.0954	10	0.0315	0.0033	0.0287	0.5604	0.0800	0.0119	0.0281	3.5670
Mp10	23.46	0.1065	0.1065	10	0.0246	0.0020	0.0367	0.6304	0.0698	0.0143	0.0379	2.0970
Mp11	24.62	0.1102	0.1102	10	0.0305	0.0025	0.0410	0.3108	0.0951	0.0174	0.0403	3.4420
				MDL	0.0004	0.0003	0.0078	0.0024	0.0005	0.0013	0.0009	0.0058
				MRL	0.0008	0.0006	0.0157	0.0047	0.0011	0.0025	0.0017	0.0116

Concentration (mg/kg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	3.05	0.28	3.79	33.7	6.42	1.40	3.63	290
Mp2	3.44	0.28	4.86	36.2	7.20	1.68	4.59	320
Mp3	3.59	0.26	4.68	33.8	7.27	1.80	4.49	314
Mp4	3.13	0.26	5.00	34.1	7.23	1.75	5.15	210
Mp5	2.00	0.20	3.89	29.5	6.75	1.21	3.97	201
Mp7	2.60	0.24	3.77	31.6	6.98	1.19	3.77	275
Mp8	2.43	0.21	3.95	28.5	6.16	1.32	4.11	253
Mp9	1.65	0.17	1.50	29.4	4.20	0.624	1.47	187
Mp10	2.31	0.19	3.45	59.2	6.55	1.34	3.56	197
Mp11	2.77	0.23	3.72	28.2	8.63	1.58	3.66	312

Content (µg) ==>

Sample #	Ag	Cd	Cr	Cu	Ni	Pb	V	Zn
Mp1	0.018	0.0017	0.023	0.20	0.038	0.0084	0.022	1.7
Mp2	0.028	0.0023	0.040	0.30	0.059	0.014	0.037	2.6
Mp3	0.0686	0.0050	0.0894	0.645	0.139	0.0344	0.0858	6.00
Mp4	0.0808	0.0068	0.129	0.882	0.187	0.0453	0.133	5.42
Mp5	0.0745	0.0075	0.145	1.10	0.252	0.0450	0.148	7.51
Mp7	0.113	0.011	0.164	1.38	0.305	0.0520	0.164	12.0
Mp8	0.162	0.014	0.263	1.90	0.410	0.0880	0.273	16.8
Mp9	0.158	0.017	0.144	2.80	0.400	0.0595	0.141	17.8
Mp10	0.246	0.020	0.367	6.30	0.698	0.143	0.379	21.0
Mp11	0.305	0.025	0.410	3.11	0.951	0.174	0.403	34.4

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., 2010.

[ND means No Data.]

Date	Sediment		*M. petalum*	
	mercury	selenium	mercury	selenium
2/9/2010	0.28 \ 0.28	ND	ND	5.0 \ 4.8
4/19/2010	ND	0.3 \ 0.2	0.19 \ 0.16	ND

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

[Recoveries are reported as the observed concentrations (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										
1/11/2010	1	42,454	7	0.36	107	30	32,323	521	78	13	141	86
	2	42,323	8	0.33	109	30	32,760	529	80	13	140	86
2/9/2010	1	42,022	8	0.35	107	30	32,828	528	80	13	139	85
	2	42,786	8	0.34	109	31	32,663	523	82	12	141	87
3/23/2010	1	42,188	8	0.34	108	30	31,875	517	78	13	140	83
	2	41,045	7	0.33	105	30	31,847	512	78	13	137	83
4/19/2010	1	46,324	8	0.33	120	32	34,519	556	82	13	152	89
	2	41,219	7	0.33	106	30	31,989	514	78	13	137	91
5/18/2010	1	41,505	7	0.33	106	30	32,017	515	79	13	139	87
	2	42,410	8	0.32	109	31	32,817	529	80	13	141	87
6/30/2010	1	42,458	8	0.33	111	30	32,615	523	80	13	142	86
	2	43,981	8	0.34	112	31	32,978	533	81	12	144	85
9/8/2010	1	42,581	8	0.33	109	30	32,886	530	81	13	142	86
	2	42,422	7	0.35	108	31	32,555	525	80	12	141	89
10/6/2010	1	42,848	7	0.36	110	31	33,160	533	82	13	144	90
	2	41,642	7	0.32	107	31	31,965	516	80	13	140	87
12/1/2010	1	42,253	7	0.35	108	30	32,708	526	81	13	141	86
	2	44,015	8	0.36	111	31	33,232	539	81	13	146	91
		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										
1/11/2010	1	58	70	96	82	90	96	98	92	73	128	83
	2	57	76	90	84	89	98	100	95	73	127	83
2/9/2010	1	57	73	94	82	87	98	100	95	73	126	82
	2	58	73	92	84	91	97	99	96	72	128	85
3/23/2010	1	57	75	93	83	87	95	98	92	73	127	81
	2	56	71	89	80	88	95	97	92	74	125	81
4/19/2010	1	63	72	89	92	95	103	105	97	74	138	87
	2	56	70	89	82	89	95	97	92	73	125	89
5/18/2010	1	56	71	90	81	89	95	97	92	75	126	84
	2	58	76	87	84	91	98	100	94	75	128	85
6/30/2010	1	58	73	90	85	89	97	99	94	74	129	83
	2	60	72	93	86	92	98	101	95	72	131	82
9/8/2010	1	58	74	88	84	89	98	100	95	75	129	84
	2	58	70	96	83	91	97	99	95	72	128	86
10/6/2010	1	58	71	96	85	91	99	101	97	76	131	87
	2	57	70	87	82	91	95	97	94	73	127	84
12/1/2010	1	57	69	94	83	88	97	99	95	75	128	84
	2	60	71	97	86	91	99	102	95	73	133	88
	Mean	58	72	91	84	90	97	99	94	74	128	84
	STD	2	2	3	3	2	2	2	2	1	3	2

Appendix 6. Observed and certified values for inorganic elements in NIST Standard Reference Material 2976 (mussel tissue) prepared in 2010.

[Observed Concentrations in NIST SRM 2976 in 2009. 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
				Observed Concentrations				
1/11/2010	<MRL	0.77 ± 0.01	0.482 ± 0.058	3.73 ± 0.12	0.580 ± 0.034	0.827 ± 0.044	0.583 ± 0.020	125 ± 3
2/9/2010	<MRL	0.84 ± 0.14	0.625 ± 0.171	4.12 ± 0.60	0.692 ± 0.170	1.01 ± 0.28	0.647 ± 0.112	142 ± 30
3/23/2010	<MRL	0.82 ± 0.01	0.530 ± 0.006	3.94 ± 0.003	0.590 ± 0.010	0.859 ± 0.010	0.587 ± 0.009	132 ± 1
4/19/2010	<MRL	0.82 ± 0.03	0.494 ± 0.132	3.91 ± 0.19	0.602 ± 0.047	0.899 ± 0.060	0.600 ± 0.026	131 ± 6
5/18/2010	<MRL	0.80 ± 0.01	0.625 ± 0.133	3.79 ± 0.08	0.598 ± 0.029	0.879 ± 0.094	0.635 ± 0.066	127 ± 3
6/30/2010	<MRL	0.79 ± 0.02	0.505 ± 0.022	3.71 ± 0.08	0.592 ± 0.045	0.844 ± 0.048	0.591 ± 0.029	126 ± 6
9/8/2010	<MRL	0.81 ± 0.01	0.471 ± 0.036	3.74 ± 0.06	0.597 ± 0.022	0.854 ± 0.049	0.592 ± 0.013	127 ± 2
10/6/2010	<MRL	0.81 ± 0.01	0.515 ± 0.117	3.73 ± 0.01	0.611 ± 0.010	0.871 ± 0.015	0.581 ± 0.012	130 ± 1
12/1/2010	<MRL	0.80 ± 0.003	0.454 ± 0.040	3.67 ± 0.12	0.580 ± 0.013	0.838 ± 0.013	0.582 ± 0.013	126 ± 1
Mean		0.80	0.522	3.82	0.605	0.876	0.600	130
Median		0.81	0.505	3.74	0.597	0.859	0.591	127
				Certified Concentrations				
	0.011	0.82 ± 0.16	0.5 ± 0.2	4.02 ± 0.33	0.93 ± 0.12	1.19 ± 0.18	nc	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	0.0005	0.0093	0.0001	0.0056	0.0029	0.0114	0.0014	0.0005	0.0020	0.0003	0.0074
	MRL	0.0010	0.0187	0.0002	0.0112	0.0059	0.0227	0.0028	0.0010	0.0040	0.0005	0.0148
Tissue	MDL	0.0004	0.0313	0.0003	0.0078	0.0024	0.0159	0.0021	0.0005	0.0013	0.0009	0.0058
	MRL	0.0008	0.0626	0.0006	0.0157	0.0047	0.0318	0.0042	0.0011	0.0025	0.0017	0.0116

Appendix 8. Observed and certified concentrations of mercury and selenium in standard reference materials (SRM) analyzed in 2010.

[Concentration is reported as parts per million (ppm).]

SRM	Mercury		Selenium	
	Observed	Certified	Observed	Certified
NIST 2709	1.4	1.40±0.08	1.5	1.57±0.08
NIST 2711	6.1	6.25±0.19	1.4	1.52±0.14
NIST 1646A	0.02	0.04	0.2	0.19±0.03
NRC MESS-3	0.10	0.091±0.009	0.7	0.72±0.05
USGS SDO-1	0.17	0.19±0.08	1.9	1.9-6.8
DORM-2	4.3	4.6±0.3	1.3	1.4±0.1
DOLT-3	3.3	3.4±0.1	7.6	7.1±0.5
TORT-2	0.26	0.27±0.06	5.4	5.6±0.7
NIST 2976	0.05	0.06	2.0	1.8±0.2
USGS GSP-2	0.02	ND	<0.1	ND

Appendix 9. Complete list of benthic species found at Palo Alto in the year 2010.

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

Species	01/25/10		2/8/2010		3/22/2010		4/20/2010		5/28/2010		6/29/2010		7/28/2010		8/24/2010		10/6/2010		12/1/2010	
	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
Ampelisca abdita	2.0	1.0	7.3	3.8	12.3	6.5	0.7	1.2	0.0	0.0	3.0	2.0	2.7	2.5	7.3	5.1	10.0	1.7	8.0	2.6
Ampithoe 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
Anthozoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus ?aquila	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus 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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus 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	0.3	0.6
Boonea bisuturalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calinoida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Callianassidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capitella "capitata"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
Chironomidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cirratulidae	0.7	1.2	0.3	0.6	1.0	1.0	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
Cirripedia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Corbula amurensis	0.7	0.6	1.7	0.6	2.0	2.0	4.0	2.0	9.7	5.5	11.7	2.3	11.7	4.7	8.0	1.0	0.7	1.2	0.7	0.6
Corophium ?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
Corophium acherusicum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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 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
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 alienense	0.3	0.6	0.3	0.6	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
Corophium spp. (female & juvenile)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Corophium spp. (male)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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

Species	01/25/10		2/8/2010		3/22/2010		4/20/2010		5/28/2010		6/29/2010		7/28/2010		8/24/2010		10/6/2010		12/1/2010	
	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
Cyprideis 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
Dynamenella 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
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	2.3	4.0
Eteone ?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
Eteone lighti	3.3	0.6	6.3	4.0	7.0	1.0	4.7	2.1	8.0	4.0	4.0	1.7	5.7	1.5	3.7	0.6	4.3	1.5	3.7	2.3
Eteone 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	0.3	0.6	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
Euchone 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
Eusarsiella zostericola	1.7	0.6	9.3	0.6	28.3	1.5	21.7	6.4	5.3	3.8	1.0	1.0	2.0	0.0	2.0	1.0	11.0	2.0	8.3	2.5
Gemma gemma	444.0	113.5	319.3	97.3	624.0	95.1	408.0	41.1	334.7	62.3	147.3	39.7	260.0	171.1	120.3	69.0	557.7	241.5	625.3	126.2
Glycera 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 polygnatha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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 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
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	7.7	3.5	7.3	3.2	6.7	3.8	1.0	1.0	2.7	0.6	2.7	3.8	0.3	0.6	2.0	1.7	5.0	4.0	4.7	6.4
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
Harpacticoida	0.0	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	0.0	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
Heteromastus filiformis	2.0	1.0	1.7	0.6	0.7	0.6	0.3	0.6	0.7	0.6	1.3	1.2	1.7	2.9	2.7	1.2	6.3	5.9	1.3	1.5
Ilyanassa obsoleta	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
Macoma petalum	3.7	2.9	2.3	2.3	4.3	1.5	2.7	0.6	1.7	0.6	2.0	1.7	2.7	2.1	0.7	0.6	0.3	0.6	0.3	0.6
Macoma spp.	0.0	0.0	0.0	0.0	0.3	0.6	0.7	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

Species	01/25/10		2/8/2010		3/22/2010		4/20/2010		5/28/2010		6/29/2010		7/28/2010		8/24/2010		10/6/2010		12/1/2010	
	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
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
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
Monocorophium acherusicum	0.3	0.6	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	0.0	0.0
Monocorophium insidiosum	2.3	0.6	2.3	2.5	2.0	2.6	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
Monocorophium spp.	2.0	1.7	2.0	1.7	2.0	1.0	0.7	1.2	1.0	1.0	0.0	0.0	1.3	1.2	2.0	1.0	0.3	0.6	0.7	0.6
Musculista senhousia	0.3	0.6	0.7	1.2	0.7	0.6	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
Mya arenaria	0.0	0.0	0.0	0.0	0.3	0.6	3.3	1.5	1.7	1.5	0.3	0.6	0.7	0.6	0.7	0.6	0.3	0.6	0.3	0.6
Mysidacea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Naididae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	1.0	1.0	1.7	0.6	3.0	1.7	1.7	1.2	0.7	0.6	0.0	0.0	1.3	0.6	1.3	1.2	1.7	0.6	0.3	0.6
Nematoda	3.7	3.1	9.0	9.0	3.7	4.7	0.7	0.6	0.3	0.6	2.0	2.6	3.3	1.2	0.3	0.6	2.3	2.1	0.0	0.0
Nippoleucon hinumensis	18.7	13.0	29.3	18.3	75.3	13.3	135.7	48.6	72.7	4.6	62.3	48.2	95.7	71.3	18.7	8.1	51.3	25.4	17.3	8.3
Odostomia fetella	0.0	0.0	0.0	0.0	2.7	2.3	0.0	0.0	5.7	9.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odostomia spp.	0.3	0.6	5.0	2.6	1.3	2.3	6.3	2.5	5.0	4.6	1.7	2.1	0.0	0.0	0.7	1.2	0.7	1.2	0.0	0.0
Oligochaeta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6
Planariidae 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
Polydora cornuta	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	0.0	0.0	0.0	0.0	0.0	0.0
Polydora 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
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 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
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
Sinelobus stanfordi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sphaeromatidae (juv.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Species	01/25/10		2/8/2010		3/22/2010		4/20/2010		5/28/2010		6/29/2010		7/28/2010		8/24/2010		10/6/2010		12/1/2010	
	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
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
Streblospio benedicti	55.3	22.5	7.7	6.1	21.3	7.6	8.0	3.0	23.0	10.1	3.0	1.0	3.3	1.2	6.3	6.1	16.0	8.7	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	0.3	0.6	0.0	0.0	0.0	0.0
Tellinidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tharyx 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	33.3	16.8	34.7	13.6	47.0	35.8	10.7	7.2	19.0	9.5	15.0	9.5	23.0	19.3	17.3	13.6	39.7	18.0	2.3	4.0
Turbellaria	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	0.0	0.0	0.0	0.0
Unid. Actiniaria	1.0	1.0	0.0	0.0	1.0	1.0	0.3	0.6	0.0	0.0	0.0	0.0	1.3	1.5	3.0	2.6	2.7	1.2	1.3	1.2
Unid. Amphipod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Balanomorpha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Bivalvia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Copepod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Cumacea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Gastropoda	0.0	0.0	1.7	1.2	3.0	1.0	2.0	1.0	2.0	1.7	3.3	2.1	0.0	0.0	0.3	0.6	0.3	0.6	0.7	0.6
Unid. Isopoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Malanidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Nudibranchia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Ostracoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Polychaeta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Spionidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Syllidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Tanaidacea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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

Appendix 10. Annual mean silver in sediments and the clam *Macoma petalum*, Palo Alto, Calif., 1977–2010.

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

Year	Silver in sediment	Silver in clams
1977	0.65 ± 0.59	87 ± 21
1978	1.39 ± 0.35	106 ± 17
1979	1.62 ± 0.28	96 ± 29
1980	1.28 ± 0.38	105 ± 24
1981	1.41 ± 0.15	63 ± 18
1982	0.74 ± 0.21	45 ± 13
1983	0.56 ± 0.26	56 ± 11
1984	0.64 ± 0.20	57 ± 18
1985	0.78 ± 0.14	58 ± 6
1986	0.61 ± 0.14	50 ± 20
1987	ND	55 ± 18
1988	ND	20 ± 10
1989	ND	11 ± 4
1990	0.39 ± 0.09	7.7 ± 3.4
1991	0.25 ± 0.07	3.3± 2.0
1992	0.35 ± 0.11	5.9 ± 1.9
1993	0.36± 0.09	6.9 ± 3.2
1994	0.46 ± 0.07	5.4 ± 1.1
1995	0.27 ± 0.05	5.5 ± 1.2
1996	0.24 ± 0.06	7.5 ± 1.6
1997	0.34 ± 0.04	3.6 ± 1.0
1998	0.34 ± 0.04	3.3 ± 0.6
1999	0.22 ± 0.01	3.6 ± 0.3
2000	0.34 ± 0.02	3.0 ± 0.4
2001	0.43 ± 0.03	3.0 ± 0.4
2002	0.31 ± 0.02	3.0 ± 0.5
2003	0.49 ± 0.03	2.1 ± 0.5
2004	0.29 ± 0.06	2.4 ± 1.3
2005	0.41 ± 0.04	1.8 ± 0.3
2006	0.36 ± 0.05	3.8 ± 0.8
2007	0.37 ± 0.02	4.5 ± 0.9
2008	0.20 ± 0.01	1.8 ± 0.3
2009	0.20 ± 0.01	1.9 ± 0.3
2010	0.27 ± 0.02	2.1 ± 0.3

Appendix 11. Annual mean copper in sediments and the clam *Macoma petalum*, Palo Alto, Calif., 1977–2010.

[Values are the annual (grand) means for 7 to 12 separate samples per year and standard errors of those means. Samples were collected between January and December of each year. Units are milligram 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.]

Year	Copper in sediment		Copper in clams
	HCl	Total	
1977	28±6	45±13	130±23
1978	42±11	57±13	187±104
1979	55±13	86±18	248±114
1980	47±5	66±9	287±66
1981	48±7	57±22	206±55
1982	35±4	34±24	168±35
1983	22±9	38±21	191±48
1984	26±10	40±16	159±55
1985	27±3	45±7	138±22
1986	24±3	49±9	114±49
1987	21±3	47±6	95±25
1988	27±3	53±5	53±24
1989	23±6	44±13	35±10
1990	23±2	51±4	35±11
1991	25±2	52±5	24±8
1992	27±6	52±5	46±14
1993	21±3	43±7	60±14
1994	19±2	45±4	59±12
1995	19±2	44±5	61±16
1996	19±2	43±4	71±11
1997	18±1	43±3	32±7
1998	20±1	46±2	35±4
1999	18±1	44±2	34±2
2000	18±1	39±3	32±3
2001	17±1	35±2	31±3
2002	13±1	38±2	36±4
2003	19±4	34±8	29±16
2004	17±4	34±8	33±11
2005	16±2	30±2	26±2
2006	18±2	46±2	45±8
2007	17±1	47±2	43±7
2008	13±1	38±2	28±3
2009	13±1	36±2	26±2
2010	13±1	40±2	29±2