Metal trends and effects in *Potamocorbula amurensis* in North San Francisco Bay

Cynthia L. Brown and Samuel N. Luoma

ABSTRACT

Long-term, multi-disciplined field sampling was used to assess both the fate and effects of trace metals in northern San Francisco Bay. Bioaccumulation in the bivalve *Potamocorbula amurensis* was measured at near-monthly intervals between 1990 and 1997. Three accumulation patterns were detected. One pattern indicates that biological regulation of Cu and Zn is an important control on tissue concentrations. This was evident by the absence of persistent spatial or temporal trends in the tissue concentrations of Cu or Zn, and the correlation of Cu and Zn tissue concentrations with the weight of the clam. The pattern in Cr, Ni, and V tissue concentrations was related to the combined influences of riverine inputs and local industrial inputs. Seasonally, the highest tissue concentrations of Cr, Ni, and V coincided with high delta inflows. Cadmium and Ag tissue concentrations were not clearly related to any obvious source. However, they were linked inversely to condition index, glycogen content, reproductive status, and histopathology. The histopathological changes are biomarkers indicative specifically of contaminant stress.

Trace metals can be an influential variable in ecosystem processes, affecting the well-being of organisms, populations and communities (Luoma, 1996). Metal bioaccumulation in macroinvertebrate tissues is an indicator of metal exposures that can either adversely affect the health of the organism, or be transferred up the food web to affect higher organisms. Bioaccumulation in the bivalve *Potamocorbula amurensis* has been used to assess both the fate and effects of trace metals in San Francisco Bay (Brown and Luoma, 1995). The present study began in 1990 and consists of monthly sampling at five sites in Northern San Francisco Bay (Figure 1). Four of these are deep water sites in the ship channel; near Chipps Island, near Roe Island, in Carquinez Strait near Martinez, and in San Pablo Bay northeast of Pinole Point. One site is in the shallow water of Honker Bay. Clams (60-100) are collected at each site and separated into replicate size composites (1mm shell length difference) of 12-15 clams each. Ag, Cd, Cr, Cu, Ni, V, and Zn are measured in the whole soft tissues of the clam. Condition index (mg dry weight for a standard shell length), glycogen content (% tissue dry weight), and reproductive status (Parchaso, USGS) are determined monthly to evaluate influences of metals and other environmental factors on the energetics and reproduction in *P. amurensis* as indicators of stress. Surface sediments are collected at the same time and analyzed for metals (Hornberger and Bouse, USGS). Collaborators from UC Davis (Drs. Hinton, Werner, Teh, Clark, Fan, Higashi, Kaufman) are simultaneously studying enzymatic, histopathologic, and biochemical biomarkers in these populations of *P. amurensis* to compare with the trends in contaminants.

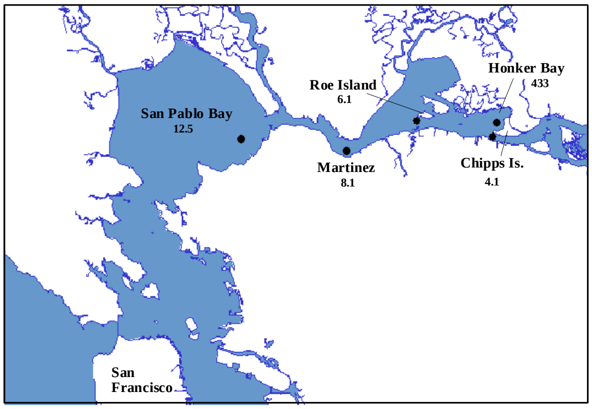


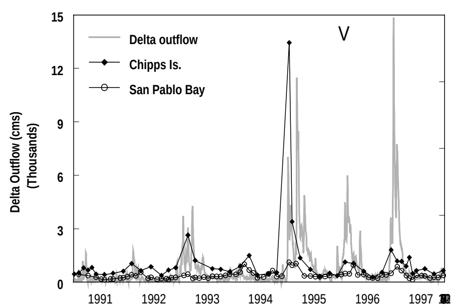
Figure 1. Map of sampling sites in Northern San Francisco Bay.

Since the beginning of this study, we have observed metal trends over a wide variety of hydrographic regimes. These include three very low flow years (1991, 1992, and 1994) where annual mean delta outflow was less than 220 m^3sec^{-1}, and years of moderate to high delta outflow (1993, 1995, 1996, and 1997) where annual mean delta outflow was between 760 - 1710 m^3sec^{-1} (Oltmann, USGS data). Each of the metals showed slightly different accumulation patterns in *P. amurensis* and thus indicated the variety of factors that control bioaccumulation. Three basic patterns were detected. One pattern indicates that biological regulation of Cu and Zn is an important control on tissue concentrations. The pattern in Cr, Ni, and V tissue concentrations is related to the combined influences of riverine inputs and local industrial inputs. The third pattern in Cd and Ag tissue concentrations is not clearly related to any obvious source, but is linked to patterns in biomarker indicators of metal stress.

Earlier studies (Luoma et al., 1990, Hornberger et al., 1999) showed that Cu contamination increases substantially in the industrialized regions of the Bay-Delta. However, there is no distinct spatial or temporal trend in the tissue concentrations of Cu (or Zn) in *P. amurensis* in the North Bay. Variability in Cu (and Zn) appears to be dominantly controlled by biological processes. Among all times at all sites, the amount of Cu in a 15mm shell length clam is strongly correlated (r^2 = 0.53) with the weight of tissue. The same relationship occurs within each site. As animals add (or lose) tissue mass, they add (or lose) Cu. Changes in weight, which occur seasonally and site-to-site, control 53% of the Cu variability in *P. amurensis*. It is known that the bioaccumulation response to environmental Cu and Zn contamination differs among species (Phillips and Rainbow, 1993). *P. amurensis* appears to be a species that biologically regulates its tissue burden of Cu and Zn, and thus does not appear to be a useful indicator of Cu and Zn contamination patterns (Brown and Luoma, 1995).

The second accumulation pattern shows that Cr, Ni, and V in the tissues of *P. amurensis* are related to both natural and anthropogenic inputs into the ecosystem. These metals are enriched in the ultramafic rocks that are common throughout the watershed and thus are naturally high in the sediments in the bay. Vertical cores of sediments indicate that the enrichment of Cr, Ni, and V extends back to before the Gold Rush and the acceleration of human activities in the area (Hornberger et al., 1999). These metals also have industrial sources in the North Bay. Chromium, Ni, and V concentrations in the tissues of the clams have a distinct temporal pattern that suggests the amount of freshwater flow into the bay from the delta affects their bioaccumulation. Vanadium has the strongest relationship with delta outflow. Vanadium concentrations increase during pulses of high inflows and are low in the tissues at all channel stations during low flow periods (Figure 2a). Tissue concentrations at the most landward site, near Chipps Island, are often as low as tissue concentrations at the most seaward site, San Pablo Bay, during low flows. However, when delta outflows increase, concentrations of V are higher in clams at Chipps Island than clams in San Pablo Bay. Chromium and Ni tissue concentrations behave similar to V during high flows (see also Abu-Saba and Flegal, 1997). But during low flow periods, tissue concentrations of Cr (and Ni) do not decrease to the lowest levels seen in San Pablo Bay (Figure 2b). Input of Cr and Ni from internal industrial or sedimentary sources appear to add to the source of Cr and Ni from the watershed; the influence of these internal sources is most evident when freshwater residence times increase (i.e. low flows). The trends of Cr, Ni, and V in the tissues of *P. amurensis* show how physical processes and natural sources within an ecosystem interact with anthropogenic inputs to affect bioavailable metal concentrations.

a.



b.

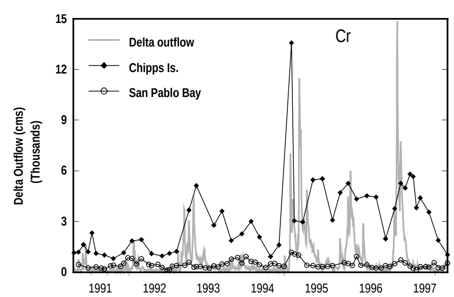


Figure 2. Vanadium concentrations (a) and Cr concentrations (b) in *P. amurensis* at Chipps Island and San Pablo Bay compared with delta outflow.

The third accumulation pattern is seen with Cd tissue concentrations which are linked to adverse effects in *P. amurensis*. Potential sources of cadmium include oceanic upwelling, urban/industrial effluents, and mining. There is not the distinct flow-related temporal trend in the Cd tissue concentrations that is seen in Cr, Ni, and V. However, there is a seasonally consistent and distinct spatial pattern (Figure 3): Cd concentrations are highest in clams near Chipps Island and in Honker Bay, and lowest in clams in San Pablo Bay. This pattern is consistent among all the years of the study. The source of the Cd contamination is not clear, but both geochemical processes and anthropogenic inputs could contribute.

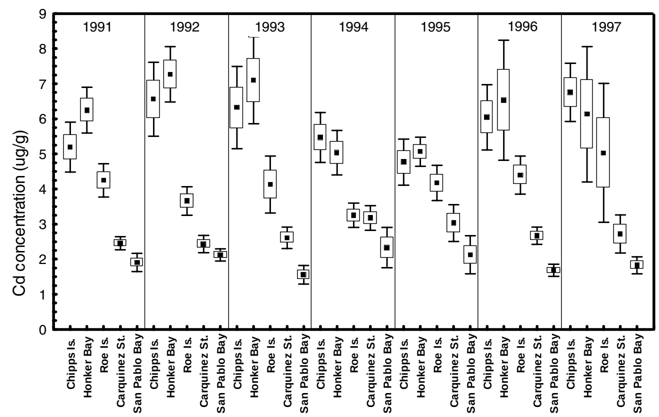


Figure 3. A seasonally consistent and distinct spatial pattern in Cd concentrations in *P. amurensis* occurs among years.

The biomarkers measured coincident with the metal data show significant correlations with the Cd tissue concentrations. Glycogen and condition index follow a pattern that is the inverse of the Cd tissue concentrations. The condition index is an indicator of overall fitness of the clam. Clams have their lowest condition index near Chipps Island and in Honker Bay. They have their highest condition index in San Pablo Bay with strong seasonal fluctuations that follow reproduction. Figure 4 shows that clams with the highest Cd in their tissues are unable to gain (and lose) weight, unlike the clams with lower tissue concentrations of Cd. Glycogen is used by an organism as a source of energy and is consumed during times of stress or reproduction when extra energy is needed. Initial time series show that glycogen levels in *P. amurensis* are lowest overall in the clams from the most contaminated site. Glycogen levels in the clams at both sites are depleted when the clams begin gametogenesis, but the depletion occurs earlier and lasts longer at the more contaminated site. The differences in reproductive status of *P. amurensis* among the stations also show a relationship with Cd tissue concentrations. Clams at the most contaminated site (lower condition, lower glycogen) have a lower proportion of reproductively mature individuals than clams at the least contaminated site. At least in the years of high Cd exposure (e.g. 1991-1993) reproduction is synchronous among animals in San Pablo Bay (least contaminated), but asynchronous at Chipps Island (most contaminated) (Thompson et al., 1996, Parchaso et al., 1997). Histopathologic biomarker alterations are also correlated with metal body burden. Preliminary analyses show stress occurring in the kidneys, gonad and digestive tract of *P. amurensis* at Chipps Island (Teh et al, 1999). Although other anthropogenic and natural stressors probably have some influence on the differences among the different populations in *P. amurensis* in North Bay, the correlations of general physiological indicators and the histochemical biomarkers with Cd body burdens indicate that metals must be considered a variable of potential importance when assessing the processes that influence this ecosystem.

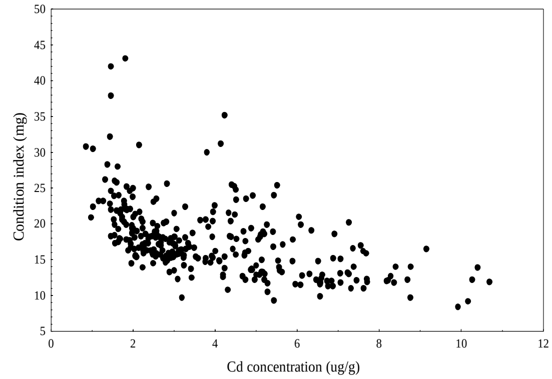


Figure 4. Cd concentration and condition data in P. amurensis for all months at all sites from 1991-1997. Clams with the highest Cd tissue concentrations are unable to gain (and lose) weight, unlike clams with lower Cd tissue concentrations.

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AUTHOR INFORMATION

Cynthia L. Brown and Samuel N. Luoma, U.S. Geological Survey, Menlo Park, California