Chapter 6

TOXIC METALS IN SOUTH RICHMOND MARSH PLANTS

Cori Chase-Dunn

Introduction

The salt marshes of South Richmond are endangered by recent plans for waterfront development. Among several suggested land uses of the salt marshes and mudflats, a park or refuge would preserve this area for its open space and natural habitat values. The success of such a plan would depend upon the ability to maintain the habitat. With urban development encroaching upon the borders of these marshes, their survival depends on the careful study of the dynamics of the salt marsh habitat before development occurs. Marsh plants are excellent indicators of the physical factors that control growth. Measurements of metal contamination in the marsh plants will give some idea of the past pollution of these salt marshes and whether the contamination might constitute a threat to the marshes, the wildlife, or even the people who use the area. This information can be used to assess the value of these marshes as a public recreation area or refuge, since that value will be determined by the aesthetic beauty of the shoreline along with the health of its vegetation and wildlife.

The salt marshes accrue more value when they are the last refuge of an endangered species. This paper will look at the metal contamination of the marshes along the southern Richmond shore (Figure 1) because it could affect an endangered species, the salt marsh harvest mouse, *Reithrodontomys raviventris*. The mouse eats the dominant vegetation in the marshes, *Salicornia virginica* (pickleweed). Metal toxicity in animals can occur when contaminated plants are the sole food supply (Bohn *et al*., 1985). This could be the case for the salt marsh harvest mouse in the South Richmond marshes.

Past Studies

Many studies have used toxic metal concentrations in sediments to assess the metal contamination of aquatic systems (Forstner and Wittmann, 1981). Peterson and others (1972) have found lead and cadmium in sediments throughout San Francisco Bay. Sediments and surface water have been tested by the consultants of the Southern Pacific Transportation Company for their clean-up work at the Liquid Gold site (Figure 1) (Kennedy/Jenks/Chilton Engineers, 1986). Both cadmium and lead concentrations in the sediments of the marshes were measured by Sutton (this report).

Studies of toxic metals in plants have been made on many terrestrial species (Lepp, 1981; Nriagu, 1978; Kabata-Pendias and Pendias, 1984; Sinha, 1984; OECD, 1975). There have been a few studies of metal contamination in marsh plants, but information on the tolerance levels of *Salicornia virginica* to toxic metals is not readily available. Banus and others (1975) have studied the effects

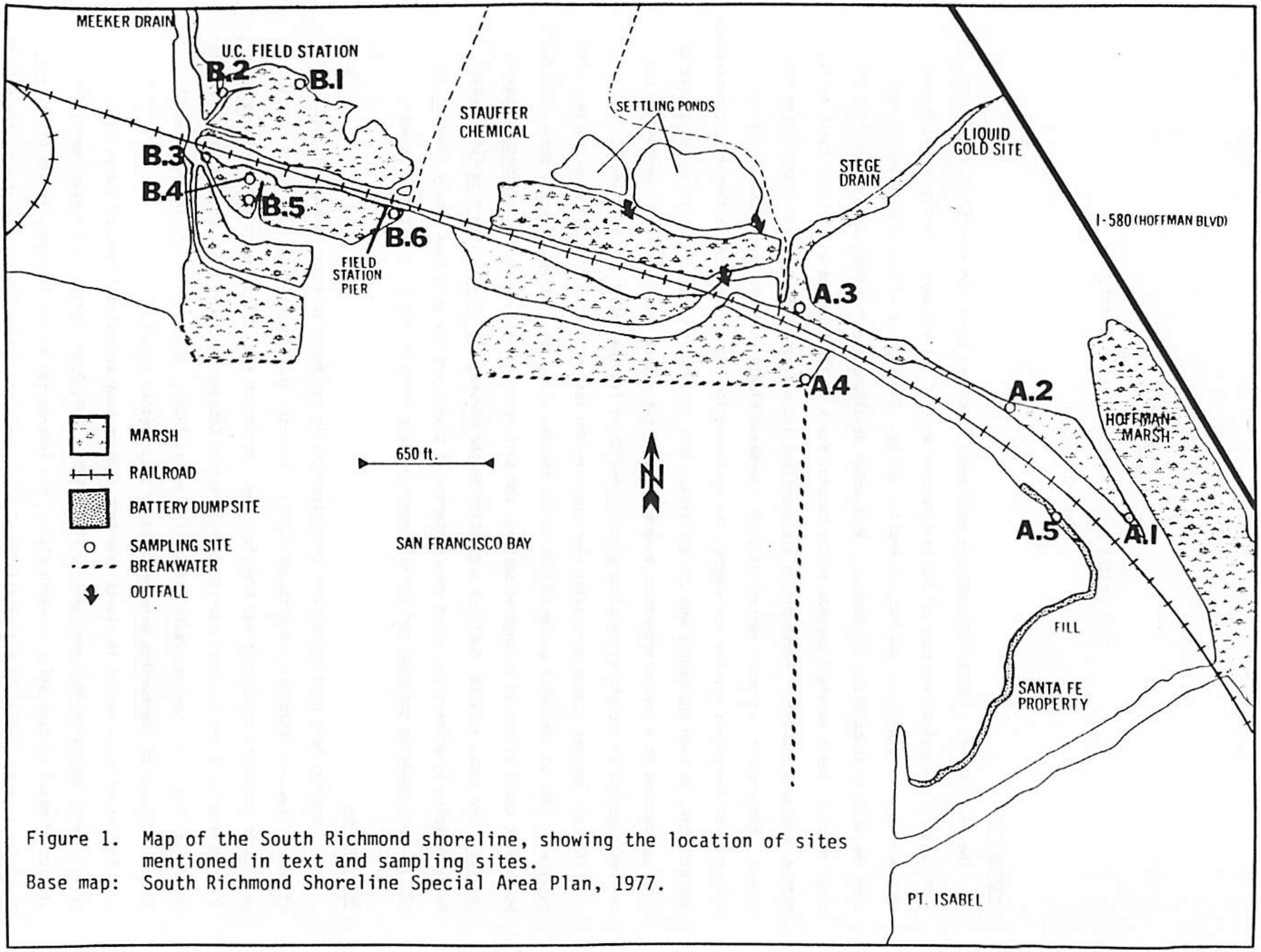

Figure 1. Map of the South Richmond shoreline, showing the location of sites mentioned in text and sampling sites.
Base map: South Richmond Shoreline Special Area Plan, 1977.

of toxic metals from sewage on Spartina alterniflora (cordgrass), which is commonly associated with Salicornia. They found that Spartina accumulated metals through the roots and incorporated them into above-ground tissues. Their study indicates that Spartina is tolerant of an increase of metal concentrations in the sediments, because productivity increased by 30% as lead concentrations increased by 50% and cadmium increased by 150%. Other marsh plants are known to tolerate different toxic metals: Atriplex (fat hen) is tolerant of aluminum (Peterson and Girling, 1981), and Grindelia (gum plant) has been found to tolerate selenium (Peterson et al., 1981). Kaplan (1984) studied the marsh contamination levels in marsh plants at the Emeryville Crescent and compared them to levels in marsh plants from Tomales Bay, a relatively natural setting on the Pacific coast north of San Francisco.

Background of Study Area

The salt marshes along the South Richmond shoreline are only relicts of the vast marshes that bordered the Bay before large urban populations developed. The marshes have been subjected to many stresses, the most destructive being landfill. Other subtler stresses, such as increases in pollutants, are applied by the urban areas surrounding the remaining marshes. Over the years, many industries have occupied the sites near the marshes, affecting them in many ways. These industries are probably the major sources of metal contamination.

Contamination by toxic metals has occurred on the north shore of Point Isabel (Figure 1), where thousands of large automobile batteries were dumped on the shoreline illegally (Thomas, 1982). Acids and metals spilled out all along the shore for many years until it was cleaned up in 1986.

Due north of the battery dump site and next to Stege drain is a Superfund site formerly occupied by the Liquid Gold Company. Many oil wastes which contained metals were discharged at this site onto the ground and possibly into Stege drain (Williams, 1987, pers. comm.).

East of the Liquid Gold site is the Stauffer Chemical Company. Stauffer used to be a chemical refinery but now is devoted to research. They own two large settling ponds that have common outflows to the marshes (Figure 1). The UC Berkeley's Field Station, located north of Stauffer, is a research facility. New development on this site is being investigated and studies on the effect this development would have on the site have been requested by the University. The field station is situated near marshes on a former gunpowder factory site.

Methods

Salicornia virginica (Faber, 1982) was collected in the fall when growth would be at a minimum. The plants were collected at 11 sites in two areas (A, B, Figure 1). Each sample was cut off near the ground with stainless steel scissors and stored in sealed plastic bags. Some of the samples were covered with a fine layer of dried mud that had accumulated on them at the last high tide, particularly at site B.3. In order to simulate the condition of the plant as eaten by the salt marsh harvest mouse, the samples were not washed before they were analyzed. Fisler (1965) suggests that salt marsh harvest mice do not wash their food but eat it with the sediments stuck to the food. The roots were not collected, as this is not a portion of the plant that is eaten.

The two areas sampled were chosen to include marsh plants growing furthest inland, sites A.1 and B.1, and those most exposed to the Bay, sites A.5 and B.6. The latter are actually located on the shore among cement riprap and driftwood. Site A.5 was chosen to test whether any toxic metals remain from the batteries. The presence of residual Liquid Gold effluents along with unintentional discharges from Stauffer Chemical in the inner marsh were examined in area A, specifically, at sites A.1 through A.3. Area B was chosen to show if any metals were present on the UC property.

The unwashed plants were dried at 58-65°C for four days, and then the upper portions of the plant were ground in a Wiley mill of mesh size 40. One gram of powdered sample was weighed out and digested in 10 ml of hot concentrated (16N, 70%) nitric acid for 12-14 hours. Where there was less than one gram of sample, proportionately less acid was added. Each sample was then diluted to 20 ml with distilled water. The samples were stored in plastic vials until readings of the concentrations could be made.

Concentration determinations were made on a Perkin-Elmer 360 Atomic Absorption Spectrophotometer with a microprocessor set at a four second integration time. The spectrophotometer was standardized with acidic solutions of the same acidity as the samples. Thanks to Professor Harvey Doner of the Plant and Soil Biology Department for his help with these procedures and the use of the Wiley mill. Also, thanks to Mr. Tom Morrison of the Chemistry Department for his help in preparation and standardization of the spectrophotometer.

Four to eight readings were taken of each sample. The standard deviations of each sample are reported with the average of the readings (Table 1).

Results

Concentrations of cadmium in Area A ranged from 1.5 to 2.6 ppm by dry weight of plant matter, and concentrations of lead ranged from 37.4 to 53.8 ppm (Table 1, Figure 2). In area B, concentrations of cadmium ranged from 0.4 to 5.4 ppm, and concentrations of lead from 50.4 to 179.3 ppm. The average concentrations of both metals were higher in area B than in area A. The average cadmium concentration was 2.1 ppm in area A and 2.8 ppm in area B. The average lead concentration was 46.7 ppm in area A and 82.2 ppm in area B. The highest concentrations of each metal occurred at sites B.3 and B.6. The concentrations in area B varied more than those in A (Figure 2). Lead concentrations in samples from area B were higher than those from Area A, whereas the concentrations of cadmium fluctuate. There are no obvious inland-to-bayward trends.

Concentration of Metals

Sites	Cadmium [ppm dry weight]	SD	Lead [ppm dry weight]	SD
A.1	2.6	0.33	53.8	3.23
A.2	1.5	0.11	42.8	2.61
A.3	2.2	0.19	52.8	3.12
A.4	2.2	0.23	46.5	4.60
A.5	1.9	0.18	37.4	2.77
average	2.1		46.7	
B.1	1.9	0.16	56.8	4.32
B.2	0.4	0.07	57.6	4.26
B.3	5.1	0.22	179.3	9.50
B.4	2.1	0.25	50.4	1.81
B.5	1.7	0.07	63.6	5.72
B.6	5.4	0.51	85.2	5.54
average	2.8		82.2	

Table 1. Concentrations of cadmium and lead in Salicornia virginica samples at the South Richmond marshes. SD = standard deviation. Sites shown on Figure 1.

Discussion

All but one of the concentrations of cadmium and lead found in pickleweed along the South Richmond shoreline were above average concentrations found in plant matter, which tends to have cadmium concentrations of 0.2-0.8 ppm and lead concentrations of 0.1-10 ppm (Bohn et al., 1985). The pickleweed may be incorporating metals into the plant tissue. Banus and others (1975) have shown incorporation of metals into Spartina. Elevated lead and cadmium concentrations were found in samples of washed Spartina that had been treated with sewage that doubled the amount of metals in the sediments (Banus et al., 1975).

The average cadmium concentrations found in this study were five times higher than those Kaplan (1984) found in the Emeryville marsh, where the concentration of cadmium in Salicornia virginica was 0.42 ppm dry weight. The high concentrations in Salicornia in this study were not unexpected because the samples were not washed. Soils generally have more metals than plant matter (Bohn et al., 1985); the same may be true of marsh sediments. The sediments that remained on the plants might be ingested by the salt marsh harvest mouse, and it is important to know how much metal the mouse eats. A determination of the lead and cadmium concentrations in washed samples of Salicornia would be important to a better understanding of the availability of these metals to animals eating the plants.

The time of year could also affect the concentration of metals. Salicornia concentrates salts in the most extreme segments of its stems in the fall and drops these off in the winter (Faber, 1982).

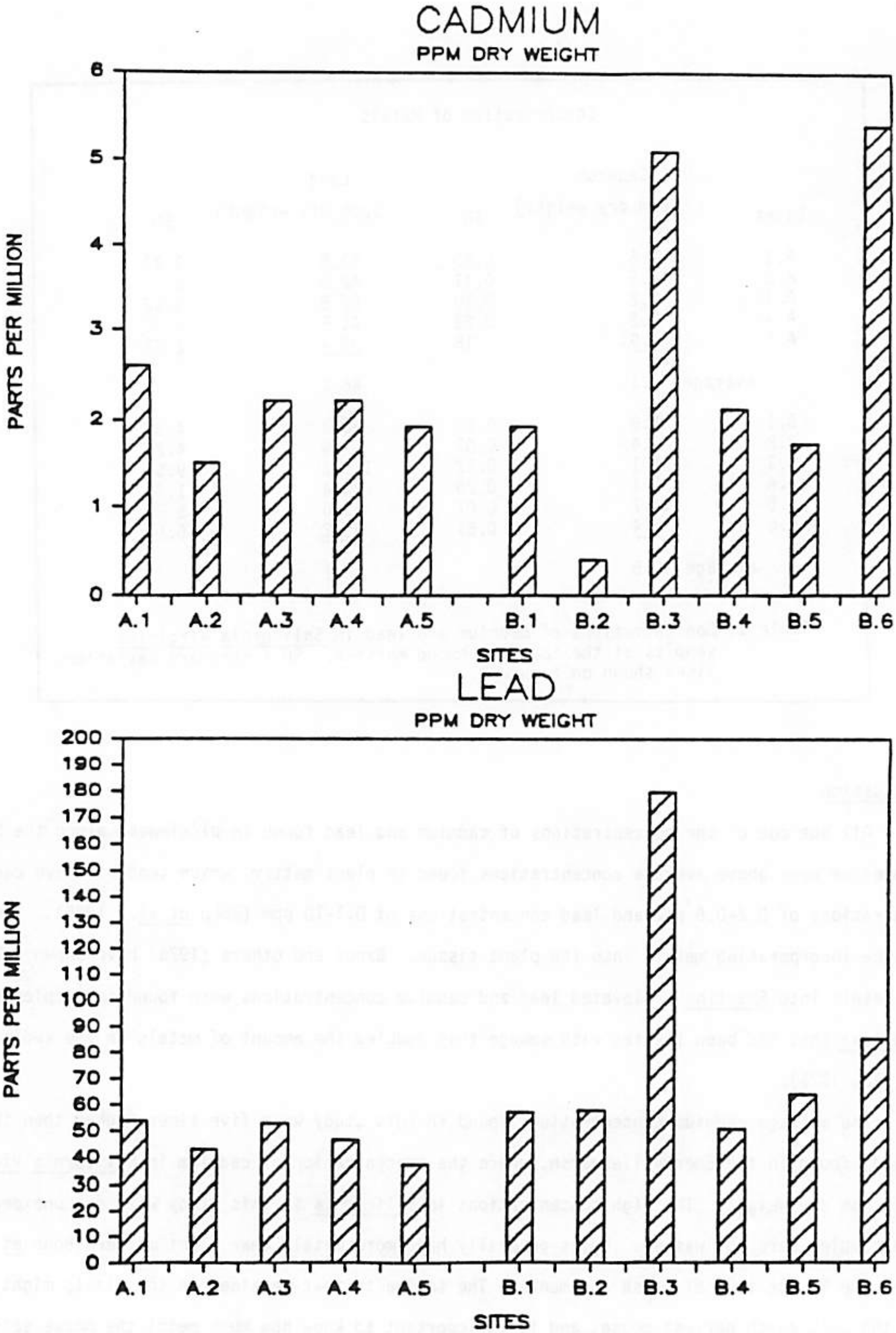

Figure 2. Cadmium and lead concentrations in Salicornia virginica samples at the South Richmond marshes.

Although cadmium is known to accumulate in the roots of plants, translocation to other plant parts is possible (Kabata-Pendias and Pendias, 1984). Lead is deposited in roots, leaves, and stems in the form of crystals and precipitates (Kabata-Pendias and Pendias, 1984). It is possible that both metals are passed out of Salicornia in the winter. The samples collected in this study still had the reddened end-section which soon would be dropped from the rest of the plant. Many of the digested samples contained these end-sections and this may account for the high concentrations found.

The surface water and sediments at a site close to site A.3 (Figure 1) were tested in November of 1985 for lead contamination, and levels were found to be $<$0.01 mg/L (ppm) in the water and 110 mg/kg (ppm) in the sediments of the drainage canal (Kennedy/Jenks/Chilton Engineers, 1986). The lead found in the sediments could be a sign of contamination and should be studied further.

Pathways

Metals can travel by many vectors (paths) to reach the marsh plants, by water, through soil and by wind. The analysis of these pathways is important to discovering where the metals are coming from.

Most natural waters do not contain high concentrations of metals; however, in acidic waters, such as those that might have been present when the batteries released their contents, metals can go into solution and be easily transported by water (Forstner and Wittmann, 1981). In neutral conditions, metals easily complex with organic matter to form chelated molecules and so are less harmful to organisms. Acids attack these chelates and strip the organic part from the metal, leaving the metal ion free and very reactive.

Water currents can also carry larger particles onto which metals adhere (Forstner and Wittmann, 1981). Marshes slow down the current to such a velocity that everything but the smallest particles settle out either onto the surface of the mud or plants.

The soil of the marshes could itself be a source of the metals, but high concentrations of these metals in the typical clay of the sediments is rare. The sediments usually consist of montmorillonite clays which do not contain lead and cadmium naturally (Bohn et al., 1985). The soil has a high capacity to collect metals, however, and this may be the most important mechanism by which the plants receive their metals.

Metals also travel through the air on larger pieces of solid matter, such as dust particles from exhaust and industrial effluents (Sinha, 1984). These can be transported by wind to the marshes and land on the fleshy stems of Salicornia.

Sources of Contamination

The two sites, B.3 and B.6 (Figure 1), which showed much higher concentrations of both cadmium and lead, were located in two different environments. Site B.6 was on the shoreline, B.3 in the salt marsh. Therefore the sources of the metals could be very different. The UC Field Station's water sampling pier is just a few meters from site B.6. Possibly the construction or operation of that pier generated the higher concentrations of metals. More likely sources of the pollution are up-current in the Bay or from runoff emptying from the storm drains into the Meeker drain (Figure 1). Meeker drain is the most likely source of pollution at site B.3 if the nearby train bridge made no contribution of metals.

Possible sources of the lead and cadmium at the South Richmond site include the battery dumpsite, the Liquid Gold site, storm runoff, Hoffman Boulevard (I-580), STauffer Chemical Company, and the UC Field Station.

The decaying batteries were left for a long period of time while various agencies and the Santa Fe Railroad Company (which owns the property) argued over who should dispose of the batteries. By the time the batteries were cleaned up, just recently, their casings were cracked, and the contents were leaking out. The chemicals in these batteries were probably strong acids as well as reactive, toxic metals such as lead and cadmium. The combination of acids and metals could have increased the effects of the metals released. Lead has already been found in high concentrations in the sediments and shellfish on this site (Thomas, 1982). The batteries are now encased in a lined landfill (near site A.5) that was completed in January of 1987 ("fill" in Figure 1).

The Liquid Gold Oil Corporation subleased property near the salt marshes in southern Richmond (Figure 1) from Southern Pacific Transportation Company (Kennedy/Jenks Engineers, 1985). Liquid Gold purchased used oil and sold it to refiners for reuse as lubricating and fuel oils, and for dust control. In 1981 they had 27 storage tanks of various sizes that stored six kinds of liquid materials. The company bought used oil from service stations and other wastes such as tank bottoms, which contained high levels of toxic metals. In the early 1970's, several spills into the adjacent marshes were reported. Southern Pacific removed the tanks in April of 1983, and will pay for remedial clean-up of the site. A plan for clean-up of the contaminated soil around the site was proposed in 1985 (Kennedy/Jenks Engineers, 1985). This work has been completed but further testing for contamination of the site needs to be done (Williams, 1987, pers. comm.).

The Liquid Gold site is a probable source of both lead and cadmium since the used oil stored on the property and subsequently discharged into the ground or the waterways would have contained high concentrations of these metals. Surface clean-up has been done to some extent. Surface runoff from this site also moves southward towards Hoffman marsh. It is possible that the site has still not been properly cleaned up, since there could be a mass of oil that has seeped deep into the ground (Williams, 1987, pers. comm.). Groundwaters could carry this pollution to the marshes (Banus et al., 1975).

Another source of metals is urban runoff. There are two urban streams, Meeker and Stege drains, that empty into the marshes (Figure 1). When it rains, these waterways collect all of the city's dirt which includes parking lot oil and exhaust residues. The heaviest discharge of these wastes occurs after the long dry period of the summer months, resulting in an accumulation of these in the marshes during the fall (Simonitch, 1983).

Hoffman Boulevard (Interstate 580) is a possible source if unusual wind patterns occur on the eastern side of the Bay. Winds commonly blow from the northwest, carrying particulates (which contain metals) and metal aerosols to the eastern side of the roadway away from the marshes. Sinha (1984) found roadside hay contained large amounts of lead that was aerially deposited from highway exhaust. However, metal deposition would be a source to the pickleweed only under rare conditions when the wind blows from the north.

Stauffer Chemical Company is discharging waste waters within current standards for effluents out of an outfall at the eastern end of their settling ponds. A second outfall, located between the two ponds, serves as a storm drain as well as an effluent outlet. The UC property is not discharging metals into the Bay as effluents but possibly as runoff from the parking lots and roadways.

San Francisco Bay has a problem with pollutants of all kinds, including heavy metals. A recent Environmental Impact Report on the discharge from Chevron Oil reported difficulties in keeping some of the more sensitive species alive in San Pablo Bay water (Jefferson Associates, 1987). This pollution is a Bay-wide problem, and it needs to be addressed.

How Metals Threaten the Marshes

One of the areas of highest accumulation of garbage and pollutants occurs in the marginal regions of estuaries such as the salt marshes of San Francisco Bay (Banus et al., 1975). Toxic metals are then tolerated to an extent in these systems (Banus et al., 1975). Although the marshes can be thought of as fulfulling an important role in the removal of these metals from the Bay, the wildlife of the marshes could be endangered by the metals.

Salicornia could be tolerant of the metals as is *Spartina*. The stand of pickleweed in the marshes is probably not threatened at this time by the concentrations found in the plants. A washed plant study would be helpful in determining whether the plant was incorporating the metals. More study needs to be done to determine the tolerance of pickleweed to toxic metals.

The salt marsh harvest mouse may be suffering effects due to recent increased levels of all pollutants in the marshes including lead and cadmium. Metal contamination should be investigated as another stress upon the population of mice since they are already in danger of extinction due to drastic reduction in habitat (Olson, 1982).

People used to eat pickleweed. It was used for pickling other food and for a source of salt. Washing the plant is certainly recommended by this author if it is to be consumed at all. However, until it is known whether the plant incorporates the metals, the consumption of these plants should be avoided.

Recommendations and Conclusions

If the marshes are developed as a park, it would be necessary to ensure the safety of those who use it. Kids, if unattended, will make mudpies of the marsh muds and possibly ingest the sediments or eat unwashed pickleweed. Access into the marshes should be restricted. The marshes are a delicate habitat with plants and birds' nests that are easily trampled by people or dogs. The South Richmond area would make a lovely park with upland walkways and trails for birdwatchers and those who like to walk, run, ride bikes, or just enjoy the open shoreline. It may be possible to restore this area to a viable habitat for sensitive species, such as the salt marsh harvest mouse, where the varied topography might provide upland hiding places for the mouse.

The metal pollution in the area should be cleaned up, if at all possible. The expense of such a clean-up would probably be high, and recently it has been hard to get polluters to admit fault and pay for a clean-up effort. Since some of the major causes of pollution in the area are non-point sources, it is more difficult to work on a clean-up effort and find the money for it. Runoff pollution can be reduced, however, by increasing street cleanings and reducing the amount of garbage and oil wastes that are poured onto the streets by the residents of the cities surrounding the Bay.

REFERENCES CITED

Banus, M.D., I. Valiela, and J.M. Teal, 1975. Lead, zinc, and cadmium budgets in experimentally enriched salt marsh ecosystems; Estuarine and Coastal Marine Science, v. 3, pp. 421-430.

Bohn, H., B. McNeal, and G. O'Connor, 1985. Soil Chemistry, 2nd edition; New York, Wiley-Interscience, 341 pp.

Faber, P.M., 1982. Common wetland plants of coastal California; Mill Valley, California, Pickleweed Press, 111 pp.

Fisler, G.F., 1965. Adaptation and speciation in harvest mice of the marshes of San Francisco Bay. University of California Publications in Zoology; Berkeley and Los Angeles, University of California Press, Vol. 77, 108 pp.

Forstner, U. and G.T.W. Wittmann, 1981. Metal pollution in the aquatic environment; Berlin, Springer-Verlag, 486 pp.

Jefferson Associates, 1987. Draft Environmental Impact Report. Chevron USA Richmond Refinery Deep Water Outfall Project; prepared for City of Richmond, California, Report Number EID 85-36, n.p.

Kabata-Pendias, A. and H. Pendias, 1984. Trace elements in soils and plants; Boca Raton, Florida, CRC Press, Inc., 315 pp.

Kaplan, G.L., 1984. Metal pollution in San Francisco Bay salt marsh plants. In Hazardous substances: a community perspective; D. Sloan, ed., U.C. Berkeley Environmental Sciences Senior Seminar report, Berkeley, California, pp. 47-56.

Kennedy/Jenks Engineers, 1985. Phase I Soil Remediation Plan, report prepared for Southern Pacific Transportation Company; San Francisco, California, n.p.

Kennedy/Jenks/Chilton Engineers, 1986. Status Report on Phase III Technical Activities performed for the Southern Pacific Transportation Company; San Francisco, California, n.p.

Lepp, N.W., ed., 1981. Effect of heavy metal pollution on plants, V. 1; London and New Jersey, Applied Science Publishers, 352 pp.

Nriagu, J.O., ed., 1978. The biogeochemistry of lead in the environment, V. A and B; Amsterdam, Elsevier/North-Holland Biomedical Press, 422 pp.

Olson, D., 1982. The salt marsh harvest mouse in the Emeryvill Crescent marsh. In The East Bay shoreline: selected environmental issues; D. Sloan, ed., U.C. Berkeley Environmental Sciences Senior Seminar report, Berkeley, California, pp. 135-146.

Organization for Economic Cooperation and Development (OECD), 1975. Cadmium and the environment: toxicity, economy, control; Paris, OECD, 88 pp.

Peterson, D.H., D.S. McCulloch, T.J. Conomos, and P.R. Carlson, 1972. Distribution of lead and copper in surface sediments in the San Francisco Bay estuary, California; U.S. Geological Survey, Basic Data Contribution 36.

Peterson, P.J., L.M. Benson and R. Zieve, 1981. Metaloids. In Effect of heavy metal pollution on plants, V. 1; N.W. Lepp, ed., London and New Jersey, Applied Science Publishers, pp. 279-342.

Peterson, P.J. and C.A. Girling, 1981. Other Trace Metals. In Effect of heavy metal pollution on plants, V. 1; N.W. Lepp, ed., London and New Jersey, Applied Science Publishers, pp. 213-279.

Simonitch, T., 1983. Effects of storm drain discharge on water quality. In Berkeley water: issues and resources; D. Sloan, ed., U.C. Berkeley Environmental Sciences Senior Seminar report, Berkeley, California, pp. 165-172.

Sinha, K.C., 1984. Yield, quality and lead content of forage along Indiana highways; Joint Highway Research Project, School of Engineering, Purdue University and Indiana Department of Highways, 50 pp.

South Richmond Shoreline Special Area Plan Citizens Advisory Committee, 1977. South Richmond Shoreline Special Area Plan; Richmond, California, 114 pp.

Thomas, J.C., 1982. Hazardous waste sites along the Eastbay shoreline. In Eastbay Shoreline; Doris Sloan, ed., U.C. Berkeley Environmental Sciences Senior Seminar report, Berkeley, California, pp. 113-122.

Williams, Paul, Senior Hazardous Management Specialist, California Department of Health Services. Personal communication, 1987.