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Trace Metals in Fish and Invertebrates of Three California Coastal Wetlands

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Metal concentrations were measured in selected fish and invertebrate species from Mugu Lagoon, Malibu Lagoon and Ballona Wetlands in southern California in order to assess the extent of metal contamination in these three wetlands. Ranges of element concentrations (in μg/g) found in biota were: Zn 12–650; Cu 1.9–440; Ni < 1–37; Cr < 1–55; Pb < 0.5–6.8; As < 1–8.5; Se < 1–3.8; Cd < 0.2–0.90; and Ag < 0.3–5.9. Relative to previous studies of California biota, the highest metal concentrations found were for chromium and nickel. The highest levels were in one of the two bottom-dwelling fish (juvenile *Leptocottus armatus*) (55 μg/g) and the two water-column fish sampled (*Fundulus parvipinnis* and *Atherinops affinis*) (30 and 24 μg/g). At Ballona Lagoon, elevated levels of copper and silver were found in the bivalve *Tagelus californianus* (440 and 5.9 μg/g). Chromium and nickel appeared to be most persistent in fish from Mugu (4.6–55 and 2.6–37 μg/g), the most northern site and an active military base, and Ballona (< 1–30 and < 1–16 μg/g), believed to be the most metal-contaminated site. Compared to previously measured metal concentrations in species of California coastal waters, these regions revealed higher levels of chromium, nickel, silver, arsenic, zinc, copper and, to a lesser extent, cadmium and selenium. Chromium and silver were present at high enough levels at all three sites to be considered environmental health hazards.

Keywords: California; estuaries; metals; pollution monitoring; wetlands.

Introduction

The oceanic burden of both essential and non-essential trace metals is a serious environmental concern (Sadiq, 1992; Salomons and Forstner, 1984). Public interest and research efforts have focused primarily on estuarine and coastal environments since these are often directly and most seriously affected by urban runoff, industrial effluents and domestic discharges (NOAA, 1991; Salomons and Forstner, 1984; SWRCB, 1991, 1993; WRCB, 1990). Metal body loads of aquatic biota are often measured and used to evaluate ecological risks and potential sublethal effects (Bryan *et al.*, 1980, 1985; Phillips, 1980a, 1990; Phillips and Rainbow, 1993; Rainbow, 1995). Although body loads provide a simplistic indicator of toxic effects, they nonetheless yield information about potential exposure that can be used to assess both spatial and temporal trends in the health of aquatic ecosystems.

The metals arsenic, cadmium, chromium, copper, lead, nickel, selenium, silver, and zinc are of particular interest because: (1) in excess, they are toxic to aquatic organisms and persistent in the aquatic environment (NOAA, 1991; Sadiq, 1992; Salomons and Forstner, 1984); (2) they all have anthropogenic sources that are likely to cause elevated levels in estuarine and coastal environments (NOAA, 1991; Sanudo-Willhelmy and Flegal, 1992; Salomons and Forstner, 1984); (3) there is sufficient information available to discuss general behaviour and biotoxicity (Sadiq, 1992; Luoma, 1983); and (4) biota concentrations for these metals have been reported for naturally occurring aquatic organisms (and transplanted *Mytilus*) along the Southern California Bight (NOAA, 1991; Que Hee and MacNeil, 1994; SWRCB, 1995).

We sampled metal concentrations in water and biota (fish and bivalves) in three Californian coastal wetlands (Mugu Lagoon, Malibu Lagoon, and Ballona Wetlands) in the Los Angeles, CA, USA region. The three wetlands were chosen to represent diversity in metal loads. We expected metal loads to be lowest in Malibu Lagoon, whose watershed consists primarily of residential and undeveloped areas, intermediate in Mugu Lagoon, which has an active naval base and whose watershed is primarily agricultural and residential, and highest in the Ballona Wetlands, whose watershed is highly industri-

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alized. We compared the metal levels determined in this study to those measured over the past 25 years to evaluate temporal trends.

Study Areas

Mugu Lagoon is located in the southeast corner of the Oxnard Plain (Fig. 1) in Ventura County, USA, and covers about 7.5 km^2. Although the US Navy previously dredged the center region of the lagoon, it is one of the largest remaining relatively undisturbed coastal wetlands in Southern California. The main freshwater drainage into the lagoon is from the Calleguas Creek system, although several drainage ditches also empty into the lagoon. The entire lagoon/stream system acts as a catchment basin for debris and effluent transported from the surrounding watershed, which supports extensive agricultural activities and recent commercial and residential development (Richmond, 1976). Consequently, there is the potential for large amounts of contaminants to concentrate in the lagoon (Richmond, 1976).

Malibu Lagoon covers about 0.13 km^2 and is located in Los Angeles County, north-west of the city of Los Angeles. It is situated at the base of the Malibu Creek watershed (270 km^2), which runs through the Santa Monica Mountains. Malibu Creek drains into the lagoon, bringing freshwater, nutrients, detritus, sediments, and urban runoff from surrounding developed areas. Tertiary treated wastewater is also discharged into the upper Malibu Creek from the Tapia Water Reclamation Facility (Ambrose *et al.*, 1994). Non-point urban pollution sources to the lagoon and adjacent watershed result from the surrounding residential land, recreational areas, and the proximity to the Pacific Coast Highway.

The Ballona Wetlands consist of a degraded salt-marsh situated on the western edge of the Los Angeles Basin, surrounded by a highly urbanized area of Los Angeles that drains into the concrete-lined Ballona Creek. The Creek is one of the major drainage channels entering Santa Monica Bay, and serves about 316 km^2 of west Los Angeles County, delivering about 20% of the total runoff annually discharged into the bay and contributing 2–9% of the total pollutant mass emissions entering the bay (Maguire-Thomas, 1991). Non-point pollution sources from developed land uses surrounding the wetlands are the major pollutant contributors during dry weather and stormwater runoff (Maguire-Thomas, 1992; SCCWRP, 1990–1992). Dry weather urban runoff results from landscape irrigation, street cleaning, occasional accidental sewer overflows, and illegal industrial and commercial discharges (Maguire-Thomas, 1992). Stormwater runoff contributes a more diffuse assortment of pollutants resulting from the many areas that rainfall can reach (including the atmosphere).

Materials and Methods

Sampling was conducted during March and April 1995 at four stations within Malibu Lagoon and Ballona Wetlands and at three stations within Mugu Lagoon (Fig. 1). Not every species was successfully collected at

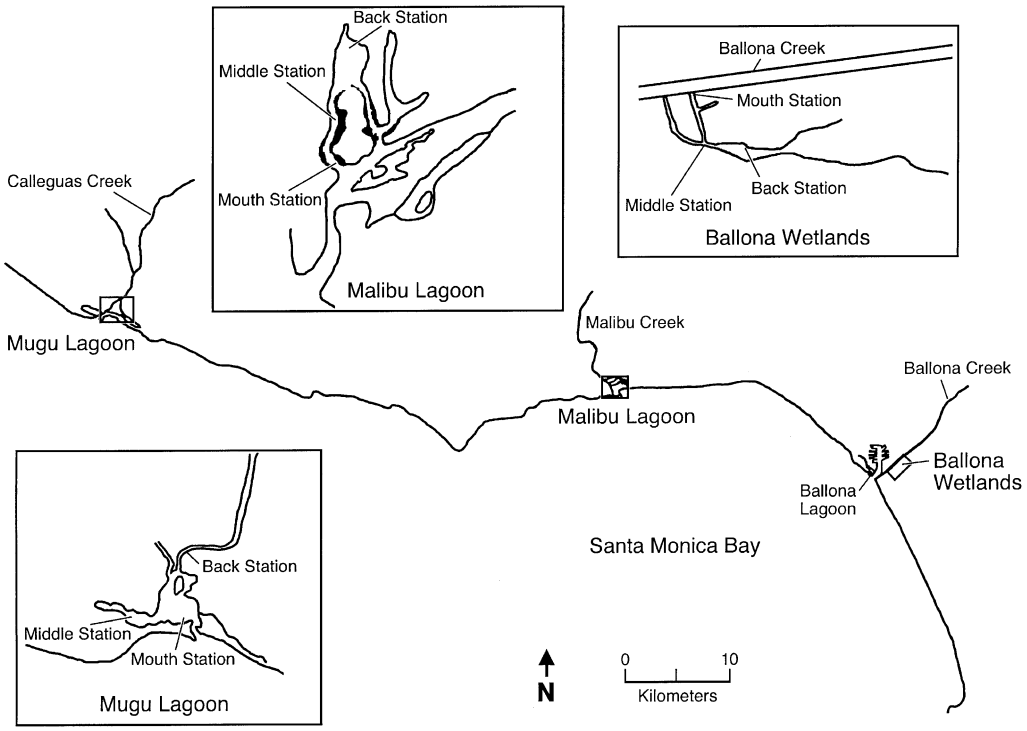

Fig. 1 Locations of sampling sites.

each station and the species of interest were not found at two stations (Malibu Back and Mugu Back). The number of individuals collected at each station varies and is given in the next section with the elemental concentrations. *Tagelus californianus* (jack-knife clams) were not found in the Ballona Wetlands, so were instead collected from Ballona Lagoon, a small lagoon near the Ballona Wetlands that, like the Wetlands, is connected to Ballona Creek. Salinity, temperature, and pH were measured at each station at the time of sampling. *Fundulus parvipinnis* (California killifish), *Leptocottus armatus* (Pacific staghorn sculpin), and *Atherinops affinis* (topsmelt) were collected by sweeping a beach seine (1 cm mesh) through the area. *Gillichthys mirabilis* (long-jaw mudsucker) was collected using 45-cm long conical plastic minnow traps (0.6-cm mesh) with a 23-cm width at the widest mid-point. *Tagelus californianus* (jack-knife clams) were collected along transects using a 1-m long plastic corer with a diameter of 15.2 cm, and *Mytilus galloprovincialis* (California blue mussels), previously known as *M. edulis* (McDonald and Koehn, 1988), were collected by hand at minimal low tide levels. Animals were placed in metal-free plastic bags, transported to the laboratory in ice chests, and washed and frozen in polypropylene bags at −20°C until processing. Samples were kept in storage for a maximum of 12 weeks prior to analysis.

Of the selected species, *M. galloprovincialis* and *T. californianus* are sessile, attaching to hard substrates or living within soft sediments. *G. mirabilis* and *F. parvipinnis* also probably remain within the sample site areas for their entire lifespan due to their preference for protected areas (Barlow, 1963; Fritz, 1975). *Leptocottus armatus* may move out of protected areas to offshore waters after spawning (Tasto, 1975; Jones, 1962); however, this occurs at age one or later when standard lengths are approximately 10 cm (Jones, 1962). *Atherinops affinis* move into open waters and coastal beds as juveniles (>2 cm) and thus represent the most mobile species of those sampled. It is possible the juveniles used for this study had moved in and out of the lagoons in which they were collected (Mugu and Malibu).

Water samples were prepared and analysed, in triplicate, according to the procedure described by the US Environmental Protection Agency Method 200.7 (Martin *et al.*, 1991) for analysis of total recoverable elements in marine and estuarine waters.

Biological samples were digested, after stomach contents were purged, using a microwave digestion technique developed and thoroughly tested at the same UCLA facilities by Moeller *et al.* (1998). Organisms from each station with sufficient collections were pooled into size classes based on total length for fish and shell length for bivalves. For *L. armatus* at Ballona (5.5–7.0 cm) and Mugu (8.8–9.0 cm), individuals from the mouth and mid-stations were pooled together in order to provide a sufficient sample size. The soft tissues (excluding byssal threads in mussels i.e. edible portions in bivalves) were cut into pieces (shells excluded) using an inert stainless steel scalpel and homogenized using an inert laboratory stainless steel blender. The stainless steel used was 306 grade and showed no significant differences in all elemental concentrations when homogenization time was varied in preliminary studies. Triplicate masses of 10 g each were added to Teflon or glass containers and dried in a vacuum desiccator (1–2 weeks) to obtain dry weights. The resulting masses were placed in 150 ml Nalgene wide-mouth bottles, and allowed to react overnight in 100 ml of 70% HNO_3 (Fisher Optima). They were then heated in a teflonized 600 W microwave oven (modified to allow thorough ventilation of acid vapour) at lowest power (10%) with the lids loosely screwed on. Heating was for 30-min periods, separated by 5-min periods with the caps off at room temperature, and continued until brown–red N_2O_4 fumes were no longer detected. The solutions were transferred to 150-ml glass beakers, 0.5 ml perchloric acid was added, and the volume was evaporated to approximately 80 ml on a hot plate at 80°C. The solutions were then transferred to 100 ml beakers and evaporated to approximately 0.100 ml or until white fumes just appeared. The solid residue was dissolved in 120 ml of 11.6% HCl/2.8% HNO_3 (v/v) (Que Hee *et al.*, 1985), placed in an ultrasonic bath for approximately 2 h, and shaken overnight on a mechanical shaker. All transfers were completed with three washes of 5 ml of HNO_3.

Hydrochloric and perchloric acids were Fisher Scientific analytical grade. Water used for all dilutions was Milli-Q deionized. Trace element impurities were removed from glassware, Nalgene and teflon-ware by meticulously cleaning, acid washing (soaking for 16 h in 10% HNO_3 followed by soaking in Milli-Q deionized water), rinsing with deionized water at least five times before drying in a dustless oven and storing in closed plastic bags. All samples, in addition to the appropriate blanks and controls, were performed in triplicate.

Metal concentrations for As, Cd, Cr, Cu, Pb, Ni, Se, Ag, and Zn were determined using the Applied Research Laboratory, simultaneously inductively coupled plasma atomic emission spectrometer (ICP-AES) at the University of California at Los Angeles using an ultrasonic nebulizer and an argon plasma. Detection limits were: 6, 1, 1, 1, 5, 2, 5, 0.1, and 0.5 μg/l, respectively.

Metal concentrations are reported on a dry weight basis. Using dry weights rather than wet weights provides a more accurate measure of metal load since water content in biota varies with species, age, condition, etc. Wet weight concentrations are also given since previous data for California biota were so reported. Wet weight concentrations are presented as ratios (concentrations/EDL85) for each metal. This provides a better comparison between species and regions by using previously reported concentrations of comparable fish and bivalve species in California. The elevated data level (EDL) is a comparative measure developed by the California State Water Resources Control Board's Toxics Substances

TABLE 1

EDL85 for trace elements in whole fish (SWRCB, 1991) and mussels (SWRCB, 1995), calculated using 1978–1989 data (μg g^{-1}, wet wt).

	Zn	Cu	Ni	Cr	Pb	As	Se	Cd	Ag
Fish	36.8	3.4	0.2	0.2	0.3	0.5	1.5	0.1	< 0.02
M. galloprovincialis	43.29	1.92	0.75	0.52	1.92	NA	NA	1.02	0.05

Monitoring Program (TSMP) based on all metal concentrations obtained by the Program between 1978 and 1989, thereby producing a cumulative distribution where percentile rankings were calculated (WRCB, 1990). The broad assumption is that EDL values provide a useful standard of comparison despite the fact that they are averages derived from aggregates of different species. The 85th percentile (EDL85) corresponds to approximately 1.5 SD above the mean of a normally distributed data set and was used by TSMP to indicate that a metal was unusually elevated. EDL85 values are given in Table 1. For bivalves, the EDL values calculated from *M. galloprovincialis* (formerly *M. edulis*) data were used for both *M. galloprovincialis* and *T. californianus*. Although EDL values provide a standard for comparison, the comparison is simply to other species and locations in California during the 1978–1989 period. Thus, EDL values can be used to evaluate the relative concentration of a sample but do not indicate toxicity.

Results

Malibu had the lowest concentrations of metals in water for all nine metals measured (Table 2). Compared to Malibu, concentrations were significantly higher for chromium, arsenic, selenium, cadmium, and silver at both Mugu and Ballona, for lead at Mugu, and for copper at Ballona. No significant differences were detected between Mugu and Ballona.

Many metals occurred in high concentrations in some species (Table 3), as indicated by EDL ratios greater than 1 (Fig. 2). The highest EDL ratios were for Cr, with EDL ratios >20 (i.e., concentrations more than 20 times higher than the EDL85) for *Fundulus* in Ballona, *Atherinops* in Mugu [2] and Malibu, and *Leptocottus* in Mugu. EDL ratios were also high for Ni, and paralleled the pattern for Cr, with ratios >10 for *Fundulus* in Ballona, *Atherinops* in Mugu[2] and Malibu, and *Leptocottus* in Mugu. Silver was elevated in *Fundulus* at Malibu, *Atherinops* at Malibu and Mugu,[2] *Gillichthys* at Ballona, and *Leptocottus* at Mugu; the EDL ratio was greater than 10 for *Tagelus* at Ballona Lagoon. Copper was generally present in low concentrations except in *Tagelus* at Ballona Lagoon, where the EDL ratio was greater than 15. Except for slightly elevated Pb and As in *Gillichthys* at Ballona, all other metals occurred at EDL ratios ≤ 1 for the sampled species at these sites.

The frequency of high-metal concentrations was greatest at Ballona, which had six species-metal concentrations that were more than five times higher than the EDL85. These involved three different species (*Fundulus*, *Leptocottus* and *Tagelus*) and four different metals (Ni, Cr, Cu and Ag). Mugu had four species-metal concentrations as high as these involving two different species (*Atherinops* and *Leptocottus*) and two metals (Ni and Cr), while Malibu similarly had three species-metal concentrations, involving one species (*Atherinops*) and three metals (Ni, Cr and Ag). The relative (by site) frequency of species-metal ratios greater than 5, however, show Mugu (22%) exceeding Ballona (13%), and both exceeding Malibu (11%).

Discussion

This study compares three wetlands to determine the relative degree of contamination. All three sites revealed some samples with concentrations greater than the range determined for California by the Toxic Substances Monitoring Program (as represented by EDL85 values), although Ballona and Mugu both showed greater contamination levels than Malibu. This difference was most notable between Ballona and Malibu; for the two species found at both of these wetlands (*Tagelus* and *Fundulus*), concentrations for several metals were far higher at Ballona; this difference is unlikely to be accounted for by age/size differences alone. Other differences are difficult to assess since different fish and bivalve species occurred at different sites and at different life stages. The heavy rainstorms and floods of the 1995 winter in southern California preceded the sampling done in this study and may have created additional variations and further distorted possible trends.

For all samples, 92% of chromium concentrations, 83% of nickel concentrations, and 67% of the silver concentrations were at the upper end of the range of concentrations previously measured in California biota as revealed by EDL ratios >1.5: 8.3% of zinc, arsenic, copper, and lead EDL ratios were greater than 1.5.

Compared with previous concentrations obtained for Malibu *Fundulus* in 1993 by Que Hee and MacNeil (1994), zinc concentrations in our data were elevated, and lead, arsenic, selenium, and silver were reduced (Table 4). The concentration differences are all approximately within one order of magnitude, which can

[2] It should be noted that only two individuals of this species were obtained at this station.

TABLE 2

Metal concentrations in water (mean ± SD; μg ml^{-1}, $n = 3$).

Sample site	pH	Salinity	Temperature (°C)	Zn	Cu	Ni	Cr	Pb	As	Se	Cd	Ag
Ballona	7	26	19.4	0.14 ± 0.07	0.09[a] ± 0.03	0.05 ± 0.03	0.06[a] ± 0.02	0.16 ± 0.07	0.28[a] ± 0.14	0.21[a] ± 0.05	0.05[a] ± 0.01	0.05[a] ± 0.01
Malibu	7.4	5	21.5	0.03 ± 0.02	0.02 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.05 ± 0.02	0.05 ± 0.03	0.03 ± 0.01	ND[b]	0.01 ± 0.01
Mugu	7	25.5	19	0.06 ± 0.05	0.07 ± 0.03	0.03 ± 0.02	0.05[a] ± 0.01	0.21[a] ± 0.03	0.22[a] ± 0.02	0.26[a] ± 0.11	0.05[a] ± 0.01	0.05[a] ± 0.01
Detection limit				0.03	0.009	0.008	0.0006	0.004	0.006	0.002	0.0006	0.001

[a] $p < 0.05$ (student t-test) compared to Malibu concentration.
[b] ND: Not detectable.

TABLE 3

Trace metal concentrations of selected species in three southern California coastal wetlands (mean ± SD; μg g^{-1} dry wt).

Species	Sample site	Size (cm)	N[a]	Zn	Cu	Ni	Cr	Pb	As	Se	Cd	Ag
F. parvipinnis	Malibu Mouth	4.5–6.0	11	132 ± 9.6	3.5 ± 0.8	ND[b]	2.8 ± 0.2	ND	ND	ND	0.20 ± 0.02	ND
	Ballona Mid	2.5–4.5	15	12 ± 10	4.1 ± 0.3	16 ± 1.3	30 ± 3.3	ND	ND	ND	0.30 ± 0.02	0.50 ± 0.08
A. affinis	Malibu Lagoon	8.5–9.7	15	85 ± 11	2.7 ± 1.4	8.1 ± 1.8	14 ± 2.2	0.80 ± 0.1	ND	ND	0.30 ± 0.1	0.40 ± 0.1
	Mugu Mouth	13.0–15.0	2	150 ± 15	7.5 ± 0.6	12 ± 1.8	24 ± 3.2	0.90 ± 0.3	ND	ND	0.30 ± 0.07	0.30 ± 0.08
G. mirabilis	Ballona Mouth	6.5–10.0	7	94 ± 4.7	1.9 ± 0.7	ND	ND	1.0 ± 0.9	ND	0.50 ± 0.7	ND	0.30 ± 0.1
	Ballona Back	7.0–9.5	5	99 ± 5.5	2.5 ± 0.2	1.3 ± 1.4	1.9 ± 0.1	2.2 ± 0.5	3.1 ± 1.0	0.80 ± 0.7	0.20 ± 0.1	0.30 ± 0.2
L. armatus	Ballona Mo/Mid	5.5–7.0	5	77 ± 10	5.7 ± 0.7	6.3 ± 0.8	14 ± 2.6	0.80 ± 0.7	1.2 ± 1.4	ND	0.30 ± 0.1	ND
	Mugu Mo/Mid	8.8–9.0	4	36 ± 5.6	2.4 ± 0.6	2.6 ± 0.4	4.6 ± 0.8	ND	1.4 ± 0.8	ND	ND	ND
	Mugu Mid	2.5–4.5	18	290 ± 160	12 ± 6.2	37 ± 17	55 ± 25	0.80 ± 1.5	ND	ND	0.90 ± 0.4	0.60 ± 0.8
M. galloprovincialis	Mugu Mouth	5.2–7.0	9	75 ± 23	5.8 ± 1.8	11 ± 3.3	17 ± 5.5	0.80 ± 0.4	2.8 ± 1.9	1.7 ± 1.3	0.90 ± 0.4	ND
T. californianus	Malibu Mid	5.0–6.5	8	190 ± 7.2	11 ± 0.5	6.5 ± 2.1	4.7 ± 0.3	ND	4.3 ± 1.4	2.9 ± 2.3	0.70 ± 0.05	0.40 ± 0.2
	Ballona Lagoon	6.0–8.0	13	650 ± 9.7	440 ± 33	4.4 ± 1.7	5.4 ± 0.1	6.8 ± 0.5	8.5 ± 0.5	3.8 ± 1.9	0.60 ± 0.2	5.9 ± 0.4
Detection limit				8	1	1	1	0.5	1	1	0.2	0.3

[a] N: Number of individuals.
[b] ND: Not detectable.

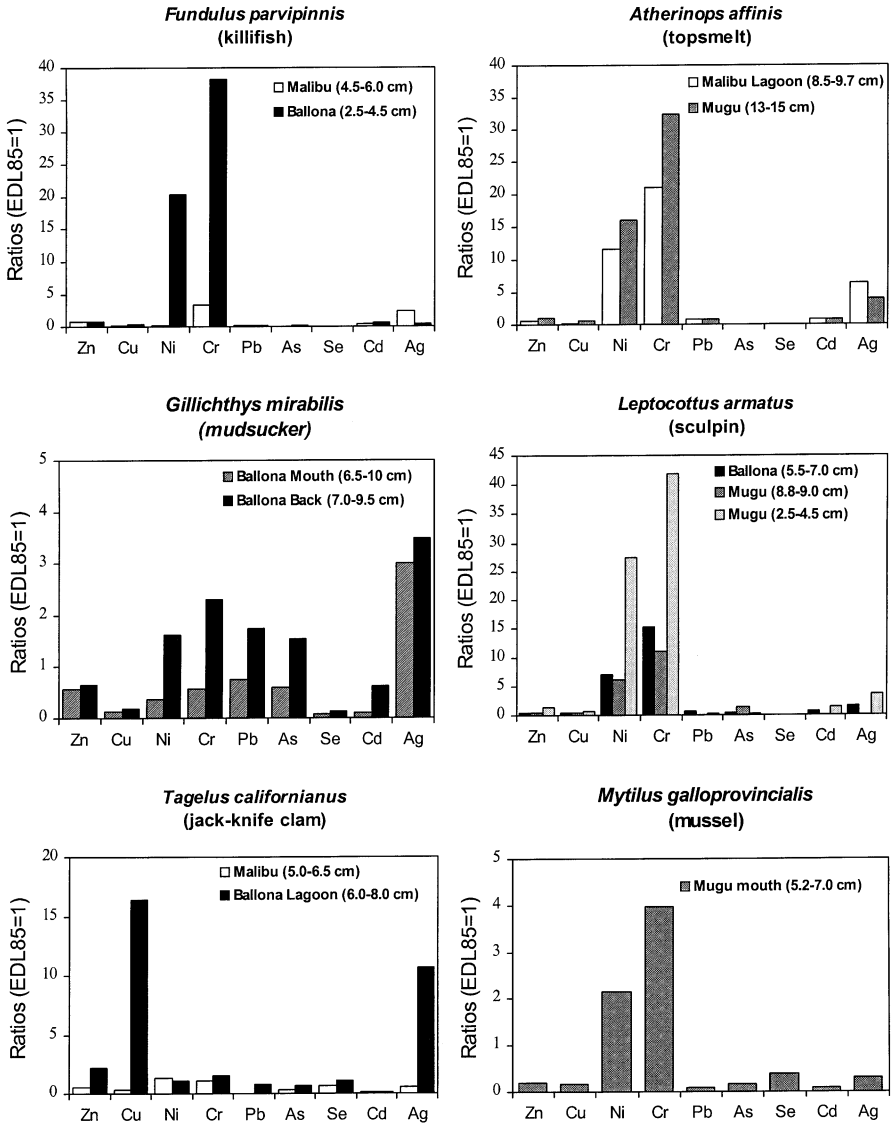

Fig. 2 EDL ratios (mean metal concentration/EDL85) for six wetland species. $N \geqslant 4$ for all samples except $N = 2$ for *A. affinis* at Mugu.

possibly be attributed to the slightly larger sizes used in our collections, natural or seasonal variation, or sampling effects. Both our results and those of Que Hee and MacNeil (1994) showed that the EDL85 was exceeded by almost all fish and bivalves sampled for chromium, nickel, silver, and to a lesser extent, arsenic. NOAA (1991) reported higher copper and lead concentrations and lower chromium concentrations in *Mytilus* sampled in Marina del Rey (from the early and mid 1980s) compared to our Mugu *Mytilus*. Recycling and waste minimization measures at industrial emission sources have led to declines in sediment chromium levels from some of the more contaminated California coastal areas during the 1980s (NOAA, 1991). This trend is not yet apparent in biota, but may in the future be indicated by lowered concentrations in mussels.

Lead concentrations, although slightly elevated at Ballona, reveal concentrations below the Median International Standard (MIS) [3] of 2.0 ppm (wet weight) for both fish and shellfish. Since organs would be expected to accumulate metals to a higher degree than edible portions, this would be indicative of low levels at this location. Mussels in the State Mussel Watch Program varied between 0.7 and 87 ppm (dry weight) during 1972–1973 and 1980–1986 and between 0.04 and 10.96 (wet weight) during 1987–1993 (SWRCB, 1995; SWRCB, 1993; NOAA, 1991). The increasing use of unleaded gasoline has resulted in declines in lead (WRCB, 1990).

[3] The Median International Standard (MIS) for fish and shellfish are taken from Nauen (1983) and are available for As, Cd, Cr, Cu, Pb, Se, and Zn. The MIS for fish is based on edible portions and thus is used only as a rough estimate for comparison with the whole fish samples analysed in this study.

TABLE 4
Trace metal concentrations in seawater (μg ml^{-1}) and biota (μg g^{-1} dry wt) from Southern California.

Location, date	Species	Zn	Cu	Ni	Cr	Pb	As	Se	Cd	Ag	References
Marina del Rey, 1980/1982	*M. galloprovincialis*	–	26.4	–	2.7	68	–	–	–	0.69	NOAA (1991)
Marina del Rey, 1986	*M. galloprovincialis*	–	10.9	–	3.7	23	–	–	–	0.73	NOAA (1991)
Malibu Lagoon, 1993	*F. parvipinnis*	49 ± 3[a]	2.6 ± 0.2	0.61 ± 0.6	1.6 ± 0.2	4.1 ± 0.5	5.1 ± 1	2.4 ± 1	0.18 ± 0.07	5.1 ± 1	Que Hee and MacNeil (1994)
		44 ± 20[b]	5.9 ± 5	0.62 ± 0.6	1.7 ± 1	2.9 ± 2	5.6 ± 3	4.0 ± 1	0.19 ± 0.1	5.9 ± 5	

[a] Total length = 2–3.5 cm.
[b] Total length = 3.5–5.5 cm.

Chromium and nickel were the most prominent metals in almost all of the species at all sites. Assessment of the risk due to chromium is difficult without knowing the chromium species; we measured only total chromium to be consistent with previous California studies and health standards. Some samples of California mussels from the State Mussel Watch Program during the period 1975–1977 exceeded the chromium MIS for shellfish of 1.0 ppm (wet weight). Similarly, our Mugu *Mytilus* (2.46 ppm wet weight) exceeded the MIS standard and Ballona Lagoon *Tagelus* (0.97 ppm wet weight) was close enough to the standard to be of concern.

Nickel concentrations are generally low in the aquatic environment. The nickel tissue and water concentrations determined in this study were below the Maximum Tissue Residue Level in inland surface waters (28.0 mg/kg) and the Water Quality Objective (0.6 mg/l) of SWRCB (1993), respectively. Thus, while nickel concentrations in biota were high relative to other concentrations in California (i.e., most EDL85 ratio >1 and many >10), they may not be presenting an ecological risk.

Although not as prominent (in terms of elevated EDL85 ratios) as chromium and nickel, cadmium, copper, lead, and silver are the most toxic of the metals measured in this study. High biota concentrations of these metals were found mostly at Ballona. Crustaceans are the most sensitive marine species to cadmium toxicity (Phillips, 1980b; Sadiq, 1992), with lethality possible at concentrations of 14.8–420 ppb in water (Eisler, 1985). Water concentrations at both Ballona and Mugu were at the lower end of this range (50 ± 10 ppb) and mollusc cadmium concentrations were well below the MIS shellfish standard of 1.0 ppm (wet weight).

Fish are able to closely regulate internal copper concentrations and fish muscle typically contains 0.2–2.5 μg/g (wet weight) (Thompson, 1990), and all study fish were within this range. The MIS for shellfish of 20.0 ppm (wet weight) was exceeded by *Tagelus* at Ballona Lagoon (78.5 μg/g wet weight). This high level may be explained by this region's urban character and proximity to Marina del Rey, the fourth most copper-contaminated site in California following the Newport shipyards, the Palos Verdes shelf, and San Diego Harbor (NOAA, 1991). NOAA (1991) determined that urban bays had the highest sediment copper concentrations and that Marina del Rey was among the few sites that had exhibited high copper concentrations in mussels (exceeding the MIS) and in sediments. These trends were found to be consistent with the historical use of copper-based ship coatings (NOAA, 1991).

High silver concentrations found in the two species of water-column fish at Malibu, *Fundulus* and *Atherinops*, and in the bivalve *Tagelus* at Ballona may indicate a problem with silver in these regions. Some species are sensitive to silver toxicity and concentrations in water as low as 0.5–14 ppb have been shown

to be lethal or extremely detrimental to the embryonic stages of clams, fish, mussels, sea urchins and phytoplankton (Luoma *et al.*, 1995; Berthet *et al.*, 1992). This water concentration was exceeded at all three wetlands. Since natural sources of silver are rare in coastal and estuarine waters (Sanudo-Willhelmy and Flegal, 1992), the presence of high silver loads is a good indication of anthropogenic inputs at Ballona and, to a lesser extent, Mugu and Malibu.

In general, the pattern of metal concentrations followed our expectations based on land uses in the watersheds, with high levels of metals in Ballona and Mugu and lower levels in Malibu. The elevated metal levels at Ballona, in particular, are not surprising given the prevalence of industrial activities, boating activities and urban runoff in the area. While Ballona and Mugu appear to be the most metal-contaminated sites, the high levels and potential toxicity of nickel, chromium and silver indicate that aquatic biota at all three sites are facing significant health risks. This risk may also extend to the various local and migratory waterfowls that feed in these wetlands. Chromium levels exceed available standards at all three sites and although silver health standards are not available, body burdens and water concentrations exceed recommended levels. Both chromium and silver levels also appear to have increased over the past 25 years. Further study should focus on mitigation efforts in order to protect these and other wetland regions.

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