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Heavy Metals in Estuarine Shellfish from Oregon

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Abstract. The concentrations of Hg, Zn, Mn, Fe, Cu, and Cd were determined in marine shellfish from the Oregon coast. The levels of these metals in both crustaceans and molluscs were generally typical of those reported from other geographic areas. The primary exception was Cd, which in crustaceans was 5 to 40 times lower and in three of the six marine bivalve molluscs studied was 5 to 25 times lower than that found in most previous studies. The low concentrations of Cd may be due to the lower level and types of industrial activity in coastal Oregon estuaries compared to other regions of the world, and/or to a lower rate of input of this metal from natural weathering processes in this region. No significant variations due either to season or geographical location were apparent in the three principal shellfish species studied.

Concern for the contamination of natural environments with heavy metals has become widespread, derived both from the potential for deleterious effects on the biota (Bryan 1971; Eisler 1971; Thurberg *et al.* 1973) and from possible human health hazards where such species are consumed by man (Takeuchi 1972). Elevated metal concentrations in marine organisms are restricted to estuaries and the narrow coastal margin and are associated with surface runoff of coastal streams, drainage from industrial areas, the disposal of solid or liquid wastes, and various ship-related inputs (Eganhouse and Young 1976; Preston 1973; Taylor 1974; Young *et al.* 1973). Human populations, concentrated in coastal regions, can mobilize metals to the marine environment in amounts similar to or even exceeding those introduced through continental weathering processes.

Certain heavy metals concentrate in marine food webs (Buhler *et al.* 1975), and filter feeding organisms such as bivalve molluscs often serve as important environmental sinks (Pringle *et al.* 1968). The principal objective of this study was to obtain information on the concentrations of six metals in selected shellfish from relatively unpolluted coastal areas in Oregon. The information resulting from examining several species including some commonly consumed by humans, could provide a baseline both in terms of mean metals concentrations and seasonal variability. In addition, the possibility that metal concentrations in shellfish from certain Oregon estuaries may be indicative of the relative degree of natural or anthropogenic contamination by heavy metals has been examined.

Materials and Methods

Marine molluscs and crustaceans were collected from various Oregon estuaries and open coast locations (Figure 1). Characteristics of the sampling locations, such as size of drainage basin, level of freshwater input, human population levels, degree of industrialization and nature of industrial activities within the riverine systems are summarized in Table 1.

Recreationally important shellfish, including cockles (*Clinocardium nuttallii*), softshell clams (*Mya arenaria*) and the commercially important Dungeness crab (*Cancer magister*), were collected quarterly in 1972 from Oregon estuaries. Additional samples were obtained on an irregular basis in 1970, 1971, and 1974. Other molluscan and crustacean species collected irregularly during 1971 and 1972 were: the freshwater clams, *Anodonta* sp. and *Corbicula fluminea;* the ghost shrimp, *Callianassa californiensis;* the sand shrimp, *Crangon franciscorum;* the spotted shore crab, *Hemigrapsus nudus;* the mussels, *Mytilus californianus* and *Mytilus edulis;* the carnivorous gastropod, *Nucella lamellosa;* the herbivorous gastropod *Tegula funebralis;* and the marine clams, *Protothaca staminea* and *Tre-*

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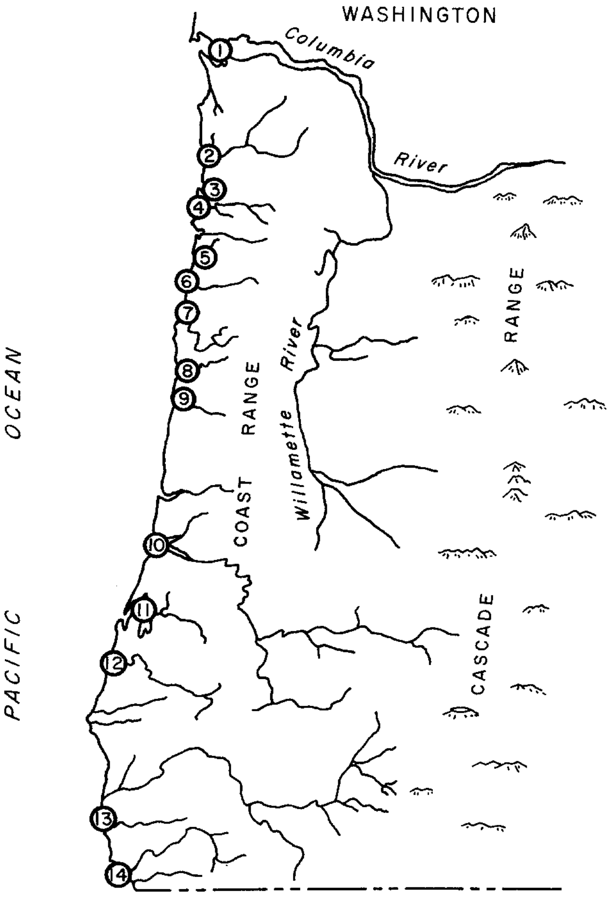

Fig. 1. Location of sampling stations along the Oregon coast

sus capax. Animals were rinsed, placed in plastic bags, and frozen for subsequent analysis.

Analyses were performed as described previously (Buhler *et al.* 1975; Phillips and Buhler 1980) on the rinsed whole soft tissues of clams and other molluscs and on hepatopancreas and muscle tissues dissected from crustaceans. Tissues were digested by boiling under reflux for three hr with concentrated nitric acid and 30% hydrogen peroxide. Mercury (Hg) was analyzed by flameless atomic absorption spectrophotometry using a Coleman Model 50 mercury analyzer. Zinc (Zn), manganese (Mn), iron (Fe), and copper (Cu) were measured in a Perkin-Elmer Model 403 atomic absorption spectrophotometer. Cadmium (Cd) was determined with the same instrument equipped with a Model HGA-2000 graphite furnace after ammonium pyrrollidine dithiocarbamate chelation and extraction of the digestion mixture with methyl isobutylketone (Koirtyohann and Wen 1973). Samples were analyzed by the method of additions and the accuracy of the analytical methods was established by the periodic analysis of a National Bureau of Standards bovine liver reference standard.

Results and Discussion

The mean concentrations of six heavy metals in the muscle and hepatopancreas tissues of *C. magister*, and in whole soft tissues of *C. nuttallii* and *M. arenaria*, from all sample sites along the Oregon coast are given in Table 2. Seasonal and geographic comparisons of metal concentrations are shown for *C. magister* in Table 3, for *M. arenaria* in Table 4 and for *C. nuttallii* in Table 5. The levels of Hg, Cd, and Zn in other shellfish species sampled on an irregular basis are presented in Table 6.

Seasonal and Geographic Variations

No persistent differences in metal concentrations with sampling location were noted for the three major species and ten estuaries studied (Tables 3–5). The results are consistent with the relatively low degree of industrialization of the bays examined (Table 1) and the absence of any major differences in mining or weathering inputs into the streams that supply these estuaries. In addition, there were no consistent seasonal trends in the present study, with the possible exception of Hg (Tables 3–5). A tendency for higher concentrations of this metal to occur during the spring and summer months was observed in the three principle species of this study. These increases varied with sampling location but not in a manner similar for each species. Concentrations of nine trace metals in the Pacific oyster *Crassostrea gigas* from the Washington coast similarly failed to show a significant seasonal variation (Pringle *et al.* 1968).

Phillips (1976) observed seasonal variation in the concentrations of Zn, Cd, and Cu in *Mytilus edulis* from Australia, ascribed in part to variations in the wet weight. The source of seasonal fluctuation in wet weight was uncertain but may have been due to differences in nutritional or sexual status of the organisms at different times of the year. Bryan (1973) observed seasonal variations of metals in scallops and suggested that alterations in the metal content of phytoplankton may have been responsible.

Crustaceans

The concentrations of Hg, Zn, and Fe found in *C. magister* (Table 2) and Hg and Zn in *C. californiensis, C. franciscorum* and *H. nudus* (Table 6) from Oregon were comparable to levels previously reported in other crustaceans and in other geographic locations (Fowler *et al.* 1975; Freeman *et al.* 1974; Reimer and Reimer 1975; Zook *et al.* 1976). Concentrations of Cu in *C. magister* muscle were also similar to those reported for four other decapods (Bryan 1964; Fowler *et al.* 1975; Topping 1973). In *C. magister* hepatopancreas, the concentrations of

Table 1. Characteristics of sampling locations shown in Figure 1

Sampling station	Location	Physical characteristics: Total estuarine area[a] (A)	Size of drainage basin (mi^2)	Mean annual freshwater input[b] (ac−ft × 10^3)	Human population + pollutional characteristics: Estimated human population[c]	Municipal sewage discharge[b,d]	Relative degree of industralization[b,e]	Comments
1	Columbia River	93,782	259,000[f]	192,575	>1,000,000	+	+++++	Pulp mills, shipping, various industries
2	Nehalem Bay	2,309	855[b]	2,700	1,188[b]	−	+	
3	Tillamook Bay	8,289	540[b]	>2,203		+	++	Seafood processing
4	Netarts Bay	2,325	14	42	930	−		
5	Nestucca Bay	1,000	322	1,600	695	+	+	
6	Salmon River	204	75	450	65	−		
7	Siletz Bay	1,187	373	1,800	1,203	+	+	
8	Yaquina Bay	3,910	253	780	8,381	+	+++	Pulp mill, seafood processing
9	Alsea Bay	2,146	474	1,500	900	+	+	
10	Umpqua River	6,830	4,560	6,700	>5,269	+	++	Pulp mill, seafood processing
11	Coos Bay	12,380	605	2,200	32,092	+	++++	Pulp mill, shipping, seafood processing
12	Coquille Bay	771	1,058	2,400	9,180	+	+	
13	Open coast	—	—	—	—	−		2 mi north of Pistol River
14	Open coast—Brookings	—	—	—	—	+	+	Sampled near municipal discharge

[a] Bourke *et al.* (1971)
[b] Percy *et al.* (1974)
[c] Human population of communities on estuary or riverine system
[d] Municipal sewage discharge present (+) or absent (−)
[e] Relative degree of industrialization indicated by the number of pluses
[f] *Anonymous* (1973)

Table 2. Concentrations of metals in three species of shellfish from all sites in Oregon sampled during 1970–1974 (expressed as μg/g wet weight)[a]

Metal	Dungeness crab (*C. magister*) Muscle	Hepatopancreas	Cockles (*C. nuttallii*)[b]	Softshell clam (*M. arenaria*)[b]
Hg	0.108 ± 0.084 (180)	0.098 ± 0.062 (131)	0.019 ± 0.009 (71)	0.025 ± 0.018 (139)
Cd	0.022 ± 0.020 (124)	0.149 ± 0.099 (98)	0.022 ± 0.031 (59)	0.028 ± 0.021 (111)
Zn	41.9 ± 3.35 (166)	21.2 ± 8.10 (123)	10.0 ± 2.42 (62)	10.7 ± 3.8 (110)
Mn	1.28 ± 0.754 (73)	6.67 ± 6.79 (59)	6.02 ± 4.45 (32)	24.4 ± 22.8 (31)
Fe	5.71 ± 4.40 (73)	40.6 ± 34.0 (59)	460 ± 360 (47)	934 ± 711 (67)
Cu	10.1 ± 4.41 (73)	27.5 ± 22.6 (59)	1.24 ± 0.445 (47)	2.54 ± 1.0 (67)

[a] Mean ± S.D. Number of animals expressed in parentheses
[b] Total soft tissues

Table 3. Concentration of metals in tissues of Dungeness crab (*Cancer magister*) from Oregon estuaries (expressed as μg/g wet weight)[a]

Collection site and date (Mo/Yr)	Concentration, μg/g wet weight Hg	Cd	Zn
Muscle			
Tillamook Bay			
2/71	0.085 ± 0.049 (13)	0.011 ± 0.007 (6)	37.5 ± 7.2 (10)
1/72	0.136 ± 0.152 (8)	0.019 ± 0.006 (6)	42.2 ± 7.8 (6)
4/72	0.092 ± 0.081 (3)	0.007 ± 0.003 (3)	40.9 ± 4.4 (3)
7/72	0.136 ± 0.056 (8)	0.022 ± 0.009 (6)	36.2 ± 8.8 (8)
10/72	0.059 ± 0.028 (8)	0.029 ± 0.032 (6)	43.1 ± 8.8 (8)
Netarts Bay			
2/71	0.124 ± 0.117 (10)	0.016 ± 0.027 (5)	36.8 ± 9.1 (8)
1/72	0.101 ± 0.030 (6)	0.014 ± 0.004 (6)	45.6 ± 2.6 (6)
4/72	0.097 ± 0.039 (7)	0.016 ± 0.014 (6)	41.0 ± 7.5 (6)
7/72	0.103 ± 0.032 (8)	0.012 ± 0.008 (6)	43.5 ± 7.6 (8)
Yaquina Bay			
12/71	0.093 ± 0.050 (6)	0.059 ± 0.024 (6)	40.5 ± 6.4 (6)
Umpqua River Estuary			
7/72	0.078 ± 0.029 (8)	0.031 ± 0.031 (6)	42.4 ± 10.6 (8)
10/72	0.088 ± 0.038 (8)	0.027 ± 0.015 (6)	50.4 ± 4.9 (8)
Coos Bay			
12/71	0.097 ± 0.070 (6)	0.019 ± 0.016 (6)	30.7 ± 3.1 (6)
4/72	0.153 ± 0.052 (16)	0.015 ± 0.009 (6)	50.6 ± 10.0 (16)
7/72	0.113 ± 0.061 (8)	0.018 ± 0.008 (6)	46.0 ± 7.5 (8)
9/72	0.051 ± 0.033 (8)	0.012 ± 0.003 (6)	44.8 ± 6.5 (8)
Coquille Bay			
3/71	0.085 ± 0.032 (13)	0.051 ± 0.039 (6)	31.6 ± 4.1 (6)
4/72	0.141 ± 0.110 (9)	0.033 ± 0.014 (6)	48.8 ± 9.6 (9)
7/72	0.126 ± 0.103 (8)	0.019 ± 0.011 (6)	45.4 ± 8.4 (8)
10/72	0.031 ± 0.019 (8)	0.021 ± 0.014 (6)	40.0 ± 7.2 (8)
Hepatopancreas			
Tillamook Bay			
1/72	0.083 ± 0.069 (8)	0.166 ± 0.044 (6)	13.1 ± 3.3 (6)
4/72	0.081 ± 0.055 (3)	0.199 ± 0.038 (3)	17.2 ± 4.4 (3)
7/72	0.165 ± 0.128 (8)	0.228 ± 0.214 (6)	18.5 ± 5.7 (8)
10/72	0.060 ± 0.029 (8)	0.150 ± 0.070 (6)	17.1 ± 8.0 (8)
Netarts Bay			
1/72	0.066 ± 0.025 (6)	0.064 ± 0.030 (6)	20.4 ± 5.2 (6)
4/72	0.073 ± 0.018 (7)	0.100 ± 0.046 (5)	16.9 ± 3.2 (5)
7/72	0.112 ± 0.045 (8)	0.163 ± 0.120 (6)	21.0 ± 10.6 (8)
Yaquina Bay			
12/71	0.058 ± 0.019 (6)	0.141 ± 0.051 (6)	20.6 ± 7.4 (6)
Umpqua River Estuary			
7/72	0.066 ± 0.032 (8)	0.169 ± 0.050 (6)	27.7 ± 6.7 (8)
10/72	0.103 ± 0.049 (8)	0.152 ± 0.075 (6)	22.0 ± 4.2 (8)
Coos Bay			
12/71	0.085 ± 0.026 (6)	0.091 ± 0.077 (6)	16.5 ± 6.2 (6)
4/72	0.148 ± 0.050 (16)	0.107 ± 0.044 (6)	19.2 ± 7.1 (12)
7/72	0.105 ± 0.052 (8)	0.109 ± 0.044 (6)	19.1 ± 4.5 (8)
9/72	0.062 ± 0.048 (8)	0.083 ± 0.028 (6)	21.7 ± 7.2 (8)
Coquille Bay			
4/72	0.158 ± 0.068 (9)	0.275 ± 0.170 (6)	35.7 ± 10.2 (9)
7/72	0.094 ± 0.048 (8)	0.122 ± 0.067 (6)	20.6 ± 6.1 (8)
10/72	0.058 ± 0.013 (8)	0.206 ± 0.089 (6)	23.6 ± 7.5 (6)

Cu were similar to those seen in *C. pagurus* (Topping 1973), but were 4 to 16 times lower than reported for the same tissues of *Homarus vulgaris* (Bryan 1964; Topping 1973). Variation in tissue Cu concentrations in crustaceans may be more related to variation in hemocyanin content of the blood than to levels of environmental contamination. The Mn concentration of *C. magister* muscle, 1.28 μg/g (Table 2), was three times that found by Fowler *et al.* 1975) in *Cancer anthonyi*.

Table 3. (cont'd)

Collection site and date (Mo/Yr)	Concentration, μg/g wet weight		
	Mn	Fe	Cu
Muscle			
Tillamook Bay			
2/71	1.57 ± 1.04 (5)	11.8 ± 5.5 (5)	6.80 ± 1.08 (5)
1/72	1.78 ± 0.40 (3)	7.81 ± 2.45 (3)	8.79 ± 2.72 (3)
4/72	1.19 ± 0.14 (3)	8.20 ± 0.98 (3)	15.9 ± 11.4 (3)
7/72	1.09 ± 0.20 (6)	2.99 ± 1.07 (6)	11.0 ± 4.6 (6)
10/72	—	—	—
Netarts Bay			
2/71	—	—	—
1/72	1.49 ± 0.04 (6)	7.46 ± 3.65 (6)	14.9 ± 3.2 (6)
4/72	—	—	—
7/72	0.82 ± 0.26 (6)	1.80 ± 0.67 (6)	13.2 ± 5.5 (6)
Yaquina Bay			
12/71	1.61 ± 0.21 (6)	9.49 ± 5.49 (6)	10.2 ± 3.7 (6)
Umpqua River Estuary			
7/72	0.79 ± 0.25 (6)	1.68 ± 0.81 (6)	9.24 ± 2.48 (6)
10/72	—	—	—
Coos Bay			
12/71	1.72 ± 0.29 (6)	6.18 ± 0.28 (6)	9.74 ± 3.29 (6)
4/72	—	—	—
7/72	0.70 ± 0.34 (5)	1.56 ± 0.24 (5)	7.54 ± 2.72 (5)
9/72	—	—	—
Coquille Bay			
3/71	2.85 ± 1.34 (5)	11.7 ± 3.4 (5)	7.28 ± 2.08 (5)
4/72	1.42 ± 0.60 (5)	7.39 ± 2.37 (5)	9.11 ± 2.79 (5)
7/72	0.53 ± 0.02 (6)	1.77 ± 0.80 (6)	7.21 ± 2.37 (6)
10/72	0.71 ± 0.31 (5)	3.73 ± 1.52 (5)	11.7 ± 3.4 (5)
Hepatopancreas			
Tillamook Bay			
1/72	13.8 ± 12.3 (3)	41.7 ± 7.26 (3)	65.3 ± 41.8 (3)
4/72	3.73 ± 0.98 (3)	44.0 ± 27.8 (3)	48.9 ± 39.4 (3)
7/72	5.29 ± 1.96 (6)	23.8 ± 3.6 (6)	34.5 ± 33.0 (6)
10/72	—	—	—
Netarts Bay			
1/72	1.75 ± 0.14 (3)	49.6 ± 33.0 (3)	38.9 ± 22.3 (3)
4/72	—	—	—
7/72	6.06 ± 6.06 (6)	24.6 ± 14.5 (6)	30.6 ± 15.3 (6)
Yaquina Bay			
12/71	2.16 ± 0.81 (6)	99.8 ± 51.6 (6)	16.3 ± 6.5 (6)
Umpqua River Estuary			
7/72	5.20 ± 2.71 (6)	14.3 ± 5.1 (6)	16.0 ± 7.5 (6)
10/72	—	—	—
Coos Bay			
12/71	10.7 ± 9.6 (6)	32.6 ± 15.6 (6)	39.4 ± 21.4 (6)
4/72	—	—	—
7/72	5.14 ± 2.17 (4)	27.0 ± 5.0 (4)	11.9 ± 4.7 (4)
9/72	—	—	—
Coquille Bay			
4/72	18.9 ± 8.0 (5)	43.5 ± 25.7 (5)	21.3 ± 8.5 (5)
7/72	3.02 ± 1.14 (6)	52.9 ± 50.2 (6)	17.5 ± 10.3 (6)
10/72	5.22 ± 3.29 (5)	28.4 ± 22.1 (5)	16.2 ± 10.7 (5)

[a] Mean ± S.D. Number of animals analyzed indicated in parentheses

The concentration of Cd in crustacean tissue was generally much lower than reported previously (Eisler *et al.* 1972; Fowler *et al.* 1975; Topping 1973; Zook *et al.* 1976). Mean Cd levels in *C. magister* muscle and hepatopancreas were 0.022 and 1.49 μg/g, respectively (Table 2), and 0.032 μg/g in whole *H. nudus* (Table 6), values approximately 5 to 40 times lower than that found in the same tissues of

Table 4. Concentration of metals in softshell clams (*Mya arenaria*) from Oregon estuaries (expressed as μg/g wet weight)[a]

Collection site and date (Mo/Yr)	Hg	Cd	Zn	Mn	Fe	Cu
Nehalem Bay						
2/71	0.018 ± 0.004 (6)	0.068 ± 0.017 (6)	13.4 ± 2.8 (6)	—	—	—
Tillamook Bay						
1/72	0.014 ± 0.009 (10)	0.012 ± 0.009 (6)	6.36 ± 1.60 (6)	—	661 ± 317 (6)	1.63 ± 0.26 (6)
4/72	0.045 ± 0.017 (4)	0.037 ± 0.013 (4)	10.4 ± 2.2 (4)	—	1397 ± 1151 (4)	2.46 ± 0.97 (4)
7/72	0.028 ± 0.007 (4)	0.033 ± 0.008 (4)	10.1 ± 1.9 (4)	—	1446 ± 831 (4)	1.99 ± 0.06 (4)
10/72	0.017 ± 0.010 (4)	0.029 ± 0.006 (4)	11.0 ± 2.9 (4)	5.27 ± 1.70 (4)	363 ± 194 (4)	2.43 ± 1.22 (4)
Nestucca Bay						
4/71	0.020 ± 0.011 (6)	0.046 ± 0.015 (6)	11.8 ± 1.5 (6)	—	—	—
Salmon River Estuary						
4/71	0.018 ± 0.006 (5)	0.067 ± 0.006 (4)	7.64 ± 1.07 (4)	—	—	—
Siletz Bay						
4/71	0.019 ± 0.005 (6)	0.058 ± 0.025 (6)	9.22 ± 1.82 (6)	—	—	—
Yaquina Bay						
6/70	0.040 ± 0.010 (3)	—	—	—	—	—
11/70	0.016 ± 0.003 (6)	0.027 ± 0.005 (4)	6.99 ± 1.12 (4)	—	—	—
1/72	0.016 ± 0.009 (10)	0.018 ± 0.013 (6)	10.7 ± 0.8 (6)	23.2 ± 16.5 (5)	869 ± 330 (5)	1.93 ± 0.68 (5)
4/72	0.014 ± 0.006 (11)	0.001 ± 0.000 (3)	8.7 ± 1.1 (6)	—	1835 ± 845 (6)	2.69 ± 1.19 (6)
7/72	0.021 ± 0.007 (8)	0.001 ± 0.001 (6)	8.4 ± 3.4 (6)	—	705 ± 569 (6)	1.83 ± 0.42 (6)
9/72	0.014 ± 0.011 (4)	0.024 ± 0.008 (4)	18.3 ± 2.0 (4)	—	241 ± 110 (4)	3.46 ± 1.40 (4)
8/74	0.025 ± 0.010 (5)	0.007 ± 0.004 (6)	8.72 ± 1.43 (6)	27.4 ± 23.0 (6)	821 ± 319 (6)	4.24 ± 1.33 (6)
Alsea Bay						
6/70	0.050 ± 0.010 (3)	0.030 ± 0.009 (3)	—	—	—	—
Umpqua River Estuary						
1/72	0.017 ± 0.004 (9)	0.016 ± 0.006 (6)	9.04 ± 0.89 (6)	—	1378 ± 441 (6)	2.97 ± 0.49 (6)
4/72	0.019 ± 0.004 (4)	0.033 ± 0.006 (4)	8.6 ± 1.4 (4)	15.8 ± 11.8 (4)	714 ± 193 (4)	2.02 ± 0.21 (4)
7/72	0.012 ± 0.004 (4)	0.043 ± 0.014 (4)	11.8 ± 1.6 (4)	—	1473 ± 1111 (4)	3.21 ± 1.41 (4)
10/72	0.031 ± 0.014 (4)	0.034 ± 0.007 (4)	17.3 ± 3.5 (4)	—	—	—
Coos Bay						
3/71	0.074 ± 0.022 (6)	0.019 ± 0.004 (3)	10.6 ± 3.1 (3)	—	—	—
4/72	0.020 ± 0.004 (4)	0.007 ± 0.003 (4)	11.3 ± 1.6 (4)	18.9 ± 15.6 (4)	524 ± 118 (4)	2.34 ± 0.77 (4)
7/72	0.032 ± 0.012 (4)	0.016 ± 0.003 (4)	11.9 ± 1.4 (4)	34.7 ± 26.5 (4)	300 ± 144 (4)	2.23 ± 0.92 (4)
9/72	0.028 ± 0.006 (4)	0.018 ± 0.011 (4)	20.9 ± 2.3 (4)	—	—	—
Coquille Bay						
3/71	0.063 ± 0.012 (5)	0.027 ± 0.007 (5)	7.82 ± 0.42 (5)	—	—	—

[a] Total soft tissues. Mean ± S.D. Number of animals analyzed indicated in parentheses

other decapods. Since there is little loss of metals from estuarine systems (Turekian 1977), the results suggest that Oregon estuaries are relatively free of man-made Cd enrichments.

Molluscs

The metal profiles for *C. nuttallii* and *M. arenaria* are similar to one another (Table 2) although the concentrations of Mn, Fe, and Cu, were generally higher in *M. arenaria* than in *C. nuttallii*. Of the other molluscs examined, *Anodonta* sp., *C. fluminea* and *M. californianus* tended to have higher tissue Zn concentrations, and *M. edulis, P. staminea* and *T. capax* had similar Zn concentrations as *M. arenaria* and *C. nuttallii* (Tables 2 and 6). The concentrations of Hg were relatively alike in all bivalve molluscs examined and ranged from a low of 0.009 μg/g in *T. capax* to a high of 0.041 μg/g in *P. staminea* (Table 6). In *C. nuttallii* and *M. arenaria* Hg concentrations were 0.019 and 0.025 μg/g, respectively (Table 2).

Molluscan Cd concentrations were substantially more variable and ranged from a low of 0.001 μg/g in two collections of *M. arenaria* and one of *C. nuttallii* to a high of 1.99 μg/g in the turban snail *T. funebralis* (Table 6). The mean Cd concentrations from all collections of *C. nuttallii* and *M. arenaria* were near the lower end of the range of concentrations found in molluscs in this study, 0.022 and 0.028 μg/g, respectively (Table 2).

Table 5. Concentration of metals in cockles (*Clinocardium nuttallii*) from Oregon estuaries (expressed as μg/g wet weight)[a]

Collection site and date (Mo/Yr)	Hg	Cd	Zn	Mn	Fe	Cu
Tillamook Bay						
1/72	0.019 ± 0.006 (8)	0.011 ± 0.007 (6)	8.67 ± 1.61 (6)	—	—	—
4/72	0.018 ± 0.005 (4)	0.023 ± 0.004 (4)	9.07 ± 0.58 (4)	13.2 ± 1.2 (4)	1288 ± 115 (4)	1.94 ± 0.14 (4)
7/72	0.029 ± 0.019 (4)	0.026 ± 0.012 (4)	11.1 ± 0.2 (4)	11.9 ± 3.7 (3)	949 ± 323 (3)	2.09 ± 0.03 (3)
10/72	0.020 ± 0.004 (4)	0.018 ± 0.007 (4)	13.0 ± 2.7 (4)	7.63 ± 3.02 (4)	738 ± 226 (4)	1.53 ± 0.61 (4)
Netarts Bay						
2/71	0.019 (1)	0.20 (1)	7.83 (1)	—	—	—
7/72	0.014 ± 0.004 (4)	0.045 ± 0.005 (4)	11.0 ± 1.4 (4)	6.35 ± 2.59 (4)	161 ± 37 (4)	0.98 ± 0.02 (4)
Yaquina Bay						
12/71	0.011 ± 0.005 (6)	0.006 ± 0.006 (6)	6.91 ± 1.13 (6)	—	225 ± 62 (4)	1.32 ± 0.24 (4)
4/72	0.024 ± 0.006 (10)	0.006 ± 0.006 (6)	10.1 ± 1.0 (6)	—	613 ± 76 (5)	1.44 ± 0.10 (5)
7/72	0.024 ± 0.007 (8)	0.005 ± 0.004 (6)	8.9 ± 1.0 (6)	—	254 ± 69 (6)	1.30 ± 0.45 (6)
9/72	0.012 ± 0.005 (4)	0.013 ± 0.003 (4)	12.6 ± 4.1 (4)	3.63 ± 2.51 (4)	395 ± 71 (4)	0.99 ± 0.05 (4)
8/74	0.012 ± 0.007 (2)	0.001 ± 0.001 (2)	9.41 ± 0.81 (2)	3.32 ± 0.44 (2)	363 ± 7 (2)	1.17 ± 0.40 (2)
Coos Bay						
1/72	0.014 ± 0.005 (6)	0.015 ± 0.012 (5)	9.10 ± 0.87 (5)	1.93 ± 0.23 (5)	271 ± 61 (5)	0.75 ± 0.16 (5)
4/72	0.033 ± 0.004 (4)	0.040 ± 0.010 (4)	11.6 ± 2.2 (4)	—	—	—
7/72	0.011 ± 0.006 (4)	0.080 ± 0.022 (4)	8.88 ± 1.32 (4)	3.67 ± 0.79 (4)	200 ± 116 (4)	0.97 ± 0.05 (4)
9/72	0.012 ± 0.006 (4)	0.021 ± 0.002 (4)	13.3 ± 1.8 (4)	2.33 ± 1.65 (4)	215 ± 70 (4)	0.99 ± 0.03 (4)

[a] Total soft tissues. Mean ± S.D. Number of animals analyzed indicated in parentheses

Compared with molluscs from other geographic areas, Oregon molluscs were typical with respect to the concentrations of Zn, Mn, Cu, and Fe. For example, Pringle *et al.* (1968) found mean Zn concentrations of 17 and 20.6 μg/g in *M. arenaria* and *Mercenaria mercenaria,* respectively, from the East coast of the U.S. compared to mean Zn concentrations of 8 to 59 μg/g for Oregon coast bivalves (Tables 2 and 6). Similar comparisons between the present findings and those of Pringle *et al.* (1968) can be made for Cu and Mn. In addition, Cu and Zn concentrations in *C. nuttallii* and *M. arenaria* are comparable to those found in Atlantic coast surf clams, *Spisula solidissima,* and ocean quahogs, *Arctica islandica* (Wenzloff *et al.* 1979). Pringle *et al.* (1968) reported a mean Fe concentration of 405 μg/g in East coast *M. arenaria,* which compares favorably to values of 460 μg/g and 934 μg/g in *C. nuttallii* and *M. arenaria* (Table 2) from Oregon. However, East coast quahogs (*M. mercenaria*) contained only 30 μg/g of Fe (Pringle *et al.* 1968).

The concentrations of Hg in the eight species of bivalve molluscs analyzed in this study, averaging about 0.02 μg/g (Tables 2 and 6), were very comparable to those reported by other authors; for example, *Mya arenaria* and *Mercenaria mercenaria* (Freeman *et al.* 1974; Zook *et al.* 1976), *Crassostrea virginica* (Freeman *et al.* 1974; Reimer and Reimer 1975), *Mytilus californianus* (Eganhouse and Young 1976), and *Anodonta grandis* (Smith and Green 1975). In contrast, Schell and Nevisi (1977) reported Hg concentrations in *Mytilus edulis* and clams from Puget Sound, Washington of approximately 0.002 to 0.004 μg/g, values 5 to 10-fold lower than reported here. The reason for this difference is unknown.

Compared to the concentrations of Cd seen in bivalve molluscs from other geographic areas, Oregon bivalves tended to have lower Cd levels. The mean concentrations of Cd in *C. nuttallii* and *M. arenaria* from Oregon were only 0.022 and 0.028 μg/g (Table 2) compared with mean values from 0.184 to 0.27 μg/g for East coast *Mya arenaria* (Pringle *et al.* 1968; Zook *et al.* 1976) and from 0.122 to approximately 0.25 μg/g for East coast *Mercenaria mercenaria* (Pringle *et al.* 1968; Zook *et al.* 1976). Other Oregon bivalves generally had higher Cd levels than *C. nuttallii* and *M. arenaria,* concentration means up to 0.283 μg/g (Table 6), but were still appreciably lower than values reported elsewhere (Eisler *et al.* 1972; Eustace, 1974; Pringle *et al.* 1968; Wenzloff *et al.* 1979; Zook *et al.* 1976). The unusually low Cd levels found in bivalves from Oregon bays presumably reflects the general lack of industrial pollution and/or geological inputs in these estuaries.

Conclusions

Concentrations of several toxic metals in Oregon were well below the maximum concentrations gen-

Table 6. Concentration of metals in miscellaneous Oregon coastal species (expressed as μg/g wet weight)[a]

Collection site and date (Mo/Yr)	Hg	Cd	Zn
Anodonta sp.			
Columbia River			
2/72	0.023 (1)	0.042 (1)	25.5 (1)
4/72	0.025 ± 0.012 (4)	0.148 ± 0.065 (4)	51.7 ± 25.4 (4)
7/72	0.033 ± 0.023 (4)	0.132 ± 0.029 (4)	51.1 ± 12.5 (4)
10/72	0.033 ± 0.023 (4)	—	—
Callianassa californiensis[b]			
Netarts Bay			
2/71	0.014[d]	—	—
Corbicula fluminea			
Columbia River			
2/72	0.019 ± 0.023 (8)	0.009 ± 0.010 (6)	12.0 ± 3.5 (6)
4/72	0.016 ± 0.005 (4)	0.069 ± 0.005 (4)	13.4 ± 1.7 (4)
7/72	0.018 ± 0.008 (4)	0.103 ± 0.006 (4)	26.3 ± 3.9 (4)
Crangon franciscorum[b]			
Tillamook Bay			
2/71	0.059[e]	—	—
Hemigrapsus nudus[c]			
Oregon Coast, Brookings			
3/71	0.056 ± 0.023 (5)	0.032 ± 0.007 (3)	37.9 ± 0.7 (3)
Mytilus californianus			
Oregon Coast, Pistol River			
3/71	0.020 ± 0.005 (6)	0.147 ± 0.065 (4)	17.8 ± 8.1 (4)
Mytilus edulis			
Umpqua River Estuary			
1/72	0.016 ± 0.005 (16)	0.283 ± 0.147 (6)	9.70 ± 2.12 (6)
7/72	0.011 ± 0.002 (4)	0.262 ± 0.101 (4)	8.0 ± 0.7 (4)
10/72	0.018 ± 0.005 (4)	0.240 ± 0.081 (4)	17.8 ± 3.5 (4)
Nucella lamellosa			
Tillamook Bay			
2/71	0.035 ± 0.033 (18)	—	—
Protothaca staminea			
Netarts Bay			
2/71	0.015 ± 0.004 (5)	0.082 ± 0.014 (5)	8.62 ± 0.96 (5)
Oregon Coast, Brookings			
3/71	0.041 ± 0.012 (5)	0.202 ± 0.027 (5)	—
Tegula funebralis			
Oregon Coast, Brookings			
3/71	0.039 ± 0.012 (16)	1.99 ± 2.14 (4)	—
Tresus capax			
Netarts Bay			
2/71	0.009 (1)	0.025 (1)	7.82 (1)

[a] Total soft tissues unless indicated otherwise. Mean ± S.D. Number of animals analyzed indicated in parentheses
[b] Abdominal muscle
[c] Claw muscle
[d] Pooled sample from 20 animals
[e] Pooled sample from 39 animals

erally regarded as safe for human consumption. These limits, set by the United States Food and Drug Administration for Hg and by the National Health and Medical Research Council of Australia (MacKay *et al.* 1975) for Cd, Cu, and Zn, are 1.0, 2.0, 30 and 1,000 μg/g wet weight, respectively. The levels of these metals found in shellfish from Oregon bays, in this study, are among the lowest levels reported in the literature. The low values and the absence of any significant correlations between locations within Oregon estuaries suggest that the levels represent normal background concentrations of metals in the organisms examined and do not reflect a measurable degree of contamination from anthropogenic sources.

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