HANDBOOK OF CHEMICAL RISK ASSESSMENT

Health Hazards to Humans, Plants, and Animals

VOLUME 1

Metals

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Metals

Ronald Eisler, Ph.D.

U.S. Geological Survey
Patuxent Wildlife Research Center
Laurel, Maryland

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VOLUME 2

Organics

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VOLUME 2

Organics

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VOLUME 3

Metalloids, Radiation, Cumulative Index to Chemicals and Species

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About the Author

Ronald Eisler received his A.B. degree from New York University in biology and chemistry, and M.S. and Ph.D. degrees from the University of Washington in aquatic sciences and radioecology, respectively. He attended the University of Miami Marine Laboratory prior to military service. He is a member of the American Chemical Society, the American Fisheries Society, the Marine Biological Association of the United Kingdom, and the Society for Environmental Geochemistry and Health. Since 1955 he has authored more than 125 technical articles and books on contaminant hazards to living organisms.

From 1984 to the present, Dr. Eisler has been a senior research biologist at the U.S. Geological Survey, Patuxent Wildlife Research Center, located in Laurel, Maryland. Prior to 1984, he held the following positions, in order: bioscience advisor, U.S. Fish and Wildlife Service, Washington, D.C.; research aquatic toxicologist, U.S. Environmental Protection Agency, Narragansett, Rhode Island; fishery research biologist, U.S. Fish and Wildlife Service, Highlands, New Jersey; radiochemist, University of Washington Laboratory of Radiation Ecology, Seattle, Washington; aquatic biologist, New York State Department of Environmental Conservation, Raybrook, New York; biochemist, U.S. Army Medical Nutrition Laboratory, Medical Service Corps, Denver, Colorado.

He has held several adjunct professor appointments and was especially active at the Graduate School of Oceanography, University of Rhode Island; the Department of Oceanography and Marine Biology, Hebrew University of Jerusalem; and the Department of Biology, American University, Washington, D.C.

Dr. Eisler is currently on the editorial board of *Marine Ecology Progress Series* and other technical journals.

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Preface

Risk assessment is an inexact science. Successful risk assessment practitioners rely heavily on extensive and well-documented databases. In the case of chemicals entering the environment as a result of human activities, these databases generally include the chemical's source and use; its physical, chemical, and metabolic properties; concentrations in field collections of abiotic materials and living organisms; deficiency effects, in the case of chemicals essential for life processes; lethal and sublethal effects, including effects on survival, growth, reproduction, metabolism, mutagenicity, teratogenicity, and carcinogenicity; proposed regulatory criteria for the protection of human health and sensitive natural resources; and recommendations for additional research when databases are incomplete. Of the hundreds of thousands of chemicals discharged into the environment yearly from agricultural, domestic, industrial, mining, manufacturing, municipal, and military operations, there is sufficient information on only a small number to attempt preliminary risk assessments.

The chemicals selected for inclusion in this handbook series were recommended by environmental specialists of the U.S. Fish and Wildlife Service and other resource managers responsible for protecting our fish, wildlife, and biological diversity. Their choices were based on real or potential impact of each contaminant on populations of free-living natural resources — including threatened and endangered species — and on insufficient knowledge on how best to mitigate damage effects. Each chapter selectively reviews and synthesizes the technical literature on a specific priority contaminant in the environment and its effects on notably terrestrial plants and invertebrates, aquatic plants and animals, avian and mammalian wildlife, and other natural resources. Early versions of individual chapters were published between 1985 and 1999 in the *Contaminant Hazard Reviews* series of the U.S. Department of the Interior. This series rapidly became an important reference tool for contaminant specialists, scientists, educational institutions, state and local governments, natural resources agencies, business and industry, and the general public. More than 105,000 copies of individual reports were distributed in response to specific requests before supplies became exhausted. The current offering is updated to reflect the burgeoning literature in this subject area. I authored the original versions and the updates while stationed at the Patuxent Wildlife Research Center; however, all interpretations are my own and do not necessarily reflect those of the U.S. government. Moreover, mention of trade names or commercial products is not an endorsement or recommendation for use by the U.S. government.

Ronald Eisler, Ph.D.
Senior Research Biologist
U.S. Geological Survey
Patuxent Wildlife Research Center
Laurel, Maryland

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CHAPTER 1

Cadmium

1.1 INTRODUCTION

There is no evidence that cadmium (Cd) is biologically essential or beneficial; on the contrary, it has been implicated as the cause of numerous human deaths and various deleterious effects in fish and wildlife. In sufficient concentration, it is toxic to all forms of life, including microorganisms, higher plants, animals, and man. It is a relatively rare metal, usually present in small amounts in zinc ores, and is commercially obtained as an industrial by-product of the production of zinc, copper, and lead. Major uses of cadmium are in electroplating, in pigment production, and in the manufacture of plastic stabilizers and batteries. Anthropogenic sources of cadmium include smelter fumes and dusts, the products of incineration of cadmium-bearing materials and fossil fuels, fertilizers, and municipal wastewater and sludge discharges; concentrations are most likely highest in the localized regions of smelters or in urban industrialized areas (Hammons et al. 1978; U.S. Environmental Protection Agency [USEPA] 1980; Nriagu 1980, 1981; Hutton 1983b; Eisler 1985; Scheuhammer 1987; U.S. Public Health Service [USPHS] 1993; Cooke and Johnson 1996). Industrial consumption of cadmium in the United States, estimated at 6000 metric tons in 1968, is increasing; projected use in the year 2000 is about 14,000 tons, primarily for electroplating of motor parts and in the manufacture of batteries. The cadmium load in soils and terrestrial biota in other industrialized countries also appears to be increasing and is of great concern in Scandinavia (Tjell et al. 1983), Germany (Markard 1983), and the United Kingdom (Hutton 1983a).

1.2 ENVIRONMENTAL CHEMISTRY

Cadmium, as cadmium oxide, is obtained mainly as a by-product during the processing of zinc-bearing ores and also from the refining of lead and copper from sulfide ores (USPHS 1993). In 1989, the United States produced 1.4 million kg of cadmium (usually 0.6 to 1.8 million kg) and imported an additional 2.7 million kg (usually 1.8 to 3.2 million kg). Cadmium is used mainly for the production of nickel–cadmium batteries (35%), in metal plating (30%), and for the manufacture of pigments (15%), plastics and synthetics (10%), and alloys and miscellaneous uses (10%) (USPHS 1993).

Cadmium is a silver-white, blue-tinged, lustrous metal that melts at 321°C and boils at 767°C. This divalent element has an atomic weight of 112.4, an atomic number of 48, and a density of 8.642 g/cm^3. It is insoluble in water, although its chloride and sulfate salts are freely soluble (Windholz et al. 1976; USPHS 1993). The availability of cadmium to living organisms from their immediate physical and chemical environs depends on numerous factors, including adsorption and desorption rates of cadmium from terrigenous materials, pH, Eh, chemical speciation, and many other modifiers. The few selected examples that follow demonstrate the complex behavior of cadmium in aquatic systems.

Microbial extracellular polymeric substances (EPS) — ubiquitous features in aquatic environments — actively participate in binding dissolved overlying and pore-water metals in sediments. Organic sediment coatings in the form of bacterial EPS equivalent to about 0.5% organic matter can adsorb cadmium under estuarine conditions (Schlekat et al. 1998). EPS aggregates rapidly sorbed up to 90% of cadmium from solution. Changes in pH affected cadmium sorption, with the proportion of freed Cd to sorbed Cd changing from 90% at pH 5 to 5% at pH 9; desorption was enhanced with increasing salinity (Schlekat et al. 1998).

Adsorption and desorption processes are likely to be major factors in controlling the concentration of cadmium in natural waters and tend to counteract changes in the concentration of cadmium ions in solution (Gardiner 1974). Adsorption and desorption rates of cadmium are rapid on mud solids and particles of clay, silica, humic material, and other naturally occurring solids. Concentration factors for river muds varied between 5000 and 500,000 and depended mainly on the type of solid, the particle size, the concentration of cadmium present, the duration of contact, and the concentration of complexing ligands; humic material appeared to be the main component of river mud responsible for adsorption (Gardiner 1974). Changes in physicochemical conditions, especially pH and redox potential, that occur during dredging and disposal of cadmium-polluted sediments may increase chemical mobility and, hence, bioavailability of sediment-bound cadmium (Khalid et al. 1981). For example, cadmium in Mississippi River sediments spiked with radiocadmium was transformed from potentially available organic forms to more mobile and readily available dissolved and exchangeable forms (i.e., increased bioavailability) under regimens of comparatively acidic pH and high oxidation (Khalid et al. 1981). The role of dissolved oxygen and aquatic plants on cadmium cycling was studied in Palestine Lake, a 92-ha eutrophic lake in Kosciusko County, Indiana, a long-term recipient of cadmium and other waste metals from an electroplating plant. The maximum recorded concentration of dissolved cadmium in the water column was 17.3 μg/L; for suspended particulates, it was 30.3 μg/L (Shephard et al. 1980). During anaerobic conditions in the lake's hypolimnion, a marked decrease in the dissolved fraction and a corresponding increase in the suspended fraction were noted. The dominant form of cadmium was free, readily bioavailable, cadmium ion, Cd^{2+}; however, organic complexes of cadmium, which are comparatively nonbioavailable, made up a significant portion of the total dissolved cadmium. Cadmium levels in sediments of Palestine Lake ranged from 1.5 mg/L in an uncontaminated area of the lake to 805 mg/L near the outlet of a metal-bearing ditch that entered the lake (McIntosh et al. 1978). The dominant form of cadmium in sediments was as a carbonate. Levels of cadmium in water varied over time and between sites, but usually ranged from 0.5 to 2.5 μg/L. It is possible that significant amounts of cadmium are transferred from the sediments into rooted aquatic macrophytes and later released into the water after macrophyte death (natural or herbicide-induced), particularly in heavily contaminated systems. In Palestine Lake, cadmium levels in pondweed (*Potomogeton crispus*), a rooted aquatic macrophyte, were about 90 mg/kg dry weight; a maximum burden of 1.5 kg was retained by the population of *P. crispus* in the lake (McIntosh et al. 1978). Release of the total amount could raise water concentrations by a maximum of 1 μg/L. This amount was considered negligible in terms of the overall lake cadmium budgets; however, it might have limited local effects.

1.3 CONCENTRATIONS IN FIELD COLLECTIONS

Small amounts of cadmium enter the environment from the natural weathering of minerals, but most is released as a result of human activities such as mining, smelting, fuel combustion, disposal of metal-containing products, and application of phosphate fertilizers or sewage sludges (USPHS 1993). In 1988, an estimated 306,000 kg of cadmium entered the domestic environment as a result

Table 1.1 Cadmium Burdens and Residence Times in the Principal Global Reservoirs

Reservoir	Concentration	Total Cd in Reservoir, in Metric Tons	Residence Time
Atmosphere	0.00003 μg/m^3	1500	7 days
Oceans			
Dissolved	0.06 μg/kg	84,000,000	21,000 years
Suspended particulates (total)	1.0 mg/kg	1,400,000	—
Particulate organic matter	4.5 mg/kg	320,000	1.3 years
Freshwaters			
Dissolved	0.05 μg/kg	16,000	—
Sediments	0.16 mg/kg	100,000	3.6 years
Groundwater	0.1 μg/kg	400	—
Glaciers	0.005 μg/kg	82,000	—
Sediment pore waters	0.2 μg/kg	64,000,000	—
Swamps and marshes, biomass	0.6 mg/kg	3600	—
Biosphere			
Marine plants	2.0 mg/kg	400	18 days
Marine animals	4.0 mg/kg	12,000	—
Land plants	0.3 mg/kg	720,000	20 days
Land animals	0.3 mg/kg	6000	—
Freshwater biota	3.5 mg/kg	7000	3.5 years
Human biomass	50 mg/person	200	1–40 years
Terrestrial litter	0.6 mg/kg	1,300,000	42 years
Lithosphere (down to 45 km)	0.5 mg/kg	2.8×10^{13}	1 billion years

Adapted from Nriagu, J.O. (ed.) 1980. *Cadmium in the Environment. Part I: Ecological Cycling.* John Wiley, NY. 682 pp.

of human activities, mostly from industrial releases that were subsequently applied to soils (USPHS 1993). Where cadmium is comparatively bioavailable, these values are very near those that have been shown to produce harmful effects in sensitive biological species, as will be discussed later.

Loadings of cadmium in uncontaminated, nonbiological compartments extended over several orders of magnitude, with most of the cadmium in lithosphere and ocean reservoirs (Table 1.1; Korte 1983). Concentrations (μg/L or μg/kg) of cadmium reported in uncontaminated compartments ranged from 0.05 to 0.2 in freshwater, up to 0.05 in coastal seawater, from 0.01 to 0.1 in open-ocean seawater, 0.1 to 14 in stormwater runoff, up to 5000 in riverine and lake sediments, 30 to 1000 in marine sediments, 10 to 1000 in soils of nonvolcanic origin, as much as 142 in human dietary items, up to 4500 in soils of volcanic origin, 1 to 600 in igneous rock, up to 100,000 in phosphatic rock, and 0.001 to 0.005 μg/m^3 in air (Korte 1983; USPHS 1993). Higher values are reported in abiotic materials and living organisms from cadmium-contaminated environments, being highest near cadmium-emitting industries such as smelters, municipal incinerators, and fossil fuel combustion facilities (Eisler 1985; USPHS 1993).

Cadmium, unlike synthetic compounds, is a naturally occurring element, and its presence has been detected in more than 1000 species of aquatic and terrestrial flora and fauna. Concentrations of cadmium in selected species of biota are shown in Table 1.2; more extensive documentation was presented by Hammons et al. (1978), NRCC (1979), Jenkins (1980), and Eisler (1981). At least six trends are evident from Table 1.2. First, marine biota generally contained significantly higher cadmium residues than their freshwater or terrestrial counterparts, probably because total cadmium levels are higher in seawater. Second, cadmium tends to concentrate in the viscera of vertebrates, especially the liver and kidneys. Third, concentrations of cadmium are higher in older organisms than in younger stages; this relationship is especially pronounced in carnivores and marine vertebrates (Eisler 1984). Fourth, higher concentrations reported for individuals of a single species collected at several locations are almost always associated with proximity to industrial and urbanized areas or to point source discharges of cadmium-containing wastes. Fifth, background levels of cadmium in crops and other plants are usually <1.0 mg/kg (ppm). Little is known about the cadmium concentrations required to reduce plant yields; however, plants growing in cadmium-contaminated soils contain abnormally high residues that may be detrimental to plant growth and to animal and human consumers. Finally, it is apparent from Table 1.2 that species analyzed, season of collection, ambient cadmium levels, and sex of organism all modify concentrations of cadmium in organisms. In freshwater isopods, for example, cadmium was stored mainly in the hepatopancreas; cadmium concentrations were higher in juveniles than in adults; and seasonal fluctuations accounted for as much as 79% of the within-population variability (van Hattum et al. 1996).

Cadmium tends to accumulate in avian tissues in the order of kidney, liver, brain, bone, and muscle, with the highest concentrations in older birds and those found closest to a point source of cadmium (Pedersen and Myklebust 1993; Ferns and Anderson 1994; Garcia-Fernandez et al. 1996). In Norwegian birds, cadmium in tissues is generally higher in adults than in juveniles, higher in winter than in other seasons, positively correlated with tissue copper burdens, and positively correlated with selective consumption of seeds of the willow (*Salix* sp., known to have a high level of cadmium) and insects living on the willow (Hogstad 1996). However, cadmium concentrations in kidneys of canvasback ducks (*Aythya valisineria*) foraging on the submerged plant *Vallisneria americana* do not seem to reflect dietary cadmium intake (Lovvorn and Gillingham 1996). Cadmium and other metals also tend to concentrate in feathers, and molting frequency is important in the depuration process (Pilastro et al. 1993). Most birds molt their body feathers once a year, but some — such as Franklin's gulls (*Larus pipixcan*) — molt twice. Therefore, they have a greater opportunity than other birds to rid the body of contaminants (Burger and Gochfeld 1996).

The relationship between reported tissue cadmium concentrations of "unstressed" populations and hazard to the organism or its consumer is not well documented. For example, cadmium in eggs of successful nests of Cooper's hawks (*Accipiter cooperii*) collected in Arizona and New Mexico ranged from 0.015 to 0.24 mg/kg fresh weight (FW); concentrations were higher in eggs from unsuccessful nests (Snyder et al. 1973). Cadmium concentrations in the livers of breeding birds were higher in two declining colonies of puffins in St. Kilda and Clo Mor (12.9 to 22.3 mg/kg DW) than in colonies of puffins from other areas, or in livers of other seabirds examined (Parslow et al. 1972). However, the link to cadmium requires elucidation. Among marine teleosts, whole-body levels exceeding 5 mg/kg FW or 86 mg/kg ash weight (AW) in laboratory-stressed fish suggested that death would follow within 4 weeks (Eisler 1971). Marine bivalve molluscs occasionally contain more than 13 mg Cd/kg soft parts FW (Table 1.2), a level considered acutely toxic to humans (Zaroogian and Cheer 1976). However, many species of marine and terrestrial mammals frequently contained more than 20 mg Cd/kg FW in various tissues without apparent adverse effects to the organism (Table 1.2; Taylor et al. 1989; Gamberg and Scheuhammer 1994). The significance of cadmium residues to organism health is further developed later.

In terrestrial mammals, cadmium tends to accumulate with increasing age in kidneys and livers of hares (Venalainen et al. 1996), moles and shrews (Talmage and Walton 1991), deer (Musante et al. 1993), and caribou (*Rangifer tarandus*) and muskox (*Ovibos moschatus*; Gamberg and Scheuhammer 1994). Concentration of cadmium in the kidneys of deer increased from <0.002 mg/kg DW at age zero to 10.5 at age 7 in males; in females, these values were 6.5 mg/kg DW at age 3, 12.5 at age 7, and 20 to 40 at age 8 (Musante et al. 1993). Cadmium concentrations were positively correlated with age in kidneys of caribou and muskox collected from the Canadian Yukon and Northwest Territories between 1985 and 1990. The highest cadmium concentration measured, 166 mg/kg DW, was in renal tissue of a 15-year-old caribou. Caribou diets rely heavily on lichens which accumulate cadmium to a greater extent than do sedges (muskox diet; Gamberg and Scheuhammer 1994). The mean kidney concentration of 467 mg Cd/kg DW of beavers from a cadmium-contaminated estuary in Germany is the greatest reported in free-ranging herbivores (Nolet et al. 1994).

Table 1.2 Cadmium Concentrations in Field Collections of Selected Species of Plants and Animals (Values shown are in mg Cd/kg fresh weight [FW], dry weight [DW], or ash weight [AW].)

Ecosystem, Taxonomic Group, Organism, Tissue, Location, and Other Variables	Concentration (mg/kg or ppm)	References[a]
MARINE		
Algae and Macrophytes		
Brown alga, *Ascophyllum nodosum*; whole		
Norway locations		
Sorfjorden	6.0–15.0 DW	1
Eikhamrane	3.5–7.7 DW	2
Flak	<1.0 DW	2
Transferred from Eikhamrane to Flak, 120 days	<1.0–4.0 DW	2
Lofoten	<0.7 DW	3
Trondheimsfjord	<0.7–1.0 DW	3
Hardangerfjord	0.7–16.0 DW	3
United Kingdom locations		
Menai Straits	1.8 DW	4
Dulas Bay	1.5 DW	4
Bladder wrack, *Fucus vesiculosus*; whole		
Sorfjorden, Norway	8.6–10.6 DW	1
Tamar estuary, U.K.	1.8–9.0 DW	5
Menai Straits, U.K.	2.1 DW	4
Dulas Bay, U.K.	1.8 DW	4
Irish Sea	1.4 DW	6
Severn estuary, U.K.	220.0 DW	7
Algae, *Ulva rigida*; Venice, Italy; 1991–93	0.03–0.59 DW	65
Algae, *Ulva* spp.		
Goa, India	Max. 18.0 DW	65
Lebanon	Max. 2.3 DW	65
Hong Kong	Max. 0.7 DW	65
Black Sea	Max. 2.2 DW	65
Molluscs		
Sydney rock oyster, *Crassostrea commercialis*		
Soft parts	0.4–18.6 FW	8
Soft parts	0.1–1.0 FW	9
Pacific oyster, *Crassostrea gigas*		
Soft parts	0.2–2.1 FW	10, 11
Soft parts	0.0–30.7 FW	8
Soft parts	3.7–9.0 DW	12
Red abalone, *Haliotis rufescens*		
Gill	4.0–10.0 DW	13
Mantle	2.8–12.8 DW	13
Digestive gland	183–1163 DW	13
Foot	0.2–0.5 DW	13
Periwinkle, *Littorina littorea*		
Soft parts	0.9–1.5 DW	14
Soft parts	0.0–0.5 FW	15
Soft parts	210.0 DW	7
Squid, *Ommastrephes bartrami*		
Liver	81–782 DW	16, 17
Muscle	0.7 DW	16, 17
Gonad	0.4 DW	16, 17

Table 1.2 (continued) Cadmium Concentrations in Field Collections of Selected Species of Plants and Animals (Values shown are in mg Cd/kg fresh weight [FW], dry weight [DW], or ash weight [AW].)

Ecosystem, Taxonomic Group, Organism, Tissue, Location, and Other Variables	Concentration (mg/kg or ppm)	References[a]
Common mussel, *Mytilus edulis*; soft parts		
U.S. West Coast	2.3–10.5 DW	18
U.S. East Coast	0.6–6.2 DW	18
Port Phillip Bay, Australia	0.2–1.3 FW	19
Western Port Bay, Australia	Max. 18.2 FW	19
Scottish waters	0.1–2.0 FW	15
Looe estuary, U.K.	0.8–2.6 DW	20
Tasmania	5.5 FW	21
Corio Bay, Australia	2.0–63.0 DW	22
Mussel, *Mytilus edulis planulatus*; soft parts		
Mean dry weight		
0.09 g	0.6 DW	23
0.39 g	0.8 DW	23
0.48 g	1.1 DW	23
0.69 g	1.3 DW	23
Scallop, *Pecten maximum*		
Soft parts	13.0–32.5 DW	24, 25
Muscle	1.9 DW	24
Gut and digestive gland	96.0 DW	24
Mantle and gills	3.2–17.0 DW	24
Gonad	2.5 DW	24
Shell	0.0 DW	24
Kidney	54–79 DW	25, 26
Kidney concretion	546.6 DW	27
Digestive gland	321.0 DW	25
Edible tissues	5.1–23.0 FW	15
Giant scallop, *Placopecten magellanicus*		
Muscle		
March	Max. 8.8 DW	28
Rest of year	<3.7 DW	28
Viscera		
March	104.1 DW max.	28
August	121.2 DW max.	28
February	161.8 DW max.	28
June	105.3 DW max.	28
Gonad	0.5–3.2 FW	29
Visceral mass	3.7–27.0 FW	29
Clam, *Scrobicula plana*; digestive gland		
Gannel estuary, U.K.	39.8 DW	30
Camel estuary, U.K.	1.7 DW	30
Transferred from Camel to Gannel estuary for 352 days	5.6 DW	30
Transferred from Gannel to Camel estuary for 352 days	21.0 DW	30
Whelk, *Thais lapillus*; soft parts	425.0 DW	7
Crustaceans		
Rock crab, *Cancer irroratus*		
Muscle	0.1–1.0 FW	31
Digestive gland	1.1–4.8 FW	31
Gills	0.7–2.7 FW	31
Brown shrimp, *Penaeus* sp.		
Muscle	0.2 DW	32
Exoskeleton	0.5 DW	32
Viscera	2.6 DW	32
Whole	<0.4 DW	33

Table 1.2 (continued) Cadmium Concentrations in Field Collections of Selected Species of Plants and Animals (Values shown are in mg Cd/kg fresh weight [FW], dry weight [DW], or ash weight [AW].)

Ecosystem, Taxonomic Group, Organism, Tissue, Location, and Other Variables	Concentration (mg/kg or ppm)	References[a]
American lobster, *Homarus americanus*		
Whole	0.5 FW; 5.3 AW	34
Meats	0.2 FW; 10 AW	34
Exoskeleton	0.6 FW; 4.1 AW	34
Gill	0.5 FW; 17 AW	34
Viscera	1.2 FW; 34 AW	34
Prawn, *Pandalus montagui*		
Tail	0.0 DW	35
Egg	0.1 DW	35
Carcass	0.3 DW	35
Hepatopancreas	6.4 DW	35
Whole	0.5 DW	35
Spiny lobster, *Panulirus interruptus*		
Muscle	0.3 FW	36
Hepatopancreas	5.6–29.3 FW	36
Grass shrimp, *Palaemonetes pugio*; whole	1.4–6.2 DW	37
Annelids		
Marine worm, *Nephtys hombergi;* whole; March vs. October	9 FW vs. 89 FW	38
Sandworm, *Nereis diversicolor*; whole	0.1–3.6 DW	20, 30
Echinoderms		
Asteroid, *Echinus esculentus*		
Intestines	8.9 DW	39
Remaining tissues	<0.7 DW	39
Fishes		
Flounder, *Platichthys flesus*; whole		
Barnstaple Bay, U.K.		
Age II	1.1 DW	40
Age III	1.4 DW	40
Age IV	1.6 DW	40
Age V	1.7 DW	40
Oldbury on Severn, U.K. (metals-contaminated area)		
Age II	4.0 DW	40
Age III	4.5 DW	40
Age IV	5.1 DW	40
Age V	5.2 DW	40
Yellowtail flounder, *Limanda limanda*		
Liver	0.4 DW	41
Skin	0.2 DW	41
Otoliths	0.2 DW	41
Gills	0.2 DW	41
Fin	0.2 DW	41
Muscle	0.1 DW	41
Backbone	0.05 DW	41
Blue marlin, *Makaira indica*		
Muscle	0.1–0.4 FW	9
Liver	0.2–83.0 FW	9
Striped bass, *Morone saxatilis*		
Muscle	0.03 FW	42
Liver	0.3 FW	42

Table 1.2 (continued) Cadmium Concentrations in Field Collections of Selected Species of Plants and Animals (Values shown are in mg Cd/kg fresh weight [FW], dry weight [DW], or ash weight [AW].)

Ecosystem, Taxonomic Group, Organism, Tissue, Location, and Other Variables	Concentration (mg/kg or ppm)	References[a]
Atlantic cod, *Gadus morrhua*		
Roe	0.0–0.5 DW	43
Muscle	0.02 DW	44
Gonad	0.0–0.07 DW	44
Liver	0.09 DW	44
Bluefish, *Pomatomus saltatrix*		
Muscle	Max. 0.08 FW	45
Shorthorn sculpin, *Myoxocephalus scorpius*		
Muscle	1.4 DW	46
Liver	4.1 DW	46
Birds		
Adelie penguin, *Pygoscelis adeliae*		
Liver	90.0 DW	47
Lesser scaup, *Aythya affinis*		
Liver	0.6 FW	48
Kidney	2.3 FW	48
Dunlin, *Calidris alpina*; 1979–82; Bristol Channel, England; kidneys; 5 sites		
Adult males	Usually <1.3 DW; Max. 13–60 DW	74
Adult females	Usually <1.3 DW; Max. 4–61 DW	74
Juveniles	Usually <0.8 DW; Max. 2–11 DW	74
Dunlin diet		
Annelid worms	2.4–24.5 DW	74
Clams	1.8–4.5 DW	74
New York Bight, 5 species, 1989		
Eggs	Max. 0.02 DW	73
Feathers, fledgling	0.03–0.57 DW	73
New Zealand estuaries, 5 spp.		
Liver	0.1–1.5 FW	49
Kidney	0.1–14.8 FW	49
Corpus Christi, Texas, 7 spp.		
Kidney	0.4–22.7 FW	50
Puffins, 2 spp. St. Kilda, Scotland		
Males		
Liver	14.6–29.4 DW	51
Kidney	67.0–133.0 DW	51
Females		
Liver	14.1–39.9 DW	51
Kidney	75.1–231.0 DW	51
Laughing gull, *Larus atricilla*		
Downy young		
Kidney	0.5 FW	52
Other tissues	<0.05 FW	52
Adults		
Muscle	0.1 FW	52
Heart	0.1 FW	52
Brain	0.5 FW	52
Bone	0.4 FW	52
Liver	0.6 FW	52
Kidney	5.0 FW	52

Table 1.2 (continued) Cadmium Concentrations in Field Collections of Selected Species of Plants and Animals (Values shown are in mg Cd/kg fresh weight [FW], dry weight [DW], or ash weight [AW].)

Ecosystem, Taxonomic Group, Organism, Tissue, Location, and Other Variables	Concentration (mg/kg or ppm)	References[a]
Franklin's gull, *Larus pipixcan*; Minnesota; 1994		
Breast feathers	0.5–0.6 DW	75
Eggs	0.04 DW	75
Diet (earthworms)	0.4 DW	75
Kittiwake, *Rissa tridactyla*; nestlings; North Sea; 1992–94; age 1 day vs. age 21–40 days		
Feather	0.02 DW vs. 0.03 DW	91
Kidney	0.02 DW vs. 0.12 DW	91
Liver	0.01 DW vs. 0.03 DW	91
Common eider, *Somateria mollissima*		
Egg	1.0 DW	53
Muscle	2.0 DW	53
Liver	13.0 DW	53
Kidney	25.0 DW	53
Brown pelican, *Pelecanus occidentalis*		
Florida		
Liver	1.3–2.4 FW	54
Muscle	0.2–0.3 FW	54
California		
Liver	0.6–13.6 FW	54
Muscle	0.2–0.4 FW	54
Seabirds; liver	Usually 5–35 FW	89
Seabirds		
Liver, 11 species	8–71 DW	95
3 species, maximum values		
Brain, fat, bone, feather	<2 DW	95
Stomach, muscle, skin, eyeball, esophagus, trachea	2–10 DW	95
Intestine, liver, pancreas, spleen, gallbladder, gonad	23–39 DW	95
Kidney	180 DW	95
Common tern, *Sterna hirundo*		
Liver	3.8 FW	54
Kidney	21.3 FW	54
Mammals		
Northern fur seal, *Callorhinus ursinus*		
Kidney	0.1–15.6 FW	55
Liver	0.5–4.6 FW	55
Pilot whale, *Globicephala macrorhynchus*		
Blubber	0.4–0.8 FW	56
Liver	11.3–19.0 FW	56
Kidney	27.1–41.8 FW	56
Pilot whale, *Globicephala melas*; Faroe Islands; 1986		
Erythrocytes	(0.8–699) FW	76
Kidney	86 (2–194) FW	76
Liver	77 (2–167) FW	76
Plasma	(0.6–238) FW	76
Marine mammals; 13 species; liver	Usually <8 FW; (not detectable –35) FW	77
Pacific walrus, *Odobenus rosmarus divergens*		
1981–84		
Kidney	46.5 FW; Max 99 FW	79
Liver	9.5 FW; Max. 50 FW	79
1991; Spring; Alaska; Bering Sea; diet		
Clam, *Mya* sp.	6.8 DW	78
Other food items	0.7–2.7 DW	78

Table 1.2 (continued) Cadmium Concentrations in Field Collections of Selected Species of Plants and Animals (Values shown are in mg Cd/kg fresh weight [FW], dry weight [DW], or ash weight [AW].)

Ecosystem, Taxonomic Group, Organism, Tissue, Location, and Other Variables	Concentration (mg/kg or ppm)	References[a]
Baikal seal, *Phoca sibirica*; Siberia; 1992; Immatures vs. adults		
Kidney	0.6 FW vs. 2.4 FW	96
Liver	0.07 FW vs. 0.35 FW	96
California sea lion, *Zalophus californianus*		
Liver	2.0–2.6 FW	57
Kidney	10.2 FW	57
Cerebellum	0.6 FW	57
Other tissues	<0.2 FW	57
Sea otter, *Enhydra lutris*		
Kidney	89.0–300.0 DW	54
Walrus, *Odobenus rosmarus divergens*		
Kidney	51.6 FW	54
Liver	7.7 FW	54
Muscle	0.3–0.7 FW	54
FRESHWATER		
Macrophytes		
Water lily, *Nuphar luteum*		
Whole	0.5–1.8 DW	54
Pondweed, *Potamogeton richardsoni*		
Leaf and stem	0.6–4.9 DW	54
Root	1.3–6.7 DW	54
Molluscs		
Clams, Illinois River		
Soft parts, 3 spp.	0.2–1.4 FW	58
Crustaceans		
Isopods, various species; the Netherlands		
1986, whole	Max. 0.21 DW	66
1987–89, whole	Max. 12.0 DW	66
River Dommel, 1987–89; contaminated (0.1–18 mg Cd/L)		
Hindgut	119 DW	66
Hepatopancreas	253 DW	66
Head, exoskeleton	3–6 DW	66
Annelids		
Whole, Illinois River	0.5–3.2 FW	58
Fish		
United States, Nationwide, 1976–1977; whole	0.07 FW (0.01–1.0)	59
Upper Clark Fork River, western Montana		
Muscle, 3 spp.	0.2–0.6 FW	58
Liver, 7 spp.	0.3–0.8 FW	58
Great Lakes		
Whole, 3 spp.	0.0–0.14 FW	58
Liver, 10 spp.	0.1–1.4 FW	58
Illinois River		
Whole, 10 spp.	<0.08 FW	58