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MERCURY HAZARDS TO FISH, WILDLIFE, AND INVERTEBRATES: A SYNOPTIC REVIEW

by

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Hg conc. in field collections of selected species of flora & fauna, Values in mg Hg/kg fresh weight (FW), or dry weight (DW).

Table 6. (Continued)

Taxonomic group, organism, tissue, and other variables	Concentration[a] (ppm)	Reference[b]
Lake St.Clair		
Carcass	0.1.0.2 FW	
Liver	0.5-1.1 FW	
Florida		
Liver	0.1 FW	
Frog, Rana temporaria		
Yugoslavia, 1975		
From Hg-mining area		
Liver	21.0 FW	Terhivuo
Kidney	16.2 FW	et al. 1984
Muscle	3.4 FW	
Egg	1.3 FW	
From uncontaminated area		
All tissues	<0.08 FW	
BIRDS		
Goshawk, Accipiter gentilis		
Sweden		
Feather		
1860-1946	2.2 FW	Jenkins 1980
1947-1965	29.0 FW	
1967-1969	3.1-5.1 FW	
Finnish sparrowhawk, Accipiter nisus		
Feather		
Finland		
1899-1960	4.1 (2.1-7.7) DW	Solonen and
1961-1970	11.1 (2.3-42.0) DW	Lodenius 1984
1971-1982	7.4 (1.0-29.0) DW	
Germany		
1972-1973	4.9 (0.4-20.3) DW	
Norway		
1976	2.0-20.0 DW	
Wood duck, Aix sponsa		
Tennessee, 1972-1973		
Juveniles		
Liver	0.4 (0.1-1.1) FW	Lindsay and
Muscle	0.1 (0.05-0.4) FW	Dimmick 1983
Fat	0.1 (0.01-0.40 FW	

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Table 6. (Continued)

Taxonomic group, organism, tissue, and other variables	Concentration[a] (ppm)	Reference[b]
Adults		
Liver	0.2 (0.1-0.3) FW	
Muscle	0.08 (0.06-0.11) FW	
Fat	0.06 (0.01-0.11) FW	
Blue-winged teal, Anas discors		
Muscle		
Lake St. Clair	0.1-2.3 FW	Jenkins 1980
Ontario	3.8-10.4 FW	
Wisconsin	0.0-0.5 FW	
Illinois	0.05 FW	
Great blue heron, Ardea herodius		
Liver		
Lake St. Clair	97.0 (14.6-175.0) FW	
New Brunswick	4.5 FW	
Lake Erie	0.7-4.3 FW	
Wisconsin	0.5 (0.2-1.1) FW	
Birds		
Antarctic		
Liver		
1977-1979		
4 spp.	0.5-1.3 FW	Norheim et al. 1982
3 spp.	2.7-2.9 FW	
1980		
5 spp.	0.5-2.1 FW	Norheim and Kjos-Hanssen 1984
Belgium, 1970-1981		
Liver, 30 spp.		
Aquatic birds	0.11-35.0 FW	Delbekke et al. 1984
Terrestrial birds	ND-14.0 FW	
Hawaiian, 1980		
Egg, 3 spp.	0.12-0.36 FW	Ohlendorf and Harrison 1986
North America		
Feather		
From areas with mercury-treated seed dressing		
Seed-eating songbirds	1.6 DW	NAS 1978
Upland game birds	1.9 DW	

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Table 6. (Continued)

Taxonomic group, organism, tissue, and other variables	Concentration[a] (ppm)	Reference[b]
From untreated areas		
Seed-eating songbirds	0.03 DW	
Upland game birds	0.35 DW	
Northwestern Ontario, Canada		
From a heavily mercury-contaminated freshwater system		
Liver		
Scavengers	57.0 (13.8-121) FW	Fimreite 1979
Fish eaters	39.5 (1.7-91) FW	
Omnivores	26.6 (9.5-53) FW	
Invertebrate feeders	12.4(3.2-28) FW	
Vegetarians	6.2(1.9-28)FW	
Diving ducks	Max. 175.0	NAS 1978
Muscle		
Diving ducks	Max. 23.0 FW	
Mallard, Anas platyrhynchos	Max. 6.1 FW	
Eagle-owl, Bubo bubo		
Sweden, 1963-1976		
Feather		
Inland populations	3.2 DW	Broo and
Coastal populations	6.5 DW	Odsjow 1981
1829-1933	0.3-3.6 FW	Jenkins 1980
1964-1965	12.8-41.0 FW	
Peregrine, Falco peregrinus		
Feather		
1834-1849	2.5 DW	NAS 1978
1941-1965	>40.0 DW	
Swedish gyrfalcon, Falco rusticolus		
Nestlings, feather		
Percent aquatic birds in diet		
None	0.035 FW	Lindberg 1984
4.8% biomass	0.66 FW	
10.6% biomass	1.22 FW	
American bald eagle, Haliaeetus leucocephalus		
Egg		
Maine (highest concentrations Nationwide)		
1974	0.35-0.58 FW	Wiemeyer
1975	0.22-0.63 FW	et al. 1984

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Table 6. (Concluded)

Taxonomic group, organism, tissue, and other variables	Concentration[a] (ppm)	Reference[b]
Age 14 years		
Total Hg	4.5 FW	
Methyl Hg	2.6 FW	
Age 20 years		
Total Hg	10.7 FW	
Methyl Hg	3.5 FW	
Red fox, Vulpes vulpes		
Hair		
Georgia, USA		
Upper coastal plain	2.3 DW	Jenkins 1980
Lower coastal plain	0.5 DW	
Wisconsin, 1972-1975		
Fur	0.6 FW	Sheffy and
Other tissues	<0.14 FW	St. Amant 1982
California sea lion, Zalophus californianus		
Liver		
Mother	73.0-1,026.0 DW	Jenkins 1980
Pup	0.9-16.0 DW	
Kidney		
Mother	4.1-43.2 DW	
Pup	0.6-6.7 DW	

[a]Concentrations are listed as mean, range, or maximum (Max.).

[b]Each reference applies to the value in the same row and in the rows that follow for which no other reference is indicated.

BIRDS

Signs of mercury poisoning in birds included muscular incoordination, falling, slowness, fluffed feathers, calmness, withdrawal, hyporeactivity, hypoactivity, and eyelid drooping. In acute oral exposures, signs appeared as soon as 20 minutes postadministration in mallards and 2.5 hours in pheasants. Deaths occurred between 4 and 48 hours in mallards and 2 and 6 days in pheasants; remission took up to 7 days (Hudson et al. 1984). In studies with coturnix (Coturnix coturnix coturnix), Hill (1981) found that methylmercury was always more toxic than inorganic mercury, and that young birds were usually more sensitive than older birds. Furthermore, some birds poisoned by inorganic mercury recovered after treatment was withdrawn, but chicks that were fed methylmercury and later developed toxic signs usually died, even if treated feed was removed. Coturnix subjected to inorganic mercury, regardless of route of administration, showed a violent neurological dysfunction that ended in death 2 to 6 hours posttreatment. The withdrawal syndrome in coturnix poisoned by Hg^{2+} was usually preceded by intermittent, nearly undetectable tremors, coupled with aggressiveness towards cohorts; time from onset to remission was usually 3 to 5 days, but sometimes extended to 7 days. Coturnix poisoned by methylmercury appeared normal until 2 to 5 days posttreatment; then, ataxia and low body carriage with outstretched neck were often associated with walking. In advanced stages, coturnix lost locomotor coordination and did not recover; in mild to moderate clinical signs, recovery usually took at least 1 week (Hill 1981).

Mercury toxicity to birds varies with the form of the element, dose, route of administration, species, sex, age, and physiological condition (Fimreite 1979). For example, in northern bobwhite chicks fed diets containing methylmercury chloride, mortality was significantly lower when the solvent was acetone than when it was another carrier such as propylene glycol or corn oil (Spann et al. 1986). In addition, organomercury compounds interact with elevated temperatures and pesticides, such as DDE and parathion, to produce additive or more-than-additive toxicity, and with selenium to produce less-than-additive toxicity (Fimreite 1979). Acute oral toxicities of various mercury formulations ranged between 2.2 and about 31.0 mg/kg body weight for most avian species tested (Table 8). Similar data for other routes of administration were 4.0 to 40.0 mg/kg for diet and 8.0 to 15.0 mg/kg body weight for intramuscular injection (Table 8).

Residues of mercury in experimentally poisoned passerine birds usually exceeded 20 mg/kg fresh weight, and were similar to concentrations reported in wild birds that died of mercury poisoning (Finley et al. 1979). Mercury levels in tissues of poisoned wild birds were highest (45 to 126 mg/kg fresh weight) in red-winged blackbirds (Agelaius phoeniceus), intermediate in

Table 8. Toxicity to birds of mercury administered by oral, dietary, or other routes.

Route of administration (units), organism, and mercury formulation	Concentration	Exposure interval	Effect	Reference[a]
ACUTE ORAL (mg Hg/kg body weight)				
Chukar, *Alectoris chukar*				
Ethyl	26.9	Within 14 d posttreatment	LD-50	Hudson et al. 1984
Mallard, *Anas platyrhynchos*				
Methyl	2.2-23.5	"	LD-50	
Ethyl	75.7	"	LD-50	
Phenyl	524.7	"	LD-50	
Northern bobwhite, *Colinus virginianus*				
Methyl	23.8	"	LD-50	
Coturnix, *Coturnix coturnix coturnix*				
Methyl	11.0-27.0	"	LD-50	Hill 1981
Inorganic	26.0-54.0	"	LD-50	
Japanese quail, *Coturnix japonica*				
Methyl	14.4-33.7	"	LD-50	Hill and Soares 1984; Hudson et al. 1984
Ethyl	21.4	"	LD-50	Hudson et al. 1984
Inorganic	31.1	"	LD-50	Hill and Soares 1984
Rock dove, *Columba livia*				
Ethyl	22.8	"	LD-50	Hudson et al. 1984
Fulvous whistling duck, *Dendrocygna bicolor*				
Methyl	37.8	"	LD-50	
Domestic chicken, *Gallus domesticus*				
Phenyl	60.0	"	LD-50	Mullins et al. 1977

starlings (Sturnus vulgaris) and cowbirds (Molothrus ater), and lowest (21 to 54) in grackles (Quiscalus quiscula); in general, Hg residues were highest in the brain, followed by the liver, kidney, muscle, and carcass. Some avian species are more sensitive than passerines (Solonen and Lodenius 1984): liver residues (in mg Hg/kg dry weight) in birds experimentally killed by methylmercury ranged from 17 in red-tailed hawks (Buto jamaicensis) to 70 in jackdaws (Corvus monedula); and values were intermediate in ring-necked pheasants, kestrels (Falco tinnunculus), and magpies (Pica pica). Experimentally poisoned grey herons (Ardea cinerea) seemed to be unusually resistant to Hg; lethal doses produced residues of 415 to 752 mg Hg/kg dry weight of liver (Van der Molen et al. 1982). However, levels of this magnitude were frequently encountered in livers from grey herons collected during a massive die-off in the Netherlands during a cold spell in 1976; the interaction effects of cold stress, mercury loading, and poor physical condition of the herons are unknown (Van der Molen et al. 1982).

MAMMALS

Methylmercury affects the central nervous system in man--especially the sensory, visual, and auditory areas concerned with coordination; the most severe effects lead to widespread brain damage, resulting in mental derangement, coma, and death (Clarkson and Marsh 1982). In mule deer (Odocoileus hemionus hemionus), after acute oral Hg poisoning was induced experimentally, additional signs included belching, bloody diarrhea, piloerection (hair more erect than usual), and loss of appetite (Hudson et al. 1984). The kidney is the probable critical organ in adult mammals due to the rapid degradation of phenylmercurials and methoxyethylmercurials to inorganic Hg compounds and subsequent translocation to the kidney (Suzuki 1979), whereas in the fetus the brain is the principal target (Khera 1979). Most human poisonings were associated with organomercury compounds used in agriculture as fungicides to protect cereal seed grain (Elhassani 1983); judging from anecdotal evidence, many wildlife species may have been similarly afflicted.

Organomercury compounds, especially methylmercury, were the most toxic mercury species tested. Among sensitive species of mammals, death occurred at daily organomercury concentrations of 0.1 to 0.5 mg/kg body weight, or 1.0 to 5.0 mg/kg in the diet (Table 9). Larger animals such as mule deer and harp seals appear to be more resistant to Hg than smaller mammals such as mink, cats, dogs, pigs, monkeys, and river otters; the reasons for this difference are unknown, but may be related to differences in metabolism and detoxication rates. Tissue residues in fatally poisoned mammals (in mg Hg/kg fresh weight) were 6.0 in brain, 10.0 to 55.6 in liver, 17.0 in whole body, about 30.0 in blood, and 37.7 in kidney (Table 9).

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Table 9. Toxicity of organomercury compounds to selected mammalian species.

Organism	Dose, route of administration, and other variables	Effects	Reference
Dog, *Canis familiaris*	0.1 to 0.25 mg/kg body weight during entire pregnancy; oral route.	High incidence of stillbirths.	Khera 1979
Cat, *Felis domesticus*	0.25 mg/kg body weight daily for 90 days (total 80-90 mg Hg); dietary route.	Mean survival time 78 days. Convulsions starting at day 68; all with signs by day 90. Liver residues of survivors were 40.2 and 18.1 mg/kg fresh weight for total mercury and inorganic mercury, respectively.	Eaton et al. 1980
Pig, *Sus* spp.	0.5 mg/kg body weight during pregnancy; oral route.	High incidence of stillbirths.	Khera 1979
Rhesus monkey, *Macaca mulatta*	0.5 mg/kg body weight during days 20-30 of pregnancy.	Maternally toxic, and abortient.	Khera 1979
Mink, *Mustela vison*	1.0 mg/kg in diet.	Fatal to 100% in about 2 months.	Sheffy and St. Amant 1982
River otter, *Lutra canadensis*	>2.0 mg/kg in diet.	Fatal.	Kucera 1983

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Table 9. (Concluded)

Organism	Dose, route of administration, and other variables	Effects	Reference
Mink	5.0 mg/kg in diet.	All dead in 30 to 37 days. Elevated residues in kidney (37.7 mg/kg fresh weight) and liver (55.6) prior to death.	Sheffy and St. Amant 1982
Humans	Various.	Lethal residues in tissues, in mg/kg fresh weight, were >6.0 in brain, >10.0 in liver, and >17.0 in whole body.	Khera 1979
Mule deer, Odocoileus hemionus hemionus	17.88 mg/kg body weight; single oral dose.	LD-50.	Hudson et al. 1984
Harp seal, Pagophilus groenlandicus	25.0 mg/kg body weight daily; oral route.	Dead in 20 to 26 days. Blood Hg levels just before death were 26.8 to 30.3 mg/l.	Ronald et al. 1977

Table 10. Sublethal effects of organomercury compounds administered to selected species of mammals.

Organism	Dose, and other variables	Effect	Reference
Rhesus monkey, *Macaca mulatta*	16 ug/kg body weight daily on days 20 to 30 of pregnancy	No measurable effect on reproduction.	Khera 1979
Human, adult	50 ug/day	Risk of paresthesia, 0.3% (burning-prickling sensation of skin).	Clarkson et al. 1984
Human, adult	200 ug/day	Risk of paresthesia, 8%.	Clarkson et al. 1984
Cat, *Felis domesticus*	250 ug/kg body weight daily on days 10 to 58 of gestation; oral route	Increased incidence of anomalous fetuses.	Khera 1979
Harp seal, *Pagophilus groenlandicus*	250 ug/kg body weight daily for 90 days; dietary route	Residues of 47,200 to 82,500 ug/kg fresh weight in liver, kidney, and muscle; histopathology of middle ear.	Ronald et al. 1977; Ramprashad and Ronald 1977
Rat, *Rattus* sp.	500 ug/kg body weight daily; oral route	Reduced fertility.	Khera 1979
Human, adult	1,000 ug/day	Risk of paresthesia, 50%.	Clarkson et al. 1984

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Table 10. (Continued)

Organism	Dose, and other variables	Effect	Reference
Mink, *Mustela vison*	1,100 ug/kg in diet	Residues of 7,100 to 9,300 ug/kg in brain; signs of poisoning.	Kucera 1983
Rat	2,000 ug/kg in diet (as Pacific blue marlin); gestation through post-natal day 16	Adverse behavorial changes in offspring.	Suzuki 1979
Rat	13,300 to 50,000 ug/kg body weight daily for 5 days; subcutaneous injection	Impaired cutaneous sensitivity and hearing up to one year post-treatment.	Wu et al. 1985
Monkeys, *Macaca* spp.	Various	Visual disturbances at blood Hg levels of 1,200 to 4,000 ug/l or brain Hg levels of 6,000 to 9,000 ug/kg; tremors at blood Hg levels of 2,000 to 10,000 ug/l; kidney pathology at brain Hg levels of 1,500 ug/kg.	Suzuki 1979

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