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Heavy Metal and Selenium Levels in Feathers of Young Egrets and Herons from Hong Kong and Szechuan, China

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Abstract. Several species of herons and egrets frequently nest in colonies in areas where humans also concentrate. Since the birds feed on intermediate-sized fish that themselves concentrate pollutants, they can be used not only to assess the levels of contaminants in avian tissues but as indicators of contaminants in the environment. The concentration of heavy metals and selenium in the breast feathers of fledgling black-crowned night herons *Nycticorax nycticorax* and Chinese pond herons *Ardeola bacchus* from the Tu Jing Yan heronry outside Chengdu, Szechuan Province in China; and from fledgling black-crowned night heron, little egret *Egretta garzetta*, great egret *Egretta alba* and cattle egret *Bubulcus ibis* from the Mai Po heronry in Hong Kong, were determined. Breast feathers were also collected from adult great egrets in Hong Kong. Adult great egrets had significantly higher levels of all heavy metals than did young great egrets. There were no significant interspecific differences in metal levels among the young at Szechuan China, except for chromium (pond herons had higher levels). There were significant differences among the young nesting at Hong Kong for all metals examined. Great egrets had lower, and night herons had higher, levels of lead than the other young. Night herons also had the highest levels of cadmium, manganese, and selenium compared to the other young. Great egret chicks had the lowest mercury levels, while little egret had the highest levels. Lead levels for all the birds in both Hong Kong and Szechuan were among the highest in the world, and this was attributed to the continued use of leaded gasoline.

Several species of herons, egrets, and ibises nest in colonies in coastal areas, along rivers, or near other large bodies of water that are also preferred by people. Human development often exposes nesting birds to various pollutants. Young birds are fed entirely on foods obtained from the surrounding environment by their parents, and thus pollutant levels in their tissues reflect local contamination, particularly of aquatic ecosystems. In this paper, we examine the levels of heavy metals and selenium in the feathers of fledgling black-crowned night herons *Nycticorax nycticorax* and pond herons *Ardeola bacchus* nesting at the Tu Jing Yan heronry about 50 km north of Chengdu, Szechuan, China and from fledgling black-crowned night herons, little egrets *Egretta garzetta*, great egrets *Egretta alba*, and cattle egrets *Bubulcus ibis* nesting at the Mai Po heronry in the Hong Kong New Territories. One of the objectives was to compare these levels with levels from these same species from other localities with similar or much lower exposure to pollutants.

Increasingly the public, the private sector, and governmental agencies are recognizing the importance of assessing the health of individual species populations, as well as the health and quality of the environment. Determining environmental quality is difficult (Rapport 1989), as well as time-consuming and costly, resulting in the use of indicator species to detect environmental stress (O'Connor and Dewling 1986). Several recent biomonitoring schemes in the United States and Canada have been developed to assess environmental quality on a regional or country-wide scale (Mineau *et al.* 1984; National Oceanographic and Atmospheric Administration 1989; Messer *et al.* 1991; O'Connor and Ehler 1991). Recently Peakall (1991) suggested that there is a critical need to examine and compare levels of contaminants on a larger geographical scale.

Birds are useful models for examining pollutant levels over wide geographical areas because the same or closely related species breed over large areas. In some cases, birds may breed over several continents, and feed on similar foods in widely separated areas. Birds are also ideal biomonitoring tools because they represent several higher trophic levels (including the top carnivores), are visible and conspicuous, and their population levels, reproductive success, and pathologies can be measured and monitored (Batty 1989). Although adults of some species migrate long distances, the pre-fledging young are fed entirely on food resources obtained locally.

At any point of time, the total amount of any pollutant in the body represents input from the small amount originally present in the egg plus the daily local dietary contribution, minus any excretion. As the chicks grow rapidly, the contribution of local dietary origin quickly outweighs the contribution from the egg. The latter reflects the female's body burden, some of which may have been obtained away from the breeding ground.

Impacts on birds from pollutants, such as the population declines sustained by fish-eating birds and raptors from high environmental levels of pesticides (Ratcliffe 1967; Hickey and

Anderson 1968; Peakall *et al.* 1975), are often evident long before effects on human health and other components of the ecosystem are detected.

Study Areas

Under appropriate collecting and import permits, breast feathers were collected from live fledgling birds (3–4 weeks) from the Mai Po Nature Reserve heronry in Hong Kong (early May 1992). The heronry is located in a small woodlot within town, and is protected and censused by World Wide Fund for Nature (by the Nature Reserve manager). This heronry is in a traditional Feng Shui woodlot, believed to bring good luck to the villagers (Young 1992). The birds are thus protected by the local people. At one end of the heronry, there were a small subcolony of 55 nests of little egrets and 35 nests of black-crowned night herons. Nearly 80 m away, another subcolony consisted of 20 nests of great egrets and 60 nests of cattle egrets. Colony numbers have dropped since 1989 because of some human disturbance (L Young, pers. comm.). The birds nested from 5 to 15 m above the ground. Feathers were collected from only one chick from each nest. We also collected breast feathers from adult great egrets for an age comparison.

Breast feathers were collected from live or dead fledgling pond and black-crowned night herons at the Tu Jing Yan heronry in the town of Quiqchenqshan, Szechuan Province in China (late May 1992).

Although early in the Mao revolution there was a concerted effort to eliminate the four pests (rats, mosquitos, flies, sparrows, and incidentally many other bird species; Wegman and Wegman 1989), the heronry is now protected by being within the walls of an exclusive resort hotel. The birds nested between 15 and 25 m above ground in a grove of mixed hardwoods. A recent storm had driven some chicks out of their nests to the ground, and they were abandoned by their parents. The heronry contained about 80 nests of black-crowned night herons, 40 nests of pond herons, and four nests each of little egret and cattle egret.

A pinch of feathers was plucked from the breast below each wing, placed in metal-free paper envelopes, and stored at room temperature prior to analysis. All feathers were analyzed in September 1992 in the Elemental Analysis Laboratory of the Environmental and Occupational Health Sciences Institute.

Preparation and Residue Analysis

Preparation, extraction, and analytical methods followed US Environmental Protection Agency procedures (EPA 1981). Feathers were washed vigorously in deionized water alternated with acetone to remove loosely adherent external contamination. In wild caught birds, metal concentrations in fully-formed feathers are remarkably resistant to heat, light, or other forms or weathering and external contamination (Appelquist *et al.* 1984; Walsh 1990). Hahn *et al.* (1989a, 1989b) suggested that some metal concentrations may be due to external contamination. Nonetheless, physical washing removes superficial contamination of some metals. Feathers were then digested in a warm sulfuric acid mixture with the addition of 50% hydrogen peroxide, and samples were subsequently diluted in deionized water.

Mercury was analyzed by cold vapor technique, and the other elements were analyzed by graphite furnace atomic absorption. All concentrations are expressed in μg/g (ppm) dry weight basis using weights obtained from air-dried specimens. Detection limits ranged from 0.3 ng/g for cadmium to 10 ng/g for lead. All specimens were run in batches which included a known standard from the U.S. National Bureau of Standards, method blanks, calibration standards, and spiked specimens. Recoveries ranged from 85% to 104%. Batches with recoveries less than 85% were rerun. The coefficient of variation on replicate, spiked samples ranged up to 10%. Further quality control included periodic blind analyses of an aliquot from a large sample of known metal concentrations.

Statistical Analysis

Data were analyzed with non-parametric procedures to compare concentrations between sexes; Kendall tau correlation coefficients were used to compare the various metal concentrations (P values were reported less than 0.10 due to small sample sizes). Duncan Multiple Range Tests were used to determine differences among species (SAS 1985). Both arithmetic and geometric means are given to facilitate comparisons with other studies.

Results

There were no significant interspecies differences in lead, cadmium, mercury, selenium, and manganese among young pond herons and black-crowned night herons from Szechuan, China, but there were significant differences in chromium (Table 1). However, there were significant differences among the young ardeids from Hong Kong for levels of all metals and selenium (Table 1). Overall, when young from both places were compared, there were significant species differences for all heavy metals; only selenium showed no differences (see Table 3).

Adult great egrets had significantly higher levels of lead, cadmium, chromium, selenium, and manganese than young, with levels of mercury being marginally different (Table 1). The greatest differences between young and adults was for lead, chromium, and manganese.

Overall, for all young combined, levels of most metals were highly correlated (Table 2). For individual species, sample sizes were too low for most correlations to be significant. However, lead was positively correlated with selenium (0.50, $p < 0.05$) and negatively correlated with chromium (−0.50, $p < 0.05$) for cattle egrets. For great egrets chicks lead was positively correlated with manganese (0.57, $p < 0.04$). For black-crowned night herons in China lead and cadmium ($r = 0.64$, $p < 0.009$), cadmium and selenium (0.47, $p < 0.05$), and selenium and mercury (0.47, $p < 0.05$) were positively correlated.

Discussion

Methodological Considerations

Metal levels in feathers reflect metal levels at the time of their formation when their blood supply is intact (Goede and deBruin

Table 1. Heavy metal and selenium levels in ardeids from China and Hong Kong. Given are arithmetic means ± standard errors (geometric means in parentheses), and Kruskal Wallis X^2 values (probability levels in parentheses). A = adult, C = chick, NS = not significant. All values in μg/g (parts per million)

Location—Species	Age	Number	Lead	Cadmium	Mercury	Selenium	Chromium	Manganese
Szechuan, China—								
Pond heron	C	5	4.2 ± 1.0 (3.8)	0.18 ± .03 (0.17)	2.4 ± 0.70 (0.97)	1.0 ± 0.28 (0.85)	49.1 ± 0.84 (46.9)	23.8 ± 9.2 (19.6)
Black-crowned night heron	C	10	5.6 ± 0.67 (5.0)	0.22 ± 0.4 (0.18)	2.3 ± 0.47 (1.8)	2.0 ± 0.47 (1.8)	20.8 ± 2.2 (19.2)	42.4 ± 7.3 (38.0)
X^2 comparing species in Szechuan			NS	NS	NS	NS	6.5 (0.01)	NS
Honk Kong—								
Black-crowned night heron	C	6	9.1 ± 2.2 (8.0)	0.14 ± 0.051 (0.12)	0.84 ± 0.038 (0.82)	2.8 ± 0.87 (1.9)	17.1 ± 5.9 (14.0)	45.1 ± 2.0 (44.3)
Cattle egret	C	9	4.6 ± 0.45 (4.3)	0.43 ± 7 (0.037)	1.3 ± .28 (1.0)	1.2 ± .071 (1.2)	16.1 ± 1.3 (15.7)	36.6 ± 6.7 (28.1)
Little egret	C	7	4.4 ± 0.6 (4.3)	0.048 ± 7 (0.043)	2.2 ± .88 (1.5)	1.7 ± 3.4 (1.6)	18.9 ± 2.2 (1.8)	17.5 ± 3.2 (15.2)
Great egret	C	8	1.5 ± 0.4 (1.3)	0.072 ± 14 (0.07)	.27 ± .033 (0.26)	1.3 ± .13 (1.3)	8.5 ± 1.3 (7.7)	4.2 ± 0.44 (4.0)
Great Egret	A	10	4.8 ± 0.67 (4.2)	0.120 ± 12 (0.12)	1.5 ± 0.42 (0.74)	1.8 ± 0.21 (1.7)	31.2 ± 4.7 (29.1)	63.1 ± 2.3 (41.8)
X^2 (P) Comparing great egret adults and young			14.7 (0.001)	7.2 (0.007)	3.0 (0.08)	3.5 (0.05)	12.6 (0.0004)	12.6 (0.0004)
X^2 (P) Comparing young of species in Hong Kong			20.7 (0.0001)	15.8 (0.001)	14.9 (0.002)	8.2 (0.04)	13.3 (0.004)	20.2 (0.0002)
X^2 (P) Comparing among young of all species			17.0 (0.002)	21.8 (0.002)	18.7 (0.0009)	(NS)	22.8 (0.0001)	21.9 (0.0001)

Table 2. Relationships among metal levels for all young ardeids from Hong Kong and China. Given are Kendall tau correlation coefficients above diagonal and probability levels below diagonal

	Lead	Cadmium	Mercury	Selenium	Chromium	Manganese
Lead	—	0.25	0.25	0.17	0.25	0.42
Cadmium	0.01	—	0.21	0.24	0.34	0.20
Mercury	0.01	0.04	—	0.17	0.23	0.17
Selenium	0.07	0.01	0.09	—	0.15	0.09
Chromium	0.01	0.001	0.02	0.14	—	0.22
Manganese	0.0001	0.05	0.08	0.36	0.03	—

Table 3. Significant differences among species for several metals. Species with the same letter are not significantly different with a Duncan's Multiple Range Test

Species	Mean body length[a] (cm)	Mercury	Lead	Cadmium	Manganese	Chromium
Great egret	95	A	A	A	A	A
Night heron (Hong Kong)	62	B	B	B	D	B
Night heron (China)	62	C	C	B	D	B
Little egret	60	B C	C	A	B	B
Pond heron	52	C	C	B	B C	C
Cattle egret	50	B C	C	A	C D	B

[a]After McLachlan and Liversidge (1978) and Hancock and Kushlan (1984)

1984). Circulating levels, however, can come from current ingestion (through food or water), or from mobilization from metals stored in other tissues. Indeed, one mechanism birds have for the elimination of heavy metals from their bodies is to sequester them in their feathers (Braune and Gaskin 1987a, 1987b). For mercury, 93% of the body burden is in the birds' plumage (Braune and Gaskin 1987a). Further, in experimentally dosed gulls, 49% of the mercury dose was recovered in the plumage (Lewis and Furness 1991).

Although females can sequester some heavy metals in their eggs (Fimreite *et al.* 1974, 1982: Burger and Gochfeld 1991), any metal residual from the egg is minor compared to the large weight gain from hatching to fledgling (Walsh 1990). Additionally, young herons and egrets lose the down they are born with, and grow entirely new plumage while being cared for by their parents. Thus, metal levels in the breast feathers from fledglings represent contaminants acquired from the local environment, and can be used as an indicator of local pollution.

Metal Levels in Herons and Egrets

Levels in the breast feathers of herons and egrets in this study varied depending on species, age, and location. It is instructive to compare the levels reported from Hong Kong and China with those reported in the literature for ardeids from elsewhere. Honda *et al.* (1986) reported metal levels in feathers of young and adult great egrets from Korea: mercury (range of 0.13–2.6 ppm), cadmium (0.002–0.024 ppm), manganese (0.005–7.0 ppm), and lead (range of 0.09–1.4 ppm). In comparison, levels in the feathers of adult great egrets from Hong Kong were higher for lead, cadmium, and manganese, and lower for mercury, than were those from Korea. Korea uses unleaded gasoline, while Hong Kong did not until 1991 (R. Tatsukawa, pers. comm.). Further, mercury levels in Korea are generally high due to volcanic eruptions (R. Tatsukawa, pers. comm.).

Burger *et al.* (1992) reported levels in young cattle egrets for lead (means of 0.23–9.7 ppm), mercury (means of 0.29–1.6 ppm), cadmium (means of 0.08–0.43 ppm), manganese (means of 0.33–5.3 ppm), selenium (means of 0.3–1.6 ppm), and chromium (means of 6.8–13.2 ppm) for colonies in New York, Delaware, Puerto Rico, and Egypt. The patterns were not consistent in that the highest (or lowest) levels for each metal were not obtained at any one location. The greatest locational differences were in lead; levels were 41 times higher in Cairo than Aswan (both in Egypt), and the least difference was with manganese (only a 1.6-fold difference; Burger *et al.* 1992). The difference in lead levels was attributable to the use of leaded gasoline near the heronry, located in downtown Cairo, compared to the other sites. No other studies report levels of heavy metals or selenium from the feathers of ardeids.

The metal and selenium levels from young in China and Hong Kong were generally within the range Burger *et al.* (1992) reported for cattle egrets. However, the lead levels from Hong Kong and China were three times higher than all locations Burger *et al.* (1992) reported except for Cairo (which still uses leaded gasoline). Leaded gasoline is still used in mainland China, and was used until 1991 in Hong Kong. In 1991, unleaded gasoline was introduced into Hong Kong, but there are still a large number of cars using leaded gasoline (L. Young, pers. comm.). In birds, lead causes lowered egg production, increased egg-laying interval, lowered testes weight, and decreased sperm count (Kendall and Scanlon 1981; Kendall *et al.* 1982). Lead also causes reduced hatching rate, lowered growth rate, and behavioral abnormalities (Burger and Gochfeld 1985, 1988; Burger 1990).

Chromium levels were twice as high at all places except New York. Thus, although the metals reported in this paper are within the range reported by Burger *et al.* (1992), they are at the high end of the range for most metals.

Species Differences

There were significant species differences for most metals (Table 3). In general, levels in young great egrets differed from all other species, either in being among the lowest (lead) or the highest (other metals). This suggests they eat different foods, or feed in different places. Both may well be true since they are the largest with the longest legs and thus have access to deeper water and can catch and eat larger fish that may have bioaccumulated higher concentrations of metals.

Age Differences

The concentration of metals in feathers of adults reflects both current exposure and past contributions from the body burden because they can be mobilized from internal tissues and deposited in the feathers (Braune and Gaskin 1987a, 1987b; Furness *et al.* 1986). However, since young birds are fed entirely on foods collected by parents near the breeding colony, their levels reflect exposure rather than body burden. Although females can sequester metals in their eggs, this contribution is small relative to the potential levels in food delivered by parents (see methodological considerations above).

The difference in the source of the metals for adults (local exposure plus body burden) and young (only local exposure) suggests that levels should be higher in adults than young. We examined age differences in metal levels only for great egrets nesting at Mai Po in Hong Kong. There were significant age differences for all metals except mercury and selenium.

Since the levels of metals were lower in young great egrets than adults, we suggest that the exposure acquired around the Mai Po marshes by foraging ardeids was lower than adults are exposed to on their wintering grounds. Since ardeids spread out in coastal areas of Asia during the non-breeding season, they are presumably acquiring pollutants from areas with fewer environmental controls.

Furness *et al.* (1990) failed to find age differences in mercury contamination in feathers of gulls that ranged from 2 to 12 years, but they did not look at young who would not have been exposed to metals on the wintering grounds. Honda *et al.* (1986) found that levels of iron, manganese, zinc, copper, nickel, lead, cadmium, and mercury were all higher in adults than young great egrets from Korea. Burger (1993) found differences in levels of mercury, lead, cadmium, and selenium in the feathers of fledgling brown noddy (*Anous stolidus*) compared to adults. Similarly, Burger *et al.* (1992) found that the feathers of young cattle egrets from Puerto Rico had lower levels of mercury, manganese, and selenium than adults. These data, in combination with those in the present paper, suggest that although different-aged adults may not show age differences in levels in feathers, young birds are different from adults with respect to metal levels in their breast feathers.

Locational Differences

The highest levels of lead, cadmium, mercury, manganese, and chromium occurred in young ardeids from Szechuan, although the highest levels of manganese occurred in adult great egrets from Hong Kong. The heronry in Hong Kong is near industrialized areas, and is surrounded by fish ponds (gei wais) that are drained from November to January, providing a super abundance of small fish. The rest of the year the birds feed on the edge of the fish and shrimp ponds (L. Young, pers. comm.). Although the heronry in Szechuan was not in an industrialized area, it was in a highly agricultural area. Presumably both pond herons and black-crowned night herons nesting in the Szechuan heronry fed in surrounding ponds and wet rice paddies.

The levels of metals were compared among young black crowned night herons. Presumably, this species has similar foraging behavior and food preferences in the two places. However, lead levels were twice as high, and selenium levels were also higher in Hong Kong compared to Szechuan, while cadmium and mercury levels were higher in Szechuan. Chromium and manganese levels were similar, suggesting the possibility that these metals are regulated biologically. The differences in lead levels may be due to differences in volume of vehicular traffic: Hong Kong is crowded with cars, while few private citizens in Szechuan have cars (most vehicular traffic is trucks).

The relative difference in mercury levels, with the night herons from Szechuan having nearly three times the levels as Hong Kong, suggest a local source of mercury. The source has not been identified.

Overall, there are too few published data on metal levels in any birds from China or Hong Kong, or even from Asia, for a meaningful regional comparison. However, it is important to begin to build up a data base on metal levels from Asia. Without such a data base it will be difficult to interpret results in the future, or to identify place with disturbing trends in pollution levels.

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References

Appelquist H, Askirk S, Draback L (1984) Mercury stability in bird feathers. Mar Pollut Bull 15:22–27

Batty L (1989) Birds as monitors of marine environments. Biologist 36:151–154

Braune BM, Gaskin DE (1987a) A mercury budget for the Bonaparte's gull during autumn moult. Ornis Scan 18:244–25

———, ———(1987b) Mercury levels in Bonaparte's gull (*Larus philadelphia*) during autumn molt in the Quoddy region, New Brunswick, Canada. Arch Environ Contam Toxicol 16:539–549

Burger J (1990) Behavioral effects of early postnatal lead exposure in herring gull (*Larus argentatus*) chicks. Pharmacol Biochem Behav 35:7–13

———(1993) Metals in feathers of brown noddy (*Anous stolidus*): Evidence for bioaccumulation on mid-oceanic compared to continental areas. Environ Monit Assess 24:181–187

———, Gochfeld M (1985) Early postnatal lead exposure: Behavioral effects in common term chicks (*Sterna hirundo*). J Toxicol Environ Health 16:869–886

———, ———(1988) Effect of lead on growth in young herring gulls (*Larus argentatus*). J Toxic. Environ Health 25:227–236

———, ———(1991) Cadmium and lead in common terns (Aves: *Sterna hirundo*)): Relationship between levels in parents and eggs. Environ Monit Assess 16:253–258

———, Parsons K, Benson T, Shukla T, Rothstein D, Gochfeld M (1992) Heavy metals and selenium levels in young cattle egrets from nesting colonies in the Northeastern United States, Puerto Rico and Egypt. Arch Environ Contam Toxicol 23:435–439

Environmental Protection Agency (1981) Interim methods for sampling and analyses of priority pollutants in sediments and fish tissue, US Environmental Protection Agency. US EPA 600/4-81-05 5, Cincinnati, OH

Fimreite N, Brun E, Froslie A, Fredrichson P, Gundersen N (1974) Mercury in eggs of Norwegian seabirds. Astarte 1:71–75

———, Brevik FM, Torp R (1982) Mercury and organochlorines in eggs from a Norwegian gannet colony. Bull Environ Contam Toxicol 28:58–60

Furness RW, Lewis SA, Mills VA (1990) Mercury levels in the plumage of red-billed gulls *Larus novaeholiandiae scopulinus* of known sex and age. Environ Pollut 63:33–39

Goede AA, deBruin M (1984) The use of bird feather parts as a monitor for metal pollution. Environ Pollut A 37:287–309

Hahn E, Hahn K, Stoeppler M (1989) Schwermetalie in federn von Habichen (*Accipter gentilis*) aus Unterschiedlich belasteten Gebieten. J Ornithol 130:303–309

———, Hahn K, Ellenberg H (1989). Schwermitallgenhalte in federn von elsterm (*Pica pica*) folge exogener Auglagening aus der atmosphere? Verhandlungen der Gesellschaft für Okologie (Essen 1988). XVIII

Hancock J, Kushlan J (1984). The herons handbook. Harper and Row, NY

Hickey JJ, Anderson DW (1968) Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162:271–273

Honda K, Min BY, Talsukawa R (1986) Distribution of heavy metals and their age-related changes in the eastern great white egret, *Egretta alba modesta*, in Korea. Arch Environ Contam Toxicol 15:185–197

Kendall RJ, Scanlon PF (1981) Effects of chronic lead ingestion on reproductive characteristics of ringed turtle doves (*Streptopelia risoria*) and on tissue lead concentrations on adults and their projeny. Environ Pollut (Series A) 26:203–213

———, ———, Guilio (1982) Toxicology of ingested lead in ringed turtle doves. Arch Environ Contam Toxicol 11:259–263

Lewis SA, Furness RW (1991) Mercury accumulation and excretion by labortory reared black-headed gull (*Larus ridibundus*) chicks. Arch Environ Contam Toxicol 21:316–320

McLachlan GR, Liversidge R (1978) Roberts birds of South Africa. Cape and Transvaal Printers, Capetown, South Africa

Messer JJ, Linthurst RA, Overton WS (1991) An EPA program for monitoring ecological status and trends. Environ Monit Assess 17:67–78

Mineau P, Fox GA, Norstrom RJ, Weseloh DV, Hallett DJ, Ellenton JA (1984) Using herring gull to monitor levels and effects of organochlorine contamination in the Canadian Great Lakes. In: Nriagu Jo, Simmons MS (eds) Toxic contaminants in the Great Lakes. Wiley-Interscience Publ, NY, pp 425–452

NOAA (National Oceanic and Atmospheric Administration) (1989) A summary of data on tissue contamination from the first three years (1986–1988) of the mussel watch project. NOAA, Rockville, MD

O'Connor JS, Dewling RT (1986) Indices of marine degradation; their utility. Environ Manage 10:335–343

O'Connor TP, Ehler CN (1991). Results from the NOAA National Status and Trends Program on distribution and effects of chemical contamination on the coastal and estuarine United States. Environ Monit Assess 17:3–49

Peakall DB (1991) Animal biomarkers as pollution indicators. Chapman and Hall, NY

Peakall DB, Cade TC, White CM, Haugh JR (1975) Organochlorine residues in Alaskan Peregrines. Pest Monit J 8:255–260

Rapport DJ (1989) What constitutes ecosystem health? Perspect Biol Med 33:120–132

Ratcliffe DA (1967) Decreases in eggshell weight of certain birds of prey. Nature 215:208–210

SAS (1985) SAS user's guide: Statistics. Statistical Analysis Systems, Cary, NC

Walsh PM (1990) The use of seabirds as monitors of heavy metals in the marine environment. In: Furness RW, Rainbow PS (eds) Heavy metals in the marine environment. CRC Press, Boca Raton, FL

Wegman DH, Wegman ME (1989) Lessons from Silicosis control in China. Am J Pub Health 79:1599–1600

Young L (1992) Herons in Hong Kong. Heron Conservation Newsletter 5:2–3

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