Bull. Environ. Contam. Toxicol. (1986) 37:219–225

Environmental Contamination and Toxicology

Heavy Metals and Selenium Variation in a Migratory Bird Wintering in a Mercury-Polluted Lagoon

C. Leonzio, C. Fossi, and S. Focardi

Dipartimento Biologia Ambientale, Università di Siena, Via delle Cerchia 3, 53100 Siena, Italy

Recent papers have demonstrated that waterbirds collected in the Mediterranean area accumulate remarkable amounts of mercury, usually greater than in the same species obtained from other areas (Leonzio et al., 1984; Renzoni et al., 1985).
Migratory birds spend some time in the Mediterranean region, either for wintering or for breeding. During such periods the mercury concentration increases in their tissues (Focardi et al., 1984). This information supports the well-known hypothesis that the Mediterranean basin is anomalous for mercury due both to its physical features and geochemical and anthropogenic inputs.
The critical exposure to the pollutant could negatively influence the survival of some species of birds, particularly those high in the food chain (Ohlendorf et al., 1978). In some predatory waterbirds mercury levels considered dangerous for their reproductive physiology have been recorded (Fimreite, 1979).
Nevertheless animals belonging to various phyla have the ability to adapt themselves to environmental-pollutant damage (Livingstone, 1985; Moore, 1985; Viarengo, 1985). Of the various defense mechanisms employed by birds and mammals, the retention of selenium as an antagonist to mercury toxicity is the best known (Hutton, 1981; El Begearmi et al., 1982).

In the present paper we report the results of a long term monitoring of mercury, cadmium, lead and selenium and their interaction in tissues of the Black-necked grebe (Podiceps nigricollis) wintering in the lagoon of Marano (NE Italy), an environment moderately polluted by mercury.

MATERIALS AND METHODS

The birds were collected by shooting in April 1983, September 1983, April 1984, October 1984 and April 1985. Immediately after killing,

the birds were dissected and tissues and organs kept frozen and later freeze-dried.
Analyses of trace elements were performed on subcoutaneous fat, uropygial gland, brain, muscle, kidney and liver by AAS. Freeze-dried material was treated with nitric acid in decomposition vessels of teflon (teflon bomb) under pressure at 120°C for 6-8 hours (Stoeppler and Backhaus, 1978). The mineralized solution was analysed by a Perkin-Elmer 2280 spectrophotometer using the cold vapor stream system for mercury, the graphite furnace (HGA 500) for cadmium and lead, and the hydride generator (MHS-10) for selenium. Background compensation and method of additions were commonly used.

RESULTS AND DISCUSSION

Levels of the analysed trace elements are reported in Table 1. The comparative analysis of the average values in the birds arriving at the lagoon (September 1983, October 1984) and about to leave it (April 1983, 1984, 1985) clearly shows that during their wintering mercury increases in all the six tissues analysed. In the liver (Figure 1) the average spring level is about six times higher than that at the time of the bird's arrival, in the brain five times, in the kidney almost four times, and between two and three times in the other tissues.
Concentrations of selenium do not vary seasonally as markedly as those of mercury. Nevertheless, in the liver, selenium is higher in spring than in autumn and in the kidney is higher in autumn than in the spring. The concentrations of selenium in the six tissues are quite different: in the liver, kidney and brain they are generally higher than 10 μg/g dry weight; in the muscle, uropygial gland and fat they are quite low, and usually around 5 μg/g.
Concentrations of cadmium are often below the instrumental detection limits (0.02 μg/g d.w.) except in the liver and kidney. Average values in the kidney tend to be higher in the autumn samples.
The levels of lead are low in all the organs with no variations with the season. Often the concentrations are below the detection limits (0.2 μg/g d.w.).
Correlations between selenium and mercury are shown in Table 2. With the exception of fat all the organs, particularly muscle, kidney and liver, display a more significant correlation coefficient in the spring period corresponding to the maximum mercury accumulation. In the kidney there is a good correlation in the two periods but selenium and mercury have a distinct ratio for each period (Figure 2). In the kidney of the birds with low mercury content selenium is higher than in those with high mercury levels.

Table 1. Trace elements (μg/g d.w.) in tissues ($\bar{x}$ = mean; SD = Standard Deviation; * = range).

	APRIL '83		SEPT. '83		APRIL '84		OCTOB. '84		APRIL '85	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
FAT										
Hg	1.14	0.23	0.53	0.20	1.50	0.73	0.85	0.33	0.79	0.43
Se	3.03	3.62	3.57	1.14	7.15	3.37	6.94	1.05	0.51	0.27
Cd	<0.02		<0.02		<0.02		<0.02		<0.02	
Pb	0.53	0.50	0.41	0.17	0.46	0.38	0.35	0.32	0.54	0.41
UROPYGIAL GLAND										
Hg	10.24	3.50	3.77	2.29	9.86	3.12	4.15	0.72	10.01	1.60
Se	5.24	4.25	8.98	4.03	13.83	2.57	8.91	1.42	5.37	2.21
Cd	<0.02		<0.02		<0.02-0.17*		<0.02		<0.02	
Pb	0.69	0.68	0.58	0.42	0.28	0.44	0.14	0.06	<0.10-0.63*	
BRAIN										
Hg	14.91	3.71	3.61	2.43	14.75	3.89	3.71	1.41	13.45	3.19
Se	5.51	3.06	12.79	5.49	12.03	2.32	11.93	3.53	6.35	1.03
Cd	<0.02		<0.02		<0.02-0.10*		<0.02-0.31*		<0.02-0.10*	
Pb	0.64	0.60	<0.10-1.52*		<0.10-0.52*		<0.10-0.91*		<0.10-1.03*	
MUSCLE										
Hg	11.83	3.86	3.70	1.53	5.99	1.69	4.21	1.31	10.77	3.13
Se	4.44	0.99	6.73	1.76	3.57	0.80	5.09	1.13	6.37	1.06
Cd	<0.02-0.15*		<0.02		<0.02-0.08*		<0.02-0.20*		<0.02-0.09*	
Pb	0.83	0.31	0.44	0.22	<0.10-0.67*		<0.10-2.06*		<0.10-0.79*	
KIDNEY										
Hg	35.04	6.99	7.63	1.53	14.80	4.57	10.73	5.33	28.50	2.97
Se	10.75	3.85	11.47	2.22	6.62	1.52	18.21	5.27	11.65	2.51
Cd	0.61	0.22	0.94	0.86	0.79	0.62	3.12	2.57	0.73	0.05
Pb	0.80	0.14	0.27	0.09	<0.10-0.79*		<0.10-0.84*		0.59	0.38
LIVER										
Hg	57.90	9.94	9.37	2.23	48.52	9.07	16.57	7.71	42.38	5.75
Se	15.57	1.78	10.49	2.27	16.29	0.98	10.37	2.98	14.10	1.75
Cd	0.09	0.06	<0.02-0.41*		<0.02-0.53*		0.45	0.36	0.33	0.29
Pb	0.85	0.28	<0.10-0.37*		0.24	0.14	<0.10-0.58*		<0.10-0.83*	

APRIL 1983 n = 6; SEPTEMBER 1983 n = 8; APRIL 1984 n = 6; OCTOBER 1984 n = 8; APRIL 1985 n = 5.

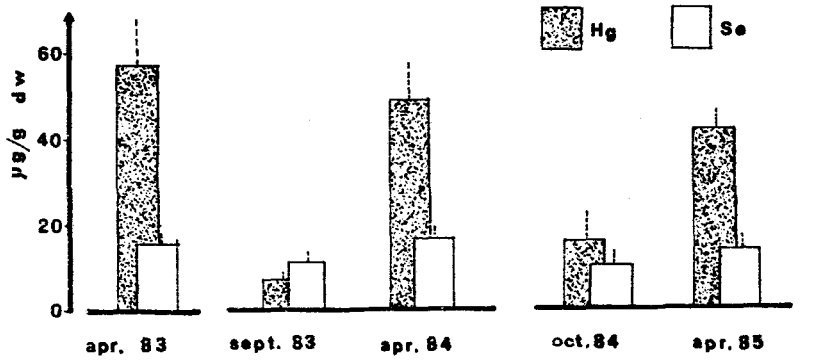

Figure 1. Concentrations of selenium and mercury (mean and SD) in the liver.

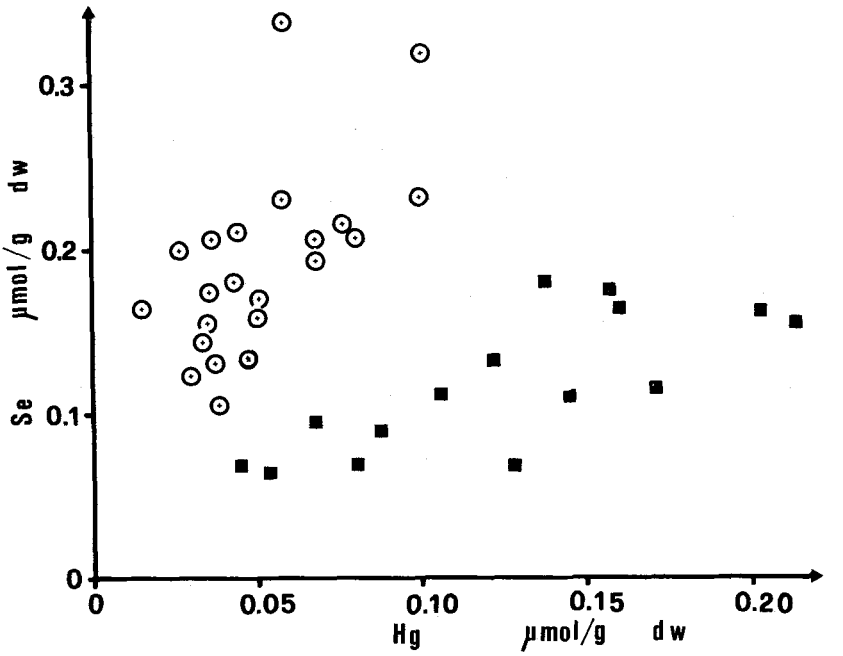

Figure 2. Relation between selenium and mercury in the kidney at the beginning (⊙) and at the end (■) of the wintering period.

Table 2. Correlation between selenium and mercury in the tissues of the grebes upon arrival (autumn) and before the departure (spring) ($p<001$ for coefficients in boldface type).

	FAT	U. GLAND	BRAIN	MUSCLE	KIDNEY	LIVER
Autumn (n=24)	**0.787**	0.115	0.136	0.057	**0.629**	0.392
Spring (n=15)	0.500	0.151	0.202	0.528	**0.753**	**0.837**

These results indicate that during the wintering period in the Marano lagoon the mercury concentrations in organs and tissues of the birds increase by several multiples; during the period they spend in the breeding quarters the concentrations decrease and the following fall they return to the lagoon with low levels of mercury residues.
Notwithstanding the difficulties of interpreting - in nature - the possible biological consequences of this mercury pollution on these migratory birds some indications have been obtained from the present data. A first aspect worth considering is the rapidity with which the annual accumulation-disaccumulation occurs. Even though it's difficult to define exactly where these birds have their breeding quarters it's likely that in such areas mercury input is very low. Considering that the experimental biological half-time of mercury for birds is calculated to be about 90 days (Soares et al., 1973), the birds would have enough time to reduce their mercury level (by 3-4 times) in an area with a background mercury level.

Regarding the interrelation of selenium and mercury in the various organs as a sign of a defense mechanism, two findings must be taken into account:

a) in the liver of the birds low in mercury selenium and mercury are not significantly correlated; this correlation becomes highly significant in the birds high in mercury;
b) the kidney accumulates a proportional amount of selenium and mercury into different ways: there is a prevalence of selenium in the birds low in mercury and a prevalence of mercury in the birds high in mercury. In the latter total selenium concentrations are reduced (Figure 3).

Before trying to explain this behaviour, we should consider two basic processes of mercury detoxification. The non specific binding of metal ions by protein-like metallothionein, which can bind mercury, allowing it to be accumulated in certain organs and removed via the kidney (Kagi and Nordberg, 1980; Bouquegneau et al., 1984). The incompletely clarified process in which selenium protects the animal body against mercury toxicity and viceversa (Spallholz et al., 1981) where, in a final step, mercury may be

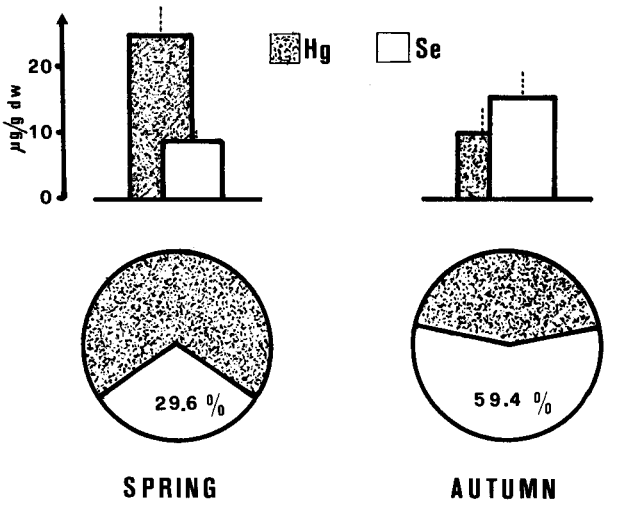

Figure 3. Concentrations (mean and SD) of selenium and mercury and percent of selenium with respect to the sum Hg+Se in the kidney.

complexed with selenium in a non-toxic compound and accumulate in the liver (Martoja and Viale, 1977; Thibaud, 1984).
In the birds of the Marano lagoon, during the wintering period, both processes could occur. The high mercury level in the kidney may indicate an efficient binding process in which the metallothioneins are involved; the decrease of selenium in the kidney and the highly significant co-accumulation of both selenium and mercury in the liver could be linked to the synthesis and stocking of the Se-Hg non toxic compound.

Aknowledgments. Many thanks to Ann Henderson for the revision of the manuscript. Research supported by the ECC (ENV 512/I).

REFERENCES

Bouquegneau JM, Martoja M, Truchet M (1984) Heavy metals storage in marine animals under various environmental conditions. In: Bolis J, Zadunaisky J, Gilles R (eds) Toxins, drugs and pollutants in marine animals. Springer Verlag, Berlin, p 147

El-Begearmi MM, Ganther HE, Sunde ML (1982) Dietary interaction between methylmercury, selenium, arsenic, and sulfur amino acids in Japanese quail. Poultry Sci 61:272-279

Fimreite N (1979) Accumulation and effects of mercury on birds. In: Nriagu OJ (ed) The biogeochemistry of mercury in the environment. Elsevier North-Holland, Amsterdam, p 601

Focardi S, Fossi C, Leonzio C, Renzoni A (1984) Uptake of contaminants by birds wintering in an italian lagoon. VIIes Journées Etud Pollut, Lucerne, (in press)

Hutton M (1981) Accumulation of heavy metals and selenium in three seabird species from the United Kingdom. Environ Pollut Ser A 26:129-145

Kagi JHR, Nordberg M (1979) Metallothioneins. Birkhauser Verlag, Basel

Leonzio C, Focardi S, Fossi C, Renzoni A (1984) Sea-birds as indicators of mercury pollution in the Mediterranean. Meeting on the Biogeochemical Cycle of Mercury in the Mediterranean, Siena, 27-31 August 1984

Livingstone DR (1985) Response of the detoxication/toxication enzyme systems of molluscs to organic pollutants and xenobiotics. Mar Pollut Bull 16:158-164

Martoja R, Viale D (1977) Accumulation de granules de seleniure mercurique dans le foie d'Odontocetes (Mammiferes, Cetaces): un mecanisme possible de detoxication du methylmercure par le selenium. C R Acad Sc Paris 285:109-112

Moore MN (1985) Cellular responses to pollutants. Mar Pollut Bull 16:134-139.

Ohlendorf HM, Risebrough RW, Vermer K (1978) Exposure of marine birds to environmental pollutants. USFWS Wildl Res Rep 9:1-40

Renzoni A, Focardi S, Fossi C, Leonzio C, Mayol J (1985) Comparison between concentrations of mercury and other contaminants in eggs and tissues of Cory's Shearwater Calonectris diomedea collected on Atlantic and Mediterranean islands. Environ Pollut Ser A 39 (in press)

Soares JH, David Miller Jr, Lagally H, Stillings BR, Bauersfeld P, Cuppett S (1973) The comparative effect of oral ingestion of methyl mercury on chicks and rats. Poultry Sci 52:452-458

Spallholz JE, Martin JL, Ganther HE (1981) Selenium in biology and medicine. AVI Publishing Co., Westport

Stoeppler M, Backhaus F (1978) Pretreatments studies with biological and environmental materials. I. System for pressurized multisample decomposition. Fresenius Z Anal Chem 291:116-120

Thibaud Y (1984) The role of biochemical processes in the accumulation of mercury by marine organisms. Meeting on the Biogeochemical Cycle of Mercury in the Mediterranean, Siena 27-31 August 1984

Viarengo A (1985) Biochemical effects of trace metals. Mar Pollut Bull 16:153-158

Received November 8, 1985; accepted January 10, 1986.