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Mercury Contamination of the Belgian Avifauna 1970–1981

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ABSTRACT

Two hundred birds found dead in Belgium between 1970 and 1981, and belonging to 30 species, were analysed for total mercury contamination. The contamination of aquatic birds ranged between 0·11 and 35 $\mu g\ g^{-1}$ wet weight. For terrestrial birds, the extreme values were: not detectable and 14 $\mu g\ g^{-1}$. In both cases, differences in diet can explain the differences in contamination. The order of diets associated with increasing mercury contamination for aquatic birds was invertebrates, zooplankton and garbage, and fish; and for terrestrial birds this consisted of plants, invertebrates, mammals and birds. For raptors and owls, this effect of diet includes geographical variations within species. A higher mercury contamination level in the winter and early spring was noted for two species of owls. For aquatic birds, the contamination of liver was higher than that of kidney, with ratios varying between 1·2 and 2·5. For terrestrial birds, the ratio was closer to 1. A few determinations were also made for muscle and heart, giving respectively 0·25 and 0·6 of the liver contamination. Among the birds analysed for their liver contamination, 15% showed levels higher than 3 $\mu g\ g^{-1}$ and could have been affected in their reproduction; 3% had levels higher than 10 $\mu g\ g^{-1}$, and could have died from mercury poisoning; and 6% showed an abnormally high liver:kidney ratio, which could reflect an acute intoxication.

There exists a striking parallelism between the levels of mercury and of organochlorine residues (DDT) in birds of prey, suggesting the existence of common ecotoxicological mechanisms.

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INTRODUCTION

In 1953, the catastrophic Minamata disease clearly showed the potential danger of mercury accumulation. Due to its high biological stability and its high absorption capacity (80 to 100%: Aberg *et al.*, 1969), mercury, and more especially its methyl form, is often found at high concentrations at the end of food webs, for instance in Japan (Swedish Expert Group, 1971), Iraq (Bakir *et al.*, 1973), or in Scandinavia, where it was utilised as seed-dressing (Westermark, 1975).

Now that the use of organochlorine pesticides is strongly limited in Western countries, heavy metals, and among them mercury, probably represent the main threat to the environment and to the health of the human population. This is why we decided to investigate the contamination of Belgian wildlife.

Birds found dead in Belgium were used as study material because enough information is available concerning their feeding habits and population dynamics. Among them, raptors are of special interest when studying the contamination of an ecosystem by stable compounds for two reasons.

1. Because of their broad territorium and long lifespan they integrate small variations in contamination level.
2. The available information concerning residues levels of other stable compounds—organochlorine pesticides and PCBs—permits a comparison of ecotoxicological mechanisms.

METHODS

Sampling

Two-hundred-and-one birds found dead in Belgium between 1970 and 1981 and belonging to 30 species were analysed. Liver, kidney and in some cases muscle and heart were kept deep-frozen (-20°C) until needed. The skins are kept at the Institut royal d'Histoire naturelle, in Brussels.

Analytical procedure

Six different procedures to determine the total mercury concentrations in biological samples were compared in the Laboratory for Analytical

Chemistry (Dehairs *et al.*, 1982); two methods gave similar results, one of which was applied in routine analyses. It consisted of the mineralisation of samples with a H_2SO_4/HNO_3 mixture in the presence of V_2O_5 as catalyst followed by $KMnO_4$ digestion, both under reflux. The excess of $KMnO_4$ is reduced with NH_4OCl and the mercury to Hg° with $NaBH_4$. The mercury concentration is measured through cold vapour atomic absorption (Coleman MAS 50). The results are expressed as $\mu g\,Hg\,g^{-1}$ wet weight. In some samples, the dry weight was also determined: this provided three to four times higher contaminations, but did not seem to influence the comparison between species or between tissues.

Statistics

Because mercury levels do not always show a normal distribution pattern, median levels were used, as we considered that they give a better evaluation of the contamination of the population than do mean values. The significance of the observed differences was evaluated by a non-parametric test (Median test: Siegel, 1956). The mean levels, as well as their standard deviation, are, however, listed in the tables, for the different tissues of each species.

RESULTS

Comparison of the mercury contamination of various species

All aquatic birds were contaminated by mercury, but at very variable levels, ranging from 0·11 $\mu g\,g^{-1}$ in a kingfisher *Alcedo atthis* to more than 35 $\mu g\,g^{-1}$ in a cormorant *Phalacrocorax carbo*. These differences between species could be explained by differences in diet: birds feeding mainly on fish were more contaminated than birds feeding on a mixture of zooplankton and garbage (significance, $P < 0{\cdot}05$), while those having a diet of fish and invertebrates showed the lowest mercury levels ($P < 0{\cdot}02$) (Table 1).

A broad range of mercury levels was also noted in the terrestrial birds: from not detectable to 14 $\mu g\,g^{-1}$. Differences in diet were associated with different mercury levels. The order of diets associated with increasing mercury contamination was: plants, insects, mammals, birds. All these differences were significant ($P < 0{\cdot}10$) when enough samples were analysed (Table 2).

TABLE 1
Mercury Levels in Liver and Kidney of Aquatic Birds with Different Feeding Habits ($\mu g\ g^{-1}$ wet weight; *n*, number of samples; SD, standard deviation)

Species (main diet)	Liver *n*	Liver Median	Liver Mean	Liver SD	Liver Min–Max	Kidney *n*	Kidney Median	Kidney Mean	Kidney SD	Kidney Min–Max
Little grebe *Tachybaptus ruficollis*	1	0·35	0·35	—	—	1	0·38	0·38	—	—
Kingfisher *Alcedo atthis*	7	0·23	0·53	0·52	0·11–1·53	—				
(invertebrates + fish)	8	0·29				1	0·38			
Fulmar *Fulmarus glacialis*	6	1·44	1·86	1·52	0·54–4·80	6	0·69	1·01	1·35	0·39–3·76
Great black-backed gull *Larus marinus*	3	1·36	1·28	0·50	0·75–1·74	3	0·89	1·06	0·52	0·64–1·64
(zooplankton, garbage)	9	1·36				9	0·64			
Red-necked grebe *Podiceps griseigena*	—					1	1·10	1·10	—	—
Great crested grebe *Podiceps cristatus*	8	4·93	8·25	6·99	1·72–20·75	8	4·35	5·30	4·11	1·53–12·40
Guillemot *Uria aalge*	9	2·19	2·39	0·80	1·22–3·62	9	1·36	1·48	0·57	0·85–2·57
Cormorant *Phalacrocorax carbo*	1	30·35	30·35	—	—	1	36·90	36·90	—	—
Grey heron *Ardea cinerea*	4	10·72	10·46	6·98	1·85–18·54	4	4·58	4·31	2·17	1·68–6·41
(fish)	22	3·41				23	2·11			

Geographical variation within terrestrial systems

Two zones have been defined in Belgium, north and south of the rivers Sambre, Meuse and Vesdre, in parallel with previous studies on organochlorine contamination (Joiris & Delbeke, 1981).

The long-eared owl *Asio otus* and the barn owl *Tyto alba* from the northern region had a three to four times higher mercury level than those from the southern region. This was again explained by dietary differences: the owls having more passerines in their diet in the northern (agricultural) zone than in the southern zone which consists mainly of forests and meadows. It was interesting to note that in the buzzard *Buteo buteo*, where the diet consists mainly of rodents in both zones, there was no significant difference in contamination (Table 3).

Distribution pattern of mercury within various tissues

For the different species of aquatic birds, the mercury levels in kidney and liver were closely related: this was noted each time the number of samples was big enough to allow the comparison. The contamination of kidney was lower than that of liver: the ratio of mercury in liver to kidney varied between 1·2 and 2·5 (Table 4, Fig. 1). A positive correlation between liver and kidney mercury levels, with a higher level in liver, was noted in birds sacrificed in previous studies (Finley & Stendell, 1978; Hutton, 1981). A higher liver than kidney mercury contamination has been noted for the fulmar, but no correlation between liver and kidney was, however, established (Osborn *et al.*, 1979).

For the raptors, the levels in liver and kidney were also positively related (Table 5, Fig. 2). The ratio between both concentrations is, however, closer to 1, varying between 0·8 and 1·1 with the exception of the barn owl, in which a higher ratio was found. With the barn owl there was also a much lower correlation coefficient, due to the presence of six birds with high liver contamination, which possibly had been exposed to acute intoxication.

As far as muscle and heart samples were concerned, only a few determinations were done. The results are summarised in Appendix 1. The relation between muscle (M) and liver (L) contamination was

$$M = 0{\cdot}24L + 0{\cdot}08 \qquad (r = 0{\cdot}61,\ n = 22)$$

and/or heart (H), the equation was

$$H = 0{\cdot}57L + 0{\cdot}06 \qquad (r = 0{\cdot}90,\ n = 12)$$

TABLE 1

Mercury Levels in Liver and Kidney of Aquatic Birds with Different Feeding Habits ($\mu g\, g^{-1}$ wet weight; n, number of samples; SD, standard deviation)

Species (main diet)	Mercury contamination: Liver					Kidney				
	n	*Median*	*Mean*	*SD*	*Min–Max*	n	*Median*	*Mean*	*SD*	*Min–Max*
Little grebe *Tachybaptus ruficollis*	1	0·35	0·35	—	—	1	0·38	0·38	—	—
Kingfisher *Alcedo atthis*	7	0·23	0·53	0·52	0·11–1·53	—				
(invertebrates + fish)	8	0·29				1	0·38			
Fulmar *Fulmarus glacialis*	6	1·44	1·86	1·52	0·54–4·80	6	0·69	1·01	1·35	0·39–3·76
Great black-backed gull *Larus marinus*	3	1·36	1·28	0·50	0·75–1·74	3	0·89	1·06	0·52	0·64–1·64
(zooplankton, garbage)	9	1·36				9	0·64			
Red-necked grebe *Podiceps griseigena*	—					1	1·10	1·10	—	—
Great crested grebe *Podiceps cristatus*	8	4·93	8·25	6·99	1·72–20·75	8	4·35	5·30	4·11	1·53–12·40
Guillemot *Uria aalge*	9	2·19	2·39	0·80	1·22–3·62	9	1·36	1·48	0·57	0·85–2·57
Cormorant *Phalacrocorax carbo*	1	30·35	30·35	—	—	1	36·90	36·90	—	—
Grey heron *Ardea cinerea*	4	10·72	10·46	6·98	1·85–18·54	4	4·58	4·31	2·17	1·68–6·41
(fish)	22	3·41				23	2·11			

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$$M = 0{\cdot}24L + 0{\cdot}08 \qquad (r = 0{\cdot}61,\ n = 22)$$

and/or heart (H), the equation was

$$H = 0{\cdot}57L + 0{\cdot}06 \qquad (r = 0{\cdot}90,\ n = 12)$$

TABLE 2

Mercury Levels in Liver and Kidney of Terrestrial Birds with Different Feeding Habits
($\mu g\,g^{-1}$ wet weight; *n*, number of samples; SD, standard deviation)

Species (*Main diet*)	*Mercury contamination* — *Liver*					*Kidney*				
	n	*Median*	*Mean*	*SD*	*Min–Max*	*n*	*Median*	*Mean*	*SD*	*Min–Max*
Jay *Garrulus glandarius*	—					1	0·05	0·05	—	—
Magpie *Pica pica*	—					2	0·11	0·11	—	0·04–0·18
Jackdaw *Corvus monedula*	—					1	0·14	0·14	—	—
Carion crow *Corvus corone*	—					4	0·15	0·26	0·26	0·09–0·64
Raven *Corvus corax*	—					3	0·05	0·05	0·01	0·04–0·06
Collard turtle dove *Streptopelia decaocto*	—					1	0·10	0·10	—	—
(omnivorous, mainly plants)						12	0·09			
Honey buzzard *Pernis apivorus*	1	0·08	0·08	—	—	1	0·03	0·03	—	—
Roller *Coracias garrulus*	—					1	0·35	0·35	—	—
(insects)	1	0·08				2	0·19			
Little owl *Athene noctua*	24	0·28	0·82	2·11	0·01–10·58	19	0·31	1·05	3·17	0·05–14·10
(mammals + invertebrates)	24	0·28				19	0·31			
Kite *Milvus milvus*	1	0·18	0·18	—	—	1	0·17	0·17	—	—
Buzzard *Buteo buteo*	24	0·59	1·10	1·67	0·02–4·38	15	0·35	0·66	0·66	0·05–2·34
Marsh harrier *Circus aeruginosus*	1	0·17	0·17	—	—	1	0·10	0·10	—	—
Kestrel *Falco tinnunculus*	15	0·34	0·69	0·73	0·05–1·33	11	0·45	0·53	0·40	0·11–1·26
Barn owl *Tyto alba*	28	0·86	1·35	1·23	0·07–4·31	23	0·89	1·09	0·92	0–3·45
Eagle owl *Bubo bubo*	1	1·67	1·67	—	—	1	0·92	0·92	—	—
Long-eared owl *Asio otus*	27	0·53	0·97	1·20	0–5·82	10	0·26	0·47	0·64	0–2·14
Short-eared owl *Asio flammeus*	1	0·70	0·70	—	—	—				
Tawny owl *Strix aluco*	8	0·36	0·65	0·62	0·12–1·92	4	0·76	0·85	0·42	0·46–1·44
(mammals)	106	0·57				66	0·54			
Goshawk *Accipiter gentilis*	2	5·04	5·04	—	0·40–10·68	1	0·34	0·34	—	—
Sparrowhawk *Accipiter nisus*	14	2·84	3·15	2·31	0·35–8·14	14	3·08	3·48	2·46	0·44–7·88
Merlin *Falco columbarius*	2	0·66	0·66	0·22	0·50–0·81	2	0·46	0·46	0·09	0·50–0·81
(birds)	18	2·84				17	2·94			

TABLE 3
Mercury Levels in Liver and Kidney of Raptors from Two Regions in Belgium
($\mu g\ g^{-1}$ wet weight; *n*, number of samples)

Species	*Region*	*Diet*[a] (*% of birds*)	*Mercury level* — *Liver* *Median*	*(n)*	*Min–Max*	*Kidney* *Median*	*(n)*	*Min–Max*
Buzzard	N	5	0·60	(12)	0·02–4·38	0·31	(7)	0·05–1·17
Buteo buteo	S	5	0·46	(4)	0·14–7·69	0·24	(2)	0·14–0·33
Long-eared owl	N	25	1·14	(14)	0·22–5·82	1·54	(2)	0·93–2·14
Asio otus	S	3	0·30	(5)	0·27–1·35	0·10	(2)	0–0·19
Barn owl	N	10	1·26	(16)	0·07–4·31	1·01	(14)	0·08–3·40
Tyto alba	S	0	0·28	(3)	0·14–1·63	0·77	(2)	0·70–0·84

N, Northern zone; S, southern zone (see text).
[a] Uttendörfer (1952); E. Delmée (personal communication); Van der Straeten (1974); Godin (1975); Leurquin (1975).

TABLE 4
Relation Between the Mercury Levels ($\mu g\ g^{-1}$ wet weight) in Kidney (K) and Liver (L) of Aquatic Birds. The Data Concern Only Determinations in Liver and Kidney of the Same Bird
(*n*, Number of samples; *r*, correlation coefficient; * $P < 0·01$; ** $P < 0·001$)

Species	*n*	*Regression*	*r*	*Ratio* $\frac{Liver}{Kidney}$
Grey heron *Ardea cinerea*	4	$K = 0·30L + 1·17$	0·97	2·44
Guillemot *Uria aalge*	9	$K = 0·63L - 0·02$	0·88*	1·61
Great-crested grebe *Podiceps cristatus*	7	$K = 0·83L - 0·03$	0·97**	1·22
Fulmar *Fulmarus glacialis*	6	$K = 0·81L - 0·41$	0·94*	1·85
Great black-backed gull *Larus marinus*	3	$K = 0·96L - 0·17$	0·91	1·20

TABLE 5
Relation Between the Mercury Levels ($\mu g\ g^{-1}$ wet weight) in Liver (L) and Kidney (K) of Raptors
(*n*, Number of samples; *r*, correlation coefficient; * $P < 0·01$; ** $P < 0·001$)

Species	*n*	*Regression*	*r*	*Ratio* $\frac{Liver}{Kidney}$
Kestrel *Falco tinnunculus*	11	$K = 0·75L + 0·11$	0·88**	1·07
Buzzard *Buteo buteo*	13	$K = 1·03L + 0·06$	0·93**	0·88
Sparrowhawk *Accipiter nisus*	13	$K = 0·90L + 0·70$	0·85**	0·89
Little owl *Athene noctua*	18	$K = 1·33L - 0·05$	0·99**	0·79
Tawny owl *Strix aluco*	4	$K = 0·78L + 0·33$	0·77	0·77
Long-eared owl *Asio otus*	10	$K = 1·08L - 0·10$	0·94**	1·12

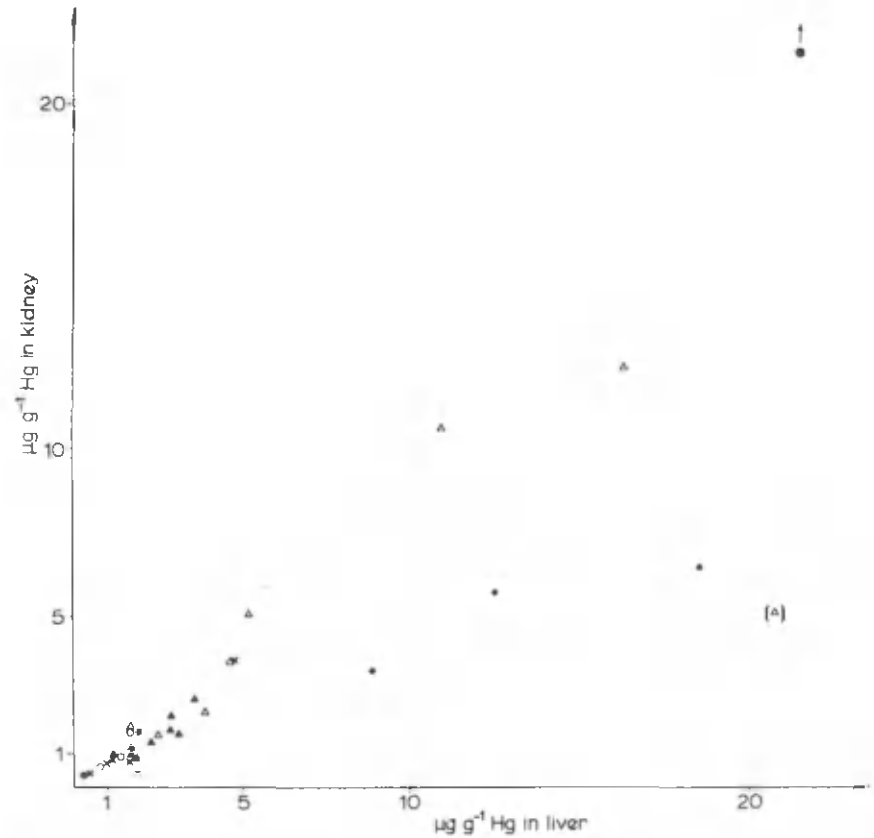


Fig. 1. Relationship between the mercury contamination of the liver and kidney of aquatic birds found dead in Belgium ($\mu g\ g^{-1}$ wet weight). ●, *Tachybaptus ruficollis*; △, *Podiceps cristatus*; ⁎, *Fulmarus glacialis*; ⊗, *Phalacrocorax carbo*; *, *Ardea cinerea*; ○, *Larus marinus*; ▲, *Uria aalge*. Correlation: $K = 0{\cdot}55L + 0{\cdot}35$ ($r = 0{\cdot}87$; $n = 30$) without taking into account: 1 *Podiceps cristatus* or the *Phalacrocorax carbo*.

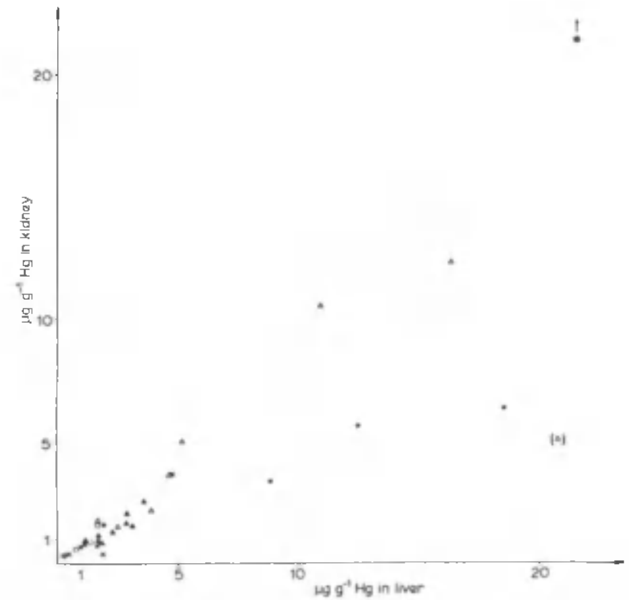
In both cases, the mercury contamination is clearly lower than the contamination of the liver, in agreement with the literature (Fimreite, 1971, 1972; Osborn *et al.*, 1979).

Seasonal variations of mercury concentration

For two species (barn owl and long-eared owl), the amount of samples was large enough and their temporal distribution regular enough to allow

TABLE 6
Mercury Levels in Liver and Kidney of Owls—Temporal Variations
($\mu g\ g^{-1}$ wet weight; *n*, number of samples)

Species	*Period (months)*	*Mercury level* Liver *Median*	*(n)*	*Min–Max*	Kidney *Median*	*(n)*	*Min–Max*
Long-eared owl *Asio otus*	I	0·45	(6)	0–1·10	0·19	(3)	0–0·93
	II	2·04	(2)	1·35–2·74			
	III	1·46	(7)	0·69–2·01	0·32	(1)	
	IV	1·80	(1)		2·14	(1)	
	V	—			—		
	VI	—			—		
	VII	0·42	(2)	0·30–0·52	—		
	VIII	0·52	(1)		0·19	(1)	
	IX	0·57	(1)		—		
	X	—			—		
	XI	1·76	(1)		—		
	XII	0·69	(1)		—		
Barn owl *Tyto alba*	I	3·10	(4)	1·03–3·54	1·21	(5)	0·64–3·45
	II	1·35	(3)	0·55–2·92	0·96	(4)	0·89–3·07
	III	—			—		
	IV	0·38	(1)		0·62	(1)	
	V	0·14	(1)		—		
	VI	0·77	(3)	0·28–0·95	—		
	VII	1·61	(1)		—		
	VIII	—			—		
	IX	0·32	(2)	0·21–0·43	0·20	(1)	



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		Liver			*Kidney*		
		Median	(*n*)	*Min–Max*	*Median*	(*n*)	*Min–Max*
Long-eared owl *Asio otus*	I	0·45	(6)	0–1·10	0·19	(3)	0–0·93
	II	2·04	(2)	1·35–2·74			
	III	1·46	(7)	0·69–2·01	0·32	(1)	
	IV	1·80	(1)		2·14	(1)	
	V	—			—		
	VI	—			—		
	VII	0·42	(2)	0·30–0·52	—		
	VIII	0·52	(1)		0·19	(1)	
	IX	0·57	(1)		—		
	X	—			—		
	XI	1·76	(1)		—		
	XII	0·69	(1)		—		
Barn owl *Tyto alba*	I	3·10	(4)	1·03–3·54	1·21	(5)	0·64–3·45
	II	1·35	(3)	0·55–2·92	0·96	(4)	0·89–3·07
	III	—			—		
	IV	0·38	(1)		0·62	(1)	
	V	0·14	(1)		—		
	VI	0·77	(3)	0·28–0·95	—		
	VII	1·61	(1)		—		
	VIII	—			—		
	IX	0·32	(2)	0·21–0·43	0·20	(1)	
	X	0·77	(3)	0·29–2·25	0·49	(2)	0·43–0·56
	XI	0·17	(2)	0·07–0·28	0·10	(2)	0·08–0·11
	XII	3·10	(2)	1·89–4·31	1·92	(3)	0·84–1·92

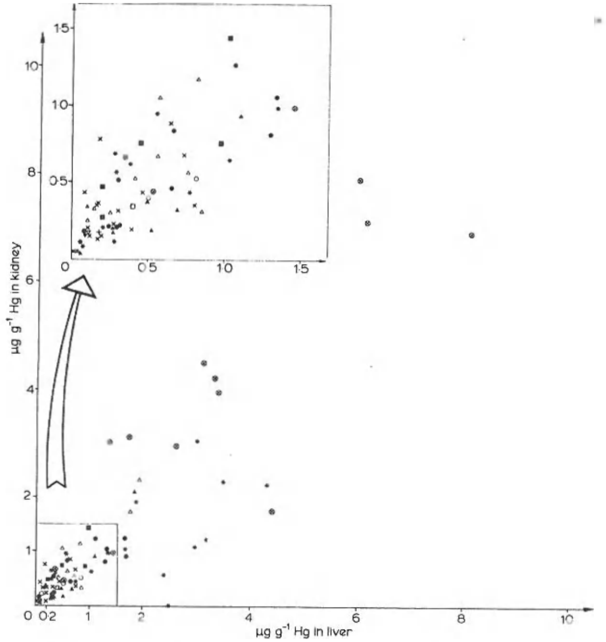

Fig. 2. Relationship between the mercury contamination of the liver and kidney of raptors found dead in Belgium ($\mu g\, g^{-1}$ wet weight). The lower part of the graph, up to $1{\cdot}5\,\mu g\, g^{-1}$, has been enlarged for clarity. ▼, *Pernis apivorus*; +, *Milvus milvus*; □, *Accipiter gentilis*; ⊗, *Accipiter nisus*; △, *Buteo buteo*; ▽, *Circus aeruginosus*; ○, *Falco columbarius*; ●, *Falco tinnunculus*; *, *Tyto alba*; ◉, *Bubo bubo*; ▲, *Asio otus*; ✖, *Athene noctua*; ■, *Strix aluco*. Correlation: $K = 1{\cdot}1L - 0{\cdot}04$ ($r = 0{\cdot}96$; $n = 76$).

the investigation of seasonal variation in mercury levels. For the long-eared owl, the levels detected in the liver were higher from February to April (median: $1{\cdot}51\,\mu g\, g^{-1}$, $n = 10$) than for the rest of the year ($0{\cdot}52\,\mu g\, g^{-1}$, $n = 12$) (Table 6). For the barn owl, the levels were higher from December to February (liver: $2{\cdot}92\,\mu g\, g^{-1}$, $n = 9$; kidney: $1{\cdot}16\,\mu g\, g^{-1}$, $n = 12$) than for the rest of the year (liver: $0{\cdot}38\,\mu g\, g^{-1}$, $n = 13$; kidney: $0{\cdot}31\,\mu g\, g^{-1}$, $n = 6$). These differences are highly significant ($P < 0{\cdot}005$).

DISCUSSION

For ethical reasons, we decided not to shoot birds, but to use birds found dead. This makes it difficult to extrapolate between our results and the levels of mercury that would be found in the living population. However, 50% to 60% of raptors found dead had died through trauma (car accident, shot, etc.) (Glue, 1971; Weir, 1971; Newton *et al.*, 1982), and several authors have taken the pollutant levels in such birds to be reasonably representative of those in the living population (see Cooke *et al.* (1982) for a discussion). This, together with the finding that mercury concentration in trauma birds and birds from other groups differ little—with the exception of the barn owl (Cooke *et al.*, 1982)—makes it unlikely that our sampling method has unduly biased our results.

The observed contamination levels of the different species have the same order of magnitude as those observed in other countries (Fimreite *et al.*, 1971; Fimreite, 1972; Greichus *et al.*, 1973; Veluz *et al.*, 1976; Juillard *et al.*, 1978; Furness & Hutton, 1979; Hutton, 1981; Cooke *et al.*, 1982).

The contamination of the various species is clearly diet-dependent. For aquatic birds, Fimreite (1971) has shown that the mercury levels are related to the percentage of animals in the food. Hutton (1981) noted differences in the mercury content of three species of aquatic birds with different feeding habits. In this study, a more detailed knowledge of the feeding habits of a large variety of species gave a better understanding of the contamination levels: birds feeding on fish have twice as high a mercury level as species feeding on fish, zooplankton and garbage. These latter bird species are in turn four times more contaminated than birds feeding on fish and insects. Using a $0{\cdot}2\,\mu g\, g^{-1}$ value for marine fish in our zone (Blaton, 1973), a concentration factor of 10 can be calculated from fish to birds. Such a value is in good agreement with published data (Fimreite *et al.*, 1971; Hölzinger, 1977). A higher mercury contamination of raptors feeding on birds than on mammals, noted earlier (Fimreite *et al.*, 1970), is also clear in our results. Not only is this difference a quantitative one to be expressed as a correlation between the contamination of the raptors and the amount of birds in their diet, but is also valid within species (owls): differences in feeding habits between two geographical regions within Belgium lead to differences in contamination.

The relation between the median mercury level in the liver (L) of raptors belonging to different species and regions (taking into account only median values consisting of at least 4 samples) and the percentage of birds in their diet (B) was

$$L = 0{\cdot}026B + 0{\cdot}35 \qquad (r = 0{\cdot}94, n = 9)$$

and for kidney (K), the equation was

$$K = 0{\cdot}029B + 0{\cdot}30 \qquad (r = 0{\cdot}97, n = 7)$$

It is worth noting that the same conclusions have been drawn earlier in studies on the contamination of raptors by DDT (Joiris & Delbeke, 1981). The DDT levels in different tissues and eggs, as well as eggshell thinning, were completely explained by the diet characteristics of the raptors, including their annual and geographical variations. The contamination of the prey items showed that passerines are indeed more contaminated than small mammals. Finally, laboratory experiments (Joiris *et al.*, details to be published later) showed a higher elimination rate in mammals than in birds, which explains the differences in contamination.

The similarity in contamination patterns of mercury and DDT suggests the existence of similar ecotoxicological mechanisms for both types of stable compounds.

A higher contamination was detected for two species of owls, during the winter and early spring. A similar trend has already been noted for the barn owl and kestrel (Bell *et al.*, 1978; Cooke *et al.*, 1982) and might be associated with different mechanisms such as a seasonal variation in the diet, more birds being consumed in the winter period, or with a seasonal variation in the contamination of prey items. For example, Osborn (1979) found higher mercury levels in the starling *Sturnus vulgaris* during the winter. Finally, a redistribution of mercury within the body could be due to the loss of fat during the winter and/or during the moulting periods.

It is difficult to give a toxicological interpretation of our data, since we have not yet determined the mercury form or the binding sites of mercury in the tissues. The greatest part of the mercury is likely to be in its methyl form (Fimreite *et al.*, 1974; Osborn *et al.*, 1979). We therefore compared our data with published results on methylmercury. Laboratory studies revealed that mercury levels of 3 to 13 $\mu g\, g^{-1}$ in the liver lowered the hatchability by pheasants (Fimreite, 1971). In our study 29 birds out of 188 (15%) had a contamination exceeding the 3 $\mu g\, g^{-1}$ level, reflecting the possibility that Hg could have a negative effect on their reproduction. Most of these birds were bird-eating raptors: sparrowhawk *Accipiter nisus* and goshawk *Accipiter gentilis*, and fish-eating birds: cormorant, grey heron *Ardea cinerea*, and great crested grebe *Podiceps cristatus*. On the other hand, a level of 17 $\mu g\, g^{-1}$ was noted in the liver of hawks that died through mercury intoxication (Fimreite & Karstad, 1971). On this basis, some of the birds we analysed might have suffered from serious mercury poisoning (3% of the total), since their mercury levels were higher than 10 $\mu g\, g^{-1}$: 3 great crested grebes, 2 grey herons, the cormorant, 1 goshawk and 1 tawny owl. Finally, a few birds showed an abnormally high liver to kidney ratio (see Figs 1 and 2), which could indicate an acute intoxication having eventually caused death: 3 grey herons, 1 great crested grebe, 6 barn owls and 1 sparrowhawk.

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APPENDIX 1

The Mercury Contamination ($\mu g\, g^{-1}$ wet weight) of the Muscle and Heart of Different Species of Birds
(n, number of samples; SD, standard deviation)

Species	*Mercury contamination*									
	Muscle					*Heart*				
	n	*Median*	*Mean*	*SD*	*Min–Max*	*n*	*Median*	*Mean*	*SD*	*Min–Max*
Cormorant *Phalacrocorax carbo*	1	1·41	1·41	—	—	1	1·41	1·41	—	—
Kingfisher *Alcedo atthis*	4	0·77	0·73	0·38	0·22–1·13	5	0·18	0·27	0·26	0·12–0·73
Honey buzzard *Pernis apivorus*	1	0·15	0·15	—	—	1	0·03	0·03	—	—
Sparrowhawk *Accipiter nisus*	3	0·71	0·81	0·19	0·70–1·03	2	0·96	0·96	0·15	0·85–1·07
Buzzard *Buteo buteo*	4	0·15	0·20	0·20	0·04–0·46	2	0·16	0·16	0·16	0·05–0·28
Merlin *Falco columbarius*	2	0·17	0·17	0·02	0·16–0·19	1	0·24	0·24	—	—
Kestrel *Falco tinnunculus*	2	0·09	0·09	0·04	0·06–0·11	2	0·09	0·09	—	—
Barn owl *Tyto alba*	5	0·18	0·18	0·15	0·01–0·41	4	0·23	0·20	0·16	0·01–0·33
Long-eared owl *Asio otus*	1	0·01	0·01	—	—	—				