Biomagnification of mercury in trophic relation of Great Cormorant (*Phalacrocorax carbo*) and fish in the Vistula Lagoon, Poland

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Abstract Total mercury (Hg) concentrations were determined by CV-AAS in selected tissues (liver, kidney, and muscle) of the Great Cormorant and some fish species (herring, ruffe, European smelt, tench, roach, Crucian carp, and Prussian carp) from the Vistula Lagoon ecosystem (Poland). Significant correlations between Hg concentrations in the kidneys and muscle of cormorants (U test, $p < 0.05$) were found; levels of the metal were highest in the birds' liver and kidneys. Total Hg concentrations in the fish decreased in the following order: roach > Prussian carp > Crucian carp > tench > European smelt > ruffe > herring. The biomagnification factor of Hg for the cormorant relative to the fish decreased in the following sequence: herring > ruffe > European smelt > tench > Crucian carp > roach = Prussian carp. It was significantly greater than unity, especially for the cormorant–herring trophic relationship. This implies that Hg is biomagnified in the cormorant in relation to its prey.

Keywords Total mercury · Great Cormorant · Fish · Biomagnifications · CV-AAS

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Introduction

In the natural environment, mercury (Hg) is derived from both anthropogenic activities and natural sources. Up to now, anthropogenic emissions of Hg to the environment have been increasing substantially relative to natural emissions. The most important sources of Hg pollution in aquatic systems are atmospheric deposition, erosion, urban discharges, agricultural materials, mining, combustion, and industrial effluents (Wang et al. 2004). Most Hg pollution resides in the aquatic environment, resulting in its rapid incorporation into the food chain and biomagnification in organisms.

As chemical elements are transported along the successive levels of the food chain, their concentrations may rise at each higher trophic level, an effect known as biomagnification (Gray 2002). One of the properties of Hg is its ability to bioaccumulate in soil, plants, animals, and humans. The harmfulness of this metal depends on the time of exposure to it and its speciation; Hg vapors entering organisms through their respiratory systems

are especially dangerous. Other chemical forms of Hg can also be ingested with food. Absorbed Hg circulates with the blood and accumulates in some tissues. Higher levels were recorded in the critical organs (kidney, liver) and muscle. Fish-eating birds, like Great Cormorant, are exposed to Hg biomagnification mostly because of their location at the end of the food chain (Houserová et al. 2007; Saeki et al. 2000). The toxic effects of Hg in birds include reduced food intake leading to weight loss, progressive weakness in the wings and legs leading to difficulty in flying, walking, and standing, and an inability to coordinate muscle movements (Kim et al. 1996; Scheuhammer and Graham 1999). High concentrations of Hg in birds most often affect their immune, detoxification, and nervous systems, and cause reproductive impairment (Boening 2000; Houserová et al. 2007).

The aims of this study were to assess the inter-tissue distribution of Hg in the Great Cormorant (*Phalacrocorax carbo*) and to estimate the extent to which this metal is biomagnified in relation to the bird's food, i.e., fish.

Materials and methods

Study area

The Vistula Lagoon is a semienclosed, shallow, coastal basin separated from the Gulf of Gdansk by the Vistula Spit and connected with the Baltic Sea via the Baltijsk Strait. The lagoon is 90.7 km long (35.1 km in the Polish Sector), has an average depth of 3.1 m, and has a maximum depth of 5.2 m; the depth of the dredged ship channel in the north-eastern part of the lagoon is 11 m. The area of the lagoon is 861 km², 473 km² of which lie within the borders of the Russian Federation and 388 km² in Poland. The Vistula Lagoon consists of shallow, brackish water with a salinity between 0.1 and 10 psu (average, 4–5.5 psu). The hydrological status of the lagoon is defined chiefly by the inflow of fresh water from 20 rivers and water exchange with the Baltic Sea. The main inflow is supplied by the Russian River Pregola; the inflow from Polish rivers comes from the Bauda, Elbląg, Pasłęka, Nogat, and Szkarpawa (Ezhova et al. 2005; Uścinowicz and Zachowicz 1996).

The Vistula Lagoon is polluted by nutrients, mostly the residues of various plant-protection products and fertilizers used in agriculture. Sewages from the mechanical–biological waste-water treatment plants at Tolkmicko, Frombork, Krynica Morska, and Piaski enter the lagoon on a continuous basis. All this raises the fertility of the lagoon—eutrophication is thus an ongoing process. Since 1950, eutrophication has increased dramatically; the fertility of the Lagoon was recently assessed as being four to five times greater than that of the Baltic Sea itself (Szefer 2002). The Vistula Lagoon has, therefore, been included in the natural environment protection program Natura 2000 and put on the list of Baltic Sea Protected Areas introduced by HELCOM (Szefer 2002).

Great Cormorant and fish

The largest European colony of Great Cormorants is located at Kąty Rybackie near the Vistula Lagoon. The number of individuals in the population rose continuously until 2004, when a total of 11,500 pairs occupied the colony; currently, the population is in regression, possibly because of aging. Great Cormorants play an important role in freshwater ecosystems like the Vistula Lagoon because they are numerous and widespread top predators and they influence the structure and dynamics of fish communities (Stempniewicz et al. 2003).

Great Cormorants are a relatively large birds, weighing from 1.3 to 3.1 kg and with a wingspan from 1.3 to 1.6 m. There is hardly any sexual dimorphism: females are slightly smaller and lighter than males. The feathers of mature birds are black with white spots on the cheeks and thighs. Immature individuals are recognized by the white belly with various numbers of dark spots (Baker 1993; Goc 2004; Przybysz 1997). Normally, three to six eggs are laid by the female at 2- to 3-day intervals. The incubation period is about 3 weeks (from 23 to 31 days). Incubation as well as care of the chicks is shared between males and females. The usual level of breeding success is two to three chicks per pair.

Great Cormorants are fish-eating birds without any particular preferences in their prey species,

mostly choosing the easiest and most numerous to catch (Goc 2004; Przybysz 1997). They hunt individually or in flocks (Przybysz 1997). Their staple diet consists mostly of fish from the families Cyprinidae and Percidae (Stempniewicz and Grochowski 1997): ruffe (*Gymnocephalus cernuus*), perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*), and more rarely tench (*Tinca tinca*) and Prussian carp (*Carassius gibelio*); in addition, fair numbers of fish from other families are taken, like European smelt (*Osmerus eperlanus*) and herring (*Clupea harengus*) (Martyniak et al. 2003; Stempniewicz and Grochowski 1997; Stempniewicz et al. 2003). Analysis of Great Cormorants' pellets in the colony (1996) showed that ruffe was the main component of the birds' diet. The percentage composition of the cormorants' diet (Fig. 1) is as follows: ruffe, 74.6%; European smelt, 11.6%; perch, 6%; roach, 3.7%; herring, 1.2%; other species, <1% (Martyniak et al. 2003). Great Cormorants eat fish species of little industrial importance: the basic item from the Vistula Lagoon area is the ruffe, known as "fish weed" by fishermen.

Herring is a commercially very important marine species that occurs in the Vistula Lagoon seasonally, mainly in spring during its spawning season. The juveniles are zooplanktivorous. Roach is a common, freshwater species in the Vistula Lagoon, foraging mainly on benthic organisms like mollusks; its spawning period is from May to June. Tench is common close to rivers; it inhabits the littoral zone and feeds on benthic organisms. Crucian carp and Prussian carp are benthivorous, medium-sized fish common in the Vistula Lagoon where they inhabit the littoral

zone. European smelt is also a common species, feeding mainly on zooplankton, including fish larvae. Ruffe is a common benthivorous species of no commercial importance (Brylińska 1991; Psuty 2010).

The cormorants from Kąty Rybackie colony make foraging trips to the Vistula Lagoon, to the Gulf of Gdańsk as well as to the mouth of the River Vistula. The availability of fish varies seasonally. The Vistula Lagoon is the main feeding area following the birds' return from their wintering grounds—from February to the beginning of April. During this time, cormorants catch small percid and cyprinid fish, like ruffe, roach, and bream (Bzoma et al. 2003). At the beginning of the breeding season, herring become the major part of the birds' diet because these fish become easy to catch during their spawning season (Kanarek and Rolbiecki 2006). Later, as the breeding season progresses, the other areas (Gulf of Gdańsk) increase in importance. This is probably due to the colony's greater food requirements when fish resources in the Vistula Lagoon are shrinking (Bzoma et al. 2003; Goc et al. 2003; Stempniewicz et al. 2003).

Sampling and analytical method

The Great Cormorants were shot by hunters (by permission of the local environment protection authorities) in the Polish Sector of the Vistula Lagoon during June 2006. The birds were identified as *P. carbo* using the method suggested by Baker (1993). Fifty-five specimens were obtained and then sorted by sex (24 females, 31 males) and age (44 adults, 11 immatures). They were

Fig. 1 Percentage composition of the diet of Great Cormorant (*P. carbo*) in the Vistula Lagoon ecosystem in 1996 (from Martyniak et al. 2003)

other species, 9.0%   herring, 1.2%   roach, 3.7%   perch, 6.0%

European smelt, 11.6%

ruffe, 74.6%
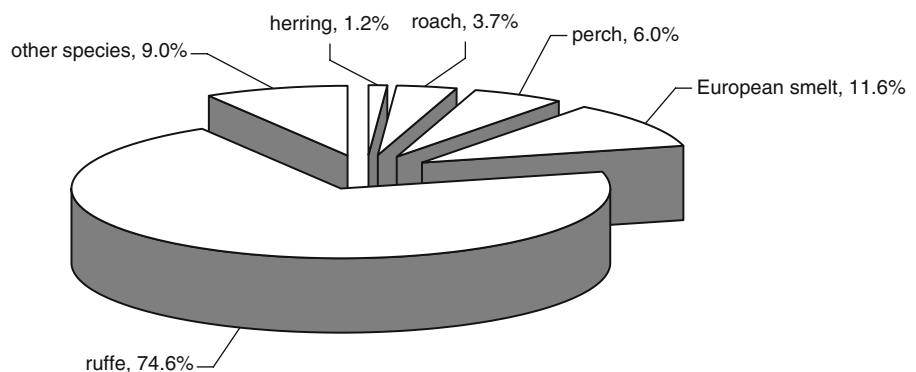
dissected in order to separate tissues and organs: kidneys, liver, muscles, oesophagus, stomach, intestines, trachea, lungs, skin, cardiac muscle, and feathers. The separate tissues and organs of the birds and whole specimens of fish were immediately deep-frozen, freeze-dried (lyophilized), and homogenized. The total Hg concentration was determined in the fish constituting the cormorant's diet in order to discover the extent to which the Hg load from the fish is passed on to the birds. The following species of fish were caught by fyke net in the north-western Vistula Lagoon near the cormorant colony at Kąty Rybackie in June 2006: herring, tench, roach, European smelt, ruffe, Crucian carp (*Carassius carassius*) and Prussian carp. The fish species were identified using Brylińska's method (1991).

Whole specimens of fish and individual cormorant tissues and organs were analyzed. The tissues and organs were lyophilized, homogenized, and weighed (from 10 ± 0.1 to 50 ± 0.1 mg), placed in precleaned combustion boats, and automatically inserted into the Mercury/MA-2000 analyzer system (NIC—Japan). Samples were thermally decomposed at 800°C under clean air flow. The total Hg concentration was determined by CV-AAS at 253.65 nm. Three analytical subsamples were prepared from each sample. Quality control was assured by analyses of certified reference materials: DORM-2 (National Research Council, Canada), BCR-463, and ERM-CE278 (IRMM, Belgium). The respective recoveries (a measure of accuracy) of total Hg were 101.0%, 97.1%, and 98.6%, and the respective standard deviations (SD; a measure of precision) were 0.09, 0.09, and 0.10%. The limit of detection was 0.12 ng. The estimated variability of Hg concentrations in three subsamples of particular tissues was satisfactory, since the coefficients of variation (CVs) were 0.49–6.65%, 0.12–11.18%, 0.30–4.68%, and 0.89–14.4% for kidney, liver, muscle, and feathers, respectively. Since CVs were generally <10%, it was possible to use <50 mg samples.

Statistical analysis

The concentration data were processed statistically using STATISTICA 8.0 for Windows (Copyright© StatSoft, Inc. 1984–2007). Cluster analysis was used to compare the Hg content in particular tissues in order to estimate the total pool of Hg in the whole bird body. To check whether there was any statistically significant difference in Hg concentrations between sex and age, the data were processed using the nonparametric Mann–Whitney U test ($p < 0.05$).

To estimate the total Hg content in birds and to calculate the biomagnification factor (BMF), Hg concentrations in cormorants and fish were recalculated from dry weight (d.w.) to wet weight (w.w.).

Estimation of the total Hg content in birds

Required data:

– wet mass of the whole bird body [in grams]
– wet mass of all the separate tissues, especially liver, kidney and muscle [in grams]
– Hg concentration in liver [in micrograms per gram w.w.]
– Hg concentration in kidney [in micrograms per gram w.w.]
– Hg concentration in all the tissues analyzed [in micrograms per gram w.w.]

The principal assumptions:

– the muscles are the main part (in terms of weight) of a bird's body
– the Hg concentration (in micrograms per gram w.w.) in all the tissues except kidney and liver is similar to that in the muscles. This assumption is supported by cluster analysis data (Fig. 2): cluster analysis shows that the concentration of Hg in muscles is similar to that in the other tissues, except kidney, liver, and feathers. Hg concentrations in bird tissues other than those analyzed in the present study may be omitted from the calculation of both total Hg content and BMF because their mass contribution to the whole body of the cormorant is insignificant. For instance, the mass contribution of bones to the whole body estimated in our study was ∼7% and the content of Hg in bones reported by Nam et al. (2005) was ∼1–2% of its total pool in the whole bird's body.

Fig. 2 Cluster analysis data concerning the intertissue distribution of Hg (in micrograms per gram w.w.) in Great Cormorants (*P. carbo*) from the Vistula Lagoon. This shows that the Hg concentration in muscle tissue is similar to that in six other tissues, except kidney, liver, and feathers
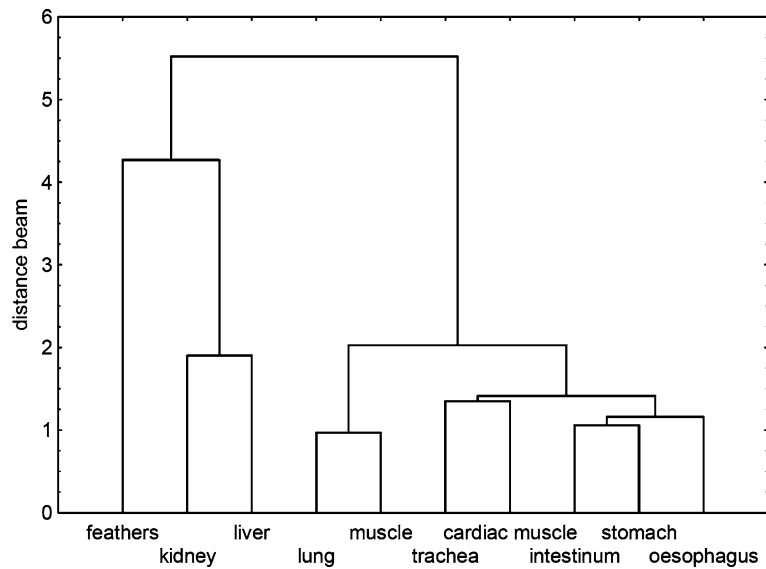
Total Hg can be then calculated as the sum of the total Hg in kidney, liver, feathers, and the rest of the body. As the weights of kidney, liver, and feathers and also the Hg concentration in these tissues are known, the total amount of Hg in kidney, liver, and feathers is:

$$M_{\text{Hg kidney}} = M_{\text{kidney}} \times C_{\text{kidney}}$$
$$M_{\text{Hg liver}} = M_{\text{liver}} \times C_{\text{liver}}$$
$$M_{\text{Hg feathers}} = M_{\text{feathers}} \times C_{\text{feathers}}$$

where M is the wet mass of kidney/liver/feathers [in grams], M_{Hg} is the total amount of Hg in kidney/liver/feathers [in micrograms], and C is the concentration of Hg in kidney/liver/feathers [in micrograms per gram w.w.].

Assuming that the whole of the remainder of the bird's body has a Hg concentration similar to that in muscle tissue, the amount of Hg in the remainder can be calculated using the following formula:

$$M_{\text{Hg rest}} = \left(M_{\text{whole body}} - M_{\text{kidney}} \right. \\ \left. - M_{\text{liver}} - M_{\text{feathers}} \right) \times C_{\text{muscle}}$$

where M is the wet mass of kidney/liver/feathers/whole body [in grams], $M_{\text{Hg rest}}$ is the total amount of Hg in all tissues except kidney, liver and feathers [in micrograms], and C is the concentration of Hg in muscle [in micrograms per gram w.w.].

The total amount of Hg in the whole bird's body can thus be calculated as follows:

$$M_{\text{Hg total}} = M_{\text{Hg kidney}} + M_{\text{Hg liver}} \\ + M_{\text{Hg feathers}} + M_{\text{Hg rest}}.$$

Biomagnification factor

Vistula Lagoon cormorants feed mainly on herring, tench, roach, European smelt, ruffe, Crucian carp, and Prussian carp (Martyniak et al. 2003). The BMF was calculated on the basis of the Hg concentrations in the liver, kidney, muscles, and total body (calculated as above) of cormorants. BMF is defined by Ciesielski et al. (2006):

$$\text{BMF} = C_{\text{(predator)}} / C_{\text{(prey)}}$$

where $C_{\text{(predator)}}$ is the concentration of Hg (in micrograms per gram w.w.) in predator, $C_{\text{(prey)}}$ is the concentration of Hg (in micrograms per gram w.w.) in prey.

Results

Total Hg concentrations in cormorant tissues decreased in the following order: kidney > liver >

Fig. 3 Concentrations of total Hg (in micrograms per gram d.w.) in muscle tissue from male and female Great Cormorants (*P. carbo*) from the Vistula Lagoon
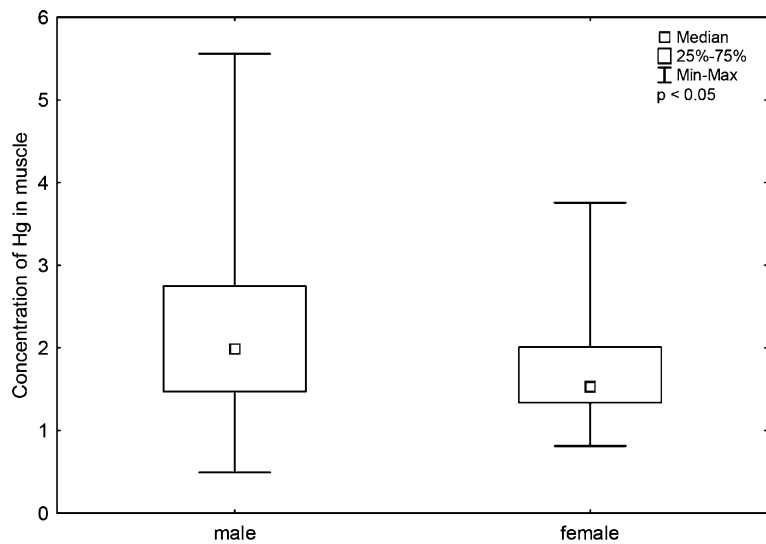
muscle. Concentrations of Hg in adults varied widely and were as follows: 30.21 ± 47.93 μg/g d.w. in kidney, 15.51 ± 17.30 μg/g d.w. in liver, and 2.15 ± 1.10 μg/g d.w. in muscle. In the case of immature specimens, the respective values were 17.58 ± 22.96, 10.96 ± 11.42, and 1.61 ± 0.82 μg/g d.w. There were statistically significant sex-dependent variations in muscle and kidney concentrations of Hg (*U* test, $p < 0.05$; Figs. 3 and 4).

All the fish (omnivorous) analyzed constitute potential food for the cormorants in the Vistula Lagoon. High levels of total Hg were found in the whole bodies of roach and Prussian carp (0.110 ± 0.060 μg/g w.w.); levels were lowest in herring (0.008 ± 0.003 μg/g w.w.). Figure 5 illustrates the variations in Hg concentration, which decreased in the following sequence: roach = Prussian carp > Crucian carp > tench > European smelt > ruffe > herring.

Fig. 4 Concentrations of total Hg (in micrograms per gram d.w.) in kidney tissue from male and female Great Cormorants (*P. carbo*) from the Vistula Lagoon
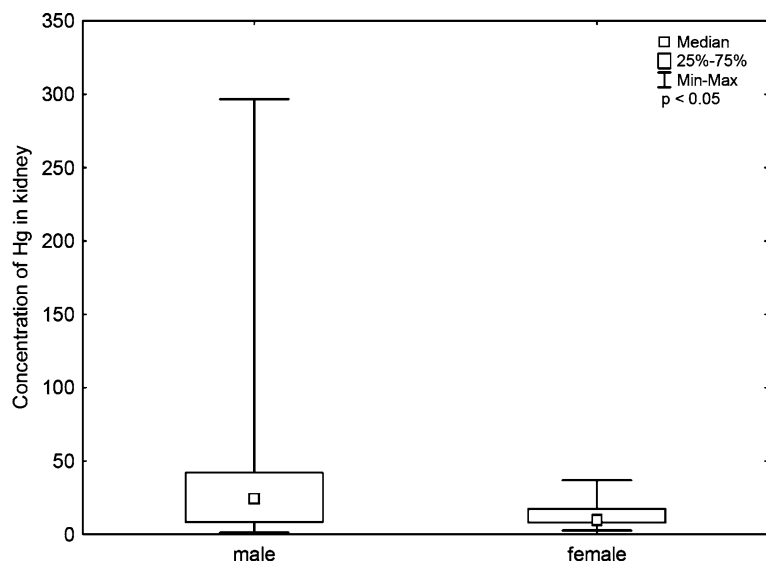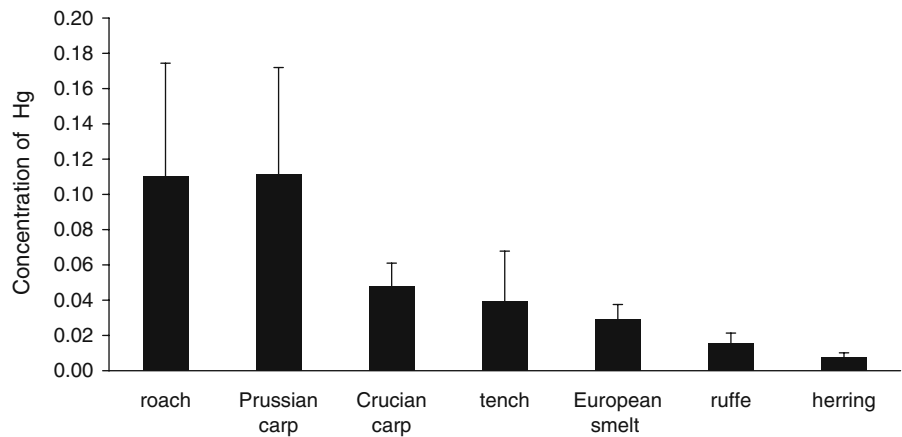
Fig. 5 Concentration of total Hg (in micrograms per gram w.w.) in the whole body of fish from the Vistula Lagoon

Discussion

Large Hg concentrations in liver and kidney, as opposed to other tissues, have been reported in fish-eating birds such as cormorants, eiders, guillemots, and gulls (Boening 2000; Houserová et al. 2007; Nam et al. 2005; Saeki et al. 2000). Total Hg concentrations decreased in the following order: liver > kidney > muscle (Houserová et al. 2007; Nam et al. 2005; Saeki et al. 2000). The data obtained in the present study are compared with those reported elsewhere (Table 1). Our study, however, indicates Hg levels were higher in kidney than in liver tissue. This discrepancy may be due to the different numbers of cormorants used in the investigations carried out by various authors. Houserová et al. (2005, 2007) noted that liver Hg concentrations were higher in adult cormorants than in immature individuals from the Záhlinice ecosystem (Czech Republic). Much higher mean renal Hg concentrations were found in both adults and immatures among the Vistula Lagoon cormorants than those reported in the available literature (Houserová et al. 2007; Nam et al. 2005; Saeki et al. 2000). Muscle concentrations, however, were similar to those (1.1–3.4 μg/g) reported elsewhere (Houserová et al. 2007; Nam et al. 2005).

Hg concentrations in different species of the genus *Phalacrocorax* vary, sometimes very significantly. Honda et al. (1990) analyzed two specimens of Japanese Cormorant (*Phalacrocorax capillatus*) from the North Pacific Ocean and obtained the following results: 1.03 μg/g d.w. for muscle, 4.00 μg/g d.w. for liver, and 2,33 μg/g d.w. for kidney. According to Henny et al. (2002), Double-crested Cormorant (*Phalacrocorax auritus*) from the Carson River ecosystem in Nevada concentrated 134.80 and 69.36 μg Hg/g w.w. in liver and kidney, respectively. Liver, muscle, and feathers were analyzed for total Hg concentration in *P. auritus* nestlings from two reservoirs in south-central New Mexico (Caldwell et al. 1999). In Elephant Butte Reservoir, the Hg concentrations in liver, muscle, primary feathers, secondary feathers, and tail feathers were 0.40, 0.17, 2.42, 2.06, and 2.34 μg/g w.w., respectively. However, generally higher levels were observed in the Caballo Reservoir in primary feathers (3.54 μg/g w.w.), secondary feathers (4.89 μg/g w.w.), and tail feathers (4.01 μg/g w.w.; Caldwell et al. 1999). The mean concentration of Hg in the feathers of six specimens of Cape Cormorant (*Phalacrocorax capensis*) from Namibia in southern Africa amounted to 251 ng/g d.w. (Burger and Gochfeld 2001).

The wide range of values obtained in our studies may be the result of the cormorants' being exposed to pollution for different lengths of time. The individual birds were placed in two age classes: adults older than 2 years and sexually immature specimens younger than 2 years. This means that, within the adult group, there were specimens belonging to the third year, fourth year,

Table 1 Comparison of mean concentrations of Hg (in micrograms per gram d.w.) in the liver, kidney, and muscle of Great Cormorant (*P. carbo*) in different areas

Tissue	Hg	SD	Range	Number	Location
Adult/immature/pull				9	Tokyo, Japan (Saeki et al. 2000)
Liver	1.2	0.5	0.6–2.0		
Kidney	0.9	0.7	0.2–2.5		
Muscle	0.3	0.2	0.2–0.6		
Adult/immature/pull				10	Lake Biwa, Japan (Saeki et al. 2000)
Liver	1.7	0.8	0.7–3.5		
Kidney	1.5	1.0	0.5–3.7		
Muscle	0.5	0.2	0.2–1.1		
Adult				8	Záhlinice, Czech Republic (Houserová et al. 2007)
Liver	42.2	6.28	–		
Kidney	7.2	1.0			
Muscle	3.4	0.37			
Immature				8	Záhlinice, Czech Republic (Houserová et al. 2007)
Liver	7.5	1.63	–		
Kidney	4.1	0.49			
Muscle	2.5	0.33			
Adult				4	Japan (Nam et al. 2005)
Liver	12	9	–		
Kidney	14	9			
Muscle	1.1	0.3			
Adult				44	Vistula Lagoon, Poland, This study
Liver	15.51	17.30	1.99–80.7		
Kidney	30.21	47.93	1.56–296		
Muscle	2.15	1.10	0.62–5.56		
Immature				11	Vistula Lagoon, Poland, This study
Liver	10.96	11.42	1.4–40.3		
Kidney	17.6	22.96	1.25–80.5		
Muscle	1.6	0.82	0.49–3.64		

etc. age classes; hence, the duration of their exposure to pollution will have been very different. In immature cormorants, the immune system and detoxification processes are not sufficiently developed.

Detoxification in these birds (elimination of Hg and other elements) takes place in their internal organs like the kidneys and liver (Boening 2000; Gray 2002; Kim et al. 1996) as well as in the feathers during molting (Braune 1987). In the case of cormorants, the molting period varies greatly, however, there is usually a partial molt from June to December (Baker 1993). Nam et al. (2005) observed that the Hg load decreases during molting

(June) since Hg is transferred to the feathers from internal tissues via the blood. In our study, the cormorants were shot in June, i.e., at the start of the molting period. Hence, the main reason for the wide variations in Hg content is that the cormorants were at different stages of individual development and molting. Table 2 compares the Hg concentrations in five species of fish analyzed in our study; the literature data refer to muscle samples. The table shows that Hg concentrations in the whole fish analyzed in our study are generally smaller than those in muscle tissue.

The BMF is discussed by Barwick and Maher (2003), Ciesielski et al. (2006), Guruge

Table 2 Comparison of mean Hg concentrations (in micrograms per gram w.w.) in fish from different areas

Fish species	Hg	Number	Localization	Reference
Herring (*Clupea harengus*)	0.021 ± 0.009 (muscle)	20	Gulf of Bothnia Gulf of Finland Baltic Sea	Perttila et al. (1982)
	0.086 ± 0.028 (muscle)	52	The Firth of Vistula	Falandysz et al. (2000)
	0.008 ± 0.003 (whole)	15	The Vistula Lagoon	This study
Roach (*Rutilus rutilus*)	1.66 0.72 0.55 (muscle)		Mouth of the Vistula River	Gajewska and Nabrzyski (1977)
	0.13 ± 0.09 (muscle)	427	Upsala, Stockholm Sweden	Sonesten (2001)
	0.058 ± 0.034 (muscle)	26	The Firth of Vistula	Falandysz et al. (2000)
	0.110 ± 0.064 (whole)	15	The Vistula Lagoon	This study
Tench (*Tinca tinca*)	0.26 (muscle)		Nogat River	Gajewska and Nabrzyski (1977)
	0.032 ± 0.013 (muscle)[a]	6	Záhlinice ecosystem Czech Republic	Houserová et al. (2007)
	0.039 ± 0.028 (whole)	15	The Vistula Lagoon	This study
European smelt (*Osmerus eperlanus*)	0.066 ± 0.028 (muscle)	41	The Firth of Vistula	Falandysz et al. (2000)
	0.029 ± 0.008 (whole)	15	The Vistula Lagoon	This study
Ruffe (*Gymnocephalus cernuus*)	0.066 ± 0.04 (muscle)	30	The Firth of Vistula	Falandysz et al. (2000)
	0.016 ± 0.006 (whole)	15	The Vistula Lagoon	This study

[a]The concentrations were recalculated from d.w. to w.w.

et al. (1996), and Slotton et al. (2004). Biomagnification is defined as the transfer of a given xenobiotic compound from one organism to another, resulting in a generally higher concentration in the predator than in the prey. If BMF is higher than unity, then biomagnification has occurred (Gray 2002). The usual approach is to compare the whole body of organisms from the bottom of the food chain to some tissues from organisms at the top (Gray 2002). This, however, may yield misleading results, since some tissues (like kidney and liver in the case of cormorants) are expected to be richer in Hg than others (like muscles). As homogenization and analysis of relatively large animals may be hard or even impossible in practice, a method of calculating total Hg needs to be applied (see the calculation of the total Hg content in the whole cormorant body in the "Sampling and analytical method" section). As can be seen in Table 3, BMFs of Hg (relative to fish species) decreased in the following sequence: herring > ruffe > European smelt > tench > Crucian carp > roach = Prussian carp. This means there

Table 3 BMF for trophic relation cormorant–fish of the Vistula Lagoon food web

Trophic relation predator–prey	Fish species						
	Herring (*Clupea harengus*)	Tench (*Tinca tinca*)	Roach (*Rutilus rutilus*)	European smelt (*Osmerus eperlanus*)	Ruffe (*Gymnocephalus cernuus*)	Crucian carp (*Carassius carassius*)	Prussian carp (*Carassius gibelio*)
Cormorant (muscle)–fish	80	15	5	20	40	10	5
Cormorant (kidney)–fish	870	170	60	222	420	140	60
Cormorant (liver)–fish	580	110	40	150	280	90	40
Cormorant (feathers)–fish	1,040	200	71	270	50	160	70
Cormorant (whole body)–fish	160	30	10	40	80	25	10

is considerable biomagnification of Hg in the cormorant relative to its fish prey, especially in the cormorant–herring trophic relationship. It should be emphasized that biomagnification in the study area was well reflected by the high BMF for the cormorant–ruffe trophic relation (the ruffe is a major item in the cormorant diet) and to a lesser extent by the cormorant–roach and cormorant–Prussian carp relations (the Prussian carp is not a common prey).

Conclusions

It was found that Hg concentrations were greater in kidney, liver, and feathers. The BMF estimated for Hg relative to diffrent fish species was significantly greater than unity, especially for the cormorant–herring trophic relationship. This means that there is biomagnification of Hg in cormorants relative to their prey. The data obtained are helpful for a better understanding of the accumulation processes of Hg in selected tissues of cormorants in the Vistula Lagoon ecosystem.

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