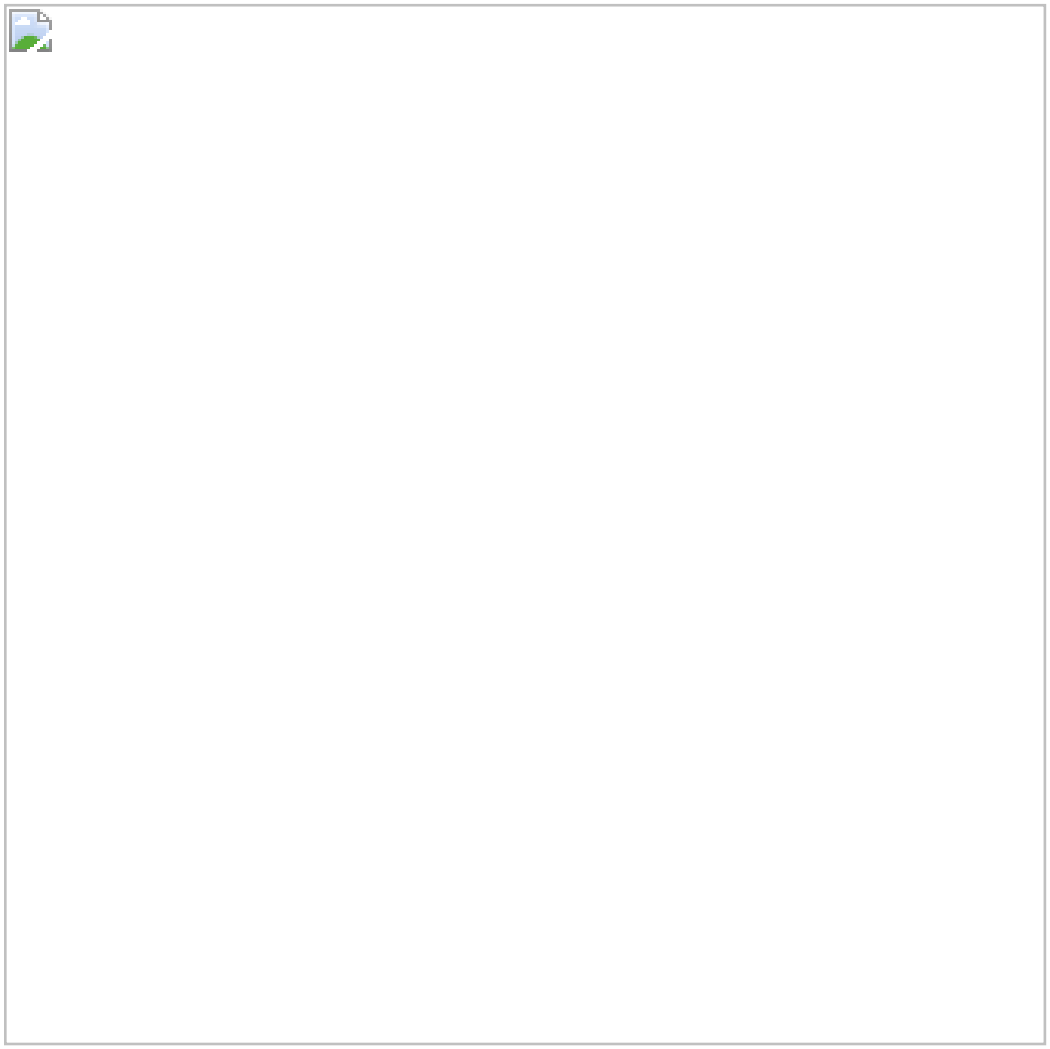

Heavy Metals, Resting Metabolism Rates and Breeding Parameters in Two Populations of Black-Headed Gull Larus ridibundus from the Industrially Polluted Areas of Upper Silesia, Poland

Authors: Migula, Paweł, and Augustyniak, Maria

Source: Acta Ornithologica, 35(2) : 159-172

Published By: Museum and Institute of Zoology, Polish Academy of Sciences

URL: https://doi.org/10.3161/068.035.0209

ACTA ORNITHOLOGICA
Vol. 35 (2000) No. 2

Heavy metals, resting metabolism rates and breeding parameters in two populations of Black-headed Gull *Larus ridibundus* from the industrially polluted areas of Upper Silesia, Poland

Paweł MIGULA, Maria AUGUSTYNIAK, Artur SZYMCZYK & Katarzyna KOWALCZYK

Department of Human & Animal Physiology, University of Silesia, Bankowa 9, 40–007 Katowice, POLAND, e-mail: migula@us.edu.pl

Migula P., Augustyniak M., Szymczyk A., Kowalczyk K. 2000. Heavy metals, resting metabolism rates and breeding parameters in two populations of Black-headed Gull *Larus ridibundus* from the industrially polluted areas of Upper Silesia, Poland. Acta orn. 35: 159–172.

Abstract. Black-headed Gulls breeding in the central part of the Upper Silesian Industrial Region (Katowice-Szopienice) in Southern Poland were compared with colony from less polluted area (Świerklaniec) situated 23 km away. Heavy metals: Cd, Pb, Zn and Cu — were determined in various organs of nestlings, fledglings and mature birds as well as egg yolks. Resting metabolic rates, hatching success and eggshell thickness were used as biomarkers of environmental exposure to industrial pollutants. The clutch size (2.97 versus 3.61) and hatching success (81.5% versus 87%) were lower in the colony from the more polluted site. The relatively high metal contents in the yolks indicate that off spring are only partially protected from toxic compounds. Gulls were able to regulate body contents of essential metals Zn and Cu, but Pb and Cd accumulated rapidly in the liver, kidneys and lungs of growing birds. Cd also accumulated in the ovaries at the similar levels as in the kidneys. Cd and Pb may have affected earlier stages of development when parents were foraged in a close vicinity of the heavily polluted area but once the young gulls had reached maturity they then foraged in distant areas. During this period they were exposed to pollutants in the same way as the gulls from the less polluted site. There was no growth impairment identified in gulls from the more polluted area, and their resting metabolism (RMR) calculated per unit of body weight was lower, indicating that energetic costs for detoxification were not as high.

Key words: Black-headed Gull, *Larus ridibundus*, heavy metals, hatching success, resting metabolism, industrial pollution

Received — Aug. 1999, accepted — March 2000

INTRODUCTION

Extraction and processing of raw materials and development of the chemical industry caused a severe degradation of the natural environment in the area of Upper Silesia in SW Poland (Godzik et al. 1999). In this strongly urbanised and densely inhabited area harmful waste materials and chemical compounds are accumulated in extremely high concentrations. Chronic exposure to heavy metals, together with other environmental toxicants, such as polyhalogenated aromatic hydrocarbons, polychlorinated biphenyls or dioxins have been recognised as potent inducers of adverse health effects in wildlife (Migula 1993, Migula et al. 1999). In order to understand the long-term effects of environmental contaminants we need to predict what concentrations may become hazardous to animals and then to estimate the ecological risk from the residue data (Peakall et al. 1999). This information is needed for determination of critical concentrations in the body, above which physiological functions are irreversibly impaired (Thompson et al. 1993, Dmowski et al. 1999). Metals without biological function tend to bioaccumulate and may biomagnify (Scheuhammer 1987, Newman & Jagoe 1996, Walker et al. 1996). The liver and kidneys as well as bones and male testes are critical organs for cadmium and lead accumulation. Lead concentrates also in the central nervous system (Pain 1996, Burger & Gochfeld 1997b).

Assessment of environmental risk can use biological monitors to determine the accumulation of a given pollutant in various biota (Drasch et al. 1987, Walker et al. 1996). Among birds there are some species which meet all necessary preconditions, such as the Feral Pigeon *Columbia livia* (Hutton 1980, Hutton & Goodman 1980, Drasch et al. 1987, Janiga et al. 1990), Starling *Sturnus vulgaris* (Grue et al. 1986), House Sparrow *Passer domesticus* (Pinowska et al. 1981), House Martin *Delichon urbica* (Newman et al. 1985), Great Tit *Parus major* (Sawicka-Kapusta et al. 1986, 1995), Magpie *Pica pica* (Dmowski 1997, 2000, Dmowski et al. 1999), gulls *Larus pipixcan, L. argentatus* or terns *Sterna dougalli, S. foersteri, S. hirundo* (Burger & Gochfeld 1988, 1991, 1997a, Gochfeld & Burger 1998). Relationships between metal and metallothionein concentrations are known in the Lesser Black-backed Gull *Larus fuscus* (Stewart et al. 1996). In a series of studies (Burger & Gochfeld 1996a,b, 1997a,b) it was presented how various heavy metals influence gulls and terns in the marine environment.

The Black-headed Gull is partially synanthropic species widely distributed in Europe and Asia, thus populations under various man-made stressing conditions could be compared. The number of pairs in breeding colonies is usually large. They are easy to catch during the breeding period, using nest traps. Life-history parameters, such as the population growth or mortality rates of gulls can be measured (Drasch et al. 1987) and used as biomarkers of exposure and effects (Mineau et al. 1984). Long-term studies carried out in recent years in Upper Silesia showed that breeding population of the Black-headed Gull has strongly increased (Tomiałojć 1990, Walasz 1992). A large breeding colony of this species has been observed even in the heart of the Upper Silesian Industrial Region (Walasz 1992). Dmowski & Golimowski (1993) studying metal concentrations in Magpie feathers from this area found a high correlation between metal burdens in feathers (as the external deposits) and the ambient concentration of a given metal at the capture sites. The Black-headed Gull is also able to excrete contaminants directly sequester them in the feathers (Lewis & Furness 1991) or as other gulls, excrete them in the eggs and eggshells (Burger 1994). On the basis of metal accumulation kinetics in the body it could not be predicted that physiological alterations would appear without taking into account a large variability in sensitivity to metals between species (Migula et al. 1990). There have been, however, some positive results from avian studies. For example, Grue et al. (1986) demonstrated significant changes in the reproductive success of ground-foraging European Starlings from lead-polluted sites. Sawicka-Kapusta et al. (1995) showed such effects in the case of the Great Tit from the metal-polluted Upper Silesia region. In multi-urban areas synanthropic populations of gulls have less problems with their food supply, but they may pay higher costs from the risk of being exposed to various pollutants which may cause adverse toxic effects (Migula 2000). Our observations indicated that during the breeding season, the feeding activity of the Black-headed Gull is restricted to the nearest area of the colony. Later they also searched for food in urban household waste, dumps or in arable areas situated farther from their breeding sites. These places can be used as foraging areas by birds from various colonies.

In this study the extent of industrial contamination differences in breeding sites are reflected in the accumulation rates of selected heavy metals, resting metabolism rates and some breeding parameters (hatching success, thickness of the eggshells, volume of the eggs). These parameters were used for the assessment of environmental impact on breeding populations of the Black-headed Gull from two colonies situated in areas of different level of industrial contamination (Cimander & Szeliga 1992). The task was to determine changes of metal burdens in target organs during the development of nestlings, fledglings and adult gulls measuring the previously mentioned biomarkers.

STUDY AREAS

Two colonies studied were located in a distance of 23 km:

1) Katowice-Szopienice a heavily polluted area (HPA) at the border between three densely populated towns: Katowice, Sosnowiec and Mysłowice. The colony was situated in shallow water in the post-industrial pond Gliniak, 900 × 600 m and 2 m deep, overgrown with the Cattail *Typha* and Reed *Phragmites.* Randomly selected material from 40 nests marked from the colony center (about 300 pairs) was used for the study.

2) Less polluted area (LPA) in the north-western part of Świerklaniec on the water reservoir of Kozłowa Góra built on the Brynica river was located in the green protective zone belt established in the 1960s for the Upper Silesian Industrial Region. The reservoir was surrounded with a pine forest,

marshy meadows and a tree plantation. The reservoir and the river in the study area have been qualified as having first class water purity. In a straight-line distance of approximately 10-km there are two point polluters: the zinc plant (Miasteczko Śląskie) and the iron plant (Orzeł Biały) in Bytom. Randomly selected material from 60 marked nests was selected out of 360 pairs of gulls from the breeding colony on small islets.

The data characterising the level of pollution in both localities during the study period 1993–1994 are relatively scant (Table 1). This data came from the Regional Sanitary-Epidemiological Station in Katowice (WSSE 1994, WUS 1994). The Polish monitoring network code number for HPA is 09.63–01; for LPA: 08.01–12.

Table 1. Allowable pollution levels in the vicinity of Black-headed Gull breeding sites in heavily polluted area (HPA) and less polluted area (LPA). * — mean values from different monitoring points from the same network grid.

Substance	Units	HPA	LPA
Dust deposition	g/m²/year	94-127*	33-89*
Lead deposition	mg/m²/year	106-516*	28-124*
Zinc deposition	mg/m²/year	877-8 796*	115-190*
Cadmium deposition	mg/m²/year	6.8-78*	1.31-2.12*
Copper deposition	mg/m²/year	41-176*	6-16*
Suspended dust	μg/m³/day	131 (43-368)	81-111*
Benzo[a]pyrene	ng/m³/day	46.8 (0-206.1)	82.7 (4.5-488.3)
Tar substances	μg/m³/day	16.7 (5.0-45.9)	41.1 (5.0-184.5)

MATERIAL AND METHODS

Both colonies were censused twice a week from April to mid-July. In each colony a hundred nesting pairs were randomly selected. The number of eggs laid, hatched, not hatched or removed from each nest was recorded. Between 6 to 10 individuals: 2–3 day old nestlings, 18-day old fledglings and adults of both sexes were captured from each colony and were used for heavy metal determinations. The resting metabolism rates (RMR) were measured in individually caged nestlings and fledglings by the open flow respirometry with a continuous recording of oxygen uptake and CO_2 output at 20°C as described elsewhere (Migula et al. 1984). Young gulls were acclimated before measurement to the experimental conditions for about 2 hours. Mature wild gulls were not considered, because they might react from both the stress of handling and effects of pollutants. The respiratory quotient and energy requirements were calculated and expressed in kJ per g body weight and in kJ/per metabolic unit of body weight — $kg^{0.75}$ (Lasiewski & Dawson 1967).

In a series of 20 washed eggs volume and weight were measured. Thickness of the shell was measured in 10 points on the equator, according to Peakall et al. (1973). Heavy metals were determined in homogenised eggs' yolk and in the shells separately.

For metal analyses birds were dissected and samples of the liver, kidneys, lungs, intestine, heart, ovaries, femur (without the bone marrow) and muscles from the femoral region were weighed separately. Samples were kept frozen at -30°C before drying. Gut contents were removed and a content of stomach was separated. Homogenised dried samples of each organ (about 1–2 g) were digested to a transparent solution in a mixture of suprapure nitric and perchloric acids in relation 4 : 1, heated gently up to 150°C in quartz test tubes. The resultant solutions were diluted to 2 ml of deionized, bi-distilled water, transferred to acid washed quartz test tubes and used for metal determination. The concentrations of Cd, Pb, Cu and Zn were measured by flame atomic absorption spectrometer Solaar Unicam 939. Samples with predicted low concentration of metals were determined using a graphite furnace atomic absorption spectrometry using PU 93090X furnace atomiser. Calibration curves were prepared from standard stock solutions (Merck) of similar acid strength to sample digests. Detection limits defined as three times the background noise were 0.1μg Pb/ml, 0.041μg Cu/ml, 0.032 μg Cd/ml and 0.013 μg Zn/ml.

The data were expressed as arithmetic means ± SE. Differences in variables were tested with one-way and two-way ANOVA, based on the LSD test as implemented in the Statgraphic v. 5.1 and Statistica v. 4.5 software packages. A test of the equality of variances was used for data from the analyses of ovaries. Correlations between organ-organ and metal burdens in a given organ were verified by the t-test.

RESULTS

Content of metals

Concentrations of lead and cadmium were high in the eggshells of both Black-headed Gull populations, without significant differences between sites ($p > 0.05$). In the yolk only biogenic zinc was accumulated at a higher level than in the shells, while

Table 2. Concentration of metals in egg yolks and their shells (μg/g dry weight $\bar{x}$ ± SE; n = 6)

Locality		Cd	Pb	Zn	Cu
HPA	yolk	0.82 ± 0.25	11.92 ± 1.15	75.22 ± 14.66	3.01 ± 1.53
	shell	5.21 ± 0.17	66.41 ± 2.78	29.71 ± 12.78	9.64 ± 2.63
LPA	yolk	0.65 ± 0.15	11.11 ± 0.98	72.23 ± 16.23	3.51 ± 2.07
	shell	5.25 ± 0.21	66.21 ± 4.55	24.58 ± 7.14	7.98 ± 3.36

other studied metals were from 3 (Cu) to 12 times (Cd) less than in the shell (Table 2).

Nestlings 2–3 days old had significantly higher levels of cadmium in the intestine (HPA) and in the heart (LPA), than in their liver (Table 3). About two weeks later levels increased by 2–4 fold in the kidneys and the liver of young fledged gulls, but surprisingly the highest amount was in the ovaries. In the ovaries of adult females the concentration of Cd was at least 10 times higher than in fledglings and exceeded the levels stated in kidneys (Table 3). Comparisons of nestlings and fledglings confirmed a significant increase of cadmium in the liver and a decrease in the bone of gulls from HPA. In gulls from LPA, there was a significant decrease of age-related cadmium level in the heart.

Lead was at the highest concentration in the bones of nestlings and fledglings from both populations. Comparisons of nestlings and fledglings confirmed a significant increase of Pb in the liver of gulls from HPA and in the liver and lungs of gulls from LPA. There was also a decrease of Pb concentration in the heart, intestine and lungs of fledglings from HPA. Such a relationship was not identified in the case of birds from LPA (Table 3). In the ovaries of adult gulls its content was 2 times higher than in ovaries of fledglings ($p < 0.001$). In the kidneys of adult gulls it was higher only in birds from LPA (by 40%; $p < 0.01$) and in lungs of gulls from both populations ($p < 0.01$; Tables 3 and 5).

The accumulation of zinc during the first three weeks of development was much slower than that of Cd and Pb and was indicated only in the liver (HPA and LPA) and copper in gulls from HPA. In other organs the level of both metals remained unchanged or even decreased with age. In gulls from HPA: Zn in the heart, Cu in the intestine, kidneys and lungs, from LPA was only in the bones of fledglings (Table 4). Zinc accumulated at the highest rates in the liver in the first three weeks of development (HPA; $p < 0.001$). Comparisons between fledglings and their par-

Table 3. Concentrations of cadmium and lead (mean in μg/g dry weight ± SE) in various organs of nestlings and fledglings of two gull populations. In each group n = 7, p — significance level of differences between the means for the same organ and age class from heavily polluted area (HPA) and less polluted area (LPA); ns — not significant. * — indicate significant differences of means for the same organ between nestlings and fledglings from the same population (ANOVA; $p < 0.05$).

Organ	Growth stage	Cd		p	Pb		p
		HPA	LPA		HPA	LPA	
Liver	Nestling	0.44 ± 0.06	0.37 ± 0.11	ns	5.84 ± 0.15	4.63 ± 0.2	< 0.001
	Fledgling	2.62 ± 1.04*	1.31 ± 0.13*	< 0.05	12.35 ± 0.36*	11.66 ± 0.71*	ns
Kidney	Nestling	0.93 ± 0.15	1.09 ± 0.17	ns	21.14 ± 2.62	15.39 ± 1.69	< 0.01
	Fledgling	3.82 ± 1.51	2.81 ± 0.13*	ns	15.77 ± 0.95	20.25 ± 1.83	< 0.01
Heart	Nestling	0.93 ± 0.15	1.32 ± 0.17a	< 0.01	13.98 ± 0.93	12.28 ± 1.11	< 0.05
	Fledgling	0.75 ± 0.11	0.68 ± 0.05*	ns	11.95 ± 0.72*	12.91 ± 1.21	ns
Intestine	Nestling	1.21 ± 0.32	1.11 ± 0.29	ns	13.96 ± 0.42	13.93 ± 1.64	ns
	Fledgling	2.36 ± 0.41	0.93 ± 0.11	< 0.001	9.31 ± 0.22*-	13.11 ± 1.19	< 0.001
Lung	Nestling	1.01 ± 0.14	1.08 ± 0.17	ns	16.65 ± 0.73	12.68 ± 1.54	< 0.001
	Fledgling	1.00 ± 0.09	0.94 ± 0.1	ns	13.64 ± 0.96*	14.18 ± 0.98*	ns
Muscle	Nestling	0.99 ± 0.09	1.06 ± 0.14	ns	12.01 ± 0.51	13.93 ± 1.65	< 0.05
	Fledgling	0.86 ± 0.25	0.68 ± 0.05	ns	12.86 ± 1.6	13.11 ± 1.7	ns
Ovaries	Fledgling	7.01 ± 3.25	4.99 ± 0.9	< 0.001	12.82 ± 0.36	20.54 ± 1.6	< 0.001
Bone	Nestling	1.91 ± 0.14	1.96 ± 0.1	ns	30.56 ± 3.41	29.78 ± 1.3	ns
	Fledgling	1.53 ± 0.05*	1.69 ± 0.05	ns	21.38 ± 1.14*	26.73 ± 3.94	ns

Table 4. Concentrations of zinc and copper (mean in μg/g dry weight ± SE) in various organs of nestlings and fledglings of two gull populations. In each group n = 7, nd — lack of data. Other explanations — see Table 3.

Organ	Growth stage	Zn		p	Cu		p
		HPA	LPA		HPA	LPA	
Liver	Nestling	93.3 ± 9.3	85.9 ± 6.1	ns	19.4 ± 1.5	17.5 ± 1.9	ns
	Fledgling	235.2 ± 11.4*	106.5 ± 9.0	ns	27.2 ± 1.5*	21.4 ± 2.0	< 0.001
Kidney	Nestling	269.3 ± 48.7	209.8 ± 15.0	< 0.05	28.6 ± 2.1	16.9 ± 1.4	< 0.001
	Fledgling	208.0 ± 31.5	203.6 ± 13.4	ns	18.8 ± 1.3*	18.4 ± 1.6	ns
Heart	Nestling	234.3 ± 29.2	199.2 ± 9.0	ns	17.5 ± 3.4	20.5 ± 1.7	ns
	Fledgling	176.4 ± 16.2*	192.9 ± 10.6	ns	21.3 ± 1.3	22.0 ± 1.6	ns
Intestine	Nestling	243.6 ± 8.6	215.1 ± 13.9	< 0.05	14.2 ± 0.7	11.5 ± 1.4	< 0.01
	Fledgling	240.9 ± 10.8	207.2 ± 21.5	< 0.05	7.0 ± 0.6*	11.4 ± 1.0	< 0.001
Lung	Nestling	165.2 ± 14.9	150.2 ± 6.9	ns	6.1 ± 0.7	5.4 ± 0.5	ns
	Fledgling	158.8 ± 20.2	133.5 ± 7.8	< 0.05	4.6 ± 0.3*	4.5 ± 0.4	ns
Muscle	Nestling	156.5 ± 5.1	181.9 ± 5.9	< 0.001	13.1 ± 1.6	17.4 ± 2.2	< 0.05
	Fledgling	198.2 ± 26.8	191.4 ± 12.5	ns	13.9 ± 1.2	18.8 ± 1.6	< 0.01
Ovaries	Fledgling	253.8 ± 39.9	198.4 ± 5.9	< 0.05	20.0 ± 1.2	22.4 ± 1.4	ns
Bone	Nestling	nd	99.2 ± 6.8		3.0 ± 0.5	4.2 ± 0.3	ns
	Fledgling	nd	81.3 ± 1.3*		4.0 ± 0.2*	2.4 ± 0.5*	< 0.05

Table 5. Concentration of four metals (mean in μg/g dry weight ± SE) in various organs of adult gulls from two studied populations. n = 6 for each population. Explanations — see Table 3.

Organ	HPA	LPA	p	HPA	LPA	p
	Cd			Pb		
Liver	28.65 ± 5.09	16.84 ± 2.11	< 0.01	18.46 ± 3.07	16.00 ± 1.26	ns
Kidney	58.97 ± 4.85	72.77 ± 2.58	< 0.01	17.95 ± 1.31	28.88 ± 2.80	< 0.001
Heart	1.06 ± 0.07	1.22 ± 0.14	ns	10.04 ± 0.43	13.06 ± 1.76	<0.05
Intestine	3.87 ± 1.24	3.10 ± 0.30	ns	7.13 ± 0.63	12.54 ± 1.51	ns
Lung	2.68 ± 0.71	1.80 ± 0.25	ns	22.38 ± 1.45	17.79 ± 1.13	< 0.001
Muscle	1.33 ± 0.44	0.88 ± 0.12	ns	10.70 ± 1.04	12.54 ± 1.52	ns
Ovaries	71.78 ± 6.25	68.87 ± 5.33	ns	27.09 ± 0.72	48.43 ± 3.86	<0.01
Bone	2.12 ± 0.16	2.09 ± 0.07	ns	44.31 ± 9.66	31.88 ± 2.95	ns
	Zn			Cu		
Liver	196.6 ± 39.1	122.8 ± 12.2	<0.05	32.2 ± 4.1	20.2 ± 0.7	< 0.001
Kidney	284.5 ± 52.6	253.4 ± 24.1	ns	22.4 ± 1.0	19.6 ± 2.4	ns
Heart	129.1 ± 7.5	143.5 ± 9.6	ns	20.5 ± 1.8	21.2 ± 0.7	ns
Intestine	255.4 ± 53.1	221.5 ± 20.2	ns	7.6 ± 0.5	8.2 ± 0.8	ns
Lung	112.0 ± 18.3	90.5 ± 5.6	ns	4.9 ± 0.4	6.4 ± 0.7	< 0.05
Muscle	246.8 ± 40.5	208.5 ± 19.1	ns	13.2 ± 1.4	13.0 ± 1.3	ns
Ovaries	317.2 ± 52.1	256.4 ± 20.3	ns	29.1 ± 4.8	24.8 ± 2.8	ns
Bone	nd	77.1 ± 3.9	nd	3.0 ± 0.8	3.2 ± 0.5	ns

ents from both populations indicated lacked significant differences (Tables 4 and 5).

Comparisons of metal accumulation in young gulls from both populations did not clearly demonstrate that organs of gulls from HPA had generally higher amounts of metals. Nestlings from HPA did not show significantly higher levels of Cd at all, Pb was higher in their liver, kidneys, heart and lungs, Zn and Cu in the intestine and kidneys (Tables 3 and 4). Fledglings from HPA had significantly higher levels of Cd in the liver, intestine and ovary, Zn in the intestine lungs and ovary and Cu in liver and bones. Surprisingly, the levels of Pb were even significantly higher in kid-

neys, intestine, and bones of fledglings from LPA. Despite Cd contents of other metals in skeletal muscles were higher in nestlings from LPA. Comparisons of metal levels in adult gulls from both populations demonstrated significantly higher Cd, Zn and Cu in the liver of birds from HPA, but Cd and Pb in kidneys of gulls from LPA (Table 5). These birds had also higher levels of Pb in the heart and ovaries, and Cu in lungs (Table 5).

Table 6. Correlation coefficients between age related accumulation of pairs of metals: Cd, Pb, Cu and Zn (μg metal/g dry weight) in different organs of gulls from two breeding sites. Data for age groups were pooled. ns — not significant, * — $p < 0.05$; ** — $p < 0.01$. Other cases — lack of significance.

Organ	Pair of metals	HPA	LPA
Liver	Cd–Pb	0.72*	0.65*
	Pb–Zn	0.93**	ns
	Pb–Cu	0.74**	0.89**
	Cu–Zn	0.67*	0.79*
Kidney	Cu–Zn	0.62*	0.66*
	Cd–Pb	ns	0.64*
	Cd–Zn	ns	0.73*
Heart	Pb–Zn	0.69*	ns
Intestine	Pb–Cu	0.81**	ns
Ovaries	Cd–Cu	0.72*	ns
	Cd–Pb	0.94**	0.91**
	Cd–Zn	ns	0.86**
	Pb–Zn	0.67*	0.79*
	Cu–Zn	0.97**	ns
Lung	Cd–Zn	-0.58*	ns
Muscles	Cd–Zn	0.66*	ns
Bones	Cd–Pb	ns	0.86**
	Cu–Zn	ns	0.79*
	Pb–Zn	ns	-0.96**

Assuming that young birds reaching the adult stage would accumulate metals to the same levels as we indicated in their parents we made an analysis of age-related correlations between determined pairs of metals in the same organs (Table 6). A significant, positive correlation between Cd and Pb was proved for the liver and ovaries of birds from both populations and bones for LPA (Table 6). Pb against Zn contents was positively correlated in the ovaries of gulls from HPA and LPA, but only in the liver and heart from HPA. A negative correlation was indicated for Cd against Zn in the lungs of gulls from HPA and in the case of Pb against Zn in the bones of gulls from LPA (data for Zn in the bones of gulls from HPA are lacking).

Positive correlations were indicated also in pairs of organs for a given metal (Table 7). For Cd they were more frequent in the case of gulls from LPA (12 pairs) than from HPA (5 pairs). Less frequent were Pb for 7 pairs from LPA and 1 pair from HPA and sporadic for Zn. Only one positive significant correlation was identified for Cu in gulls from HPA (liver–ovary, $r = 0.86$; $p < 0.01$).

Table 7. Correlation coefficients (r) between age-related metal accumulation in pairs of organs of gulls from two studied colonies (HPA and LPA). Data for age groups were pooled. ns — not significant, * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Other cases — lack of significance.

Tissue or organ	Cd		Pb		Zn	
	HPA	LPA	HPA	LPA	HPA	LPA
Liver–kidney	0.92**	0.96**	ns	ns	ns	ns
Liver–ovaries	0.99***	0.99***	ns	0.91**	ns	ns
Liver–intestine	ns	0.89**	-0.96**	ns	ns	ns
Liver–muscles	ns	0.81*	ns	ns	ns	0.72*
Liver–bones	ns	0.74*	ns	0.69*	ns	ns
Liver–lung	ns	ns	ns	0.81*	ns	ns
Kidney–ovaries	0.91**	0.96**	ns	ns	ns	ns
Kidney–lung	0.87**	ns	ns	ns	ns	ns
Kidney–intestine	ns	0.89**	ns	ns	ns	ns
Kidney–muscles	ns	0.88**	ns	0.75*	ns	ns
Intestine–ovaries	ns	0.92**	-0.76*	0.76*	-0.91**	ns
Intestine–muscles	ns	0.85**	ns	ns	ns	ns
Intestine–lung	ns	-0.81*	ns	ns	ns	ns
Lung–ovaries	ns	ns	0.82*	0.91**	ns	ns
Lung–heart	0.91**	ns	ns	ns	ns	0.68*
Lung–muscles	ns	0.71*	ns	ns	ns	ns
Heart–ovaries	ns	ns	ns	0.83**	ns	-0.73*
Muscles–ovaries	ns	0.77*	ns	ns	ns	ns

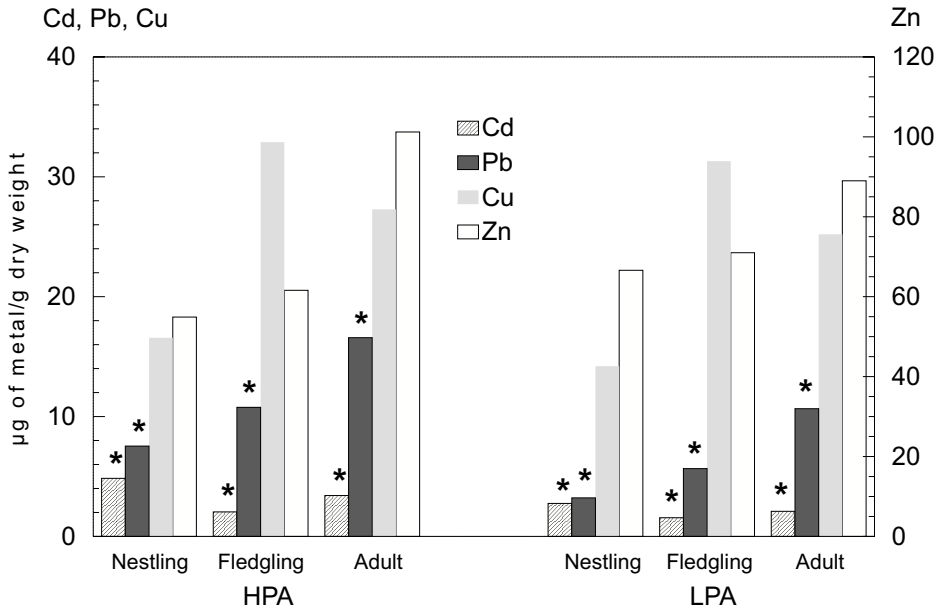

Fig. 1. Concentration of four metals in the gut contents of Black-headed Gulls from the heavily polluted area (HPA) and less polluted area (LPA). * $p < 0.05$ between sites for the same age of gulls

There was also one negative correlation for Cd (LPA; lung–intestine), two for Pb (HPA, intestine-liver; intestine–ovary) and one for zinc (LPA, heart–ovary).

The levels of cadmium and lead in the gut contents of gulls from HPA were twice as high as in the comparable material from LPA ($p < 0.01$). There was no significant difference in the concentration of zinc and copper in the gut contents taken from gulls representing both populations (Fig. 1).

Resting metabolic rates

The mean oxygen consumption of resting individuals 3–4 day old nestlings was nearly the same, independent from the location they were taken from (Table 8). Also fledged gulls consumed oxygen at rates not significantly different from their place of origin. When calculated per unit of the body weight both nestlings and fledged birds from LPA had higher oxygen consumption ($p < 0.05$). The respiratory quotient (RQ) for gulls from HPA was slightly higher than that for birds from LPA. The resting metabolism rates (RMR) of nestlings and fledglings from both breeding sites did not differ significantly in relation to location, when RMR was expressed in energy units per individual, but it was significantly higher in nestlings and fledglings from LPA ($p < 0.05$). The RMR calculated per individual increased with age more intensively (3.8 times) in gulls from LPA than in birds from HPA (3.4 times). The average RMR expressed per metabolic unit of body weight ($kg^{0.75}$) indicated lower values for the birds from HPA, but statistically homogenous with the population for LPA ($p > 0.05$).

The slopes of the allometric equations between RMR and body weight are as follows: RMR (Y) = kJ/gull/day and X = body weight in g:
HPA: $Y = 0.604 + 0.774X$; $r = 0.972$; $p < 0.001$;
LPA: $Y = 0.683 + 0.772X$; $r = 0.969$; $p < 0.001$.
RMR (Y) = kJ/g/day and X = the unit of body weight (g):
HPA: $Y = 0.603 - 0.225X$; $r = -0.76$; $p < 0.05$
LPA: $Y = 0.683 - 0.228X$; $r = 0.759$; $p < 0.05$.

The slopes of all presented pairs of equations showed no significance in relation to the origin of the populations. A negative correlation between RMR (per unit of body weight) and metal concentration was identified only for Cd in nestlings and fledglings from HPA ($r = 0.67$; $p < 0.05$) and from LPA ($r = 0.72$; $p < 0.05$).

Some breeding parameters

The average number of eggs laid by a female and success of hatching was higher in the population from LPA (Table 9), but the mean body weight of 3–4 day old nestlings was about 20% lower than of birds from HPA (Table 8). After two weeks of development fledged gulls reaching, their average body weight was still about 25% lower (Table 8).

Mean thickness of the eggshells was similar for both localities, but showed a considerable variability of about 30%. Also, the average volume of

Table 8. Mean body weight and resting metabolic rates (± SE) characteristics for nestlings and fledglings from two gull colonies. N = 6–10 for each age group and site. a — significant differences between nestlings and fledglings from the same site; b — significant differences between localities within the same age group (ANOVA; $p < 0.05$).

Parameter	Nestlings		Fledglings	
	HPA	LPA	HPA	LPA
Body weight (g)	41.0 ± 5.0[a,b]	34.0 ± 4.1[a,b]	238.0 ± 18.4[a,b]	193.0 ± 5.5[a,b]
Oxygen uptake:				
ml O_2/individual/h	168.1 ± 22.2[a]	168.2 ±15.6[a]	540.3 ± 24.6[a]	607.3 ± 67.9[a]
ml O_2/g/h	3.8 ± 0.3[a,b]	4.6 ± 0.3[a,b]	2.5 ± 0.1[a]	3.1 ± 0.3[a]
Respiratory quotient (RQ)	0.74 ± 0.03	0.70 ± 0.04	0.74 ± 0.03	0.70 ± 0.02
RMR — kJ/bird/day	78.1 ±10.6[a]	75.2 ± 7.9[a]	269.0 ±16.5[a]	288.0 ± 32.2[a]
RMR — kJ/g/day	1.91 ± 0.23[a,b]	2.21 ± 0.22[a,b]	1.13 ± 0.07[a,b]	1.44 ± 0.16[a,b]
RMR — kJ/$kg^{3/4}$/day	811.7 ± 68.4	938.0 ± 57.2	813.2 ± 31.1	9 77.1 ± 98.2

an egg calculated for both populations was similar for both populations (Table 9).

Table 9. Breeding parameters of Black-headed Gull populations from two studied colonies. Number of nests: HPA – 40, LPA- 60. p — significance level between sites.

Breeding features	HPA	LPA	p
Eggs laid/female	2.97 ± 0.31	3.61 ± 0.40	< 0.01
Nestlings hatched/nest	2.42 ± 0.33	3.13 ± 0.30	< 0.01
Hatching success	81.5%	87%	
Egg thichness [mm] (n = 20)	0.12 ± 0.05	0.13 ± 0.05	ns
Egg volume [cm^3] (n = 20)	27.7 ± 8.24	28.8 ± 9.11	ns

DISCUSSION

Metals and the development of gulls

Majority of studies indicated that cadmium and lead content in adult gulls is higher than in immature ones (Stewart et al. 1996). Adverse effects of toxic metals, Cd and Pb are well documented in the literature (Nicholson et al. 1983, Chang 1996). Concentrations of these metals were positively correlated in the liver and ovaries of gulls from HPA and LPA but also in kidneys and bones of gulls from LPA (Table 6). The background levels of lead in various species of birds were estimated as 2–15 μg/g in the bone, 1–10 μg/g in kidneys and 0.5–5 μg/g in the liver (Scheuhammer 1987). Hepatic burdens with Pb in the Black-headed Gull was at the upper "clinical" limit (Franson 1996), even in the early stage of development of nested chicks from both analysed colonies. In their kidneys it was 2–3 times higher, and the highest in nesting birds from HPA (Table 3). In such young gulls lead is more easily absorbed and accumulated faster than in older birds. Its content in soft tissues became more constant, as the result of increased transfer to bones, better voiding mechanisms and reduced uptake from the intestine (Scheuhammer 1987, Migula et al. 1990). The intestine of adult gulls from more polluted HPA accumulated a half of the lead than the nestlings from the same site (Tables 3 and 5). This means that in case of lead young gulls from this population are better adapted and more effectively eliminate excessive amounts of this element with age.

Toxic consequences of metal accumulation in gulls

Toxicity of lead may reveal in reproductive impairments and in the most sensitive species (e.g. raptors) may be indicated under 100 ppm Pb in the diet, as this was documented in laboratory studies by Hoffman et al. (1985). In chicken reared with excessive amounts of lead in their diet such effects were observed over 200 ppm of Pb (Edens & Garlich 1983). It was not the case of developing gulls in our study. A small difference in hatching success between both gulls populations suggests that they could tolerate local contamination levels. This is also confirmed lack of differences in the resting metabolism rates measured in developing birds from two populations, thus energetic costs of detoxification (if any measurable) are similar (Migula 2000). From studies of Burger & Gochfeld (1997b) on the Herring Gull chicks receiving intraperitoneally lead acetate we know more about neurobehavioral differences caused by lead in the wild and in the laboratory. They found that in the field recovery occurred sooner than in the laboratory as "parents partially compensated for the behavioural deficits and succeeded in getting surviving chicks to a similar fledging weight as control chicks". Thus predict-

ing changes only from the amounts of a contaminant intake is not sufficient because of protective behaviour of parents. Lead levels in the brain of developing Black-headed Gulls were not measured; thus we could not predict to what extent neurobehavioral impairments were caused by this element. Sawicka-Kapusta et al. (1995) supposed that heavy metals are responsible for breeding impairments of the Great Tit from the polluted area, but comparisons of metal levels in stomach contents showed proportionally lower amounts of toxic metals in tits than in the gut contents of Black-headed Gulls (Fig. 1). Probably, much faster metabolism rate in small tits decides on their higher susceptibility, followed by the reproductive losses.

Concentrations of lead in kidneys and the liver of young gulls were calculated as one tenth of the LD_{50} of oral toxicity in small vertebrates. From the interpretation of tissue lead residues in birds (Franson 1996, Pain 1996) we rather expected higher growth impairments in gulls from HPA. This was not confirmed by our measurements. Fledged gulls from this locality had even higher mean body weight than gulls of the same age from LPA. This was rather a result of easier access to the food resources for their parents than the direct impact of industrial pollutants.

Liver shows relatively high burden with cadmium and accumulates up to a half of the total body burden (White et al. 1978, Scheuhammer 1987). The range of cadmium concentration is quite large, from 0.01 to 109 μg/g dry weight of the liver and 0.03–480 μg/g dry weight in kidneys (Garcia-Fernandez et al. 1996). These authors, analysing material from 118 bird species living in the south-east of Spain, found that kidney is the primary organ for accumulation of cadmium, followed by the liver and to lesser extent the brain and bone. According to Scheuhammer (1987) the liver versus kidney concentration ratio above 1.0 indicates acute exposure, whereas a ratio below 1 indicates a chronic exposure to that metal. For comparison this ratio for wild adult Lesser Black-backed Gulls is even below 0.1 (Stewart et al. 1996). In all age groups of Black-headed Gulls from HPA and LPA colonies this ratio was below 1.0. In a sublethal exposure the critical organ for cadmium is considered to be the kidney and the testes in males (Migula et al. 1990). In young nested gulls the target organs for cadmium were the soft organs, such as the small intestine, lungs and even muscles, but also bones (Table 3). Burdens with cadmium in fledged birds from both studied populations increased in their liver and kidneys and were also high in the ovaries. This pattern of metal accumulation was similar in both populations, but with a different intensity. High ovarial burden with cadmium in gulls from both populations had probably a similar impact on changes of their eggs volume or thickness of the shells, independent of a high individual variability of these parameters.

High concentrations of cadmium in kidneys suggest that adult birds may suffer from nephrotoxic disorders. Patchy necrosis were identified in kidneys of the seabirds accumulating 94.5–228 μg/g cadmium (Nicholson et al. 1983), however this is not a rule (Eliott et al. 1992). In adult Herring Gulls *L. argentatus*, collected in Atlantic coast of Canada, renal burden with cadmium ranged from 11 to 69 μg/g dry weight, but in the liver reached values ten times lower (Elliott et al., 1992). Our data are more comparable with the levels found in kidneys of the Puffin *Fratercula arctica* or Leach's Petrel *Oceanodroma leucorhoa* studied by the same authors (Elliott et al. 1992). The levels reported in our study also demonstrate that cadmium concentrations in the ovary were as high as in the kidneys, but expected reproductive abnormalities were not confirmed when we examined pathological changes in birds. Lower accumulation of cadmium in kidneys of gulls from HPA might reflect their whole, not studied yet, life history. During non-reproductive period they may spend a part of time foraging in cleaner areas (or more polluted) than their vicinity. This may also suggest better inducibility of their metal-binding proteins (MT). Unanswered remains why these birds had higher amounts of cadmium in the liver? Metal accumulation in hepatic cells is more likely reflecting the immediate effects of food collected from the breeding area highly polluted with metals. One of explanations could be a different age of adult gulls used for metal determinations.

The ways and efficiency of metal elimination by gulls

Birds may excrete toxic metals from their body through sequestration in the feathers, uropygial or salt glands (Lewis & Furness 1991, Gochfeld & Burger 1998, Dmowski 1999), binding with the –SH groups of metallothioneins and accumulation in the kidneys or the liver (Scheuhammer 1987, Stewart et al. 1996), demethylation of methyl-mercury in the liver (Kim et al. 1996) or excretion to the eggs or eggshells (Gochfeld & Burger 1998). A comparison of metal contents in eggs and in internal organs of adult Black-headed Gulls showed pro-

tective abilities for their offspring, by reducing Cd or Pb transfer to the yolk and their accumulation in the shells.

Concentrations of cadmium in eggs of other species, such as tits, do not reflect its intake or body burdens in a female (White & Finley 1975, Sawicka-Kapusta et al. 1995). We demonstrated that the Black-headed Gull strongly reduced cadmium transfer to eggs, but its concentration exceeded at least 20 times that stated in the eggs of the Great Tit from polluted area in Southern Poland (Sawicka-Kapusta et al. 1995). High levels of Pb in gulls' eggs (our study) confirm the data for much smaller eggs of the Great Tit. The average concentration of this element in tits appeared also to be extremely high, reaching 4.25 μg/g dry weight (Sawicka-Kapusta et al. 1995). Burger & Gochfeld (1996a) demonstrated that Franklin's Gulls *Larus pipixcan* accumulate in eggs about 30% of lead present in the breast feathers of the female, but much less cadmium (0.043 vs 0.612 μg/g dry weight). According to Burger & Gochfeld (1996b) metal content measured in eggs reflects practically the levels in the circulating blood of the female during egg formation whereas in feathers reflects levels in the blood during their formation. Dmowski (1999) demonstrated that this could be true mostly for the mercury. Independently of the endogenic way of metal intake they are adsorbed on the surface of the feathers as the constituents of the dust particles and are very difficult to wash out.

Black-headed Gulls laying eggs may eliminate a considerable amount of lead accumulated in the shell of eggs, since concentration of lead in shells of eggs in *L. ridibundus* was 6 times higher than in the yolk. Similar amounts of this metal stated in shells of eggs laid by gulls from both localities indicate a close relationship between lead elimination rates and the metabolism of calcium, suggesting, according to Scheuhammer (1987), a dietary deficiency of the latter.

Zinc and copper, necessary for many physiological processes (Chang 1996) were in the yolk of gulls eggs at the physiological levels known for birds from unpolluted areas. This means that regulatory abilities are independent of local environmental factors and a quality of consumed food, knowing from earlier studies that concentrations of metals in insects, earthworms and other small invertebrates in the vicinity were quite high (Migula et al. 1990). Zinc deficiency would be more important factor than its excess for these birds, causing more distinct alterations from normal physiology, as it is highly required for many enzymatic reactions, especially during developmental processes (Chang 1996). Black-headed Gulls from both populations demonstrated only partial ability to regulate levels of Zn and Cu. The concentrations of these metals in their organs were within the range known from many other bird species exposed to heavy metal pollution (Howarth et al. 1981, Pinowska et al. 1981, Sawicka-Kapusta et al. 1995), but much higher than in many bird species from unpolluted sites (Howarth et al. 1981).

Stewart et al. (1996) studying relationships between Cd, Zn, Cu and Hg in Lesser Black-backed Gull found a positive correlation between the low-weight protein and Cd, Zn and Cu in kidney and liver and demonstrated that the metallothionein (MT) is the most important factor in heavy metal detoxification. It was also documented that zinc deficient diets may enhance accumulation of cadmium in the liver and kidney of birds (Fox et al. 1984, Bundschrerer et al. 1985). Cadmium by replacement of zinc in MTs causes that the latter induces MT biosynthesis in the intestinal cells (Elinder & Nordberg 1986). Cadmium binds stronger to MTs than zinc and bound to MTs may be less toxic (Chang 1996). A comparison of zinc content in the small intestine of adults from both sites with the concentration of their gut contents indicate clearly that Black-headed Gulls are biomagnifying this important element in their organs (Fig. 1, Table 5). In vertebrates zinc is easily absorbed by mucosal intestinal cells (Migula et al. 1990) and may exert a protective role against cadmium toxicity (Sanders et al. 1996). In studied gulls mucosal cells may act as the first barrier reducing transport of zinc to their body cavity. The concentration of cadmium increased only four times, comparing intestinal levels of nestlings and adult gulls (Tables 3 and 5). This would not be a general mechanism in birds. Laboratory studies with the Japanese Quail gave some opposite results. In birds fed zinc-deficient diet elimination of cadmium from the intestine, liver and kidneys was higher than in birds fed zinc-sufficient diet (Fox et al. 1984, McKenna et al. 1992). Probably in this situation cadmium replaced zinc in metalloenzymes, however with adverse results. In polluted areas high levels of zinc often accompanies cadmium, these relations need therefore further documentation.

Local or transboundary pollution affects on gulls

Generally higher variability of metal concentrations in organs of birds from HPA resulted from their direct uptake from the neighbourhood. This

area has been more severely affected by various industrial pollutants than LPA. Levels of cadmium and lead in the food consumed by young gulls (gut contents analysis) from HPA exceeded twice the concentrations in food consumed by young birds from LPA. Foraging in the nearest vicinity of the breeding area might explain also why site-related differences in the body burden with cadmium of young gulls were higher than in adults. After the breeding period adult gulls enlarge their foraging areas, and became more mobile with varying lengths of stay in different places (Jarman et al. 1996). This is why metal contents in tissues of adult gulls from two populations were more homogenous than in young gulls. They could meet in sites where toxic metals are more equally distributed in their collected potential diet (WSSE 1994, WUS 1994, Godzik et al. 1999). Their higher mobility may lead to unclear information on local contaminants based only on the analysis of metal contents in adult birds. This would be is opposition to the conclusion of Garcia-Fernandez et al. (1996) who stated that low-level exposure (to cadmium) occurs continuously over the life of the birds, thus accumulation of cadmium in adults is better for biomonitoring than nestlings or immature birds.

CONCLUSIONS

1) Two studied populations of Black-Headed Gulls breeding in areas which differ in a degree of environmental contamination have shown only some differences of metal accumulation during an early phase of development with higher levels in the liver, kidneys, and the intestine in nestlings from heavily polluted area (HPA).

2) Gulls were able to regulate body contents of zinc and copper but in growing birds cadmium and lead was rapidly accumulated in the liver, kidneys and lungs. Content of cadmium was also high in the ovaries.

3) The growth of young gulls from more polluted area (HPA) was not impaired, despite the fact that cadmium and lead were accumulated rapidly in their liver kidneys and lungs during development.

4) Lower resting metabolism rate (expressed per unit of body weight) of young gulls from HPA concomitant to a high growth rate suggest that low amounts of energy were allocated for detoxification processes.

5) Differences in breeding parameters, such as clutch size, nestlings hatched/female and hatching success between studied populations demonstrate better adaptation of gulls from less polluted area.

6) Significant correlations between pairs of metals were mostly between Cd and Pb or between Zn and Cu and were more often registered in organs of gulls from LPA site, indicating that strategies of gulls in metal acccumulation/ decontamination may differ in relation to each of metals studied in both populations.

7) Lack of differences in egss' thickness and eggs' volume from both populations suggest similar physiological condition of females from both populations during the egg-lying period.

8) Transboundary pollution had an effect on the accumulation of heave metals by adult gulls. For biomonitoring purposes should be rather studied in nestlings or immature than in adults. This mainly due to the foraging behaviour of the parents, determining the diffrences in accumulation of metals by young gulls from both populations studied.

REFERENCES

Bundschrerer B., Rambeck W. A., Kollmer W. E., Zucker H. 1985. Einfluss der zingehalts im futter auf die cadmium retention in leber und nieren beim huhnkuken. Z. Ernahrungswiss. 24: 73–78.

Burger J. 1994. Heavy metals in avian eggshells: another excretion method. J. Toxicol. Environ. Health 41: 207–220.

Burger J., Gochfeld M. 1988. Metals in tern eggs in a New Jersey estuary: A decade of change. Environ. Monitor. Assess. 11: 127–135.

Burger J., Gochfeld M. 1991. Cadmium and lead in common terns (Aves: *Sterna hirundo*): relationship between levels in parents and eggs. Environ. Monitor. Assess. 16: 253–258.

Burger J., Gochfeld M. 1996a. Heavy metal and selenium levels in Franklin's gull (*Larus pipixcan*) parents and their eggs. Arch. Environ. Contam. Toxicol. 30: 487–491.

Burger J., Gochfeld M. 1996b. Heavy metal and selenium levels in birds at Agassiz National Wildlife Refugee, Minnesota: Food chain differences. Environ. Monitor. Assess. 43: 267–282.

Burger J., Gochfeld M. 1997a. Age differences in the blood of Herring (*Larus argentatus*) and Franklin's gulls (*Larus pipixcan*) gulls. Arch. Environ. Contam. Toxicol. 33: 436–440.

Burger J., Gochfeld M. 1997b. Lead and neurobehavioral development in gulls: A model for understanding effects in the laboratory and the field. NeuroToxicology 18: 495–506.

Chang L. W. 1996. Toxicology of metals. CRC Lewis Publ., Boca Raton, New York.

Cimander B., Szeliga J. 1992. [Air pollution in Katowice Province]. Aura 11: 12–15.

Dmowski K. 1997. Biomonitoring with the use of Magpie *Pica pica* feathers: heavy metal pollution in the vicinity of zinc smelters and national parks in Poland. Acta orn. 32: 15–23.

Dmowski K. 1999. Birds as bioindicators of heavy metal pollution: review and examples concerning European species. Acta orn. 34: 1–25.

Dmowski K. 2000. Environmental monitoring of heavy metals with magpie (*Pica pica*) feathers — an example of Polish polluted and control areas. In: Markert B., Friese K. (eds.). Trace elements – their distribution and effects in the environment, Elsevier Sci. Ltd, pp. 455–477.

Dmowski K., Golimowski J. 1993. Feathers of the Magpie (*Pica pica*) as a bioindicator material for heavy metal pollution assessment. Sci. Total Environ. 139/140: 251–258.

Dmowski K., Kędziorski A., Kramarz P. 1999. Animals of the Katowice Administrative District (KAD). Pollution in the past and present. In: Peakall D., Walker C., Migula P. (eds.). Biomarkers; a pragmatic basis for remediation of severe pollution in eastern Europe. NATO Adv. Workshop series, Kluwer Acad. Publ., Dodrecht, pp. 111–122.

Drasch G. A., Walser D., Kösters J. 1987. The Urban Pigeon (C*olumba livia,* forma urbana) — a biomonitor for the lead burden of the environment. Environ. Monitor. Assess. 8: 1–9.

Edens F. W., Garlich J. D. 1983. Lead induced egg production decrease in leghorn and Japanese quail. Poultry Sci. 62: 1757–1763.

Elinder C. G., Nordberg, M. 1986. Metallothionein. In: Friberg L., Elinder C. G., Kjellstrom T., Nordberg G. F. (eds.). Cadmium and health: A toxicological and epidemiological appraisal. 1: 65–79.

Elliott J. E., Scheuhammer A. M., Leighton F. A., Pearce P. A. 1992. Heavy metal and metallothionein concentrations in Atlantic Canadian seabirds. Arch. Environ. Contam. Toxicol. 22: 63–73.

Fox M. R. S., Tao S. H., Stone C. L., Fry B. E. Jr. 1984. Effects of zinc, iron and cooper deficiences in tissues of Japanese quail. Environ. Health Perspect. 54: 57–65.

Franson J. Ch. 1996. Interpretation of tissue lead residues in birds other than waterfowl. In: Beyer W. N., Heinz G. H., Redmon-Norwood A. W. (eds.). Environmental Contaminants in Wildlife: interpreting tissue concentrations, CRC Lewis Publ, Boca Raton, Fl, pp. 265–279.

Garcia-Fernandez A. J., Sanchez-Garcia J. A., Gomez-Zapata M., Luna A. 1996. Distribution of cadmium in blood and tissues of wild birds. Arch. Environ. Contam. Toxicol. 30: 252–258.

Gochfeld M., Burger J. 1998. Temporal trends in metal levels in eggs of the endangered Roseate tern (*Sterna dougalli*) in New York. Environ. Res. Sect. A. 77: 36–42.

Godzik S., Kubiesa P., Staszewski T., Szdzuj J. 1999. Ecological problems of the Katowice administrative district. In: Peakall D., Walker C., Migula P. (eds.). Biomarkers: a Pragmatic Basis for Remediation of Severe Pollution in Eastern Europe. Kluwer Acad. Publ., Dodrecht, pp. 49–73.

Grue Ch. E., Hoffman D. J., Beyer W. N., Franson L. P. 1986. Lead concentrations and reproductive success in European starlings *Sturnus vulgaris* nesting within highway roadside verges. Environ. Pollut. 42: 157–182.

Hoffman D. J., Franson J. C., Pattee O. H., Bunck C. M., Anderson A. 1985. Survival, growth, and accumulation of ingested lead in nestling American kestrels (*Falco sparverius*). Arch. Environ. Contam. Toxicol. 14: 89–94.

Howarth D. M., Hulbert A. J., Horning D. 1981. A comparative study of heavy metal accumulation in tissues of the crested tern, *Sterna bergii,* breeding near industrialized and non-industrialized areas. Aust. Wildl. Res. 8: 665–672.

Hutton M. 1980. Metal contamination of feral pigeons *Columbia livia* from London area: Part 2. Biological effects of lead exposure. Environ. Pollut. 22: 281–293.

Hutton M., Goodman G. T. 1980. Metal contamination of feral pigeons *Columbia livia* from London area: Part 1. Tissue accumulation of lead, cadmium and zinc. Environ. Pollut. 22: 207–217.

Janiga M., Mankovska B., Bobalová M., Durcová G. 1990. Significance of concentrations of lead, cadmium, and iron in the plumage of the feral pigeon. Arch. Environ. Contam. Toxicol. 19: 892–897.

Jarman W. M., Hobson K. A., Sydeman W. J., Bacon C. E., McLaren E. B. 1996. Influence of trophic position and feeding location on contaminant levels in the Gulf of the Farallones food web revealed by stable isotope analysis. Environ. Sci. Technol. 30: 654–660.

Kim E. Y., Murakami T., Saeki K., Tatsukawa R. 1996. Mercury levels and its chemical form in tissues and organs of seabirds. Arch. Environ. Contam. Toxicol. 31: 519–525.

Lasiewski R. C., Dawson W. R. 1967. A re-examination of the relation between standard metabolic rate and body weight in birds. Condor 69: 13–23.

Lewis S. A., Furness R. W. 1991. Mercury accumulation and excretion in laboratory reared black-headed gulls (*Larus ridibundus*) chicks. Arch. Environ. Contam. Toxicol. 21: 316–320.

McKenna I. M., Chaney R. L., Tao S. H., Leach R. M. Jr., Williams F. M. 1992. Interactions of plant zinc and plant species on the bioavailability of plant cadmium to Japanese quail fed lecttuce and spinach. Environ. Res. 57: 73–87.

Migula P. 1993. [Functioning of animals in areas degraded by industry] In: Fleck H. G. (ed.). [Problems of environmental protection in Silesia and Eastern lands of Germany]. F. Naumann Stft., Warszawa, 1: 101–112.

Migula P. 2000. Enzymatic effects and animal population demography in polluted environments. In: Kammenga I., Laskowski R. (eds.). Demography in Ecotoxicology, Wiley & Sons, London, New York, pp. 219–240.

Migula P., Augustyniak M., Łaszczyca P., Wilczek G. 1999. Validation of selected biomarkes in invertebrates from polluted Silesian Region. In: Peakall D. B., Walker C. H., Migula P. (eds.). Biomarkers: a Pragmatic Basis for Remediation of Severe Pollution in Eastern Europe. Kluwer Acad. Publ., Dodrecht, pp. 75–90.

Migula P., Doleżych B., Kielan Z., Łaszczyca P., Howaniec M. 1990. [Stress reactions in animals from industrially contaminated areas] In: Godzik S. (ed.). [Hazards and state of the environment of Cracow-Silesia Region]. SGGW-AR, Warszawa, pp. 108–129.

Migula P., Krawczyk A., Wilczek B. 1984. Bioenergetics of Iberian tortoise *Clemmys caspica leprosa*. Zeszyty Naukowe Uniwersytetu Śląsk*iego,* Katowice 14: 71–95.

Mineau P., Fox F. A., Norstrom R. J., Weseloh D. V., Hallett D. J., Ellenton J. A. 1984. Using the herring gull to monitor levels and effects of organochlorine contamination in the Canadian Great Lakes. Adv. Environ. Sci. Technol. 14: 425–452.

Newman M. C., Jagoe Ch. H. 1996. Ecotoxicology A hierarchical treatment. CRC Lewis Publishers, Boca Raton, New York

Newman J. R., Novakova E., McClave J. T. 1985. The influence of industrial air emissions on the nestling ecology of the House Martin *Delichon urbica* in Czechoslovakia. Biol. Conserv. 31: 229–248.

Nicholson J. K., Kendall M. D., Osborn D. 1983. Cadmium and mercury nephrotoxicity. Nature 304: 633–635.

Pain D. J. 1996. Lead in waterfowl. In: Beyer W. N., Heinz G. H., Redmon-Norwood A. W. (eds.). Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. CRC Lewis Publ, Boca Raton, Fl, pp. 251–264.

Peakall D. B., Lincer J., Riscbrough E. W., Pritchars J. B., Kintner W. B. 1973. DDE induced eggshell thinning. Comp. Biochem. Pharmacol. 4: 305–313.

Peakall D. B., Walker, C. H., Migula, P. 1999. Biomarkers: a Pragmatic Basis for Remediation of Severe Pollution in Eastern Europe. Kluwer Acad. Publ., Dodrecht.

Pinowska B., Kraśnicki K., Pinowski J. 1981. Estimation of the degree of contamination of granivorous birds with heavy metals in agricultural and industrial landscape. Ekol. pol. 29: 137–149.

Sawicka-Kapusta K., Kozłowski J., Sokołowska T. 1986. Heavy metals in tits from polluted forests in Southern Poland. Environ. Pollut. 42: 297–310.

Sawicka-Kapusta K., Laczewska B., Kowalska A. 1995. Heavy metal concentrations in Great Tit nestlings from polluted forest in Southern Poland. In: Wilken R. D., Förstner U., Knöchel A. (eds.). Proc. Int. Conf. Heavy Metals in the Environment 1: 244–247.

Scheuhammer A. M. 1987. The chronic toxicity of aluminium, cadmium, mercury, and lead in birds: A review. Environon. Pollut. 46: 263–295.

Stewart F. M., Furness R. W., Monteiro L. R. 1996. Relationships between heavy metal and metallothionein concentrations in Lesser Black-Headed Gulls, *Larus fuscus*, and Cory's Shearwater, *Calonectris diomedea*. Arch. Environ. Contam. Toxicol. 30: 299–305.

Thompson D. R., Becker P. H., Furness R. W. 1993. Long-term changes in mercury concentration in Herring Gulls *Larus argentatus* and Common Terns *Sterna hirundo* from German North Sea coast. J. Appl. Ecol. 30: 316–320.

Tomiałojć L. 1990. [Birds of Poland]. PWN, Warszawa.

Walasz K. 1992. [Atlas of Breeding Birds in Małopolska, 1985–1991]. Wrocław.

Walker C. H., Hopkin S. P., Sibly R. M., Peakall D. B. 1996. Principles of ecotoxicology. Taylor & Francis Ltd, London.

White D. H., Finley M. T. 1975. Uptake and retention of dietary cadmium in mallard ducks. Environ. Res. 17: 53–59.

White D. H., Finley M. T., Ferrell J. F. 1978. Histopatologic effects of dietary cadmium on kidneys and testes of mallard ducks. J. Toxicol. Environ. Health. 4: 551–558.

WSSE — Wojewódzka Stacja Sanitarno-Epidemiologiczna Katowice. 1994. [Air pollution in Katowice Voivodeship 1991–1993]. Katowice.

WUS — Wojewódzki Urząd Statystyczny Katowice 1994. [Environmental protection in Katowice district 1990–1993]. WUS OP, Katowice.

STRESZCZENIE

[Skażenie metalami ciężkimi, metabolizm tlenowy i parametry lęgowe dwóch populacji lęgowych mewy śmieszki na obszarach zanieczyszczonych przez przemysł (Górny Śląsk)]

Niektóre gatunki ptaków (gołębie, sroki, wróble) mogą być przydatne do biomonitoringu obszarów zanieczyszczonych, szczególnie przez przemysł, a mewy są wykorzystywane także dla biomonitoringu środowisk morskich. Śmieszka może być również wykorzystana dla tych celów na obszarach zurbanizowanych i uprzemysłowionych. Umożliwia to jej szerokie rozprzestrzenienie w Europie i Azji, duże kolonie lęgowe, łatwość odłowu i mierzenia parametrów populacyjnych, a także przydatność do badań z zastosowaniem biomarkerów, również bezinwazyjnych. Liczne występowanie śmieszki na terenach zdegradowanych działalnością przemysłu sugeruje jej wysoką tolerancję w stosunku do toksycznych czynników antropogenicznych. Również na Górnym Śląsku kolonie lęgowe tych ptaków są coraz liczniejsze. Celem pracy było wykazanie jak zanieczyszczenia środowiska metalami wpływają na poziom metabolizmu śmieszek i niektóre parametry rozrodu, i czy gatunek ten może być bioindykatorem. Porównano jak zmienia się obciążenie metalami w trakcie rozwoju osobniczego mew z 2 stanowisk — Katowice-Szopienice (HPA) i Świerklaniec (LPA), położonych w centrum (HPA) i na obrzeżu (LPA) obszaru Górnego Śląska, odległych od siebie o 23 km. Oba stanowiska były pod wpływem przemysłu, jednak różniły się pod względem obciążenia środowiska zanieczyszczeniami (Tab. 1). Jako biomarkery toksycznych efektów zanieczyszczeń przyjęto zmiany poziomu metabolizmu tlenowego mew w warunkach spoczynkowych, zmiany grubości skorupy i objętości jaj, a także ocenę sukcesu lęgowego.

W obu koloniach wyznaczono losowo i oznakowano 60 (LPA) i 40 (HPA) gniazd, w których liczono złożone jaja, pisklęta po wykluciu i jaja nie wyklute lub usunięte z gniazd. Oznaczenia prowadzono na 2–3 dniowych pisklętach, 18-dniowych podlotach i dorosłych mewach, po 6–10 osobników z każdej grupy wiekowej z danego stanowiska. Metabolizm tlenowy oznaczano u piskląt i podlotów, lecz nie badano u ptaków dorosłych ze względu na efekt stresu. Metale (Cd, Pb, Zn, Cu) oznaczano w różnych narządach: wątroba, nerki, płuca, jelito cienkie, serce, jajniki, kość udowa, mięśnie szkieletowe z okolicy udowej, oraz w treści żołądkowej, części żółtkowej i skorupce jaj. Zastosowano metodę płomieniową w spektrometrze absorpcji atomowej (Solaar Unicam 939), a przy niższych stężeniach metali metodę bezpłomieniową z użyciem kuwety grafitowej PU 93090X.

Zawartość metali w skorupce była w obu populacjach wyższa niż w żółtku jaj (Tab. 2). Wartości te były znacząco wyższe od wykazywanych u innych gatunków ptaków z terenów uprzemysłowionych. Zawartość kadmu i ołowiu gwałtownie wzrastała w trakcie rozwoju a najwyższe wartości wykazano w jajniku dorosłych, nerkach i wątrobie mew z obu populacji. Poziom Cd i Pb w tych narządach u dorosłych ptaków z obu stanowisk był 30–70-krotnie wyższy niż w innych narządach (Tab. 3, 5). Wykazano dodatnie korelacje między poziomem poszczególnych par metali w trakcie rozwoju mew (pisklęta, podloty, doro-

słe), głównie w wątrobie, nerce i jajniku mew z HPA i, podobnie, w wątrobie, nerce, jajniku oraz kości u mew z LPA (Tab. 6). Ołów kumulował się w tkankach miękkich już u młodych ptaków, lecz później w tych tkankach u dorosłych ptaków jego poziom zasadniczo nie wzrastał i pierwiastek ten kumulował się w kościach. Jelito dorosłych mew z HPA miało nawet dwukrotnie mniejszy poziom tego metalu niż u mew z LPA.

Wysoka zawartość ołowiu w nerce i wątrobie sugerowała zaburzenia wzrostu młodych ptaków, jednak średnia masa podlotów był niższa w populacji z LPA, a nie z HPA, gdzie stężenie w środowisku było wyższe (Tab. 8). Zmiany poziomu Cu i Zn w trakcie rozwoju mew nie wskazują na kumulację tych pierwiastków z wiekiem ptaków, lecz na ich endogenną regulację (Tab. 4 i 5). Poziom Zn i Cd był zbliżony do zawartości wykazywanych u niektórych innych gatunków ptaków z terenów przemysłowych.

Przemiany tlenowe (metabolizm spoczynkowy — RMR) i współczynnik oddechowy (RQ) dla rozwijających się mew z obu populacji był podobny i tylko pisklęta z LPA wykazywały istotnie wyższy poziom metabolizmu spoczynkowego, wyrażany na jednostkę masy ciała i jednostkę metaboliczną ciężaru ciała, $kg^{0.75}$ (Tab. 8). Tylko w niektórych przypadkach wykazano ujemną korelację między koncentracją metali a RMR i RQ — lecz dodatnią z masą wątroby. Wskaźnik stężenia kadmu wątroby w stosunku do nerki w każdym z badanych przypadków był mniejszy od 1. Oznacza to chroniczne narażenie ptaków w środowisku. Samice kumulują ten metal w jajnikach, na poziomie podobnym jak w nerkach. Mogą więc one mieć nie tylko zaburzenia nefrotoksyczne, lecz również kadm (wraz z Pb) może indukować zaburzenia rozrodu. Wielkość lęgu była niższa w HPA. Jednak niższy poziom Cd w nerkach dorosłych ptaków z tego stanowiska może wskazywać na ich większe zdolności do unieczynniania kadmu, nie tylko przez wiązanie z metalotioneinami. Nie dotyczy to jednak MT wątrobowej, gdyż poziom kadmu w wątrobie, a także w jajniku dorosłych mew z HPA, był wyższy niż u mew z LPA, co mogło wpłynąć negatywnie na wielkość zniesienia i klucie piskląt.

Średnia liczba złożonych jaj (2.97 — HPA, 3,61 — LPA; $p < 0.01$; Tab. 9) i sukces klucia (81.5% i 87%) sugerują, że występowały negatywne skutki skażeń w populacji bardziej narażonej na zanieczyszczenia. Jednak grubość skorupki jajowej (0.12 i 0.13 mm; $p > 0.05$) oraz objętość jaj (27.7 i 28.8 mm^3; $p > 0.05$; Tab. 9) — odpowiednio u mew z HPA i LPA — nie potwierdzają tego wniosku. Nie stwierdzono również wyższych kosztów energetycznych, wynikających z nasilania enzymatycznych procesów detoksykacji, o czym świadczy podobieństwo wielkości metabolizmu spoczynkowego ptaków z obu populacji. Kadm i ołów mogły wpływać negatywnie na wcześniejsze fazy rozwoju mew, kiedy rodzice zbierali pożywienie w pobliżu miejsc lęgowych. Jednak po osiągnięciu dojrzałości różnice w obciążeniu metalami toksycznymi ptaków z obu analizowanych populacji zmniejszyły się (Tab. 5). Wtedy zapewne pokarm był zbierany na większych obszarach, co zmniejszyło zróżnicowanie zawartości metali w diecie. Stosunkowo wysoki sukces wylęgu przy tak znacznym obciążeniu metalami miękkich narządów (jajniki, wątroba, nerki) dorosłych ptaków z obu populacji wskazuje na ich zdolności przystosowawcze.

Dorosłe śmieszki mogą więc być biowskaźnikami większych areałów pozostających pod wpływem skażeń przemysłowych, natomiast ich młode mogą być wykorzystane dla biomonitoringu terenów przyległych do miejsc lęgowych.