Ecotoxicology and Environmental Safety 97 (2013) 67–72

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

Diet composition as a cause of different contaminant exposure in two sympatric passerines in the Middle Urals, Russia

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ARTICLE INFO

Article history:
Received 13 March 2013
Received in revised form
5 July 2013
Accepted 7 July 2013
Available online 31 July 2013

Keywords:
Contaminant exposure
Heavy metal
Diet
Ficedula hypoleuca
Parus ater

ABSTRACT

Contaminant exposure can vary between species but primary causes of it are often unclear. In order to estimate heavy metal intake of two sympatric passerines – *Ficedula hypoleuca* Pall. and *Parus ater* L. – we studied nestling diet and metal concentrations in prey invertebrates, near the Middle Ural copper smelter and in an unpolluted area. Diet of *P. ater* contained more Cu, Cd and Zn compared to *F. hypoleuca* and the same amount of Pb. Contribution of different prey taxa to bird metal intake was not equal to their dietary proportion. Proportion of Cu, Zn, Pb and Cd provided to birds by spiders and molluscs, as well as Cd and Pb provided by ants and imagoes Diptera, exceeded their dietary fraction by several times. In contrast, the contribution of Lepidoptera and sawfly larvae to bird metal intake was less than their dietary proportion. Pollution-related changes in the diet modified bird contaminant exposure along with pollutant concentrations in preys.

1. Introduction

Contaminant exposure is one of the key factors determining toxic effects. Researchers use different measures of exposure including pollutant concentrations in food, faeces and organs of birds (Berglund et al., 2010, 2011; Eeva and Lehikoinen, 1996; Janssens et al., 2003; Nyholm, 1995; Schipper et al., 2008). Studies of pollutant intake of birds are scarce and usually deal with one species (Morrissey et al., 2005; Schipper et al., 2012), which does not allow comparisons between species.

The aim of the study was to estimate contaminant exposure in two forest passerines in the Middle Urals, Russia, both near a metallurgy complex and in an unpolluted area, and to estimate the contribution of different food components to bird metal intake. We tested two hypotheses. (1) Different bird species can experience different contaminant exposure within the same habitat due to differences in diet structure. (2) Alteration of the diet of insectivorous birds induced by transformation of the invertebrate community can affect contaminant exposure in two ways. Elevated exposure in the polluted area (as a result of total contamination of the environment) can either increase additionally (if the proportion of food objects with high pollutant concentrations grow) or decrease (if the proportion of less toxic preys increases).

2. Material and methods

2.1. Study area

This study was performed in the year 2000 in vicinities of the Middle-Ural copper smelter (Russia, Revda, 56°51′N, 59°53′E). It is a strong source of sulphur dioxide and polymetallic dust. Total emissions in the year 2000 equalled 63100 t including 56300 t sulphur dioxide (GSO, 2001). A geochemical anomaly with soil metal concentrations exceeding 10–100 times background levels has formed around the smelter since being put into operation in 1940 (Vorobeichik et al., 1994). Zones with different levels of pollution and degradation of forest ecosystems were distinguished in vicinities of the plant based on complex investigations (Vorobeichik et al., 1994). The zone of high pollution (impact zone) extends westwards up to 2.5 km from the smelter. Cu and Pb concentrations in the soil (horizon A1) exceed regional background levels by 43.4 and 9.5 times respectively (Belskii et al., 2005). The relatively unpolluted (background) zone is situated ≥16 km to the west of the smelter.

Plots with nestboxes were established in two forest types along the pollution gradient. One type was aspen-birch forest with some admixture of conifers; in the other, spruce and fir dominated with admixture of pine, birch and aspen. In the impact zone, the forest was rarefied due to the long-term effect of pollution. For this study, we used two plots in the impact zone and two plots in the background zone, so that impact plots corresponded to background plots by vegetation type. Impact plots were situated 1 km to the west of the smelter (deciduous forest, area 41 ha with 81 nestboxes) and 1.5 km to the southwest of the smelter (conifer forest, 23 ha, 46 nestboxes). Background plots were situated 16 km to the west of the smelter (deciduous forest, 21 ha, 42 nestboxes) and 20 km to the west of the smelter (conifer forest, 32 ha, 64 nestboxes).

2.2. Model species

Nestboxes were commonly occupied by pied flycatchers *Ficedula hypoleuca* Pall. and coal tits *Parus ater* L. The pied flycatcher is larger than the coal tit with body mass (± SE) during breeding in the study area 13.04 ± 0.02 g (n = 1840) and 9.20 ± 0.06 g (77), respectively (Belskii, unpublished). Both species are insectivorous but differ in foraging habitats and techniques. Pied flycatchers catch

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http://dx.doi.org/10.1016/j.ecoenv.2013.07.014

invertebrates in tree crowns, on the ground and in the air when taking off from a perch. Coal tits forage mainly in crowns of conifers but also use deciduous trees in the west of the species range. The pied flycatcher is a long-distant migrant with winter grounds in West Africa, south of the Sahara. Coal tits winter in the forest zone (Cramp and Perrins, 1993).

2.3. Sampling and measurements

Nestling diet was studied using neck collars. Samples were collected in 14 nests of *F. hypoleuca* from 21st June to 10th July at nestling age 4–13 days (hatching day 0, 177 boluses containing 325 specimens of invertebrates) and in 8 nests of *P. ater* from 31st May till 11th July at nestling age 5–15 days (205 boluses, 412 specimens of invertebrates). Food boluses were kept individually in Eppendorf tubes in 70% ethanol. In the laboratory, boluses were placed on filter paper and invertebrates were separated carefully. Invertebrates were dried on filter paper until the liquid disappeared from integuments and mass stabilised. Each specimen was weighed using electronic scales, Kern 770 with accuracy 0.1 mg. Differences between species and study sites in diet structure based on number of food objects (Appendix 1) were tested with χ^2-test.

Invertebrates belonging to bird preys were sampled for chemical analyses. Invertebrates were caught by hands and an entomological net in plots with nestboxes in both zones. The invertebrates were dried in a muffle furnace at 70 °C for 3 days. The objects were weighed before and after drying in order to calculate conversion factor between wet and dry mass (Appendix 2). Since no molluscs were sampled from vegetation in the impact zone shells dropped by birds in nests were analysed. The shells were not swallowed by nestlings and contained dry soft tissues inside. It is known that shells, together with soft tissues, dissolve in acidic medium of the nestling stomach, and so their analysis is appropriate when estimating metal intake in birds. These shells were washed in distilled, deionised water with a brush to remove superficial dirt.

2.4. Chemical analyses and data processing

Mass of samples for chemical analyses varied from 20 to 100 mg, and one sample usually contained several specimens of invertebrates. Samples were digested in a microwave oven in Teflon vessels in a mixture of 1 ml nitric acid and 4 ml double-distilled, deionised water, at pressure 900 kPa. Metal (Cu, Pb, Cd, Zn) concentrations were measured with an AAS 6 Vario atomic absorption spectrometer (Analytik Jena, Germany) at the Institute of Plant and Animal Ecology (Yekaterinburg, Russia). Standard tissue of bovine liver CRM-185 R was used as a control sample. Calibration solutions were prepared from liquid standards produced by the Urals plant for chemical reagents. In total, 142 samples were analysed.

Because of differences in feeding type within the order Hymenoptera, we distinguished groups of herbivores (sawflies Symphyta) and polyphages (ants Formicidae). Imagoes and larvae of butterflies and sawflies were analysed separately since insects of different developmental stages differ in caloric value and metal concentrations. Differences between zones in metal concentrations were tested with Mann–Whitney U test.

Contaminant exposure of nestlings before leaving the nest was calculated as daily metal intake per unit of body mass as follows. Average weighted metal concentrations in food were multiplied by daily food intake and divided by bird body mass. Average weighted metal concentrations in food were calculated based on metal concentrations in different preys and diet structure (proportions of different components in food dry mass) (Tables 1–3, Appendix 3). Daily food intake was calculated on the basis of daily energy of maintenance (DEM) and assimilable energy density of invertebrate preys (Dolnik and Postnikov, 1990; Appendix 2). DEM for passerine fledglings reaching adult body mass (m_f) is:

$DEM_f = 6.12 * m_f^{0.688}$ kJ/day (Dolnik and Dolnik, 1994). Body mass of the species is shown in Section 2.2. Assimilable energy content of food in *F. hypoleuca* equalled 16.2 kJ/g dry mass in the background zone and 16.3 kJ/g in the impact one, and in *P. ater* 14.8 kJ/g and 16.1 kJ/g respectively. Contribution of invertebrate groups to intake of each metal to birds was calculated in % of metal intake with 1 g of food (Tables 1 and 2, Appendix 4).

Standard errors of composite indices (dietary average weighted metal concentrations and daily metal intake) were calculated as described in Taylor (1982). Significance of differences between species and areas was tested with Student's *t*-test.

3. Results

The diet of *F. hypoleuca* in the background zone was more diverse compared to *P. ater* (11 and 5 orders of invertebrates, Shannon diversity index 1.79 and 0.99 respectively) (Tables 1 and 2). In the background zone, Lepidoptera larvae prevailed among preys of *F. hypoleuca* and together with Araneae in the diet of *P. ater*. Proportion of Lepidoptera increased in diets of both bird species in the impact zone compared to the background zone; the same was true for Araneae in the diet of *F. hypoleuca*. Diet diversity decreased in polluted area compared to background one both in *F. hypoleuca* and *P. ater* (Shannon diversity index 1.02 and 0.80 respectively). Differences between zones by number ratio of food objects (Appendix 1) were significant in *F. hypoleuca* ($\chi^2 = 40.7$, $df = 5$, $p < 0.001$) and *P. ater* ($\chi^2 = 17.5$, $df = 3$, $p < 0.001$).

In the background zone, the highest concentrations of Cu and Zn were registered in Araneae, and Pb and Cd in Mollusca (Table 3). The lowest concentrations of Cd and Zn were observed in sawfly larvae, Cu in Lepidoptera larvae, and Pb in Lepidoptera imagoes. In the impact zone, the highest concentrations of all metals were registered in molluscs. The lowest concentrations of Cu and Pb were observed in Lepidoptera larvae, Cd in sawfly larvae, and Zn in Hemiptera (Table 3). Concentrations of metals in most invertebrate taxa were higher in the impact zone compared

Table 1
Nestling diet (% air-dry mass) and contribution (%) of invertebrate taxa to dietary metal intake of *F. hypoleuca* in two zones near the Middle-Ural copper smelter.

Taxon, developmental stage	Background zone					Impact zone				
	Dietary proportion	Contribution to dietary metal intake				Dietary proportion	Contribution to dietary metal intake			
		Cu	Zn	Cd	Pb		Cu	Zn	Cd	Pb
Lepidoptera, i *	3.0	2.6	3.1	1.0	1.8	4.0	2.9	4.1	2.8	4.1
Lepidoptera, l *	34.8	14.0	27.4	6.5	22.0	66.5	26.7	42.2	16.6	35.1
Diptera, i	19.6	19.5	27.3	51.6	28.1	5.7	4.9	5.4	11.0	9.3
Hymenoptera, Symphyta, i	4.4	4.8	2.4	2.2	3.5	1.2	1.6	0.6	0.8	3.3
Hymenoptera, Symphyta, l	7.7	3.9	3.5	0.9	8.9	2.3	1.1	1.5	0.4	2.1
Hymenoptera, Formicidae, i	1.8	1.4	2.4	5.3	2.9	0.7	0.8	1.8	3.3	2.6
Araneae	7.4	29.1	19.5	22.4	9.7	15.1	57.1	42.3	62.9	38.3
Coleoptera, i	6.2	5.0	2.3	2.2	8.2	2.2	2.5	1.5	1.2	4.3
Coleoptera, l	0.3	n.a. **	n.a.	n.a.	n.a.	0	0	0	0	0
Homoptera, i	6.1	9.4	9.0	3.4	7.2	0.3	0.9	0.2	0.3	0.3
Hemiptera, i	6.1	9.6	2.5	3.6	6.3	1.0	1.5	0.4	0.7	0.6
Opiliones	1.6	n.a.	n.a.	n.a.	n.a.	0	0	0	0	0
Megaloptera, i	0.6	n.a.	n.a.	n.a.	n.a.	0.3	n.a.	n.a.	n.a.	n.a.
Mollusca	0.3	0.7	0.6	0.9	1.4	0	0	0	0	0
Raphidioptera, i	0.1	n.a.	n.a.	n.a.	n.a.	0	0	0	0	0
Trichoptera, i	0	0	0	0	0	0.7	n.a.	n.a.	n.a.	n.a.

* i – imagoes, l – larvae
** n.a. – not analysed

Please cite this article as: Belskii, E., Belskaya, E., Diet composition as a cause of different contaminant exposure in two sympatric passerines in the Middle Urals, Russia. Ecotoxicol. Environ. Saf. (2013), http://dx.doi.org/10.1016/j.ecoenv.2013.07.014