Chapter 12
Pollutants in Urbanized Areas: Direct and Indirect Effects on Bird Populations

Jaana Kekkonen

Abstract Industrialization, traffic, intensification of agriculture, and development of human lifestyle in general during the last century have resulted in elevated levels of various chemical compounds in our environment. Especially in urbanized areas, harmful substances are produced in such quantities that they can have a deleterious effect on the development, survival, and reproduction of organisms. Many bird species have adapted to living alongside with humans and even discovered new resources within the urban lifestyle. However, these birds are in greatest risk of being harmfully effected by various chemicals.

This chapter reviews the effects of heavy metals and organic pollutants on avian populations in urban areas. Case studies are brought together in order to gain comprehension on how well we understand the role of these pollutants as factor influencing the well-being of urban bird populations. The examples highlight the fact that pollutants do not have only direct physiological effects but also indirect effects through, e.g., decreased food availability. As populations of many urban bird species are declining, new research developments for pollution studies are also proposed.

Keywords Pollution • Heavy metals • Organic compounds • Biomonitoring

12.1 Introduction

Industrialization, traffic, intensification of farming, and development of human lifestyle in general during the last century have resulted in elevated levels of various chemical compounds in our environment (Candelone et al. 1995). As humans alter the environment drastically, other species are also affected and need to adapt to the potentially deteriorating conditions. Especially in urbanized areas, harmful substances are produced from traffic, housing, energy production, construction, and production of goods in such quantities that they can have deleterious effects on the development, survival, and reproduction of organisms. This has become a

J. Kekkonen (✉)
University of Helsinki, Viikinkaari 1, 00014 Helsinki, Finland
e-mail: jaana.kekkonen@helsinki.fi

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particularly large-scale problem given that more than half of the world's human population now lives in urban areas with a projected 68 % (6.3 billion people) expected to live in cities by 2050 (World Urbanization Prospects 2012). Organisms that have become closely associated to human housing are at greatest risk of being affected. Bird populations in urban environments represent upper trophy levels of food chains consuming both plants and other animals. Thus, as many pollutants bioaccumulate as they pass between the trophy levels, birds are likely being affected both directly and indirectly by pollutants (Burger 1993; Furness and Greenwood 1993). Harmful substances can, for instance, reduce breeding performance (reduced fertility, hatching failure), delay growth and development, cause damages in organs, and in the end hamper survival (Romanowski et al. 1991; Burger 1993; Janssens et al. 2003; Eeva et al. 2009). On the other hand, pollutants also decrease the availability of, for example, invertebrates that the urban birds feed on (McIntyre 2000). Urbanization has therefore created opportunities and new living environments for bird species but, on the other hand, also deteriorating conditions and challenges. As many bird species nowadays have declining trends (BirdLife International), the role of pollution should also be considered (see also Macías-García et al. 2016).

Pollution in this chapter is defined as chemicals produced by human activities into the environment. In urban environments, also light and noise pollution are growing concerns (Fuller et al. 2007; Barber et al. 2010; Kempenaers et al. 2010; Dominoni 2016). The scope here, however, is on chemicals because they already form a highly problematic issue. The two main groups of pollutants studied in birds are heavy metals and organic pollutants. Since the beginning of industrialization, their amounts have increased almost exponentially in the urban habitats (Candelone et al. 1995). Even though many regulations and cleaner production techniques have helped to regulate and even decrease some of their amounts these days, the ever growing human population and its demands make it difficult to stay on top of the situation (Järup 2003). Pollutants which have already been banned over the years remain problematic due to their persistent nature, and they tend to stay in the environment for very long times (Beyer et al. 1996; Agarval 2009). Thus, studies on how the pollutants accumulate in food chains, how they affect different development stages of urban birds, and, in the end, population demographics are needed to evaluate for potential conservation actions.

For these reasons, it is very important to conduct research not only in laboratory conditions but on wild populations (cf. Burger and Gochfeld 1997). Environmental pollution has without a doubt a role in the declines of many bird species, but it is not always easy to demonstrate the causal relationships as there are many other factors affecting simultaneously in urban environments (Lepczyk and Warre 2012). In this chapter I bring together some of the case studies done in urban environments and, this way, bring forth on what is already known and what may be the gaps where more research should be focused on. I aim to present the various chemical compounds potentially found in urban environments, introduce interesting case studies of pollution-influenced urban birds, and suggest directions for future studies.

12.2 Different Pollutants

12.2.1 Heavy Metals

Heavy metals occur naturally in the environment in small quantities. However, due to human actions, excessive amounts of heavy metals have ended up in the ecosystems. Heavy metals are especially problematic for biological organisms due to their accumulative properties and persistent nature. Some of the heavy metals are even necessary to organisms as small amounts (Valko et al. 2005). For instance, copper and zinc are essential for the immune system and iron for transportation of oxygen (Percival 1998; Prasad 1998). However, other metals are biologically not needed at all (e.g., cadmium, lead, mercury, nickel, arsenic). Moreover, heavy metals can even bind to important molecules preventing biologically important processes. Since heavy metals are known to have long lasting toxic effects that will not easily biodegrade, chronic exposure can have harmful effects (Ikeda et al. 2000; Dauwe et al. 2006; Nam and Lee 2006). In some cases the damages may appear only after several years (Furness 1996).

Large proportion of heavy metal pollution is airborne. Atmospheric concentrations of heavy metals primarily result from burning of urban and industrial wastes, mining, smelting processes, gas emission from motor vehicles, and combustion of fossil fuels (Harrop et al. 1990; Mohammed et al. 2011). Heavy metal pollution is thus spread effectively both at local and regional levels. Heavy metals access water systems and soils from which they effectively accumulate in the food chains (Suedel et al. 1994; Kaminski 1995; Labare et al. 2004). The heavy metals often studied in birds are, e.g., lead, cadmium, zinc, iron, copper, and chromium.

Lead is probably the most measured one possibly because lead poisoning can have so many physiological and behavioral impacts. Physiological effects include anemia, emaciation, weakness, and poor growth and development (Franson 1996; Kaminski and Matus 1998), which all affect overall body condition and survival. Behavioral problems can include increased aggressiveness (Janssens et al. 2003) and difficulties in flying and walking (Sanderson and Bellrose 1986). Also breeding can be affected from lowered ability to attract a mate, build a nest, and adequately feed nestlings (De Francisco et al. 2003). Previously, one of the main sources of lead pollution was leaded fuel, but since the 1970s, most of the industrialized countries have restricted the use of lead additives in motor fuels (Ancillotti and Fattore 1998). As a result, the amount of atmospheric lead has reduced significantly, but the lead residues have persisted in the soils. Moreover, lead is still produced as a by-product in several industries like ore and metal processing, piston-engine aircraft operating on leaded aviation gasoline, glass and chemical industries, and energy production (Agarval 2009).

Cadmium poisoning in birds can cause growth retardation, anemia, and testicular damage as well as renal failure which affects the calcium balance causing proteinuria and bone decalcification (Larison et al. 2000). Cadmium pollution comes mainly from enrichment of zinc and steel industry and energy production (Agarval 2009).

Birds can regulate *zinc* effectively within a wide range of exposure. However, when the exposure is too high, they exhibit symptoms like abnormalities in their exocrine pancreas and decreased motor function (Zdziarski et al. 1994). The main sources of zinc pollution these days are energy production, traffic, and metal industry (Agarval 2009).

Physiological signs of *copper* toxicosis include weakness, anemia, and decreased egg production, body and tissue weight, and feather growth (Stohs and Bagchi 1995; Isanhart et al. 2011). Sources of copper include, e.g., copper sulfate, antifouling paints, mining and metal industries, and coal-using power plants (Christian Franson et al. 2012).

When accumulated in tissues, *iron* can increase hemosiderosis, i.e., iron deposits in local tissues (Cork 2000). Most important sources of iron pollution are iron and steel industries (Agarval 2009).

High levels of *chromium* can cause altered growth patterns and reduction in survival. Moreover, there can be mutagenic, teratogenic, and carcinogenic effects (Eisler 2000). Phosphate fertilizers, industrial and sewage wastes, landfill dumping chromium-containing consumer products, and atmospheric emissions are main sources of chromium pollution (Fishbein 1981; Outridge and Scheuhammer 1993).

There are many studies which measure the amounts of heavy metals in birds in urban habitats and compare them to birds from rural habitats. However, it is not always easy to show which levels result in deteriorated survival or reproduction and, moreover, population declines. However, as the amount of studies increases, these causality relationships can be determined more easily. Moreover, in urban habitats when the amount of one heavy metal is increased, often also other heavy metals are more pronounced. Thus, there are cumulative effects which may not be easy to measure but surely affect the well-being of organisms living in the cities.

12.2.2 Organic Compounds

Organic compounds are produced in immense varieties by human housing, industrial processes, and the production of a range of goods (Harrad 2009). Some of the compounds are harmful already in small amounts, but at least excess amounts make many of these compounds harmful to living organisms. The pathways and effects of these contaminants in ecosystem level are not well known. However, some more recent studies also on bird populations are shedding light into these important issues since these compounds are being produced increasingly especially in urban environments (Beyer et al. 1996).

Of particular interest is the chemical group of organohalogens, which constitutes of thousands of compounds. Interestingly, some of them occur naturally in the environment. However, the artificially excessively produced compounds have become problematic in the nature. The occurrence of organohalogen pollutants has been of great concern because of their persistent, lipophilic properties, bioaccumulative nature, capability of long-distance transportation, and adverse effects on variety of different taxa (Beyer et al. 1996; Yu et al. 2014). Thus, we need to be concerned of both humans and wildlife sharing the urban environments. The use of some of these persistent organic pollutants (POPs) has been restricted by international treaties. For example, the Stockholm Convention (United Nations Environment Programme 2001) had 179 countries to agree to restrict and/or eliminate the production and use of the compounds classified as POPs as well as to study and potentially list new ones. However, many of the already restricted pollutants will still persist for a long time in the environment. Moreover, other compounds are still being produced, and thus information on their effects is needed.

The organic pollutants mostly studied in birds include pesticides and herbicides like aldrin, dieldrin, endrin, hexachlorobenzenes (HCBs), hexachlorocyclohexanes (HCHs), mirex, chlordanes (CHLs), and dichlorodiphenyltrichloroethane (DDTs) and its metabolites, heptachlors, and toxaphenes (Beyer et al. 1996). Moreover, chemicals like polychlorinated biphenyl (PCB), polybrominated diphenyl ether (PBDE), and hexabromocyclododecanes (HBCDs) are used, for example, as solvents, synthetic polymers, flame retardants, insulants, and intermediates in the preparation of dyes and pharmaceuticals (Hale et al. 2006; Marvin et al. 2011).

The harmful effects of these organic compounds are often related to reproduction in birds. DDT through its metabolite DDE causes thinning of eggshells by inhibiting calcium metabolism. The eggs break more easily and embryo mortality increases. Moreover, DDTs are involved in reproductive impairment and affect thyroid hormones, i.e., metabolic activity (Ratcliffe 1967; Hickey and Anderson 1968; Fry 1995). PCBs reduce clutch sizes, lower hatching and fledgling rates, and cause hormonal disruptions as well as embryonic and offspring abnormalities. Thus, increased levels of PCBs reduce the overall reproductive success of birds (Fry 1995; Fernie et al. 2001).

PBDEs can affect the birds to delay the timing of reproduction, lead to fewer copulations, cause longer egg-laying intervals, and reduce clutch sizes. Birds may lay smaller eggs which have reduced fertility (Marteinson et al. 2010; Winter et al. 2013). HBCDs affect hormonal levels like increasing testosterone and reducing thyroxine levels. Birds affected by HBCDs also present less active courtship, produce eggs with reduced mass, have lower incubation temperatures, and may present less active parenting behavior (Marteinson et al. 2010, 2012).

One of the first and most famous examples of harmful effects on birds is the discovery of relationship between introduction of DDT as a pesticide and the thinning of eggshells of birds of prey. This was linked to decreased reproductive success (Ratcliffe 1967; Hickey and Anderson 1968). These types of studies showed such clear causalities between organic compounds and deleterious effects that they have contributed in banning the use of those compounds. However, there are so many others produced and new ones developed from which the effects in different trophy levels are not fully known and that these types of studies are needed to fill the gaps that exist now.

12.3 Sampling and Analysis Methods

Sampling designs vary between studies depending on the questions asked, the geographical scale covered, and the type of samples aimed for. As birds are capable of moving distances exceeding urban boundaries, the source of the pollution is not always easy to pinpoint (i.e., point-source pollution like a factory). On the other hand, the interest may not even be on the particular source but measuring the general pollution level in the environment. However, in all studies, there needs to be some type of references for the measured levels of pollutants in the birds. These can be, for example, references measured from laboratory animals (e.g., Beyer et al. 1996; Burger and Gochfeld 1997). Many studies also use comparisons between samples from urban and rural sites (Table 12.1). Thus, I would like to stress that when sampling of any pollution-related study is designed, these issues need to be considered carefully so that the samples gained best describe the issues the researchers wish to address.

Moreover, pollutants can be analyzed in many types of samples from birds depending on the research questions. First of all, sampling can be done on dead or live birds and, secondly, on different development stages, i.e., eggs, nestlings, or adults. The potential differences between sexes in adult birds need to be taken into account as well (Burger and Gochfeld 1992; Eeva et al. 2009). Eeva et al. (2009) suggested that due to their higher reproductive effort, females might be more susceptible to the negative health effects of pollution stress. Another possible reason would be that because of differences in dispersal, sexes would have experienced different environments as young. Also ages need to be taken into account in adult birds as we did, for example, in Kekkonen et al. (2012).

Tissues that are most interesting for pollution studies are the liver, kidney, lungs, and blood. Blood samples can be taken from live birds. However, the pollutant levels in blood are considered to generally reflect more recent exposure (Furness and Greenwood 1993). The intestine organs represent a longer term accumulation and thus can present different information. However, noninvasive sampling is increasingly done by determining pollution levels also from the feathers of birds (Jaspers et al. 2007). Birds can reduce their body burden of toxic substances by excretion in their feathers (Dauwe et al. 2000; Dauwe et al. 2003). Pollution levels in feathers reflect the conditions and diet during the period of feather growth, when the feather is connected to the body with blood vessels. Feathers grow for few weeks and thus they represent longer term pollution levels than blood samples (Furness and Greenwood 1993). When birds are molding, they tend to stay in a confined area, and thus, feather pollution levels also represent quite local pollution (Fasola et al. 1998; Burger et al. 2007).

Very interesting information is also gained by linking nestling growth rates, survival, and potential deformities to amounts of pollutants. Developing organisms have a potentially elevated susceptibility to pollution compared to adults. Eggs can also be sampled for levels of pollution because females sequester pollutants into them (Gochfeld 1997; Fasola et al. 1998). Concentrations in eggs typically reflect

Table 12.1 Pollutant levels measured in birds in urban and rural habitats

Pollutant	Measured from (unit)	Concentration urban	Concentration	Significance	Problematic level	Other results	References
Lead							
Gray catbird	Blood (ppm = µg/g wet weight)	0.09	0.01	<0.05	0.2 poisoning, 0.5 sub-lethal (15, 16)		1.
Gray catbird (nestling)	Blood (ppm)	0.10	0.01	0.001		Neg linked to body condition	1.
American robin	Blood (ppm)	0.26	0.08	<0.05			1.
Northern cardinal	Blood (ppm)	0.11	0.29	<0.05			1.
Northern mockingbird	Blood (ppm)	0.19	0.01	<0.05			1.
House sparrow	Blood (ppm)	0.15	0.02	<0.05			1.
Song sparrow	Blood (ppm)	0.05	0.02	<0.05			1.
Carolina wren	Blood (ppm)	0.07	0.03	Non-sign			1.
Blackbird	Blood (ppm)	0.15	0.05	<0.05	0.2 poisoning, 0.5 sublethal	Earthworms higher Pb in urban	2.
House sparrow	Liver (µg/g dry weight)	0.54	0.10		20.0 indicate toxicosis (17)	Potential link to pop declines	3.
House sparrow	Liver (µg/g dry weight)	37.60	18.00		20.0 indicate toxicosis		4.
House sparrow	Liver (µg/g dry weight)	3.70	2.70		20.0 indicate toxicosis		5.
Feral pigeon	Liver (µg/g wet weight)	2.30	1.80	<0.05	20.0 indicate toxicosis	Urban nestlings a bit smaller	6.
	Kidney (µg/g wet weight)	4.10	3.00	<0.05			

(continued)

Table 12.1 (continued)

Pollutant	Measured from (unit)	Concentration urban	Concentration	Significance	Problematic level	Other results	References
	Bone (µg/g wet weight)	30.00	11.00	<0.05			
	Egg (µg/g wet weight)	1.60	1.10	<0.05			
Rook	Egg (ppm)	4.11	2.90	<0.05			7.
House wren	Feather (ppb → ppm)	~0.70	~4.00	<0.001	4 ppm (18)		8.
White stork (nestling)	Blood (µg/L)	0.11	0.02	<0.001			9.
Cadmium							
Feral pigeon	Kidney (µg/g wet weight)	1.10	0.43	<0.05	2.0 exposure, >100 toxic (19, 20)		6.
House sparrow	Liver (µg/g dry weight)	0.16	0.09		3.0 exposure, >100 toxic	Potential link to pop declines	3.
House sparrow	Liver (µg/g dry weight)	0.07	0.07		3.0 exposure, >100 toxic		4.
House sparrow	Liver (µg/g dry weight)	1.31	0.48		3.0 exposure, >100 toxic		5.
Copper							
House sparrow	Liver (µg/g dry weight)	4.03	3.69			Potential link to pop declines	3.
House sparrow	Liver (µg/g dry weight)	38.20	27.00				4.
House sparrow	Liver (µg/g dry weight)	42.00	61.80				5.
House wren	Feather (ppb → ppm)	~6.50	~4.50				8.

Zinc							
House sparrow	Liver (μg/g dry weight)	21.10	18.40			Potential link to pop declines	3.
House sparrow	Liver (μg/g dry weight)	121.00	97.00				4.
House sparrow	Liver (μg/g dry weight)	205.00	154.00				5.
House wren	Feather (ppb → ppm)	~160.00	~150.00				8.
Iron							
White stork (nestling)	Blood (μg/L)	386.90	269.60				9.
House wren	Feather (ppb → ppm)	~370.00	~60.00				8.
Chromium							
House wren	Feather (ppb → ppm)	~1.20	~0.30				8.
DDTs							
Eurasian tree sparrow	Muscle (ng/g)	92.00	150–1400				10.
Little egret	Egg (ng/g)	1170–40,200	4320–11,400			Comparably high DDT	11.
p,p′-DDE							
Peregrine falcon	Egg (ng/g)	4040–12,400	1380–3930	Nonsign	2800 (ng/g) (21)		12.
Eurasian dipper	Egg (ng/g)	2541	1085		2800 (ng/g)		13.
PCBs							
Eurasian tree sparrow	Muscle (ng/g)	44.00	59–88.00				10.
Peregrine falcon	Egg (ng/g)	4910–12,500	3250–12,800	Nonsign			12.

(continued)

Table 12.1 (continued)

Pollutant	Measured from (unit)	Concentration urban	Concentration	Significance	Problematic level	Other results	References
Eurasian dipper	Egg (ng/g)	946.00	2491.00	<0.0001		High for passerine eggs	13.
PBDEs							
Eurasian tree sparrow	Muscle (ng/g)	28.00	32–250				10.
Peregrine falcon	Egg (ng/g)	32.80	126–354	Nonsign			12.
Eurasian dipper	Egg (ng/g)	387.00	1714.00	0.0002		High for passerine eggs	13.
HBCDs							
Eurasian tree sparrow	Muscle (ng/g)	2.8–51	Not detected				10.
Light-vented bulbul	Muscle (ng/g)	15.0	2.8			Diet differences between species	14.
Long-tailed shrike	Muscle (ng/g)	8.6	–			Diet differences between species	14.
Oriental magpie-robin	Muscle (ng/g)	16.0	380.0			Diet differences between species	14.

The reference for each study is given as numbers. Harmful levels of toxicity are given if there are known examples from the literature which can be used as indicative value. However, because these levels are from the same tissue but most often from different species, they are merely indicative and should be considered with great caution. The reference for the clinical value is given in parenthesis

References: 1. Roux and Marra (2007), 2. Scheifler et al. (2006), 3. Kekkonen et al. (2012), 4. Swaileh and Sansur (2006), 5. Gragnaniello et al. (2001), 6. Nam and Lee (2006), 7. Orłowski et al. (2014), 8. Hofer et al. (2001), 9. De la Casa-Resino et al. (2014), 10. Yu et al. (2014), 11. Lam et al. (2008), 12. Potter et al. (2009), 13. Morrissey et al. (2013), 14. Sun et al. (2013), 15. De Francisco et al. (2003), 16. Sanderson and Bellrose (1986), 17. Shealy et al. (1982), 18. Burger and Gochfeld (2000), 19. Scheuhammer (1987), 20. Larison et al. (2000), 21. Lam et al. (2008)

both circulating levels of contaminants in the blood as well as the stored reserves of the females at the time of egg formation (Burger and Gochfeld 1996).

There is great variety of laboratory analysis methods to determine the levels of different pollutants in different sample types. Whichever procedure is used, it should be properly executed following certified protocols and laboratory conditions. For heavy metals, in many cases so-called EPA methods are used (US Environmental Protection Agency test methods) or other approved procedures for chemical pollutants. After careful preparations, the concentrations are most often measured using a type of mass spectrometry. Laboratory reagent blanks, metals standard reference material, and replicate samples should be analyzed with every batch of samples. For organic pollutants, the laboratory analyses are compound specific, but in each case a certified protocol and conditions should be also used. In a recent review, Tang (2013) covered recent developments in sample preparation, separation, and detection in analysis of persistent organic pollutants under the Stockholm Convention. This review provides good guidelines for future studies, but as main points (a) gas chromatography is still a prominent chromatographic technique for nonpolar POPs, and (b) mass spectrometry is prevailing in sensitive, selective detection in POPs measurement (Tang 2013). Based on clinical laboratory studies, there are benchmark values for the harmful levels for some of the substances in the tissues. However, these levels depend very much on the species and developmental stage, and thus these are not available for all case studies (some presented in Table 12.1).

12.4 Different Effects Found in Bird Studies

Chemical pollutants can have an impact on body condition, behavior, survival, breeding performance, and even DNA of avian fauna. Based on my literature search, I present here some of the intriguing case studies to demonstrate the variety of effects and, on the other hand, the challenges within the research field of urban birds facing environmental pollution.

12.4.1 Pollutant Levels Discovered in Urban vs. Rural Adult Birds

Based on the literature search, most of the studies have measured the levels of different pollutants in different tissues of the birds, and either compared the results to levels found from other studies or to benchmark values that relate to subclinical, clinical, or lethal effects (Franson 1996; Pain 1996; Friend and Franson 1999). Further, several studies have done comparisons between urban and rural sites. These studies give very important information on what are the actual levels that the birds have to deal with in the urban habitats and whether these levels could be harmful for individuals' survival or reproduction. This helps to evaluate whether there could be consequences for population level demographies.

In an interesting study linking body condition and lead pollution, Roux and Marra (2007) measured lead concentrations in blood samples of seven passerine species in urban and rural environments. They used both adults and nestlings and assessed their body condition based on body mass in relation to length. They determined soil lead concentrations on rural to urban gradient in the Washington DC study area. Expectedly, the soil lead concentration was significantly higher in urban sites compared to rural ones. Accordingly, urban adult and nestling birds had significantly higher blood lead concentrations than rural ones. Interestingly, ground-feeding birds had higher differences between urban and rural birds than canopy/shrub feeding species. However, from the seven passerine species studied, only gray catbird *Dumetella carolinensis* nestlings were found to have lower body condition due to lead contamination. The levels of lead in adult urban birds of all species ranged between 0.01 and 0.08 ppm in rural sites and between 0.07 and 0.26 ppm in urban sites. In general, the level of blood lead considered as lead poisoning is confirmed at 0.2 ppm and above (De Francisco et al. 2003) and sublethal at 0.5 ppm (Sanderson and Bellrose 1986). Here, despite urban birds were found to have blood lead concentrations at and above the 0.2 ppm benchmark value, no negative impact on body condition was found in adults. Birds may be able to remove pollutants by excreting them throught vascular system or into feathers. Moreover, e.g., protein- or calcium-rich diets can reduce the absorption of lead (Sanderson and Bellrose 1986). With nestling birds, however, gray catbirds with higher blood lead concentrations were also found to be in poor physical condition.

Lead concentrations were measured also in a study on blackbirds *Turdus merula* and one of their main prey, earthworms (Scheifler et al. 2006). Sampling was done in Besançon, France, and in a rural reference site. Blood samples, washed and unwashed outermost tail feathers and breast feathers were collected from the blackbirds. Individual body condition index was determined based on body mass and tarsus length. Results showed that the lead concentrations in earthworms were significantly higher in urban individuals than in rural ones. Moreover, concentrations in outermost tail feathers, breast feathers, and blood were significantly higher in urban than rural blackbirds. The use of washed and unwashed outermost tail feathers allowed estimating the external contamination from, e.g., dust as opposed to internal contamination. The result was that 37 % of the total lead concentration was from external sources and the remaining 63 % can be linked to food chain. The blood concentrations in urban blackbirds were on average 0.15 ppm which is similar than what was found by Roux and Marra (2007). As the benchmark value of 0.20 ppm for subclinical and physiological effects was not exceeded, it was not so surprising that body condition did not vary with lead concentration. Nevertheless, this study shows that even though the atmospheric lead emissions have been reduced dramatically globally, urban birds remain exposed to lead pollution. Moreover, food transfer from soil invertebrates may be an important route of lead exposure.

The causal relationships between pollutants and urban bird populations may indeed be quite complex, and the indirect effects of the pollutants should be also considered. In a previous study, I and my collaborators studied levels of eight heavy metals in house sparrows *Passer domesticus* in urban and rural habitats in Finland (Kekkonen et al. 2012). The house sparrow has declined >60 % during the last couple of decades. One suggested reason for this decline (especially in cities) is heavy metal pollution. A museum collection from the 1980s was used to investigate the accumulation of heavy metals (Al, Cr, Mn, Fe, Cu, Zn, Cd, Pb) in the livers of these birds. Significantly higher heavy metal concentrations were found in the livers of urban than rural birds which could support this hypothesis. Heavy metal levels in urban birds were, however, not as high as in other house sparrow studies by, e.g., Gragnaniello et al. (2001) and Swaileh and Sansur (2006). Nevertheless, in their study in the area of West Bank, Swaileh and Sansur (2006) found also clearly more copper, lead, and zinc in the organs and tissues in house sparrows from urban areas. When considering the Finnish house sparrow, the heavy metal pollution is unlikely to be a sole cause of the severe declines. However, pollution is more pronounced in cities and could thus contribute to declines through indirect effects, such as insect availability, as shown for the house sparrow in Leicester, UK (Vincent 2005; Peach et al. 2008). Along with other environmental factors, heavy metals decrease the amount of some invertebrate groups in cities (Pimentel 1994; McIntyre 2000) that are used as nestling food in many bird species. Vincent (2005) found annual productivity (the number of fledged young) to be lower in urban areas due to starvation of chicks when their diet contained a high proportion of vegetable material or ants instead of, e.g., spiders. Moreover, Peach et al. (2008) reported that years of poor reproduction were characterized by, e.g., high concentration of air pollution from traffic.

Besides the heavy metal studies, information is increasing on organic pollutants and urban birds. For example, Sun et al. (2013) linked diet and concentrations of hexabromocyclododecane (HBCD) and its enantiomeric distributions on passerines. These chemical compounds were determined in muscle and stomach contents of three terrestrial birds from e-waste (electrical waste) and urban and rural locations in South China. The study species light-vented bulbul *Pycnonotus sinensis*, long-tailed shrike *Lanius schach*, and oriental magpie-robin *Copsychus saularis* are all resident birds which have quite small-scale territories and foraging areas, making them interesting for bioindicator monitoring of local pollution. Urbanization and industrialization were found to relate to levels of HBCD. In turn, birds from the rural site had the lowest concentrations of HBCD, urban site the highest, and e-waste site the second highest. The diet seemed to be the most important pollutant source for the birds. Moreover, the concentrations of HBCD were highest in the oriental magpie-robin in all habitats which could indicate differences in their diet. The oriental magpie-robins often feed in urban gardens and cultivated areas which are likely more polluted by HBCD.

Yu et al. (2014) also studied contamination of organohalogen pollutants, including DDT and its metabolites, PCBs, PBDEs, decabromodiphenylethane (DBDPE), hexabromocyclododecanes (HBCDs), and dechlorane plus (DP) in Eurasian tree sparrows *Passer montanus* and common magpie *Pica pica*. They had three metropolises of China (Beijing, Wuhan, and Guangzhou) and a reference rural site. The results were very similar to Sun et al. (2013), i.e., levels of the organohalogen pollutants were in general lower in the reference site than in the urban sites. There were some differences between the urban area concentrations in the muscle samples. The levels of DDTs were higher in Wuhan, whereas flame retardants dominated in Guangzhou and Beijing. PCBs exhibited different homologue profiles among different sites which is a likely result of different dietary sources of the bird species. In general, PCB concentrations were at the low end of worldwide figures which was not unexpected because PCBs are not used as much in China as in other parts of the Northern Hemisphere. PBDE levels, however, were in the same range as those of North America, and generally higher than in Europe.

Based on these examples, markedly increased levels of pollutants have been found from urban birds compared to rural ones in many studies and different taxa. In some cases, a link to the diet was established, and possible deteriorating effects could be evaluated based on benchmark values. However, I consider that more research on testing the effects on individual condition, survival, and breeding parameters could be done. Even though a direct causal relationship to population declines has not been established in many cases so far, all of the research done so far are important pieces adding up to growing knowledge. When considering environmental pollution, it is very important to remember that there are likely combined effects which need to be taken into account. This means that environmental, population demographic or other anthropogenic factors might interplay with the effects of pollutants.

12.5 Effects of Pollution on Eggs and Nestling Stages in Urban Areas

Earlier developmental stages of organisms may be more vulnerable to environmental effects and thus give different points of view also on pollution studies. Egg characteristics such as egg size and eggshell thickness were the early signs of detrimental effects of pollution on reproduction, growth, and nestling survival of birds (Ratcliffe 1967; Bize et al. 2002). Both egg and nestling stages have been studied in urban birds, and their importance in monitoring bioaccumulation of contaminants in the human-inhabited environment has been quite well established.

Orłowski et al. (2014) studied the concentrations of chromium, nickel, cadmium, and lead in rook *Corvus frugilegus* eggshells from rural and urban areas of western Poland. They found that eggshells in large industrial cities had significantly higher concentrations of chromium, nickel, and lead than crook egg shells collected from small towns and villages. They highlighted the importance of taking into account also local habitat effects when considering population declines. In another heavy metal study, Nam and Lee (2006) investigated the heavy metal accumulation on breeding feral pigeons *Columba livia* in South Korea. They compared the egg size, eggshell thickness, and reproductive parameters in colonies from cities of Seoul and Ansan and found that the concentrations of lead in the bone and cadmium in the kidney of adult pigeons in Seoul were three times higher than in Ansan colony. No significant differences were, however, observed in egg characteristics, clutch size, incubation periods, or hatchability of eggs between the two study sites. Body size measurements of nestlings from Seoul were somewhat smaller, but the difference was not statistically significant. Nestlings at Seoul fledged significantly later and with a lower success than in Ansan. As Seoul is more polluted than Ansan, these results indicate that heavy metal pollution may have negative effects on feral pigeon breeding.

Organohalogen compounds were measured in urban birds of prey in two studies by Dell'Omo et al. (2008) and Potter et al. (2009). In both cases the eggs contained organohalogen pollutants but the effects on, for example, population level are unclear. Dell'Omo et al. (2008) studied PCBs and DDTs in Eurasian kestrel *Falco tinnunculus* eggs in Rome, Italy. Organohalogen congeners were determined from 27 unhatched eggs in years 1999 and 2005. The authors concluded that the concentrations were not so high as compared to other kestrel study from earlier period, and as the animals in the study area do not perform long migratory movements, the contamination levels in the eggs are likely to present local pollution levels. Potter et al. (2009) measured also organohalogen concentrations in 23 eggs of the peregrine falcon *Falco peregrinus*. These eggs were obtained between 1993 and 2002 from 11 locations in the Chesapeake Bay region, USA. Different congeners of PBDE and PCB as well as PBB153 and 4,4′-DDE were measured. In general, the levels or organohalogen compounds detected were similar to other birds of prey studies in Europe and the USA (Potter et al. 2009). When considering the habitat effect, only BDE 209 concentrations were significantly correlated with the human population density of the area surrounding the nest. The authors considered that urban falcons may feed on prey which has less of the last mentioned compounds than their rural counterparts but the mechanism for this is not clear.

On contrary, as Lam et al. (2008) measured a great variety of organohalogen compounds (aldrin, dieldrin, endrin, hexachlorobenzene, mirex, chlordanes, DDTs, heptachlors, toxaphenes, PCBs, PBDEs, dioxin-like equivalents (TEQH4IIEluc)) in eggs of the little egret *Egretta garzetta* and black-crowned night heron *Nycticorax nycticorax*, they found some physiologically significant levels of pollutants. The study was done in three Chinese harbor cities: Hong Kong, Xiamen, and Quanzhou. Concentrations of DDTs, PCBs, and chlordanes were significantly greater than concentrations of other residues, and all in all DDTs were found to be most abundant. The high levels of these compounds indicate that they pose likely physiological health risks to the study populations.

Organohalogen compounds were also studied in the eggs of a river passerine, the Eurasian dipper *Cinclus cinclus* (Morrissey et al. 2013). Among other pollutants, compounds like PCBs and PBDEs are ending up into the urban streams and from there secreted by female birds to the eggs. Morrissey et al. (2013) sampled dipper eggs from 33 rural and urban rivers in South Wales and the English borders and found that concentrations of both total PCBs and PBDEs were positively related to urbanization, whereas organochlorine pesticides such as *p*,*p*′-DDE, lindane, and hexachlorobenzene were found in higher concentrations at rural sites. Levels of PBDEs in urban dipper eggs were among the highest ever reported in passerines, and some pollutant levels were even sufficient for causing adverse effects on development. In another study, Morrissey et al. (2014) studied also dipper nestlings for early development in respect to the same pollutants. They measured breeding performance, as well as nestling growth, condition, and plasma thyroid hormones in 87 nests on urban and rural streams. They collected also invertebrate prey data for knowledge on potential food scarcity. Interestingly, clutch sizes and egg fertility were similar in both habitats and nest success was even higher at urban sites (food abundance was not reduced). However, urban nestlings were significantly lighter than rural ones, and brood sex ratios were increasingly male biased. In addition, increased amounts of PCBs and PBDEs in urban sites were found to be linked to reduced levels of thyroid hormones (T3) and poorer body condition. The authors concluded that pollutant levels recorded from urban streams could have detrimental effects on dipper nestling development.

These case studies show how studies on egg and nestling stages complement the knowledge gained from monitoring bioaccumulation of pollutants in adult birds.

12.6 Interaction Between Pollutants and Pathogens in Urban Birds

It has been noted that pollutants can affect epidemiology of wildlife diseases, but the studies in this field have focused so far more on the function of immune systems. Interestingly, pollutants can also potentially affect ecological interactions between species like hosts and their pathogens or parasites. This approach was taken by Gasparini et al. (2014) on Parisian pigeons *Columba livia*, who found that heavy metals can indeed affect the epidemiology of diseases especially in the urban environment. They used feathers of the pigeons to measure concentrations of copper, cadmium, lead, and zinc. Moreover, they did cloacal swabs from the pigeons to estimate prevalence and intensity of the parasite *Chlamydiaceae* and blood smears to estimate the prevalence and intensity of haemosporidian parasites. The study revealed that copper or cadmium levels in the feathers were not correlated with parasites, but elevated levels of zinc were associated with both low prevalence of *Chlamydiaceae* (ornithosis disease) and low intensity of *Haemosporidian* parasites. However, high concentrations of lead in the feathers were linked to high blood pathogen intensities. The interesting results from this study give indications on heavy metal pollution having a role in host-parasite interactions and encourage for further research.

12.6.1 Behavioral Effects

Direct physiological effects are most often measured in pollution studies, but there can be other types of indicators in bird populations on environmental contaminants. In an interesting study, Gorissen et al. (2005) examined the expression of dawn singing behavior in male great tits *Parus major* in relation to environmental pollution. They compared the singing behavior of the males from an area extremely polluted with heavy metals (in particular lead), with that of males from less-polluted ones. However, all the sites can be considered to be located in an urbanized environment near Antwerpen, Belgium. Males at the most polluted site had a significantly smaller repertoire size in their singing. They also produced a significantly lower total amount of song during the dawn chorus than the males at a distance of 4 km from the pollution source. Effect of age was also accounted for as older birds have a larger repertoire. These results may be linked to a lowered male quality at the polluted site. Lead pollution is known to have adverse effects to brain development (e.g., Burdette and Goldstein 1986), and this decreased ability of a male to invest in brain tissue has been suggested to be an important physiological mechanism that links singing repertoire size to male quality (Garamszegi and Eens 2004). Thus, the expression of singing behavior could potentially be a used as an indicator of environmental stress at the population level in birds. Moreover, there could be other behavioral indicators which could be used for similar purposes (Miranda 2016).

12.6.2 Effects on DNA

One of the latest developments in pollution studies with birds is the investigation of effects to DNA. Pollutants which are genotoxic cause chemical and/or physical modifications to the DNA, and this may lead to, for example, reduced fitness (through gene and protein dysfunction), tumor initiation, growth impairment, embryonic malformations, or reduced fecundity (Sadinski et al. 1995; Theodorakis 2001). Skarphedinsdottir et al. (2010) studied adult and young herring gulls *Larus argentatus* in Sweden and Iceland to find out whether there is a link between polycyclic aromatic hydrocarbons (PAH) measured in nearby surface sediments and indications of genotoxic effects. They determined (a) the level of DNA adducts (piece of DNA bonded to the chemical) and (b) the frequency of micronucleated erythrocytes (red blood cells which have DNA disrupted outside nucleus). They used blood, liver, kidney, and intestinal mucosa of the gulls. The results indicated that both Swedish and Icelandic herring gulls are exposed to genotoxic pollution. Urban samples had higher levels of DNA adducts than rural ones, and also the levels of PAHs were higher in the urban sites. The frequency of micronucleated erythrocytes was slightly elevated in all the sampling sites, reflecting a significant background exposure. This study showed that the DNA adducts and potentially micronucleated erythrocytes can be useful as biomarkers for genotoxicity in birds. However, there was no direct measurement of pollution levels in the tissues of the gulls. Nevertheless, this study provides an interesting start for future studies, and it can be used as a basis when designing next level research.

12.7 Future Directions for Studies on Urban Birds and Pollution

Based on the literature search, there is growing number of research on chemical pollution on birds in urban areas. However, as the study cases presented here show, there are still many unanswered questions regarding the potential role and mechanisms pollutants have on survival and breeding of individuals and, in particular, how these issues may be linked to changes in population demographic level.

In order to tackle these issues more in depth, future studies in my opinion would need to combine measuring mere levels of pollutants with other types of data like body condition, survival indices, or breeding performance. These aspects need to be considered already during project planning. Secondly, when possible, data on food availability, environmental factors, population demographies, and anthropogenic factors would be good to include. This way combined effects with other factors could be mapped. Implementing many different factors is by no means easy but can provide important new insights into, e.g., declining bird species.

There are also new research developments which open possibilities in this field. Studying oxidative stress as a response to heavy metal pollution has been quite recently lifted as one very potential way also to measure effects of environmental pollutants. This response capacity of antioxidant defense plays an important role in the protection of organisms against toxic-induced oxidative stress. Indeed, the maintenance of a high antioxidant capacity in cells may increase tolerance against different types of environmental stress (reviewed by Koivula and Eeva 2010). Herrera-Dueñas et al. (2014) studied house sparrows in two differently polluted areas and found that oxidative stress markers, hemoglobin (Hb) and total antioxidant capacity (TAC), were both lower in urban populations. Analysis methods are quite well established in this field, but it has not been implemented much for urban fauna in particular. Moreover, the rapid development of genomic methods can also provide new ways to gather information on responses to environmental stress. Effects of pollutants on DNA are studied in some field examples so far (e.g., Baos et al. 2006; Eeva et al. 2006), but not too much is yet known. Some heavy metals and organohalogens are known be mutagenic, and thus in highly polluted urban environment, there might be local effects. Moreover, DNA studies can reveal it is possible to adapt to urbanization in terms of pollution and how this differs between bird species.

One important factor which comes up frequently in these studies is the suitability of birds to be used as bioindicators of environmental pollution (e.g., Cui et al. 2013;

Valladares et al. 2013). The use of avian populations as biological monitors can be an effective method in quantifying the overall health of the ecosystem since they represent the upper trophy levels. Previously, raptors were the main focus because they are in the highest level of food chains, but more often nowadays other species are acknowledged as well. As seen from the case studies in this chapter, many passerine species are of interest nowadays. Residential passerine species are especially suitable to reflect local contamination because of their small home ranges, territories, and foraging areas whereas passerines with widespread populations enable large geographical-scale monitoring (Dauwe et al. 2006; Van den Steen et al. 2009). Water fowl are also used since they indicate the pollution in water bodies (Pereda-Solís et al. 2012). Sampling designs depend on the study questions, but feathers are increasingly used as a noninvasive source of samples for biomonitoring of all sorts of pollutants (e.g., Malik and Zeb 2009; Hofer et al. 2010; Padula et al. 2010). All in all, the techniques and knowledge are available for executing multifaceted pollution studies of urbanized environments in the future.

12.8 Concluding Remarks

This chapter highlights the importance of studies on urban bird populations and the threats which are posed to them by environmental pollutants. Despite the many restrictions that have already been made for production of harmful substances, many heavy metals and persistent organic pollutants will not be phased out from the urban environment for a very long time. This is another stress factor that urban fauna needs to deal with. Moreover, new chemical compounds are being developed. Bird studies will not only help to understand the underlying mechanisms between population demographics and environmental pollutants but the results can be linked to protecting other taxa. Moreover, we humans share the urban living environment with the birds, and thus, biomonitoring them will be of great benefit for us as well. As a positive concluding remark, however, I want to end with a study from Eeva and Lehikoinen (2000). They found that after a copper smelter was closed and the side product lead decreased in the environment, the breeding success of two bird species markedly increased as a result. These types of positive examples should encourage researchers to gather in-depth data and bring forth the potential causal relationships when studying organisms in our urbanized environments.

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