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Levels of heavy metals in House Sparrows (*Passer domesticus*) from urban and rural habitats of southern Finland

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Urbanization has led to increasing amounts of pollutants which can harm organisms that share our living environment. In Finland, the House Sparrow has declined by two thirds during the last couple of decades. One hypothesis suggested to lead to this decline is heavy metal pollution. We used a museum collection from the 1980s to investigate the accumulation of eight heavy metals (Al, Cr, Mn, Fe, Cu, Zn, Cd, Pb) in the livers of House Sparrows living in either rural or urban habitat. We used principal components derived from these as dependent variables in the statistical analyses, and found significantly higher heavy metal concentrations in the livers of urban than in those of rural House Sparrows. There was a tendency for males to accumulate more heavy metals, but age dependence in this respect was not found. Heavy metal levels in urban habitat were not as high as in some other House Sparrow studies. Even though heavy metal pollution is an unlikely sole cause of House Sparrow declines, pollution is more pronounced in cities and could thus contribute to declines through indirect effects, such as insect availability.

1. Introduction

Industrialization, 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. As humans alter the environment drastically, other species need either to adapt or perish. 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. Organisms that have become closely associated to human housing are at greatest risk of being affected. One such species is the House Sparrow *Passer domesticus*, which is closely associated with human settlements ranging from small farms in the countryside to large cities, but is completely absent from areas outside human settlement in Western countries.

The House Sparrow is a sexually dimorphic, social and sedentary bird (Summers-Smith 1988). Its natural range includes Europe, North Africa and parts of Asia. The species' large-scale spread from these areas has been supported by humans who have intentionally or accidentally introduced it to, for example, North and South America, South

Africa, Australia and New Zealand (Summers-Smith 1963, 1988, Anderson 2006). The House Sparrow was abundant all over the world, but major declines have been reported in large parts of Europe during the last few decades (Summers-Smith 1999, Hole *et al.* 2002, Crick *et al.* 2002, Anderson 2006, De Laet & Summers-Smith 2007). Moreover, declines in non-native populations have been reported in, for example, North America (Peterjohn *et al.* 1994).

These declines have been taking place in both rural and urban habitats, but different causes may be responsible for the declines in these different habitats. If this is indeed the case, then habitat type and their associated mechanisms for declines should be considered in studies of population dynamics. The reasons for the declines of the House Sparrow are poorly understood, and several of them may act together. However, changes in agricultural practices and urban lifestyle may have led to a shortage of nest sites (Siriwardena *et al.* 2000) and food for both adults and nestlings (Hole *et al.* 2002, Vincent 2005). Additionally, predation, inter-specific competition (McCarthy 2003) and diseases (Kruszewicz 1995) have been proposed as causes of decline. Yet another suggested cause, especially in urban environments, is pollution (Summers-Smith 1999). Heavy metal pollution is known to detrimentally affect different phases of the avian life cycle, from egg development to adult reproduction (Eeva & Lehikoinen 1995, 1996, 2000, Janssens 2003a, 2003b, Scheuhammer 1987). Studies of House Sparrows support the hypothesis of heavy metals being related to population declines, with particular emphasis on the effects of lead, zinc, cadmium and copper. High environmental concentrations of these metals are known to have an adverse effect on organisms. In Poland, for example, markedly increased levels of lead were found in dead House Sparrows in comparison to healthy birds (Pinowski *et al.* 1994), suggesting a lethal effect of this heavy metal, which is used in industry and (formerly) in petrol. In another Polish study, increased levels of lead and zinc were found in livers of ill and dead House Sparrows, whereas the livers of healthy birds were relatively clean (Romanowski *et al.* 1991). Lead, zinc and cadmium were also correlated with delayed development of House Sparrow nestlings (Romanowski *et al.* 1991).

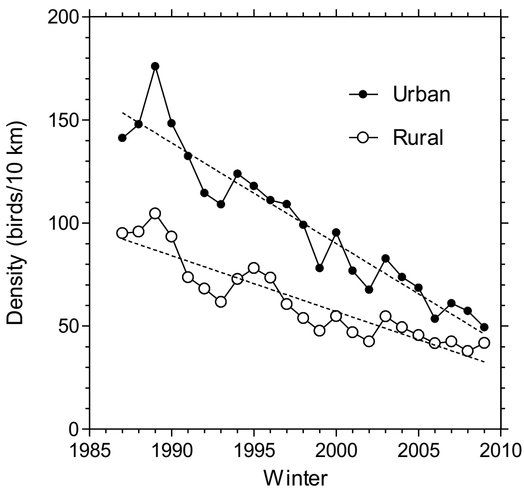

Fig. 1. House Sparrow densities (birds per 10 km of transect) derived from Finnish winter-bird counts in urban and rural areas between the winters 1986/1987 and 2008/2009.

Traffic and industry result in more heavy metals in urban areas than in the surrounding landscape. Consequently, higher heavy metal concentrations would be expected in urban than in rural areas. The levels of lead found in urban House Sparrows in Vermont, USA were indeed significantly higher than levels in an agricultural control group (Chandler *et al.* 2004). In the densely-populated West Bank, Middle East, birds from rural areas had markedly less copper, lead and zinc in their eggs, organs and tissues than urban House Sparrows (Swaileh & Sansur 2006). Also significant correlations between age and the concentration of copper, lead and zinc were identified, suggesting that these heavy metals accumulate in individuals over time (Swaileh & Sansur 2006).

The present study was conducted from material collected in Finland in the 1980s, which coincides with major national declines in House Sparrow abundance (Fig. 1; Väisänen 2003, 2006). In common with other European countries (De Laet & Summers-Smith 2007), the decline has been somewhat faster in urban than rural areas in Finland (Fig. 1). Here, we investigate (a), the possible role of heavy metal pollution in the decline of House Sparrows and (b), whether the mechanisms driving declines are similar in urban and rural environments. More specifically, we investigate the following questions. Firstly, can birds living in cities be negatively influenced by their living environment i.e., are there more heavy metals in the tissues of urban birds than in those of rural birds? Secondly, do heavy metal levels recorded in House Sparrows show evidence of accumulation with age? Lastly, are the levels of heavy metals similar in males and females? Even though the focal species is one of the most human associated birds, the results from this study are applicable to a large number of other passerine species that occupy urbanized habitat.

2. Material and methods

2.1. Long-term population trend data

We estimated the population trends of the House Sparrow in urban and rural habitats in Finland during 23 winters 1986/1987–2008/2009 using the national winter-bird counts. These counts are carried out mainly by volunteers, who repeat 5–15 km long routes each year around Finland. For a detailed description of the method, see Koskimies and Väisänen (1991). These data were based on transect counts constituting of 1,500–2,100 km in urban and 1,300–1,900 in rural environments each winter.

2.2. Tissue sampling for heavy metal analysis

Samples were collected in 1983–1986. Five sites were located in urban areas: four in the city of Helsinki (southern Finland) and one in the city of Jyväskylä (south-central Finland). In addition, House Sparrows were sampled at three rural areas outside the capital area (Fig. 2). Birds were sampled using mist nets, killed with carbon dioxide (permissions were not required at the time of the study) and dissected. Livers were preserved at –18°C. Skull ossification from the dissected birds was used as a proxy for age and as such, individuals with incompletely ossified skulls were considered juveniles, and those with fully ossified skulls included mainly adults and some juveniles. All juveniles were collected during November at the year of birth or later. The sexes were also determined. Altogether, we used 56 individuals for heavy metal analysis (Table 1). This analysis was conducted in the laboratory of the Finnish Environment Institute (SYKE).

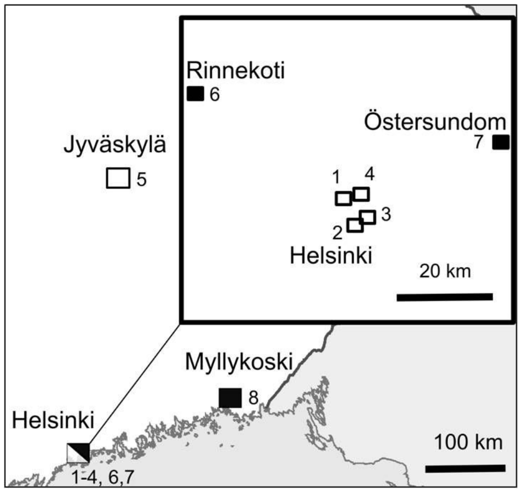

Fig 2. The spatial distribution of the tissue-sampling sites (1-8; compare Table 1) in southern and central Finland. Filled squares are rural sites and hollow ones are urban sites.

2.3. Heavy metal laboratory analysis

Levels of eight heavy metals were analyzed as mg kg^{-1} of dry weight from liver samples: aluminium (Al), chrome (Cr), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), cadmium (Cd) and lead (Pb). The analytical procedure was based on the US EPA (1994) method 3051A "Microwave Assisted Acid Digestion of Sediments, Sludges, Soils and Oils" with modifications for biological material: the heating time for the goal temperature was 25 min, goal temperature was 200°C (CEM Mars Xpress microwave), time held at the goal temperature was 5 min and the amount of strong nitric acid (HNO_3) was 9 ml. After digestion, the heavy metal concentrations were measured using an ICP mass spectrophotometer (ELAN 6000, Perkin-Elmer Co.). As a quality control (reference material), NIST 1577b Bovine Liver was analyzed alongside with the actual samples. The quality of the analysis is considered good if the recoveries from the reference material are close to the values given in the certificate. In this case, for certified metals (Fe, Mn, Cu, Zn, Cd, Pb), the recoveries from the reference material were within the acceptable range of uncertainty given by the certificate, i.e., the quality

Table 1. Sampling scheme for tissue collection. Locality (numbers 1–8) refers to sampling localities (Fig. 1). Type column shows if the locality was urban (U) or rural (R). Season refers to sampling done either in the autumn (A) or in the spring (S). Year shows the year of sampling. The total number of collected individuals is shown for each locality; the numbers of males and females, and juveniles and adults (in parentheses, separated by a slash line), are shown separately.

Locality	Type	Season	Year	Name	No. males (juv/adult)	No. females (juv/adult)
1	U	juv A/adult S	1983	Helsinki (Botanical Garden)	4 (2/2)	4 (2/2)
2	U	A	1984	Helsinki (Vuorimiehen puistikko)	4 (2/2)	4 (2/2)
3	U	S	1986	Helsinki (Snellmanin puisto)	4 (2/2)	4 (2/2)
4	U	S	1984	Helsinki (Torkkelinmäki)	4 (2/2)	4 (2/2)
5	U	S	1983	Jyväskylä	2 (0/2)	2 (0/2)
6	R	A	1985	Espoo (Rinnekoti)	4 (2/2)	4 (2/2)
7	R	S	1986	Vantaa (Östersundom)	4 (2/2)	4 (2/2)
8	R	S	1984	Myllykoski	2 (0/2)	2 (0/2)
Total	U+R	A+S	1984–1986		28 (12/16)	28 (12/16)

is considered good (National Institute of Standards and Technology, 1577b certificate). For uncertified metals (Al, Cr) the results should be interpreted with caution.

2.4. Statistical analysis

We used SPSS Statistics 17.0 (SPSS Inc., Chicago, USA) for all statistical analyses. We applied a principal component analysis (PCA), where the number of dimensions in the data can be reduced to a limited number of important components. We used this approach instead of examining each metal separately, because the levels of heavy metals are usually correlated with each other. We applied the Kaiser criterion (Kaiser 1960) by which principal components with eigenvalues >1 are used in further analysis.

We used a general linear mixed model (GLMM) to analyze the data. The principal components derived from the eight heavy metals were treated as the dependent variables, and habitat, skull ossification and sex as fixed variables. Because several samples were collected from a given sampling site, site was included in the model as a random factor. We also included all combinations of interactions between explanatory variables.

Table 2. PCA loadings of eight heavy metals in principal components with eigenvalues greater than 1. Heavy metals accounting for most of the variance in each component are in boldface. Eigenvalues and percentages of total variance are also reported.

Metal	PC1	PC2	PC3
Al	0.11	0.01	**0.95**
Cr	–0.12	**0.70**	0.17
Mn	0.20	0.47	**0.75**
Fe	**0.79**	0.39	–0.02
Cu	0.35	**0.79**	–0.02
Zn	0.42	**0.69**	0.18
Cd	**0.78**	0.05	0.22
Pb	**0.82**	0.07	0.11
Eigenvalue	3.45	1.28	1.10
% of total variance	43.06	16.02	13.47

3. Results

The number of House Sparrows declined during the study winters from about 30,000 to 10,000 in urban and from about 19,000 to 7,000 in rural habitats (Fig. 1). Thus, the species decreased approximately 70% in urban and 65% in rural areas during 1987–2009.

PCA reduced the eight original heavy metal variables to three independent principal components with eigenvectors in excess of 1, which explained 43.1%, 16.0% and 13.5% of the total variance, respectively. To support the interpretation of this result, we applied an orthogonal Varimax rotation for the correlation matrix. According to the analysis, different metals contributed differen-

Table 3. Concentrations (mean ±SE mg kg^{-1}) of eight heavy metals in livers of House Sparrows from rural and urban habitats. Values represent mean ± standard error. Sample size is 56 for all metals (Rural *N* = 20, Urban *N* = 36).

Metal	Rural	Urban
Al	0.21 ± 0.14	2.70 ± 1.83
Cr	0.23 ± 0.03	0.18 ± 0.02
Mn	1.25 ± 0.07	1.39 ± 0.06
Fe	429.50 ± 19.93	563.61 ± 20.71
Cu	3.69 ± 0.17	4.03 ± 0.15
Zn	18.35 ± 0.75	21.08 ± 0.75
Cd	0.09 ± 0.01	0.16 ± 0.02
Pb	0.10 ± 0.02	0.54 ± 0.06

tially to different PCA axes: iron (Fe), cadmium (Cd) and lead (Pb) contributed most to PC1, chrome (Cr), copper (Cu) and zinc (Zn) to PC2 and aluminum (Al) and manganese (Mn) to PC3 (Table 2). Metal concentrations mostly had positive loadings on the principal components, indicating positive correlations between all metals in the House Sparrow livers.

According to the GLMM, habitat type was the only significant variable explaining variation in metal levels ($F = 32.09$, $p = 0.001$; Table 3). Urban birds thus had more heavy metals accumulated in their livers (Fig. 3, up). The effects of skull ossification (age; $F = 0.90$, $p = 0.348$) or the interaction terms were not significant. There was a marginally significant trend for differences between males and females along PC1, however ($F = 3.90$, $p = 0.068$; Fig. 3, down): males had slightly higher levels of heavy metals than females. None of the factors were significant in explaining sample variation along PC2 or PC3.

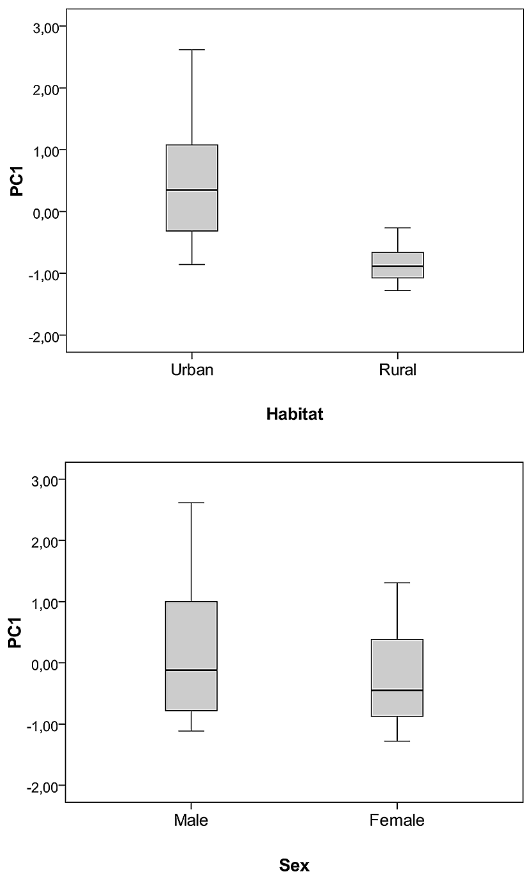

Fig 3. Box plots representing PC1 in urban and rural sites (up) and in males and females (down). Horizontal lines show median, hinges show lower and upper quartiles, and vertical lines show 1.5 × inter-quartile range.

4. Discussion

We found that concentrations of heavy metals in the livers of House Sparrows sampled in the 1980’s were higher in urban than in rural areas. However, we did not find strong evidence that heavy metals would accumulate with age or differ between the sexes. Higher heavy metal concentrations in urban than in rural House Sparrows have also been reported in previous studies. For example, heavy metal levels increased across a rural-urban gradient in the West Bank, Middle East (Swaileh & Sansur 2006) and Vermont, USA (Chandler *et al.* 2004). Thus, there is evidence from sites on three different continents that urban House Sparrows are accumulating heavy metal pollution at a higher rate than rural ones.

From the heavy metals studied here, Zn, Cu, Mn, Cr and Fe are essential for organisms at certain amounts but become harmful when in excess. Organisms usually do not need Cd, Pb or Al. The amounts of the heavy metals that are harmful depend on species, tissues and environmental factors, and specific knowledge is not always available. However, some studies have used liver samples from House Sparrows, and serve as a benchmark for the present results: Gragnaniello *et al.*

(2001) and Swaileh and Sansur (2006) analyzed Cu, Zn, Cd and Pb from rural and urban birds. In our study only Cd concentrations were slightly higher than those measured by Swaileh and Sansur (2006) from West Bank (0.07 mg kg^{-1} dry weight; Table 3). All the other measures from Italy (Gragnaniello *et al.* 2001) and West Bank were higher than in our study. In those studies the amount of Cu ranged between 27 and 61.8, Zn between 97 and 205 and Pb between 2.7 and 37.6 mg kg^{-1} (dry weight). In liver tissue, 2 mg kg^{-1} (dry weight) of lead causes subclinical physiological effects on several bird species (Franson 1996). Although the levels reported in the aforementioned other House Sparrow studies exceed this threshold, the concentrations in our study were lower, suggesting that lead may not have caused direct physiological effects to Finnish House Sparrows.

Heavy metals often accumulate in the organs of longer-lived animals. House Sparrows live on average for a couple of years and although older birds would be expected to have high liver concentrations of heavy metals, we found no such relationship. In contrast, Swaileh and Sansur (2006) present evidence of age-dependent heavy metal accumulation in the liver as well as other parts of the body. However, this discrepancy may be partly explained by methodological differences: Swaileh and Sansur (2006) classified 1 to 4 weeks old sparrows as juveniles and the rest as adults. Heavy metals accumulated during the juvenile stages and were lower than in adults. In our study, young individuals (with incompletely ossified skulls) were several months old, and our findings thus suggest that heavy metal levels quickly reach the same concentration as in adults.

There was an indication of male House Sparrows having larger amounts of heavy metals in their livers, and studies have indeed found sexes to differ in this respect (Burger 1991, Eeva 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. Even though the House Sparrow is considered to be a sedentary species, females are more prone to dispersal from native areas than males (Summers-Smith 1988, Skjelseth *et al.* 2007). Because heavy metals do not move very far from the source and their levels may vary remarkably over rather short distances (e.g., Janssens *et al.* 2003), there might be proportionally more females than males that have dispersed from less polluted rural areas in our sample. Whether or not heavy metal concentrations in House Sparrows differ between the sexes remains unclear, as Swaileh and Sansur (2006) did not report such differences.

Our results showed that in Finland urban House Sparrows accumulated more heavy metals than rural ones. It is difficult to establish however, to what extent these differences could impact the population. Also, when interpreting these results one should remember that the sample size was relatively small. We found relatively low amounts of heavy metals in livers of House Sparrows, suggesting that heavy metal pollution alone may not have caused House Sparrow declines in urban areas in Finland. This is supported by the fact that heavy metal emissions have decreased simultaneously with the House Sparrow declines, and even though heavy metal levels were generally lower in rural than in urban birds, both have been declining.

Even if a given factor is not the main driver in one of the studied habitat types, it may still be important in the other, or contribute to other factors, and may have indirect effects. In Finland, the decline of House Sparrows has been somewhat faster in urban than in rural populations (Fig 1; see also Väisänen 2003) and in some other countries urban populations have been declining at a considerably higher rate than rural ones (De Laet & Summers-Smith 2007). Because all studies to date (including ours) show that heavy metal concentrations are higher in urban areas, heavy metals may play some role, perhaps indirectly through other mechanisms. Besides the direct physiological effects, heavy metals can have indirect effects, as recently shown for the House Sparrow in Leicester, UK (Vincent 2006, Peach *et al.* 2008). Along with other environmental factors, heavy metals decrease the amount of some invertebrate groups in cities (Pimentel 1994, McIntyre 2000). As invertebrates are used as nestling food in many bird species, including the House sparrow, this can have an effect if the decreasing invertebrates represent high-quality food (e.g., Eeva *et al.* 1997). Vincent (2006) 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, for example, spiders. In addition, lower post-fledgling survival was predicted based on nestling weights. Peach *et al.* (2008) reported that years of poor reproduction were characterized by – among other things – high concentration of air pollution from traffic. This, together with removed vegetation, seemed likely to decrease invertebrate availability in urban areas.

To conclude, the detrimental levels of heavy metals for passerines are poorly understood, and thus the impacts on populations remain difficult to evaluate. In the case of the House Sparrow, heavy metals are unlikely to be the only reason for population declines, but they may contribute to the puzzle through indirect effects. The urbanized lifestyle of us humans has on one hand created new possibilities for other species, but on the other hand, deteriorates environmental conditions at many levels.

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Varpusista tavatut raskasmetallit kaupunki- ja maaseutuympäristöissä Etelä-Suomessa

Kaupungistuminen on lisännyt sellaisten saasteiden määrää, jotka voivat olla vahingollisia elinympäristömme jakaville eliöille. Suomen varpuskannasta (*Passer domesticus*) on hävinnyt kaksi kolmasosaa viimeisten vuosikymmenien aikana. Yhtenä syynä taantumiselle on esitetty raskasmetallipäästöjä. Museokokoelmia 80-luvulta käyttäen tutkimme kahdeksan raskasmetallin (Al, Cr, Mn, Fe, Cu, Zn, Cd, Pb) kertymistä joko kaupungissa tai maaseudulla eläneiden varpusten maksoihin. Raskasmetalleista johdettuja pääkomponentteja käytettiin vastemuuttujina tilastollisissa analyyseissä.

Löysimme merkitsevästi enemmän raskasmetalleja kaupungissa kuin maaseudulla eläneiden varpusten maksoista. Raskasmetallit vaikuttivat kertyvän enemmän koiraisiin, mutta iän myötä tapahtuvaa kertymistä ei havaittu. Raskasmetallien määrät kaupunkiympäristön linnuissa olivat kuitenkin pienempiä kuin eräissä muissa vastaavissa tutkimuksissa. Tämän perusteella ne eivät ole aiheuttaneet suoraan varpusten taantumista Suomessa, mutta niillä on voinut olla epäsuoria vaikutuksia esimerkiksi poikasajan hyönteisravinnon vähenemisen kautta.

References

Anderson, T. R. 2006: The Ubiquitous House Sparrow: from genes to populations. — Oxford University Press.

Burger, J. & Gochfeld, M. 1991: Cadmium and lead in Common Terns (Aves: *Sterna hirundo*): relationship between levels parents and eggs. — Environmental Monitoring and Assessment 16: 253–258.

Chandler, R. B., Strong, A. M. & Kaufman, C. C. 2004: Elevated lead levels in urban House Sparrows: A threat to Sharp-shinned Hawks and Merlins? — Journal of Raptor Research 38: 62–68.

Crick, H. & Siriwardena, G. 2002: National trends in the breeding performance of House Sparrows *Passer domesticus*. — In Investigation into the causes of the decline of Starlings and House Sparrows in Great Britain (ed. Crick, H., Robinson, R., Appleton, G., Clark, N.A. & Rickard, A.). BTO Report Number 290 (BTO/DEFRA).

De Laet, J. & Summers-Smith, J. D. 2007: The status of the urban House Sparrow *Passer domesticus* in north-western Europe: a review. — Journal of Ornithology 148 (Suppl. 2): 275–278.

Eeva, T. & Lehikoinen, E. 1995: Egg shell quality, clutch size and hatching success of the Great Tit (*Parus major*) and the Pied Flycatcher (*Ficedula hypoleuca*) in an air pollution gradient. — Oecologia 102: 312–323.

Eeva, T. & Lehikoinen, E. 1996: Growth and mortality of nestling Great Tits (Parus major) and Pied Flycatchers (Ficedula hypoleuca) in a heavy metal pollution gradient. — Oecologia 108: 631–639.

Eeva, T., Lehikoinen, E. and Pohjalainen, T. (1997) Pollution related variation in food supply and breeding success in two hole nesting passerines. — Ecology 78: 1120–1131.

Eeva, T. & Lehikoinen, E. 2000: Pollution and breeding success in wild birds. — Nature 403: 851–852.

Eeva, T., Hakkarainen, H. & Belskii, E. 2009: Local survival of Pied Flycatcher males and females in a pollution gradient of a Cu-smelter. — Environmental Pollution 157: 1857–1861.

Gragnaniello, S., Fulgione, D., Milone, M., Soppelsa, O. & Cacace, P. 2001: Sparrows as possible heavy-metal biomonitors of polluted environments. — Bulletin of

Environmental Contamination and Toxicology 66: 719–726.

Hole, D. G., Whittingham, M. J., Bradbury, R. B., Anderson, G. Q. A., Lee, P. L. M., Wilson, J. D. & Krebs, J. R. 2002: Widespread local House Sparrow extinctions. — Nature 418: 139–149.

Janssens, E., Dauwe, T., Pinxten, R., Bervoets, L., Blust, B. & Eens, M. 2003a: Effects of heavy metal exposure on the condition and health of nestlings of the Great Tit (*Parus major*), a small songbird species. — Environmental Pollution 126: 267–274.

Janssens, E., Dauwe, T., Pinxten, R. & Eens, M. 2003b: Breeding performance of Great Tits (*Parus major*) along a gradient of heavy metal pollution. — Environmental Toxicology and Chemistry 22 (5) 1140–1145.

Koskimies, P. & Väisänen, R. A. 1991. Monitoring bird populations. A manual of methods applied in Finland. — Zoological Museum, Finnish Museum of Natural History, Helsinki.

Kruszewicz, A. G., Kruszewicz, A. H., Pawiak, R. & Mazurkiewicz, M. 1995: Bacteria in House Sparrow (*Passer domesticus*) and Tree Sparrow (*Passer montanus*) nestlings: occurrence and influence on growth and mortality. — In Nestling mortality of granivorous birds due to microorganisms and toxic substances: Synthesis, (ed. Pinowski, J., Kavanagh, B. & Pinowska, B.). The International Symposium of the Working Group on Granivorous Birds – Granivorous Birds as Agricultural Pests and Epidemiological Vectors.

McCarthy, M. 2003: Wood Pigeons' grain diet linked to the demise of House Sparrows. – The Independent (3 September 2003).

McIntyre, N. 2000: Ecology of urban arthropods: a review and a call to action. — Annals of the Entomological Society of America 93: 825–835.

Peach, W. J., Vincent, K. E., Fowler, J. A. & Grice, P. V. 2008: Reproductive success of House Sparrows along an urban gradient. — Animal Conservation 11: 493–503.

Peterjohn, B. G., Sauer, J. R. & Link, W. A. 1994: The 1992 and 1993 summary of the North American Breeding Bird Survey. — Bird Populations 2: 46–61.

Pimentel, D. (1994) Insect population responses to environmental stress and pollutants. — Environmental Reviews 2: 1–15.

Pinowski, J., Barkowska, M., Kruszewicz, A. H. & Kruszewicz, A. G. 1994: The causes of the mortality of eggs and nestlings of Passer spp. — Journal of Bioscience 19: 441–451.

Romanowski, J., Pinowski, J., Sawicka-Kapusta, K. & Wlostowski, T. 1991: The effect of heavy metals upon development and mortality of *Passer domesticus* and *Passer montanus* nestlings – preliminary report. — In Nestling mortality of granivorous birds due to microorganisms and toxic substances, (ed. Pinowski, J., Kavanagh, B. and Gorski, W.). The International Symposium of the Working Group on Granivorous Birds.

Scheuhammer, A. M. 1987: The chronic toxicity of aluminium, cadmium, mercury, and lead in birds: a review. — Environmental Pollution 46: 263–295

Siriwardena, G.M., Robinson, R,A., Crick, H.Q.P., 2002. Status and population trends of the House Sparrow Passer domesticus in Great Britain. In Investigation into the causes of the decline of starlings and House Sparrows in Great Britain (ed. Crick, H. Q. P., Robinson, R. A., Appleton, G. F., Clark, N. A. & Rickard, A. D.): 33–52. Research Report 290, BTO, Thetford.

Skjelseth, S., Ringsby, T. H., Tufto, J., Jensen, H. & Sæther, B. E. 2007: Dispersal of introduced House Sparrows *Passer domesticus* – an experiment. — Proceedings of the Royal Society Ser. B 274: 1763–1771.

Summers-Smith, J. D. 1963: The House Sparrow. — Collins, London.

Summers-Smith, J. D. 1988: The Sparrows. — T & AD Poyser, Staffordshire.

Summers-Smith, J. D. 1999: Current status of the House Sparrow in Great Britain. — British Wildlife 10: 381–386.

Swaileh, K. M. & Sansur, R. 2006: Monitoring urban heavy metal pollution using the House Sparrow (*Passer domesticus*). — Journal of Environmental Monitoring 8: 209–213.

US EPA 1994: Microwave-assisted acid digestion of sediments, sludges, soils and oils. — Technical Report, Washington, District of Columbia.

Vincent, K. 2005: Investigating the causes of the decline of the urban House Sparrow *Passer domesticus* population in Britain. — PhD thesis, De Montfort University, Great Britain.

Väisänen, R. A. 2003: Varpusen ahdinko. — Linnut 38: 26–27.

Väisänen, R. A. 2006: Maalinnuston kannanvaihtelut Etelä- ja Pohjois-Suomessa 1983–2005. [Monitoring population changes of 86 land bird species breeding in Finland in 1983–2005.] — Linnut-Vuosikirja 2005: 83–98. (In Finnish with English summary)