Population densities of forest birds in a heavy metal pollution gradient

Tapio Eeva[1], Vesa Koivunen[2] and Harri Hakkarainen[1]

We censused forest birds along the pollution gradient of a copper smelter in southwest Finland to investigate whether a long-term heavy metal pollution has decreased bird densities in the surroundings of a pollution source. Point counts were performed at nest-box sites for which there are long-term data on the breeding densities of cavity-nesting species. In addition, control points without nest-boxes were chosen to obtain density estimates free from the possible effect of artificial nest-sites. Six habitat variables were measured at each sampling point to separate the pollution effect from habitat variation. Species richness was slightly lower in the polluted area, but the difference could be explained by habitat variables. In general, the bird community structure in the polluted area of Harjavalta corresponds relatively well with that of the background area. Of the 37 species analysed, six showed decreased density in the polluted area that could not be explained by any of the habitat variables. These species can be divided into two categories according to their ecology and feeding habits: ground feeders (robin *Erithacus rubecula*, blackbird *Turdus merula*, song thrush *T. philomelos*) and conifer foliage gleaners (goldcrest *Regulus regulus*, crested tit *Parus cristatus*, willow tit *P. montanus*). Ground feeders are probably affected negatively by pollution-related changes in the soil and ground layer. Foliage gleaners may have suffered from the loss and poor quality of needles in coniferous trees and consequent decrease in abundance of their invertebrate food.

Key words: population density, forest birds, community changes, pollution, heavy metals.

[1]Section of Ecology, Department of Biology, FIN–20014 University of Turku, Finland; e-mail: tapio.eeva@utu.fi; [2]Laurea Polytechnic, Hyvinkää-institute, Uudenmaankatu 22, FIN–05800, Finland. Corresponding author: tapio.eeva@utu.fi

Birds are considered to be good indicators of environmental changes (Koskimies 1989, Furness & Greenwood, 1993). Environmental pollution has led to some of the most prominent examples of negative human impact on bird populations (e.g. Ratcliffe 1967, Cooke 1973, Newton & Wyllie 1992, Furness 1993). In addition to many well documented cases of detrimental effects on individual species, a few studies have reported pollution-related changes at the level of bird communities (Flousek 1989, Tomek 1992, Gilyazov 1993). Despite an increasing number of pollution impact studies there is still a lack of studies connecting community level changes to environmental pollution. The probable reason for this is that most often the wide geographic scale of pollution makes it difficult to acquire comparable and accurately controlled data on the effects of pollution on bird communities. An exception to this are point sources of pollutants which are surrounded by a heavily polluted zone, across which pollutant levels decrease with distance from the pollution source.

To determine what kind of effects air pollution might have on the population densities of breeding forest birds, we performed point counts at increasing distances from a point source of air pollutants, a copper smelter, which emits large quantities of heavy metals into the surroundings (Jussila & Jormalainen 1991). Point counts were carried out at nest-box sites for which there are long-term data on breeding densities of cavity-nesting species. We can thus compare the results of the point counts to the known densities of cavity-nesting species. In addition, control plots without nest-boxes were chosen to estimate bird densities free from the possible effect of artificial nest-sites. At the same time, we measured six habitat variables from each sampling point to separate the effects of pollution from habitat variation. We aim to identify the species or groups of species that are vulnerable to the long-term effects of heavy metal pollution.

Material and methods

Study area

The study was conducted in the surroundings of the town Harjavalta (61° 20' N, 22° 10' E), SW Finland in the summer of 2001. The main source of local air pollutants is a factory complex producing copper, nickel and fertilisers in the centre of the town. Sulphuric oxides and heavy metals (especially Cu, Zn, Pb and Ni) are common pollutants in the area (Kubin 1990, Jussila 1997). Elevated heavy metal concentrations occur in the polluted area due to current and long-term deposition from the copper smelter (e.g. Jussila 1997, Koricheva & Haukioja 1995, Eeva & Lehikoinen 1996). Heavy metal concentrations decrease exponentially with increasing distance from the smelter and approach normal background levels at sites farther than 5 km from the smelter. Some cavity-nesting birds breeding in the vicinity of the smelter suffer from low breeding success (Eeva & Lehikoinen 1996, Eeva et al. 1997) and reduced survival rates (Eeva & Lehikoinen 1998).

Bird censuses

The data were collected at 14 study sites between 0.8 and 11 km from the copper smelter, each of which had 30–50 nest-boxes (in total 587). Study sites were classified into three categories according to the distance to the pollution source (zone I, <2 km; zone II, 2–7 km; zone III, >7 km), corresponding to heavy, moderate and low levels of pollution (see also Eeva et al. 1997). Relative bird densities of forest birds were estimated by point counts between May 21 and June 21. Point counts are considered a preferred method in fine-grained forest habitats that are typical of our study area (Bibby et al. 1992). Two points were counted at each nest-box site and, in addition, two control points were chosen outside the nest-box sites to provide density estimates free from the possible effect of artificial nest-sites on bird densities. The average minimum distance between sampling points was 278 m, which should guarantee that same birds are not recorded twice (recommended minimum distance is 250 m; Koskimies & Väisänen 1991). Point counts were performed by the method of Koskimies & Väisänen (1991) for counting breeding land birds. The censuses were carried out between 04.00 and 09.00 hrs, avoiding windy and rainy days. Each point was censused for 5 min. and for each species the number of observed individuals (pairs) was recorded. All censuses were done by the same observer. Each point was counted four times, once a week. The total number of point counts was 224 (14 sites × 4 points per site × 4 weeks). The mean density of four successive counts was calculated for each point and this was used as a dependent variable in analyses.

Habitat variables

The forests in the area are dominated by Scots pine *Pinus sylvestris*, which forms mixed stands with Norway spruce *Picea abies* and birches *Betula* spp. The field layer is dominated by dwarf shrubs *Vaccinium vitis-idaea* and *V. myrtillus*. At sites closest to the factory complex, ground layer vegetation is patchy and poorly developed due to the long-term effect of pollution (Salemaa & Vanha-Majamaa 1993).

Special attention was paid in selecting sampling points so that they would represent a similar habitat type, i.e. relatively barren pine-dominated forests typical of the study area. To account for the remaining variation we measured, at each sampling point, six habitat variables that we considered should describe the major natural habitat differences within our study area. Sampling sites were classified from the most barren to the most luxuriant according the type of ground layer vegetation, following Kalliola (1973): 1 = absent, 2 = *Cladonia* and *Calluna* types, 3 = *Vaccinium vitis-idaea* type, 4 = *Vaccinium myrtillus* type, 5 = *Oxalis acetosella – Vaccinium myrtillus* type. The relative proportions of the three dominant tree species were estimated visually as follows: 1 = absent, 2 = sparse, 3 = moderate, 4 = dominant. Timber volume was measured by using a relascope and hypsometer: volume (m^3/ha) = basal area (m^2/ha) × 0.5 × tree height (m). Habitat patch size (ha) was estimated from digitised maps with Mapinfo 5.0 by measuring the size of continuous forest area around each point. From the habitat variables, three principal components (PC) were calculated using the PRINCOMP procedure of SAS (SAS Institute Inc. 1989). PC1 explained 37 %, PC2 28 % and PC3 13 % of the variation in data. From zones I to III the percentage of pine decreased from 55 to 32 %, spruce increased from 11 % to 28 % and birch remained relatively constant (from 23 % to 21 %).

Statistics

Bird densities were calculated from the point count data using the formula of Järvinen (1978): D (pairs/km^2) = $3 \times N \times c^2 / \pi$, where N = number of observations per counting point and c = species-specific constant that corrects for the differences in detectability (Järvinen & Väisänen 1983). Density estimates were not calculated for those species for which we had fewer than 10 observations. These species are included, however, in the calculations of species diversity. Shannon-Wiener diversity indices ($H = -3p_i \times \log_2 p_i$, where p_i = the proportion of i^{th} species of the total density) were calculated from the corrected density estimates, not from the original counts.

From the five years of nest-box data (1996–2000) we calculated the nest-box occupancy rate (%) and the density of nests per km^2 at each study site and in each year, using the nearest-neighbour distance method (Krebs 1989): $D = n / [\pi \times 3(r^2)]$, where D = population density, n = number of nests and r = distance to nearest nest of the same species.

The relationship between distance from the copper smelter and bird density was analysed by an ANCOVA model where distance (2^{nd} order, km) to smelter, nest-box effect (0 = absent, 1 = present) and habitat variables were used as explaining factors. For the ANCOVA we selected the habitat variables that best correlated with the first three principal components (see above). These were: 1. the proportion of spruce, 2. habitat patch size and 3. timber volume. By including habitat variables as covariates in the models we aimed to explain natural habitat-related variation in our census data. Because long-term pollution has also affected vegetation, especially the field layer, habitat effects cannot totally be separated from pollution effect. However, this will only make our analysis more conservative with regard to the number of species that show significant pollution-related changes. Log-transformation was made on the distance and habitat patch size before the analyses to normalise distributions. All means are presented with their standard errors (± s.e.).

Results

The mean number of species observed at sampling points was slightly lower in zone I (16.4 ± 0.54, n = 20) than in zones II and III (18.8 ± 0.57, n = 24 and 19.4 ± 0.38, n = 12, respectively; Tukey's test, df = 53, $P < 0.05$). However, the difference was due to the habitat effect: after adding the habitat variables into the model the effect of distance was no longer significant (ANCOVA, for distance $F_{1,49} = 0.04$, $P = 0.83$). The proportion of spruce explained the majority of the variation in the data, even though the effect was only marginally significant (ANCOVA, for spruce $F_{2,49} = 3.02$, $P = 0.058$). Similarly, the Shannon-Wiener diversity index was slightly lower in zone I (3.2 ± 0.05, n = 20), than in zones II and III (3.5 ± 0.05, n = 24 and 3.5 ± 0.05, n = 12, respectively; Tukey's test, df = 53, $P < 0.05$), but the difference could be explained by the habitat effect (ANCOVA, for distance $F_{1,49} = 0.34$, $P = 0.56$).

Bird densities are shown in Table 1. After taking into account the habitat effects there were six species that showed a positive relationship and two species showing a negative relationship to the distance from the pollution source. Species that were less abundant in the polluted area (decrease in % from background level; Fig. 1) were: crested tit *Parus cristatus* (77 % decrease), willow tit *Parus montanus* (77 %), goldcrest *Regulus regulus* (94 %), robin *Erithacus rubecula* (78 %), blackbird *Turdus merula* (83 %) and song thrush *Turdus philomelos* (87 %). Tree pipits *Anthus trivialis* and yellowhammers *Emberiza citrinella* were more abundant in the moderately polluted area (zone II) than in the polluted or unpolluted areas (Table 1).

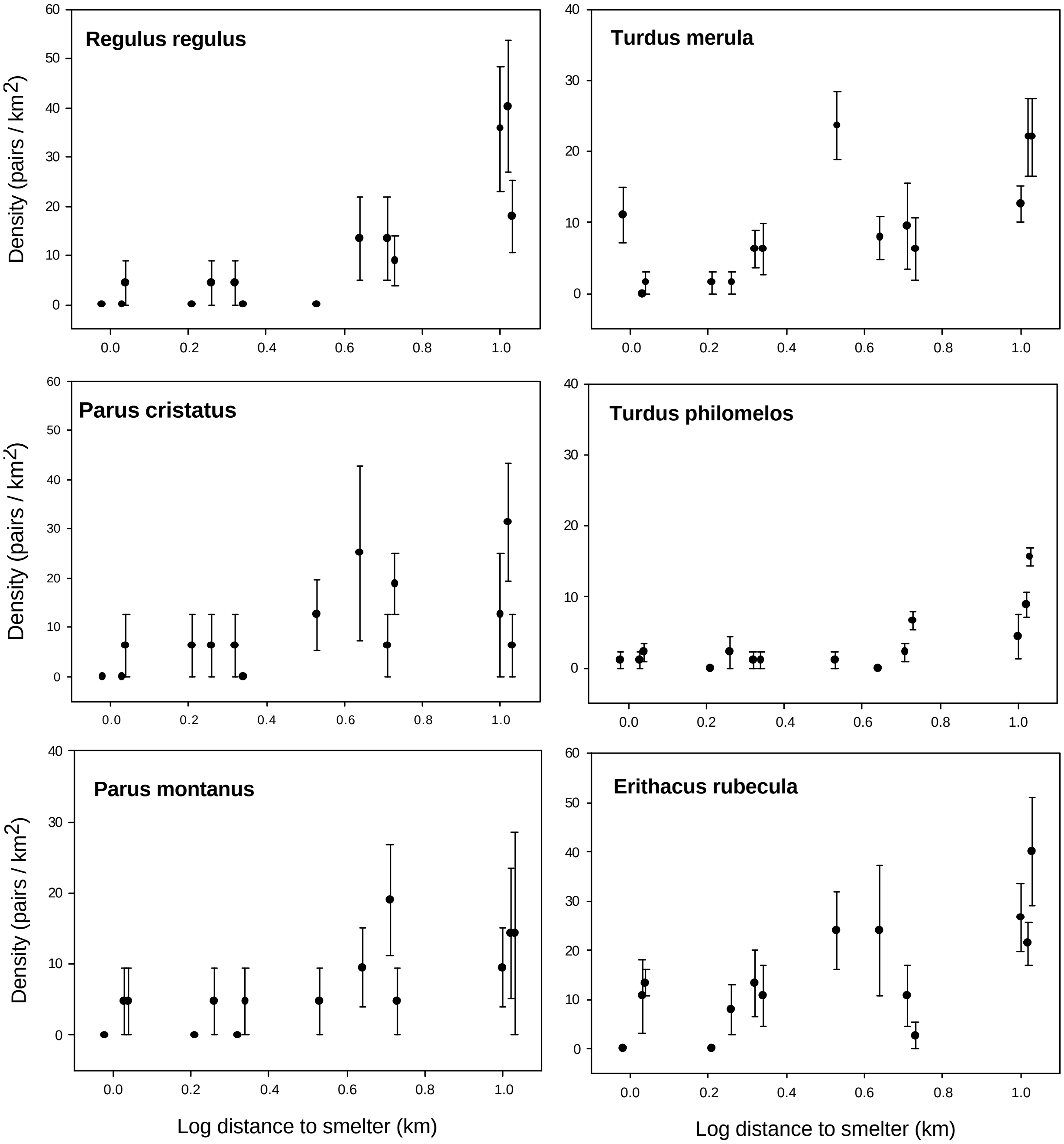
The availability of nest-boxes significantly increased the density of three of the most common cavity-nesting birds (increase in % for combined data): pied flycatcher *Ficedula hypoleuca* (355 %), blue tit *Parus caeruleus*

Table 1. Mean (± s.e.) bird densities at three distance zones (I: <2 km, II: 2–7 km, III: >7 km) around the pollution source (Tukey's test: means with the same letter are not significantly different). The effect of distance to pollution source is shown after removing the habitat effects in an ANCOVA model. Significant ($P < 0.05$) habitat effects shown by '+' or '–'. Separate values for areas with and without nest-boxes (nb) are shown for species in which density was dependent on the availability of nest-boxes.

Species	Acronym	Density (pairs/km^2)			Non-habitat-related effect of distance[1]	Habitat			
		Zone I n = 20	Zone II n = 24	Zone III n = 12		Boxes	Spruce	Patch	Volume
Anthus trivialis	ATRI	7.2 ± 2.4^{a}	11.8 ± 1.9^{a}	5.6 ± 1.7^{a}	–			+	
Carduelis chloris	CCHL	6.4 ± 1.4^{a}	6.9 ± 1.4^{a}	1.0 ± 0.50^{b}	0			–	
Carduelis spinus	CSPI	7.8 ± 1.5^{a}	15.6 ± 1.7^{b}	15.3 ± 1.7^{b}	0				
Columba palumbus	CPAL	0.14 ± 0.09^{a}	0.39 ± 0.08^{a}	1.5 ± 0.26^{b}	0		+		
Corvus monedula	CMON	0.35 ± 0.13^{a}	0.11 ± 0.05^{ab}	0.0 ± 0.0^{b}	0			–	
Corvus corone	CNIX	1.6 ± 0.28^{a}	1.0 ± 0.18^{a}	1.1 ± 0.20^{a}	0			–	
Dentrocopos major	DMAJ	2.1 ± 0.67^{a}	2.3 ± 0.72^{a}	1.0 ± 0.68^{a}	0				
Emberiza citrinella	ECIT	17.2 ± 4.4^{a}	22.0 ± 4.1^{a}	11.6 ± 3.5^{a}	– –				
Erithacus rubecula	ERUB	6.4 ± 2.1^{a}	14.2 ± 3.3^{a}	29.4 ± 4.8^{b}	+				
Ficedula hypoleuca[2]	FHYP	38.6 ± 11.5^{a}	33.9 ± 10.9^{a}	19.1 ± 18.3^{a}	0	+			
Ficedula hypoleuca[2], nb		115.6 ± 13.8^{a}	116.3 ± 11.5^{a}	111.1 ± 15.4^{a}					
Fringilla coelebs	FCOE	65.4 ± 5.3^{a}	89.8 ± 3.6^{b}	90.6 ± 5.0^{b}	0			+	
Garrulus glandarius	GGLA	0.64 ± 0.64^{a}	2.7 ± 1.1^{a}	4.3 ± 1.8^{a}	0				
Loxia curvirostra	LCUR	0.04 ± 0.04^{a}	0.50 ± 0.19^{ab}	0.65 ± 0.22^{b}	0		+		
Loxia pytyopsittacus	LPYT	0.48 ± 0.26^{a}	1.32 ± 0.63^{a}	0.53 ± 0.36^{a}	0				
Motacilla alba[2]	MALB	5.4 ± 5.4^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0	+		–	
Motacilla alba[2], nb		14.5 ± 5.9^{a}	10.6 ± 5.2^{a}	0.0 ± 0.0^{a}					
Muscicapa striata	MSTR	11.2 ± 3.2^{ab}	22.2 ± 4.5^{a}	4.7 ± 3.2^{b}	0			+	
Parus ater	PATE	0.0 ± 0.0^{a}	2.2 ± 1.2^{a}	10.3 ± 4.6^{b}	0				
Parus caeruleus[2]	PCAE	70.8 ± 19.0^{a}	23.6 ± 9.0^{b}	5.9 ± 5.9^{b}	0	+		–	
Parus caeruleus[2], nb		106.2 ± 19.0^{a}	44.2 ± 15.2^{ab}	17.7 ± 7.9^{b}					
Parus cristatus	PCRI	3.8 ± 2.1^{a}	11.5 ± 3.7^{a}	16.7 ± 6.4^{a}	+				
Parus major[2]	PMAJ	75.0 ± 8.3^{a}	37.7 ± 3.8^{b}	31.7 ± 2.5^{b}	0	+			

Species	Acronym	Density (pairs/km²) Zone I n = 20	Zone II n = 24	Zone III n = 12	Non-habitat-related effect of distance[1]	Habitat Boxes	Spruce	Patch	Volume
Parus major[2], nb		96.4 ± 9.5^a	82.3 ± 8.3^a	73.4 ± 7.8^a					
Parus montanus	PMON	2.9 ± 1.6^a	7.1 ± 2.2^{ab}	12.7 ± 5.4^b	+				
Passer domesticus	PDOM	22.3 ± 6.7^a	0.0 ± 0.0^b	0.0 ± 0.0^b	0			–	
Phoenicurus phoenicurus	PPHO	4.0 ± 1.0^a	0.64 ± 0.37^b	0.0 ± 0.0^b	0			–	
Phylloscopus collybita[2]	PCOL	0.56 ± 0.37^a	3.0 ± 1.8^a	10.2 ± 2.1^b	0	–	+		
Phylloscopus collybita[2], nb		0.28 ± 0.28^a	0.70 ± 0.36^a	6.5 ± 1.2^b					
Phylloscopus trochilus	PLUS	46.7 ± 3.6^a	56.6 ± 2.9^a	44.8 ± 5.4^a	0				
Phylloscopus sibilatrix	PSIB	1.1 ± 0.51^a	8.9 ± 1.7^b	0.93 ± 0.63^a	0				
Pica pica	PPIC	2.9 ± 0.50^a	1.1 ± 0.32^b	0.66 ± 0.35^b	0			–	
Pyrrhula pyrrhula	PPYR	2.0 ± 0.71^a	2.8 ± 1.1^a	4.5 ± 1.3^a	0				+
Regulus regulus	RREG	1.8 ± 1.2^a	6.7 ± 2.4^a	31.3 ± 6.6^b	+++				
Sylvia borin	SBOR	1.6 ± 0.84^a	2.1 ± 0.9^a	1.2 ± 0.6^a	0				
Sylvia communis	SCOM	1.4 ± 0.8^a	3.1 ± 1.9^a	0.78 ± 0.78^a	0				+
Sylvia curruca	SCUR	7.7 ± 1.9^a	3.6 ± 1.3^a	8.6 ± 2.4^a	0				
Turdus iliacus	TILI	2.6 ± 0.81^a	9.9 ± 2.1^b	3.1 ± 1.4^a	0		+		
Turdus merula	TMER	3.2 ± 1.3^a	10.0 ± 2.0^a	18.9 ± 2.8^b	+				
Turdius philomelos	TPHI	1.3 ± 0.57^a	2.0 ± 0.6^a	9.7 ± 1.8^b	+				
Turdus pilaris	TPIL	14.1 ± 3.3^a	12.2 ± 3.5^a	2.3 ± 1.6^a	0				
Turdus viscivorus	TVIS	0.40 ± 0.22^a	1.8 ± 0.63^a	1.1 ± 0.61^a	0			+	

[1] From ANOVA model where distance, nest-box effect, proportion of spruce, forest patch size and timber volume were used as explaining factors (+++ $P < 0.001$, ++ $P < 0.01$, + $P < 0.05$, 0 = not significant).
[2] The number of sampling points per zone for I: n = 10, II: n = 12, III: n = 6.



Figu Mean (± s.e.) bird densities (pairs) at 14 study plots along the pollution gradient for those six species which showed a decreasing trend towards the pollution source that could not be explained by any of the habitat characteristics studied.

(166 %) and great tit *Parus major* (172 %) (Table 1). Pied wagtails *Motacilla alba* also showed higher densities at sites with nest-boxes, whereas chiffchaffs *Phylloscopus collybita* bred at somewhat lower densities at the nest-box sites (Table 1). For cavity-nesting birds, comparison of density estimates with observed breeding densities in our nest-box sites revealed that point counts gave good estimates for the density of pied

Table 2. Mean (± s.e.) densities of nests and nest-box occupation rate (%) of hole-breeding bird species in three distance zones (I: <2 km, II: 2–7 km, III: >7 km) around the pollution source in 1996–2000. Tukey's test: means with the same letter are not significantly different. The number of study sites where nest-boxes were regularly checked during five years (n = 27, 30, 15 for three zones, respectively). Chi-square test for occupied v. unoccupied nest-boxes. The number of nest-boxes which were regularly checked during five years (n = 2990). Second and replacement nests are not included.

	Density (pairs/km^2) Occupation (%)				
Species	Zone I	Zone II	Zone III	Π^2	P
Ficedula hypoleuca	108.0 ± 10.2^a	116.7 ± 8.59^a	121.1 ± 13.4^a		
	36.6	41.9	35.6	5.7	0.059
Parus major	49.1 ± 6.83^a	47.2 ± 5.11^a	56.8 ± 9.53^a		
	15.8	21.5	22.0	13.2	0.0014
Parus caeruleus	7.4 ± 2.13^a	11.4 ± 3.32^a	4.6 ± 2.34^a		
	4.4	4.9	4.6	0.3	0.86
Parus ater	0.0 ± 0.00^a	0.13 ± 0.07^a	9.4 ± 5.74^b		
	0.07	0.18	2.5	44.6	<0.0001
Parus cristatus	0.49 ± 0.44^a	0.76 ± 0.49^a	0.76 ± 0.17^a		
	0.15	0.82	1.7	14.3	0.001
Phoenicurus phoenicurus	3.1 ± 2.12^a	0.06 ± 0.06^a	0.0 ± 0.00^a		
	0.74	0.27	0.0	5.8	0.054

flycatcher, coal tit *Parus ater* and redstart *Phoenicurus phoenicurus*, whereas point counts seemed to overestimate the breeding numbers of great tit and blue tit (Table 2).

Of the six habitat characteristics, the proportion of spruce (1st principal component) explained most of (36 %) the habitat variation in our data. Because several bird species are known to favour spruce dominated forests the proportional effects of the two intercorrelated environmental factors, air pollution and proportion of spruce, on bird densities was further studied using partial correlations (Figure 2). The smaller amount of spruce in the polluted area, which may be partly a consequence of a sensitivity of spruce to air pol-

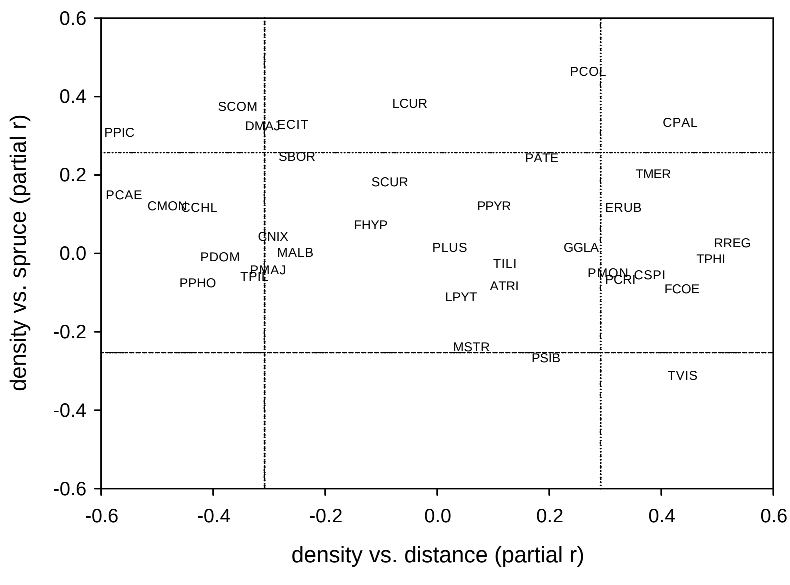


Figure 2. Partial correlations of bird densities in relation to two environmental factors: air pollution (distance to the pollution source) and habitat (proportion of spruce). Vertical and horizontal lines show the borders of statistically significant correlations at a level <0.05. Acronyms for the species are shown in Table 1.

lution, explains the smaller densities of such spruce favouring species as common crossbill *Loxia curvirostra*, chiffchaff and coal tit (Table 1).

Discussion

Six out of 37 bird species showed decreased densities in the polluted area, and they can be divided into two categories according to their ecology and feeding habits: ground feeding Turdidae (robin, blackbird, song thrush) and conifer foliage gleaners of the tit guild (goldcrest, crested tit, willow tit). The result is in agreement with earlier studies on pollution effects on forest bird populations. For example, the three turdid species were also observed to suffer from the effects of pollution in a Polish study near a heavily industrialised area (Tomek 1992). Similarly in the Czech Republic, Flousek (1989) found that especially goldcrest, firecrest *Regulus ignicapillus*, song thrush, wren *Troglodytes troglodytes*, chaffinch *Fringilla coelebs* and coal tit showed decreased densities in spruce forests affected by industrial emissions.

Both direct toxic effects as well as indirect effects (via lowered food availability) have been shown to lower the breeding success of some hole-breeding birds in the vicinity of the pollution source (Eeva & Lehikoinen 1996). There are no data on reproduction for the remaining species and the reasons for their decreased densities may involve both factors. There is no indication, however, of increased adult mortality due to toxicity in our study area for any species. Ground feeders are probably affected negatively by pollution-related changes in soil and the ground layer. Emissions of sulphuric oxides and accumulation of heavy metals in the ground over a timespan of c.50 years have caused clear changes in the ground layer vegetation and invertebrate fauna. Ground layer vegetation is almost absent in the vicinity of the factory complex (Salemaa & Vanha-Majamaa 1993). The species number and biomass of ground living invertebrates are also known to have decreased in the polluted area of Harjavalta (Koponen 1995, Eeva et al. 1997), as well as at other similar sites (Bengtsson & Rundgren 1984). Unfortunately, there is no information available on the number of earthworms (lumbricids) in our study area. Earthworms are an important source of food for ground feeding thrushes (Cramp et al. 1988) and their biomass and species number decrease around the sources of heavy metals (Tyler 1984, Spurgeon et al. 1994). Earthworms effectively accumulate heavy metals from polluted soils and pass them on to secondary consumers such as shrews (Pankakoski et al. 1994). Accordingly, Beyer & Storm (1995) found that shrews and ground feeding songbirds accumulated high concentrations of lead in the vicinity of a zinc smelter. Another important food source for thrushes are ground living snails, which are known to be sensitive to acidification (Graveland & van der Wal, 1996). Recently, Hames et al. (2002) demonstrated a strong negative effect of acidification on the breeding population of wood thrushes *Hylocichla mustelina* in North America, and suggested calcium depletion and consequent snail loss as a cause of the population decrease.

Foliage gleaners may have suffered from the loss and poor quality of needles in coniferous trees and a consequent decrease in the abundance of their invertebrate food. In the polluted area of Harjavalta, 31 % of pines suffer from severe needle loss (>20 %) compared to 25 % in the background area (Jussila 1997). In the stands nearest to the smelter the trees have only current and one-year old needles, compared to the normal 3–4 age classes in southern Finland (Kukkola et al. 1998). Correspondingly, the mean sulphur content of pine needles are significantly higher in the polluted (over 1000 mg/kg) area than background (mean 930 mg/kg) area (Jussila 1997). For example, canopy-living spiders are sensitive to air pollution and a consequent needle-loss (e.g. Gunnarsson 1988, Sundberg & Funnarsson 1994, Brotons et al. 1998). Reduced numbers of canopy-living spiders and other invertebrates might explain the decreased densities of conifer foliage gleaners in Harjavalta. Reduced needle biomass may also cause other negative effects for foliage gleaners: for example, several *Parus* species foraging in pines with high needle-loss have been shown to spend proportionally more time scanning for predators and less time handling prey than those living in the area with low needle-loss (Hake 1991, Brotons et al. 1998).

The density of cavity-nesting species was increased by 2–3 fold at sites provided with nest-boxes. On the other hand, increased numbers of cavity-nesting species had little effect on abundance of other species. Comparison of the results from point counts with the long term (1996–2000) breeding data on cavity-nesting birds reveals an interesting contradiction regarding to the use of census data for bioindicator purposes. Pied flycatchers and great tits produce, respectively, 30 % and 22 % fewer fledglings in the polluted area of Harjavalta (T. Eeva, unpubl. data). Nevertheless, for these two species, no indication of these detrimental effects could be observed on the basis of point count data. This means that bird censuses alone cannot reveal the species that are potentially in danger in polluted environments. Instead, bird censuses may reveal only those species most sensitive to pollution, whose populations have already collapsed.

Overall, bird densities and bird community structure in Harjavalta resembled relatively well those at the unpolluted control sites (see also Ryösä & Reiniaho 1999). Much more dramatic changes in bird communities have occurred elsewhere, e.g. in the Monchegorsk area of the Kola peninsula, where an 80 % decrease in density of forest species has been reported (Gilyazov 1993). Due to forest decline, species of open habitats now prevail in the most heavily polluted area around the Monchegorsk smelter complex (Gilyazov 1993). We suggests that, in Harjavalta, ground feeders are affected negatively by pollution-related changes in soil and the ground layer. Foliage gleaners may have suffered from the loss of needles in coniferous trees and a consequent decrease in the abundance of their arthropod food. Further studies are needed to reveal the mechanisms behind the changes.

Acknowledgements. We wish to thank Juha Sjöholm and Minna Takalo, who performed the bird counts and collected the data on habitat variables. Esa Lehikoinen and Petri Suorsa gave valuable comments on the manuscript. The study was financed by grants from the Laurea Polytechnic, the Academy of Finland (project number 50332) and the Emil Aaltonen Foundation.

References

Bengtsson, G. & Rundgren, S. 1984. Ground-living invertebrates in metal-polluted forest soils. Ambio 13: 29–33.

Beyer, W. N. & Storm, G. 1995. Ecotoxicological damage from zinc smelting at Palmerton, Pennsylvania. Pp 356–391 in: Hoffman, D. J., Rattner, B. A., Burton, G. A. Jr & Cairns, J. Jr (eds). Handbook of ecotoxicology. Lewis Publications, Boca Raton.

Bibby, C. J., Burgess, N. D. & Hill, D. A. 1993. Bird census techniques. Academic Press, London.

Brotons, L., Magrans, M., Ferrús, L. & Nadal, J. 1998. Direct and indirect effects of pollution on the foraging behaviour of forest passerines during the breeding season. Can. J. Zool. 76: 556–565.

Cooke, A. S. 1973. Shell thinning in avian eggs by environmental pollutants. Environ. Pollut. 4: 85–152.

Cramp, S. (ed.). 1988. The birds of the Western Palearctic, Volume 5. Oxford University Press, Oxford.

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. 1998. Local survival rates of the pied flycatchers (*Ficedula hypoleuca*) and the great tits (*Parus major*) in an air pollution gradient. Ecoscience 5: 46–50.

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

Flousek, J. 1989. Impact of industrial emissions on bird populations breeding in mountain spruce forests in Central Europe. Ann. Zool. Fenn. 26: 255–263.

Furness, R. W. 1993. Birds as monitors of pollutants. Pp 86–143 in: Furness, R. W. & Greenwood, J. J. D. (eds). Birds as monitors of environmental change. Chapman & Hall, London.

Furness, R. W. & Greenwood, J. J. D. (eds). 1993. Birds as monitors of environmental change. Chapman & Hall, London.

Gilyazov, A. S. 1993. Air pollution impact on the bird communities of the Lapland biosphere reserve. Pp 383–390 in: Kozlov, M. V., Haukioja, E. & Yarmishko, V. T. (eds). Aerial pollution in Kola peninsula. Kola Scientific Centre, Apatity.

Graveland, J. & van der Wal, R. 1996. Decline in snail abundance due to soil acidification causes eggshell defects in forest passerines. Oecologia (Berlin) 105: 351–360.

Gunnarsson, B. 1988. Spruce-living spiders and forest decline; the importance of needle-loss. Biol. Conserv. 43: 309–319.

Hake, M. 1991. The effects of needle loss in coniferous forests in south-west Sweden on the winter foraging behaviour of willow tits *Parus montanus*. Biol. Conserv. 58: 357–366.

Hames, R. S., Rosenberg, K. V., Lowe, J. D., Barker, S. E. & Dhondt, A. A. 2002. Adverse effects of acid rain on the distribution of the Wood Thrush (*Hylocichla mustelina*) in North America. Proc. Nat. Acad. Sci. USA 99: 11235–11240.

Jussila, I. 1997. A bioindicator study on the effects of air pollution on forest ecosystem at the Pori-Harjavalta district and northern Satakunta in SW-Finland. SYKEsarja B 12: 1–78.

Jussila, I. & Jormalainen, V. 1991. Spreading of heavy metals and some other air pollutants at Pori-Harjavalta district in SW-Finland. SYKEsarja B 4: 1–58.

Järvinen, O. 1978. Estimating relative densities of land birds by point counts. Ann. Zool. Fenn. 15: 290–293.

Järvinen, O. & Väisänen, R. 1983. Correction coefficients for line transect censuses of breeding birds. Ornis Fenn. 60: 97–104.

Kalliola, R. 1973. Suomen kasvimaantiede. WSOY, Porvoo, 308 pp. [in Finnish].

Koponen, S. & Niemelä, P. 1995. Ground-living arthropods along pollution gradient in boreal pine forest. Entomol. Fenn. 6: 127–131.

Koricheva, J. & Haukioja, E. 1995. Variations in chemical composition of birch foliage under air pollution stress and their consequences for *Eriocrania* miners. Environ. Pollut. 88: 41–50.

Koskimies, P. 1989. Birds as a tool in environmental monitoring. Ann. Zool. Fenn. 26: 153–166.

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

Krebs, C. J. 1989. Ecological methodology. Harper & Row, New York.

Kubin, E. 1990. A survey of element concentrations in the epiphytic lichen *Hypogymnia physodes* in Finland in 1985–86. Pp 421–446 in: Kauppi, P., Anttila, P. & Kenttämies, K. (eds). Acidification in Finland. Springer-Verlag, Berlin.

Kukkola, M., Helmisaari, H.-S. & Saarsalmi, A. 1998. Puusto kärsii raskasmetalleista. Ilmansuojelu 28: 19–22. [in Finnish].

Newton, I. & Wyllie, I. 1992. Recovery of a sparrowhawk population in relation to declining pesticide contamination. J. Appl. Ecol. 29: 476–484.

Pankakoski, E., Koivisto, I., Hyvärinen, H., Terhivuo, J. & Tähkä, K. M. 1994. Experimental accumulation of lead from soil through earthworms to common shrews. Chemosphere 29: 1639–1649.

Ratcliffe, D. A. 1967. Decrease in eggshell weight in certain birds of prey. Nature 215: 208–210.

Ryösä, M. & Reiniaho, T. 1999. Pesimälinnusto Harjavallan metallisulattojen ympäristössä. Satakunnan linnut 30: 30–34. [in Finnish].

Salemaa, M. & Vanha-Majamaa, L. 1993. Forest vegetation change along a pollution gradient in SW Finland. Proc. 1st Finn. Conf. Environ. Sci. 14: 101–104.

SAS Institute Inc. 1989. SAS/STAT User's guide, 4th edn. Volume 1–2. SAS Institute Inc., Cary, NC.

Spurgeon, D. J., Hopkin, S. P. & Jones, D. T. 1994. Effects of cadmium, copper, lead and zinc on growth, reproduction and survival of the earthworm *Eisenia fetida* (Savigny): Assessing the environmental impact of point-source metal contamination in terrestrial ecosystems. Environ. Pollut. 84: 123–130.

Sundberg, I. & Funnarsson, B. 1994. Spider abundance in relation to needle density in spruce. J. Arachnol. 22: 190–194.

Tomek, T. 1992. Formation of bird communities in the forest sample plots under-going the action of industrial pollution in the Ojców National Park. Acta Zool. Cracov. 35: 351–372.

Tyler, G. 1984. The impact of heavy metal pollution on forests: A case study of Gusum, Sweden. Ambio 13: 18–24.

Received
Revision accepted