Bird diversity and dissimilarity show contrasting patterns along heavy metal pollution gradients in the Urals, Russia

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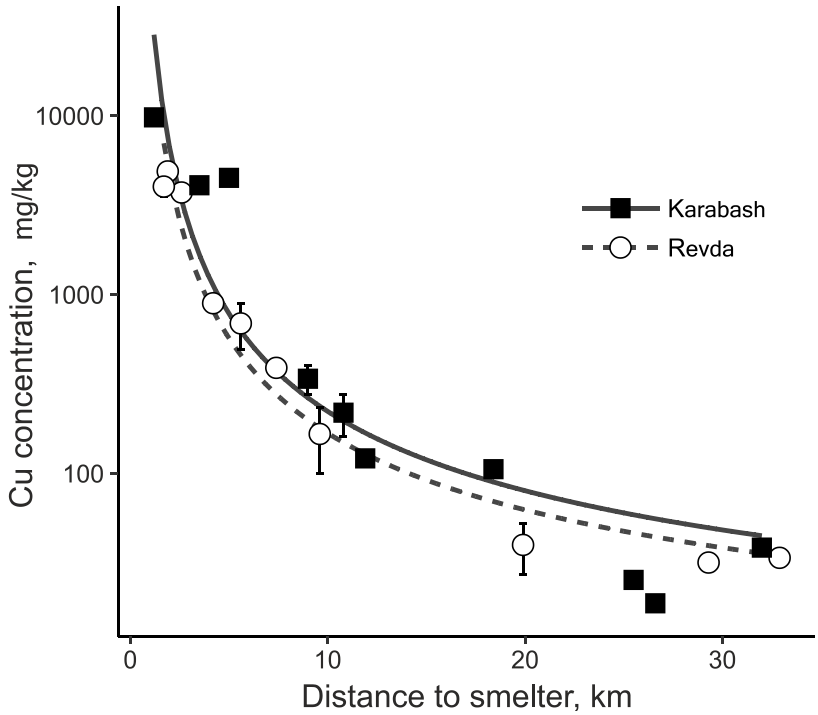

Fig. S1. Litter copper concentrations at different distances near Karabash (filled squares, solid line) and Revda (open circles, dashed line) smelters. The bars denote standard deviation. Data are from Smorkalov and Vorobeichik (2011).

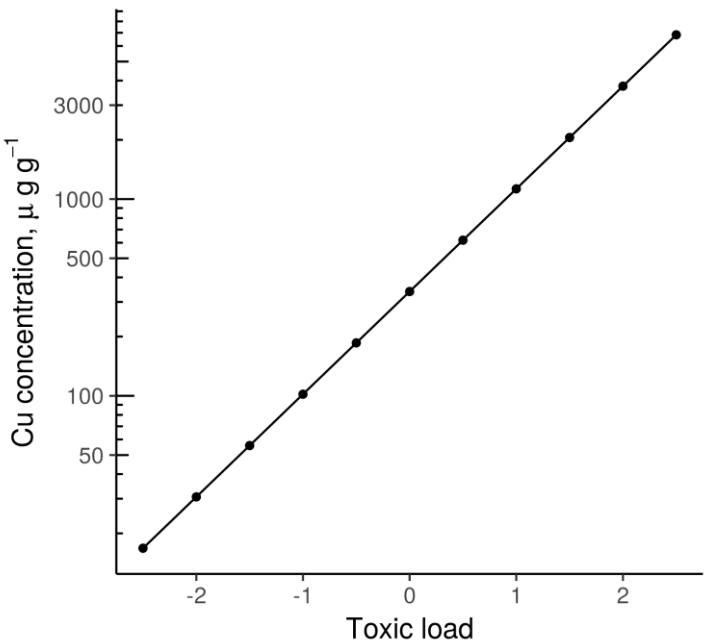

Fig. S2. Relation between the toxic load and copper concentrations in litter (both study regions combined).

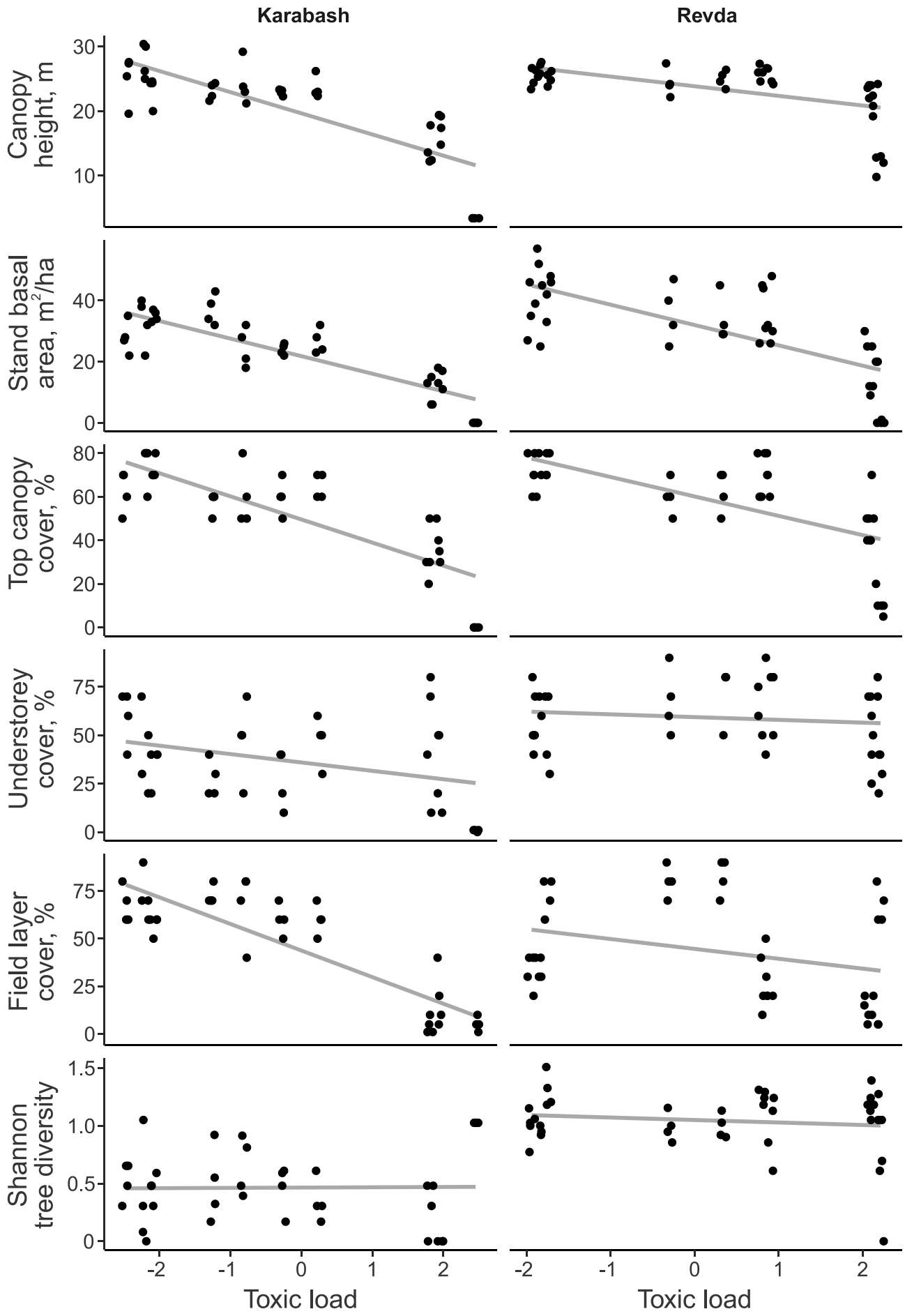

Fig. S3. Pollution-induced changes in habitat characteristics near Karabash (left column) and Revda (right column). The toxic load can be converted into litter Cu concentrations using the Fig. S2. Circles refer to individual plots (*n*=40 in each region).

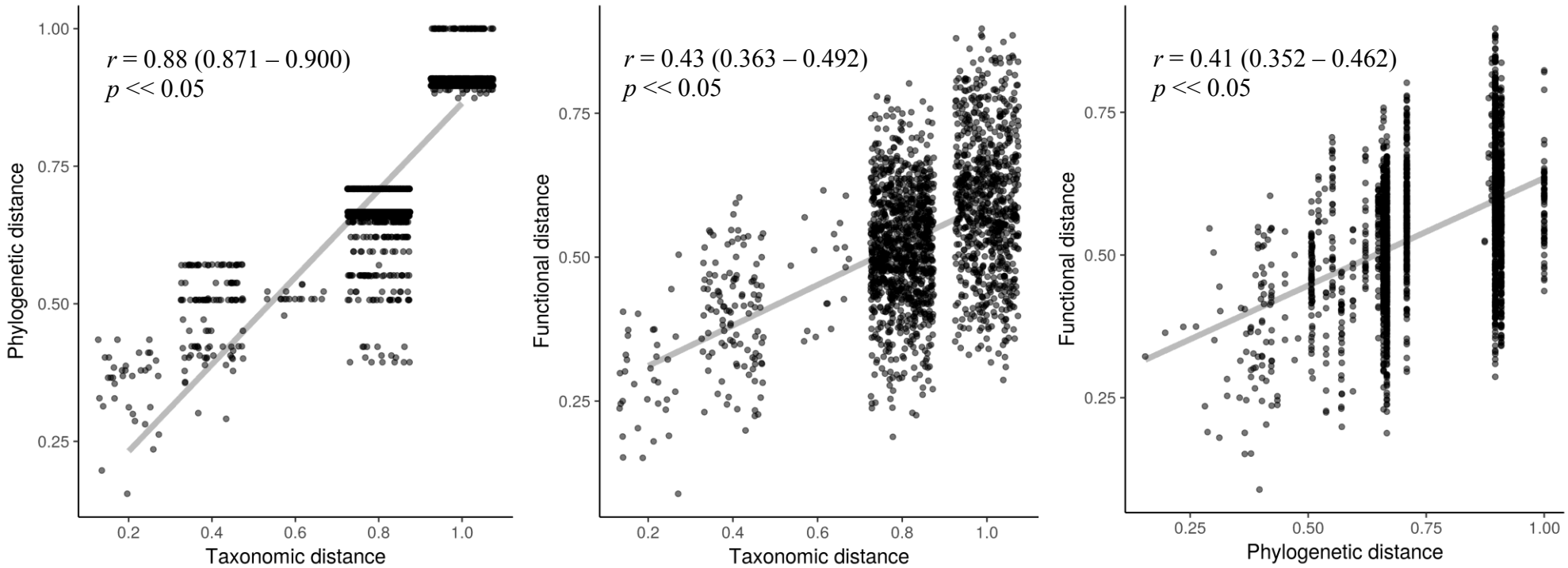

Fig. S4. Correlation between distance matrices. To avoid overplotting, points along the axis with taxonomic distance were slightly jittered. Phylogenetic distance was square root transformed and all distances were scaled to the unit interval. Values on the plot denotes Mantel coefficient (*r*, based on the Spearman correlation), its 95% confidence interval, and permutation-based two-tailed *p*-value (null hypothesis: $r = 0$).

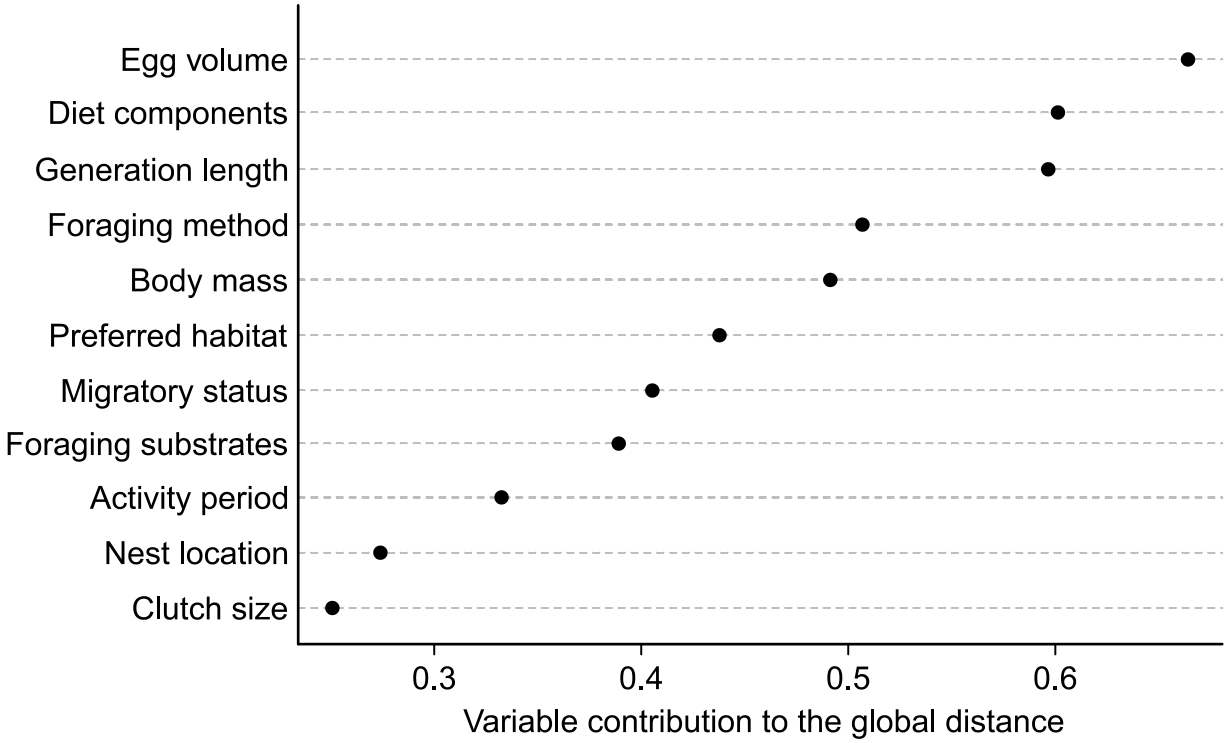

Fig. S5. Contribution of different variables to the global functional distance between species.

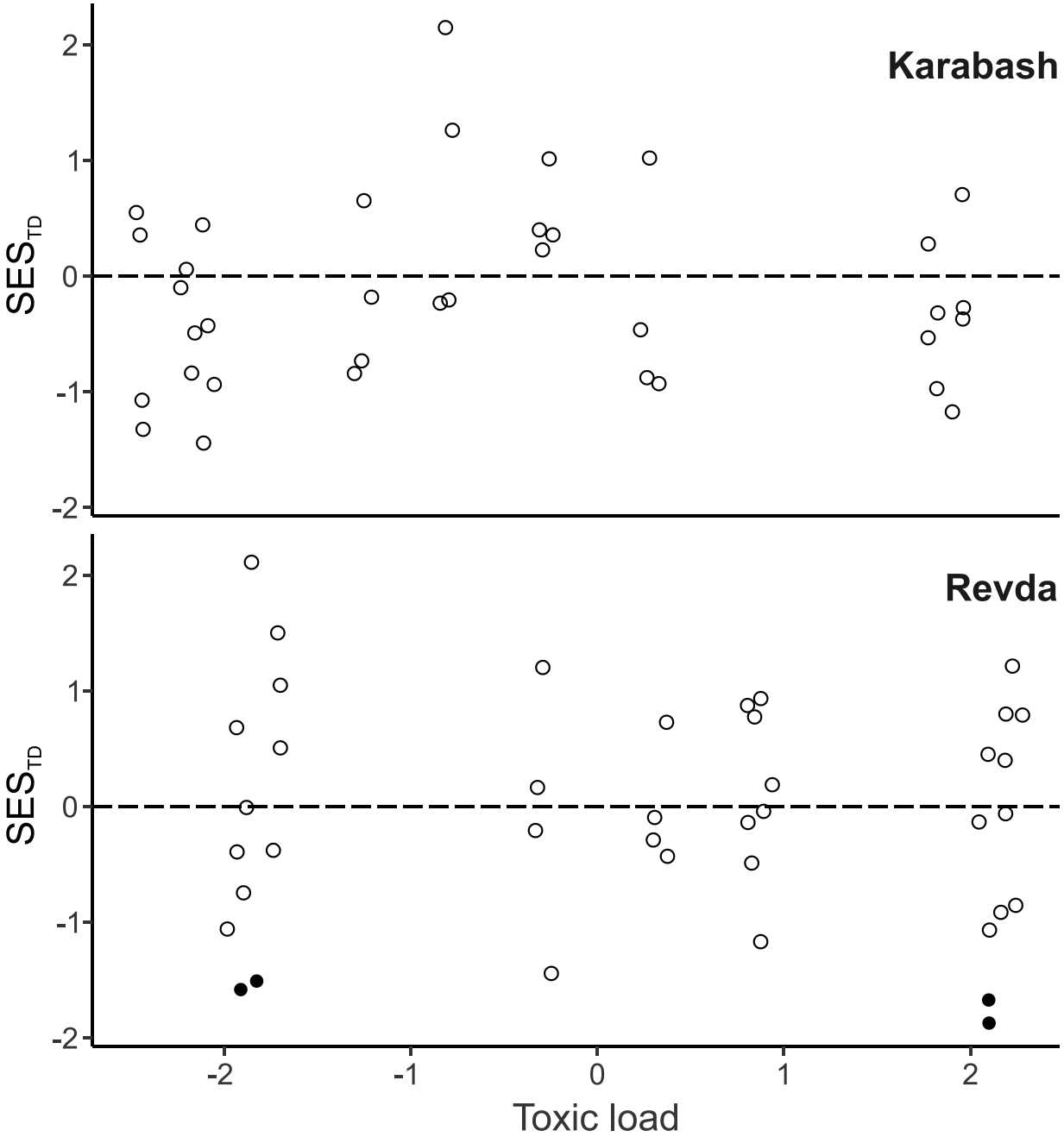

Fig. S6a. Standardized effect sizes of within-community taxonomic (SES_{TD}) dissimilarity of forest birds along pollution gradients near Karabash (industrial barren excluded, upper graphs) and Revda (lower graphs) copper smelters. Circles refer to individual plots. Filled circles denote SES values that differ significantly from the null model ($p < 0.05$). To avoid overplotting, points along the axis with toxic load were slightly jittered.

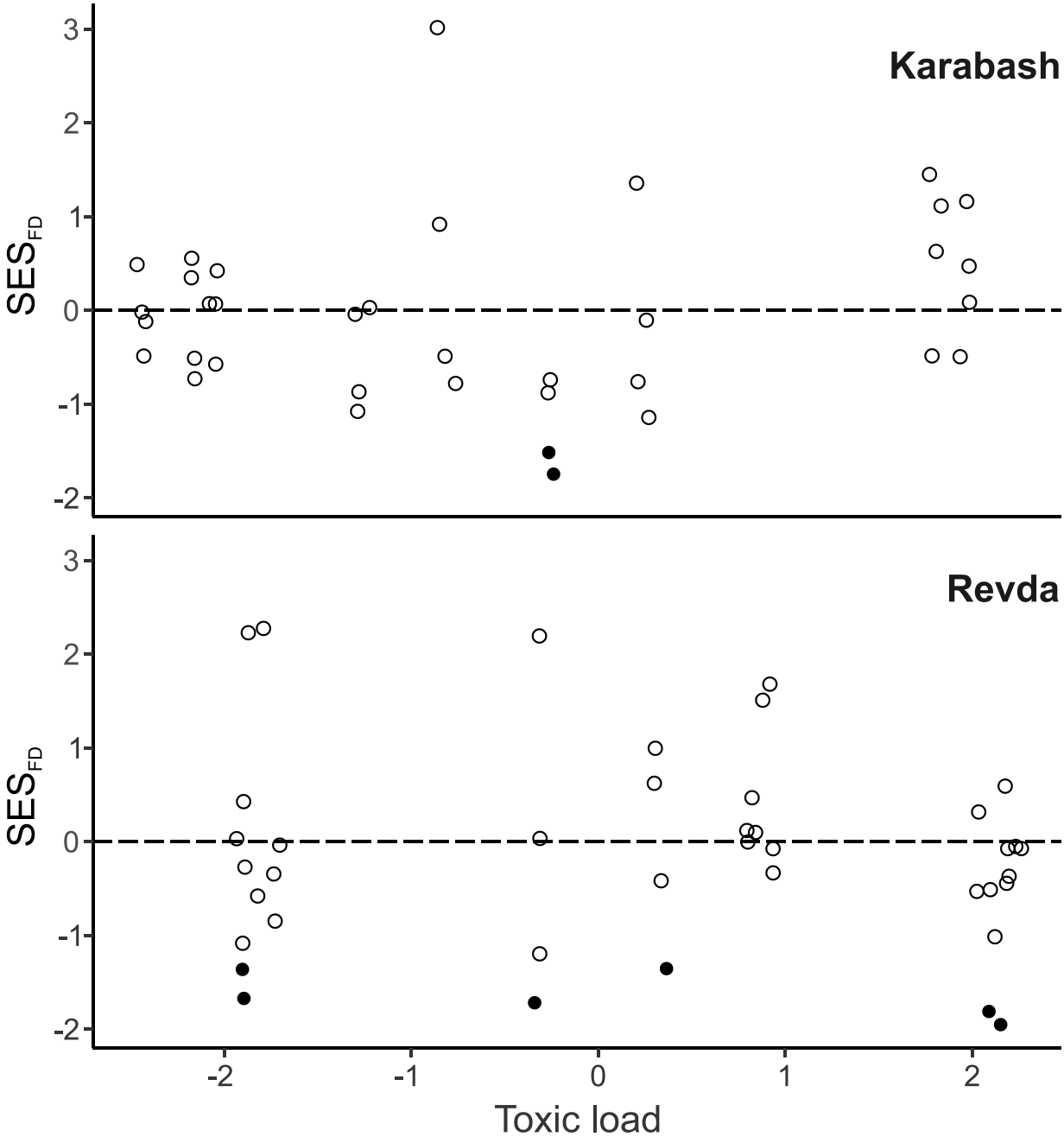

Fig. S6b. Standardized effect sizes of within-community functional (SES_{FD}) dissimilarity of forest birds along pollution gradients near Karabash (industrial barren excluded, upper graphs) and Revda (lower graphs) copper smelters. Circles refer to individual plots. Filled circles denote SES values that differ significantly from the null model ($p < 0.05$). To avoid overplotting, points along the axis with toxic load were slightly jittered.

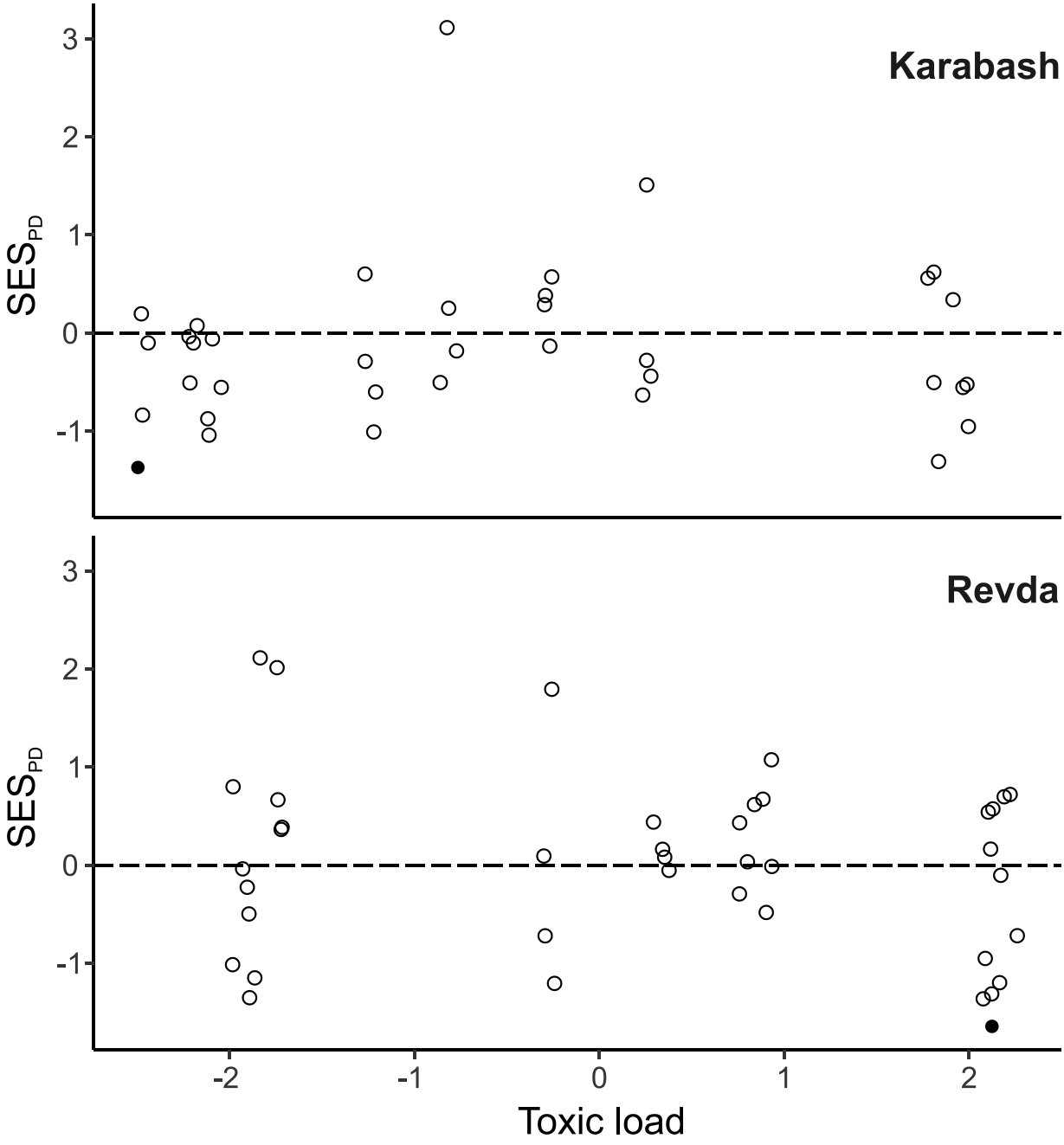

Fig. S6c. Standardized effect sizes of within-community and phylogenetic (SES_{PD}) dissimilarity of forest birds along pollution gradients near Karabash (industrial barren excluded, upper graphs) and Revda (lower graphs) copper smelters. Circles refer to individual plots. Filled circles denote SES values that differ significantly from the null model ($p < 0.05$). To avoid overplotting, points along the axis with toxic load were slightly jittered.

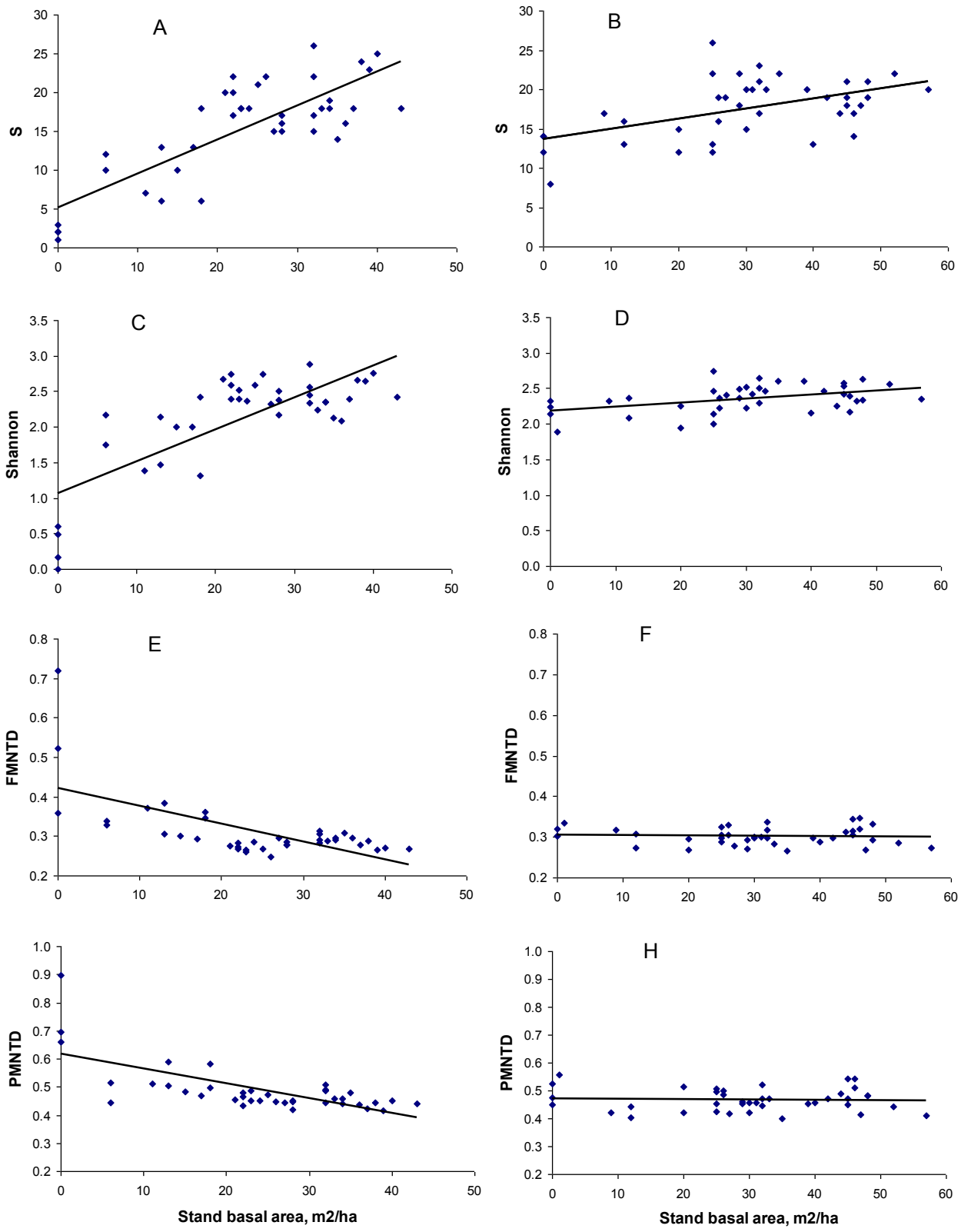

Fig. S7. Association of bird diversity indices (species richness per plot, Shannon diversity, functional and phylogenetic nearest neighbor distances) with stand basal area near Karabash (A, C, E, G) and Revda (B, D, F, H) copper smelters. Points refer to individual plots.

Table S1
Habitat characteristics (mean and standard deviation) and their dependence on toxic load and study region (*n*=10 sites in each region, *df*=3, 16). Significant values are in bold

Variables	Karabash		Revda		Source of variation					
	Mean	*SD*	Mean	*SD*	Region		Toxic load		Region × Load	
					F	*p*	*F*	*p*	*F*	*p*
Height of the top tree canopy, m	20.5	7.2	23.5	4.3	**5.54**	**0.032**	**20.03**	**<0.001**	2.80	0.114
Stand basal area, m^2/ha	23.3	11.8	30.3	13.6	**10.22**	**0.006**	**42.91**	**<0.001**	0.18	0.675
Dead stand basal area, m^2/ha	0.8	0.8	2.1	2.6	2.12	0.164	2.19	0.158	**5.37**	**0.034**
Top canopy cover, %	52.4	22.7	57.9	20.6	2.96	0.104	**28.35**	**<0.001**	0.26	0.616
Understorey cover, %	36.8	16.5	59.0	12.0	**14.26**	**0.002**	2.50	0.133	0.68	0.423
Field layer cover, %	48.6	27.8	44.5	28.2	0.01	0.941	**9.32**	**0.008**	1.92	0.185
Shannon tree diversity	0.46	0.26	1.04	0.21	**27.10**	**<0.001**	0.08	0.780	0.13	0.724

Table S2
Mean population densities (pairs/km^2) of the most common species at two copper smelter regions and Spearman correlations between density and toxic load. Correlations significant at alpha < 0.05 are shown in bold

Karabash (*n*=10 sites)

Species	*Mean*	*SD*	r_s	*p*	FDR-adjusted *p*-value
Anthus trivialis	23.248	12.63	−0.53	0.111	0.220
Cuculus canorus	0.37	0.19	−0.35	0.321	0.498
Dendrocopos major	9.59	8.67	−0.58	0.079	0.180
Emberiza citrinella	7.746	7.91	0.10	0.784	0.876
Ficedula hypoleuca	29.36	18.91	**−0.71**	**0.022**	0.098
Fringilla coelebs	65.79	26.947	**−0.68**	**0.030**	0.111
Muscicapa striata	29.25	23.84	0.006	0.986	0.986
Parus major	15.54	11.36	−0.53	0.113	0.220
Parus montanus	36.97	32.71	**−0.89**	**0.001**	**0.007**
Phoenicurus phoenicurus	4.59	5.26	−0.28	0.428	0.560
Phylloscopus collybita	5.08	3.96	−0.62	0.058	0.165
Phylloscopus trochiloides	41.10	31.75	−0.34	0.334	0.498
Sylvia atricapilla	6.21	6.51	−0.31	0.377	0.534
Sylvia borin	5.12	4.36	−0.18	0.611	0.742
Turdus philomelos	4.68	3.93	**−0.74**	**0.014**	0.080

Revda (*n*=10 sites)

Species	*Mean*	*SD*	r_s	*p*	FDR-adjusted *p*-value
Anthus trivialis	7.69	9.59	0.30	0.406	0.552
Carpodacus erythrinus	8.33	2.86	0.02	0.946	0.986
Carduelis spinus	5.71	1.848	−0.15	0.677	0.794
Cuculus optatus	0.28	0.21	−0.43	0.217	0.369
Erithacus rubecula	35.051	11.80	−0.22	0.549	0.691
Ficedula hypoleuca	7.43	5.26	**−0.93**	**<0.001**	**0.004**
Ficedula parva	15.66	14.34	**−0.89**	**0.001**	**0.007**
Fringilla coelebs	54.104	9.88	**−0.81**	**0.004**	**0.029**
Parus ater	14.12	5.89	−0.58	0.076	0.180
Parus montanus	40.33	15.74	−0.01	0.973	0.986
Phylloscopus collybita	5.31	1.848	0.09	0.799	0.876
Phylloscopus trochiloides	108.348	40.97	−0.53	0.117	0.220
Prunella modularis	5.72	2.38	−0.34	0.337	0.498
Pyrrhula pyrrhula	10.99	6.29	**−0.70**	**0.023**	0.098
Regulus regulus	20.37	16.83	**−0.63**	**0.050**	0.154
Sylvia atricapilla	9.53	6.27	−0.58	0.079	0.180
Sylvia curruca	12.49	4.85	−0.46	0.176	0.315
Turdus philomelos	11.18	5.24	**−0.64**	**0.047**	0.154
Zoothera dauma	6.58	5.17	**−0.84**	**0.002**	**0.020**

Table S3
List of species abbreviations used in Fig. 5

Species	Abbreviation	Species	Abbreviation
Accipiter nisus	An	*Milvus migrans*	Mm
Acrocephalus dumetorum	Ad	*Motacilla alba*	Ma
Anthus hodgsoni	Ah	*Muscicapa striata*	Ms
Anthus trivialis	At	*Oenanthe oenanthe*	Oe
Apus apus	Aa	*Oriolus oriolus*	Or
Bonasa bonasia	Bo	*Parus ater*	Pa
Buteo buteo	Bb	*Parus caeruleus*	Pca
Carduelis carduelis	Ca	*Parus major*	Pma
Carduelis spinus	Cs	*Parus montanus*	Pmo
Carpodacus erythrinus	Ce	*Phoenicurus phoenicurus*	Ph
Certhia familiaris	Cf	*Phylloscopus collybita*	Pcl
Coccothraustes coccothraustes	Cc	*Phylloscopus sibilatrix*	Ps
Columba palumbus	Cp	*Phylloscopus trochiloides*	Pes
Corvus corax	Cx	*Phylloscopus trochilus*	Pt
Corvus corone	Co	*Pica pica*	Pp
Cuculus canorus	Cuc	*Prunella modularis*	Pr
Cuculus optatus	Cuo	*Pyrrhula pyrrhula*	Py
Dendrocopos leucotos	Dl	*Regulus regulus*	Rr
Dendrocopos major	Dm	*Saxicola rubetra*	Sr
Dryocopus martius	Dr	*Scolopax rusticola*	Scr
Emberiza citrinella	Ec	*Sitta europaea*	Se
Erithacus rubecula	Er	*Strix aluco*	Sx
Ficedula hypoleuca	Fh	*Sylvia atricapilla*	Sa
Ficedula parva	Fp	*Sylvia borin*	Sb
Fringilla coelebs	Fc	*Sylvia communis*	Scm
Fringilla montifringilla	Fm	*Sylvia curruca*	Scu
Garrulus glandarius	Gg	*Turdus iliacus*	Ti
Hippolais icterina	Hi	*Turdus merula*	Tm
Jynx torquilla	Jt	*Turdus philomelos*	Tph
Locustella fluviatilis	Lf	*Turdus pilaris*	Tpi
Loxia curvirostra	Lc	*Turdus viscivorus*	Tv
Luscinia luscinia	Lu	*Zoothera dauma*	Zd