**SUPPLEMENTARY MATERIAL FOR: SHORT-LIVED SPECIES MOVE UPHILL FASTER UNDER CLIMATE CHANGE**

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**Figure S1.** Spatial autocorrelation of the linear mixed model residuals of the relationship between the average altitudinal shift across bird species and the geographical and spatial variables. Spatial correlogram illustrates the spatial autocorrelation of the residuals from the model for a maximal distance of 4.5 degree decimal, which corresponds to 500 km of distance.



**Figure S2.** Range shift of species in a given grid cell based on the altitudinal range of the grid. One dot is one species in a given grid cell.

**Table S1.** Definitions and references of each species’ trait used for the analysis of the role of species-specific differences in the altitudinal range shifts. References to data, trait definition, and computation tool origin are included. For full references, see the main text.

|  |  |  |
| --- | --- | --- |
| **Trait** | **Definition** | **Reference(s)** |
| Clutch size  | Annual mean number of eggs | Storchová & Hořák 2018 |
| Longevity | Mean of maximum longevity (years) | De Magalhaes & Costa 2009 |
| Body mass | Mean body mass (g) | Wilman et al. 2014 |
| Main habitat | Main habitat that the species uses, divided into four categories: farmland-urban, forest, wetland and rocky outcrops, montane | Lehikoinen & Virkkala 2016 |
| Diet specialization | Quantified as Shannon’s diversity index (calculated with R package ‘vegan’, Oksanen *et al.*, 2019) of the proportional use of different diet categories: invertebrate, vertebrate (endotherm), vertebrate (ectotherm), fish, vertebrate (unknown), scavenge, fruit, nectar or pollen, seed, other plant material. | Wilman et al. 2014 |
| Migration strategy | Migration behaviour divided into four categories: resident, partial migrant (including species from which a part of the population migrates), short distance migrant (including species that winter in the Baltic countries or Western Europe), long distance migrant (including wintering further than the Mediterranean area) | Laaksonen & Lehikoinen 2013 |
| Species temperature index | Long-term average temperature experienced by individuals across the range (species temperature index, STI). The values were obtained from the combination of the spatial distribution of the mean temperature (WordlClim v. 1.0) of birds breeding season (from March to August) and data from the EBCC atlas of European breeding birds. | Devictor et al. 2008, Hijmans et al. 2015, Hagemeijer & Blair 1997 |
| Population trend | The population tendency in the study area during the breeding season between the period 1998-2019, divided into three categories: decreasing population, stable population, increasing population. | Svensk Fågeltaxering 2019 |

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**Table S2.** List of species and their traits included in the analyses. For migration strategy (Migr.), the levels are: 1 = resident, 2 = partial migrant (species from which a part of the population migrates), 3 = short distance migrant (wintering in the Baltic countries or Western Europe), and 4 = long distance migrant (wintering further than the Mediterranean area). For the habitat, the levels are: 1 = farmland-urban, 2 = forest, 3 = wetlands (rocky outcrops), and 4 = montane. Finally, for the population tendency (trend), the levels are: 1= decreasing, 2 = no trend, and 3= increasing population.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | English name | Body mass | Diet | Migr. | Habitat | STI | Trend | Clutch size | Longevity | Order | Family |
| *Acanthis flammea* | Common redpoll | 13 | 1.089 | 2 | 2 | 8.19 | 1 | 5 | 12.2 | Passeriformes | Fringillidae |
| *Actitis hypoleucos* | Common sandpiper | 48 | 1.221 | 4 | 3 | 11.21 | 1 | 4 | 14.5 | Charadriiformes | Scolopacidae |
| *Anthus pratensis* | Meadow pipit | 18.4 | 0.500 | 3 | 4 | 9.95 | 2 | 4 | 8.8 | Passeriformes | Motacillidae |
| *Anthus trivialis* | Tree pipit | 23.33 | 1.228 | 4 | 2 | 11.24 | 3 | 4 | 8.8 | Passeriformes | Motacillidae |
| *Apus apus* | Swift | 37.6 | 0.000 | 4 | 1 | 12.45 | 1 | 2.5 | 21.1 | Caprimulgiformes | Apodidae |
| *Bucephala clangula* | Goldeneye | 918.56 | 0.940 | 3 | 3 | 8.47 | 1 | 9.5 | 18.4 | Anseriformes | Anatidae |
| *Buteo lagopus* | Rough-legged buzzard | 949.76 | 0.639 | 3 | 2 | 5.23 | 2 | 3.5 | 18.8 | Accipitriformes | Accipitridae |
| *Calcarius lapponicus* | Lapland bunting | 27.84 | 0.693 | 3 | 4 | 4.06 | 1 | 5.5 | 6 | Passeriformes | Calcariidae |
| *Certhia familiaris* | Treecreeper | 9 | 0.673 | 2 | 2 | 11.12 | 3 | 5.5 | 8.2 | Passeriformes | Certhiidae |
| *Chloris chloris* | Greenfinch | 26 | 0.000 | 2 | 1 | 12.60 | 1 | 5 | 13.6 | Passeriformes | Fringillidae |
| *Chroicocephalus ridibundus* | Black-headed Gull | 284 | 0.802 | 2 | 3 | 11.07 | 1 | 2.5 | 32.9 | Charadriiformes | Laridae |
| *Columba palumbus* | Common Wood Pigeon | 490 | 1.089 | 3 | 1 | 12.22 | 3 | 1.5 | 17.7 | Columbiformes | Columbidae |
| *Corvus corax* | Raven | 927.97 | 2.025 | 1 | 2 | 11.74 | 2 | 5 | 69 | Passeriformes | Corvidae |
| *Corvus cornix* | Hooded crow | 570 | 1.557 | 1 | 1 | 12.13 | 1 | 4.333 | 16.8 | Passeriformes | Corvidae |
| *Corvus corone* | Carrion Crow | 570 | 1.557 | 2 | 1 | 12.13 | 1 | 4.5 | 19.2 | Passeriformes | Corvidae |
| *Corvus monedula* | Jackdaw | 246 | 1.314 | 2 | 1 | 12.96 | 3 | 5 | 20.3 | Passeriformes | Corvidae |
| *Cuculus canorus* | Common Cuckoo | 111.36 | 0.325 | 4 | 2 | 12.14 | 3 | 9.2 | 12.9 | Cuculiformes | Cuculidae |
| *Cyanistes caeruleus* | Blue tit | 13.3 | 1.221 | 1 | 2 | 12.74 | 3 | 11 | 14.6 | Passeriformes | Paridae |
| *Cygnus cygnus* | Whooper swan | 9349.99 | 0.000 | 3 | 3 | 6.27 | 3 | 4 | 26.5 | Anseriformes | Anatidae |
| *Delichon urbicum* | House martin | 14.5 | 0.000 | 4 | 1 | 12.35 | 1 | 4 | 15 | Passeriformes | Hirundinidae |
| *Dendrocopos major* | Great spotted woodpecker | 74.94 | 1.168 | 1 | 2 | 12.12 | 3 | 5.5 | 12.7 | Piciformes | Picidae |
| *Dryocopus martius* | Black woodpecker | 321 | 0.000 | 1 | 2 | 11.12 | 1 | 5 | 14 | Piciformes | Picidae |
| *Emberiza citrinella* | Yellowhammer | 29.7 | 0.898 | 2 | 1 | 11.55 | 1 | 4 | 13.2 | Passeriformes | Emberizidae |
| *Emberiza schoeniclus* | Reed bunting | 18.4 | 1.030 | 3 | 3 | 11.27 | 1 | 4.5 | 12.2 | Passeriformes | Emberizidae |
| *Erithacus rubecula* | Robin | 17.7 | 1.609 | 3 | 2 | 12.00 | 3 | 5 | 19.3 | Passeriformes | Muscicapidae |
| *Ficedula hypoleuca* | Pied flycatcher | 13.79 | 0.000 | 4 | 2 | 10.43 | 2 | 6.5 | 15 | Passeriformes | Muscicapidae |
| *Fringilla coelebs* | Chaffinch | 23.81 | 0.950 | 3 | 2 | 12.30 | 3 | 4.5 | 29 | Passeriformes | Fringillidae |
| *Fringilla montifringilla* | Brambling | 23.19 | 1.055 | 3 | 2 | 7.03 | 1 | 6 | 14.8 | Passeriformes | Fringillidae |
| *Gallinago gallinago* | Snipe | 112.94 | 0.639 | 3 | 3 | 10.27 | 3 | 4 | 18.2 | Charadriiformes | Scolopacidae |
| *Garrulus glandarius* | Jay | 159.46 | 1.280 | 1 | 2 | 12.47 | 2 | 6 | 17.9 | Passeriformes | Corvidae |
| *Gavia arctica* | Black-throated diver | 2251.1 | 0.802 | 3 | 3 | 6.83 | 2 | 2 | 28 | Gaviiformes | Gaviidae |
| *Grus grus* | Common Crane | 5499.99 | 1.609 | 3 | 3 | 9.50 | 3 | 2 | 43 | Gruiformes | Gruidae |
| *Hirundo rustica* | Swallow | 17.91 | 0.639 | 4 | 1 | 12.43 | 3 | 4.5 | 16 | Passeriformes | Hirundinidae |
| *Lagopus lagopus* | Willow Ptarmigan | 566.86 | 0.325 | 1 | 2 | 6.74 | 1 | 7.5 | 9 | Galiiformes | Phasianidae |
| *Lagopus muta* | Rock Ptarmigan | 535.3 | 0.802 | 1 | 4 | 6.03 | 2 | 6.5 | 12 | Galiiformes | Phasianidae |
| *Larus canus* | Common Gull | 412.53 | 1.194 | 3 | 3 | 8.57 | 2 | 3 | 33.7 | Charadriiformes | Laridae |
| *Lophophanes cristatus* | Crested tit | 11.04 | 0.950 | 1 | 2 | 11.71 | 3 | 6.5 | 11.6 | Passeriformes | Paridae |
| *Loxia curvirostra* | Crossbill | 38.29 | 1.030 | 2 | 2 | 10.49 | 3 | 4 | 16.1 | Passeriformes | Fringillidae |
| *Luscinia svecica* | Bluethroat | 17.23 | 1.089 | 4 | 4 | 10.16 | 2 | 5.5 | 11.4 | Passeriformes | Muscicapidae |
| *Lyrurus tetrix* | Black cock | 1068.66 | 0.940 | 1 | 2 | 9.00 | 2 | 8.5 | 12.2 | Galiiformes | Phasianidae |
| *Motacilla alba* | Pied wagtail | 23.93 | 0.000 | 3 | 3 | 11.99 | 1 | 5.5 | 13.7 | Passeriformes | Motacillidae |
| *Motacilla flava* | Yellow wagtail | 17.68 | 0.940 | 4 | 3 | 12.14 | 2 | 5 | 8.8 | Passeriformes | Motacillidae |
| *Muscicapa striata* | Spotted flycatcher | 15.9 | 0.500 | 4 | 2 | 12.15 | 3 | 5 | 11.8 | Passeriformes | Muscicapidae |
| *Numenius arquata* | Curlew | 802.99 | 1.089 | 3 | 1 | 10.05 | 1 | 4 | 31.8 | Charadriiformes | Scolopacidae |
| *Numenius phaeopus* | Whimbrel | 364.57 | 1.089 | 4 | 3 | 5.89 | 2 | 4 | 24.2 | Charadriiformes | Scolopacidae |
| *Oenanthe oenanthe* | Wheatear | 25.39 | 0.802 | 4 | 3 | 11.62 | 2 | 5.5 | 10.1 | Passeriformes | Muscicapidae |
| *Parus major* | Great tit | 16.25 | 1.471 | 1 | 2 | 12.34 | 3 | 10 | 15.4 | Passeriformes | Paridae |
| *Periparus ater* | Coal tit | 9.2 | 1.471 | 1 | 2 | 11.91 | 2 | 8.5 | 9.5 | Passeriformes | Paridae |
| *Phoenicurus phoenicurus* | Redstart | 14.59 | 0.500 | 4 | 2 | 11.31 | 3 | 6 | 10.2 | Passeriformes | Muscicapidae |
| *Phylloscopus collybita* | Chiffchaff | 8.3 | 0.639 | 3 | 2 | 11.95 | 3 | 5.5 | 8 | Passeriformes | Phylloscopidae |
| *Phylloscopus sibilatrix* | Wood warbler | 9.2 | 0.500 | 4 | 2 | 11.38 | 2 | 6 | 10 | Passeriformes | Phylloscopidae |
| *Phylloscopus trochilus* | Willow warbler | 8.7 | 0.639 | 4 | 2 | 10.46 | 2 | 6 | 11.8 | Passeriformes | Phylloscopidae |
| *Pica pica* | Magpie | 217.48 | 1.748 | 1 | 1 | 12.16 | 2 | 6 | 21.7 | Passeriformes | Corvidae |
| *Pluvialis apricaria* | Golden plover | 214 | 0.940 | 3 | 4 | 7.00 | 2 | 4 | 12.8 | Charadriiformes | Charadriidae |
| *Poecile montanus* | Willow tit | 11.1 | 0.950 | 1 | 2 | 10.20 | 1 | 7.5 | 11.3 | Passeriformes | Paridae |
| *Prunella modularis* | Dunnock | 20.24 | 0.693 | 3 | 2 | 10.91 | 3 | 5 | 20.8 | Passeriformes | Prunellidae |
| *Regulus regulus* | Goldcrest | 5.54 | 0.000 | 2 | 2 | 10.81 | 1 | 10 | 7 | Passeriformes | Regulidae |
| *Saxicola rubetra* | Whinchat | 16.6 | 0.802 | 4 | 1 | 11.30 | 1 | 5.5 | 6.9 | Passeriformes | Muscicapidae |
| *Spinus spinus* | Siskin | 13.24 | 1.314 | 2 | 2 | 10.24 | 3 | 4 | 13.5 | Passeriformes | Fringillidae |
| *Stercorarius longicaudus* | Long-tailed Jaeger | 287.9 | 0.898 | 4 | 4 | 3.57 | 2 | 2 | 14 | Charadriiformes | Stercorariidae |
| *Sturnus vulgaris* | Starling | 77.14 | 1.696 | 3 | 1 | 11.80 | 1 | 5 | 22.9 | Passeriformes | Sturnidae |
| *Sylvia atricapilla* | Blackcap | 16.7 | 1.168 | 4 | 2 | 12.62 | 3 | 5 | 13.8 | Passeriformes | Sylviidae |
| *Sylvia borin* | Garden warbler | 18.2 | 0.943 | 4 | 2 | 11.32 | 3 | 4.5 | 24 | Passeriformes | Sylviidae |
| *Sylvia communis* | Greater whitethroat | 15.1 | 0.898 | 4 | 1 | 12.65 | 3 | 4.5 | 8.9 | Passeriformes | Sylviidae |
| *Sylvia curruca* | Lesser whitethroat | 11.44 | 1.089 | 4 | 2 | 11.64 | 1 | 5 | 9 | Passeriformes | Sylviidae |
| *Tringa glareola* | Wood sandpiper | 62.05 | 0.000 | 4 | 3 | 7.67 | 2 | 4 | 11.6 | Charadriiformes | Scolopacidae |
| *Tringa nebularia* | Greenshank | 187 | 0.639 | 4 | 3 | 6.45 | 2 | 4 | 24.4 | Charadriiformes | Scolopacidae |
| *Tringa ochropus* | Green sandpiper | 71.4 | 0.802 | 4 | 2 | 9.88 | 3 | 4 | 11.5 | Charadriiformes | Scolopacidae |
| *Tringa totanus* | Redshank | 129 | 0.639 | 3 | 3 | 11.04 | 3 | 4 | 26.9 | Charadriiformes | Scolopacidae |
| *Troglodytes troglodytes* | Wren | 9.74 | 1.228 | 3 | 2 | 12.24 | 3 | 6.5 | 7 | Passeriformes | Troglodytidae |
| *Turdus iliacus* | Redwing | 61.2 | 1.280 | 3 | 2 | 8.25 | 1 | 5 | 18.8 | Passeriformes | Turdidae |
| *Turdus merula* | Blackbird | 102.73 | 1.221 | 2 | 2 | 12.58 | 3 | 4 | 21.8 | Passeriformes | Turdidae |
| *Turdus philomelos* | Song thrush | 67.74 | 1.089 | 3 | 2 | 11.40 | 3 | 4 | 17.7 | Passeriformes | Turdidae |
| *Turdus pilaris* | Fieldfare | 106 | 0.611 | 3 | 1 | 10.03 | 1 | 5.5 | 18.1 | Passeriformes | Turdidae |
| *Turdus torquatus* | Ring ouzel | 109 | 1.314 | 3 | 4 | 9.03 | 3 | 4 | 9.1 | Passeriformes | Turdidae |
| *Turdus viscivorus* | Mistle thrush | 117.37 | 1.332 | 3 | 2 | 11.92 | 3 | 4 | 21.2 | Passeriformes | Turdidae |
| *Vanellus vanellus* | Lapwing | 218.37 | 0.000 | 3 | 1 | 11.53 | 1 | 4 | 24.5 | Charadriiformes | Charadriidae |

**Table S3.** Results of the sensitivity mixed model analyses for different combinations of the data selection criteria: the minimum altitudinal range within the grid cell (Ar), the minimum relative abundance of the included species per grid cell (Rag), and the minimum number of grid cells where the included species occur (Nbg). Each sensitivity model was structured as follows: Mean altitude ~ Period + Grid longitude + Altitudinal range grid + (1|Species) + (1|Country/Grid identity) (in a syntax of lmer –function in R). For each variable, the slope is reported. Asterisks (\*) represents the significance of the respective slope (\*\*\* p < 0.001; \*\* p < 0.01; \* p < 0.05).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Combinations** | **Rag: 5****Ar: 300****Nbg: 1** | **Rag: 5****Ar: 300****Nbg: 3** | **Rag: 5****Ar: 300****Nbg: 5** | **Rag: 3****Ar: 300****Nbg: 1** | **Rag: 3****Ar: 300****Nbg: 3** | **Rag: 3****Ar: 300****Nbg: 5** | **Rag: 10****Ar: 300****Nbg: 1** | **Rag: 10****Ar: 300****Nbg: 3** |
| **Number of  species** | 99 | 78 | 61 | 114 | 89 | 74 | 81 | 55 |
| **Number of grids** | 37 | 37 | 37 | 37 | 37 | 37 | 36 | 36 |
| **Intercept** | 388.35\*\* | 390.66\*\* | 401.17\*\* | 374.71\* | 390.28\*\* | 385.63\*\* | 364.59\* | 363.89\* |
| **Study period** | 12.65\*\*\* | 12.29\*\*\* | 13.54\*\*\* | 12.67\*\*\* | 13.05\*\*\* | 13.75\*\*\* | 10.23\*\* | 10.28\* |
| **Mean longitude of the grid cell** | -18.75\*\* | -18.77 \*\* | -18.75\*\* | -18.19\* | -18.38\* | -18.20\* | -17.47\* | -17.52\* |
| **Altitudinal range of the grid cell** | 0.81\*\*\* | 0.81\*\*\* | 0.81\*\*\* | 0.81\*\*\* | 0.80\*\*\* | 0.80\*\*\* | 0.83\*\*\* | 0.83\* |

**Table S4**. Species-specific estimates of altitudinal density shifts of 77 bird species in Norway and Sweden.

|  |  |  |
| --- | --- | --- |
| Species | Longevity | ∆ Mean shift |
| *Acanthis flammea* | 12.2 | 62.0 |
| *Actitis hypoleucos* | 14.5 | -6.7 |
| *Anthus pratensis* | 8.8 | 14.8 |
| *Anthus trivialis* | 8.8 | 7.2 |
| *Apus apus* | 21.1 | 27.3 |
| *Bucephala clangula* | 18.4 | -23.4 |
| *Buteo lagopus* | 18.8 | -66.5 |
| *Calcarius lapponicus* | 6 | -10.3 |
| *Certhia familiaris* | 8.2 | 10.9 |
| *Chloris chloris* | 13.6 | -3.1 |
| *Chroicocephalus ridibundus* | 32.9 | -19.1 |
| *Columba palumbus* | 17.7 | 13.9 |
| *Corvus corax* | 69 | -8.2 |
| *Corvus cornix* | 16.8 | -15.1 |
| *Corvus corone* | 19.2 | 32.2 |
| *Corvus monedula* | 20.3 | -3.1 |
| *Cuculus canorus* | 12.9 | 10.3 |
| *Cyanistes caeruleus* | 14.6 | 16.5 |
| *Cygnus cygnus* | 26.5 | 28.4 |
| *Delichon urbicum* | 15 | 27.0 |
| *Dendrocopos major* | 12.7 | 30.6 |
| *Dryocopus martius* | 14 | 20.7 |
| *Emberiza citrinella* | 13.2 | -1.0 |
| *Emberiza schoeniclus* | 12.2 | 21.1 |
| *Erithacus rubecula* | 19.3 | 4.4 |
| *Ficedula hypoleuca* | 15 | 6.9 |
| *Fringilla coelebs* | 29 | 14.3 |
| *Fringilla montifringilla* | 14.8 | 10.8 |
| *Gallinago gallinago* | 18.2 | 44.3 |
| *Garrulus glandarius* | 17.9 | 31.1 |
| *Gavia arctica* | 28 | -16.4 |
| *Grus grus* | 43 | -15.5 |
| *Hirundo rustica* | 16 | 21.8 |
| *Lagopus lagopus* | 9 | 36.6 |
| *Lagopus muta* | 12 | 6.8 |
| *Larus canus* | 33.7 | 8.3 |
| *Lophophanes cristatus* | 11.6 | 31.2 |
| *Loxia curvirostra* | 16.1 | 99.3 |
| *Luscinia svecica* | 11.4 | 17.4 |
| *Lyrurus tetrix* | 12.2 | -24.0 |
| *Motacilla alba* | 13.7 | -36.3 |
| *Motacilla flava* | 8.8 | 41.6 |
| *Muscicapa striata* | 11.8 | 9.2 |
| *Numenius arquata* | 31.8 | -54.7 |
| *Numenius phaeopus* | 24.2 | -1.1 |
| *Oenanthe oenanthe* | 10.1 | 31.4 |
| *Parus major* | 15.4 | 5.6 |
| *Periparus ater* | 9.5 | 12.7 |
| *Phoenicurus phoenicurus* | 10.2 | 4.5 |
| *Phylloscopus collybita* | 8 | 27.0 |
| *Phylloscopus sibilatrix* | 10 | -19.9 |
| *Phylloscopus trochilus* | 11.8 | 11.7 |
| *Pica pica* | 21.7 | -4.8 |
| *Pluvialis apricaria* | 12.8 | 11.3 |
| *Poecile montanus* | 11.3 | 48.3 |
| *Prunella modularis* | 20.8 | 7.4 |
| *Regulus regulus* | 7 | 13.1 |
| *Saxicola rubetra* | 6.9 | 20.8 |
| *Spinus spinus* | 13.5 | 10.9 |
| *Stercorarius longicaudus* | 14 | 25.2 |
| *Sturnus vulgaris* | 22.9 | -1.8 |
| *Sylvia atricapilla* | 13.8 | -3.5 |
| *Sylvia borin* | 24 | 18.0 |
| *Sylvia communis* | 8.9 | 49.9 |
| *Sylvia curruca* | 9 | 32.1 |
| *Tringa glareola* | 11.6 | 10.7 |
| *Tringa nebularia* | 24.4 | -1.7 |
| *Tringa ochropus* | 11.5 | 15.9 |
| *Tringa totanus* | 26.9 | -26.5 |
| *Troglodytes troglodytes* | 7 | 37.6 |
| *Turdus iliacus* | 18.8 | 6.6 |
| *Turdus merula* | 21.8 | 14.0 |
| *Turdus philomelos* | 17.7 | 9.5 |
| *Turdus pilaris* | 18.1 | 3.6 |
| *Turdus torquatus* | 9.1 | -2.1 |
| *Turdus viscivorus* | 21.2 | 20.8 |
| *Vanellus vanellus* | 24.5 | 4.5 |