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The future distribution of wetland birds breeding in Europe validated against observed changes in distribution

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**1 The future distribution of wetland birds breeding in Europe validated against observed
2 changes in distribution**

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67 **Keywords:** European Breeding Bird Atlas, breeding distributions, climate change, land-use
68 change, species distribution models
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Accepted Manuscript

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3 **74 Abstract**
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5 75 Wetland bird species have been declining in population size worldwide as climate warming
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7 76 and land-use change affect their suitable habitats. We used species distribution models
8
9 77 (SDMs) to predict changes in range dynamics for 64 non-passerine wetland birds breeding in
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11 78 Europe, including range size, position of centroid, and margins. We fitted the SDMs with
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13 79 data collected for the first European Breeding Bird Atlas (EBBA1) and climate and land-use
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15 80 data to predict distributional changes over a century (the 1970s–2070s). The predicted annual
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17 81 changes were then compared to observed annual changes in range size and range centroid
18
19 82 over a time period of 30 years using data from the second European Breeding Bird Atlas
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21 83 (EBBA2). Our models successfully predicted ca. 75% of the 64 bird species to contract their
22
23 84 breeding range in the future, while the remaining species (mostly southerly breeding species)
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25 85 were predicted to expand their breeding ranges northward. The northern margins of southerly
26
27 86 species and southern margins of northerly species, both, predicted to shift northward.
28
29 87 Predicted changes in range size and shifts in range centroids were broadly positively
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31 88 associated with the observed changes, although some species deviated markedly from the
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33 89 predictions. The predicted average shift in core distributions was ca. 5 km/year towards the
34
35 90 north (5% Northeast, 45% North, and 40% Northwest), compared to a slower observed
36
37 91 average shift of ca. 3.9 km/year. Predicted changes in range centroids were generally larger
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39 92 than observed changes, which suggests that bird distribution changes may lag behind
40
41 93 environmental changes leading to “climate debt”. We suggest that predictions of SDMs
42
43 94 should be viewed as qualitative rather than quantitative outcomes, indicating that care should
44
45 95 be taken concerning single species. Still, our results highlight the urgent need for
46
47 96 management actions such as wetland creation and restoration to improve wetland birds'
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49 97 resilience to the expected environmental changes in the future.
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98 Introduction

99 Considerable effort has been invested in conserving biodiversity over recent decades. Yet,
100 biodiversity losses continue at an unprecedented rate, as reflected by ongoing declines in
101 population size and range contractions for many species worldwide (Tittensor *et al* 2014,
102 Pievani 2014). The observed changes in the distribution of many species during recent
103 decades have been primarily attributed to the ongoing rapid climate change, and to large-
104 scale habitat loss (Reif and Flousek 2012, Gillings *et al* 2015, Brommer *et al* 2012, Pavón-
105 Jordán *et al* 2019, Hovick *et al* 2016). Historical data clearly show that species may respond
106 to climate and habitat changes by adjusting their spatial distributions (Brommer *et al* 2012,
107 Pavón-Jordán *et al* 2019, Parmesan *et al* 1999, Thomas and Lennon 1999, Littlefield *et al*
108 2017). Therefore, it is recommended to consider climate as well as land-use variables to
109 better describe drivers of species distribution changes (Newbold 2018).

110 Bird species that are ecologically dependent on wetlands are commonly used as indicators of
111 wetland ecosystem health (Williamson *et al* 2013) and provide valuable ecosystem services
112 such as food supply, pest control, seed dispersal, and cultural services such as recreation and
113 hunting (Hamilton *et al* 1994, Lehtikoinen *et al* 2017, Teo 2001, Green and Elmberg 2014).
114 Still, many species of wetland birds have been declining worldwide and a subset has been
115 classified as threatened species during the 20th century (Wang *et al* 2018, BirdLife
116 International 2021).

117 The expected changes in environmental conditions due to increases in global temperatures
118 and changes in the land-use patterns that are likely to affect species distributions in the 21st
119 century (IPCC 2014). Determining the expected change in range dynamics such as the
120 direction and the magnitude of change in range margins and centroid allows for evaluating
121 current networks and boundaries of protected areas with the possibility of moving from static

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2
3 122 to dynamic designs where the boundaries of protected areas change over time (Rayfield *et al*
4
5 123 2008, Cashion *et al* 2020). The range centroid is the center of gravity of a distribution
6
7 124 polygon and represents the core distribution of a species, where the abiotic conditions are
8
9 125 assumed to be optimal for the species' biological and ecological functions (Sales *et al* 2020).
10
11 126 Range dynamics may differ between the centroid and the margins but relatively few studies
12
13 127 have considered the multiple changes in range characteristics (i.e. changes in range size,
14
15 128 centroid, and margins). Huntley *et al* (2007) used a climatic-surface model on European birds
16
17 129 to predict overall changes in range characteristics considering climate scenarios only and did
18
19 130 not incorporate land-use scenarios. However, studies have shown that incorporating land-use
20
21 131 information with climate information can significantly improve the predictive ability of
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23 132 species distribution models (Sohl 2014, Lee and Jetz 2011).
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26 133 Despite the surge in use of species distribution models (SDMs) to predict future distributions
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28 134 during the last two decades (Newbold 2018, Soutan *et al* 2019), few studies have been able
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30 135 to use independent data to evaluate the predictive accuracy and temporal transferability of
31
32 136 SDMs (Areias Guerreiro *et al* 2016, Barbet-Massin *et al* 2018). Nevertheless, the few studies
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34 137 available have reported interesting differences between the observed and predicted changes in
35
36 138 species ranges, which provide new insights that will help to improve SDM methods (Brun *et*
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38 139 *al* 2016, Virkkala and Lehikoinen 2014).
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41 140 Here, we investigate the potential impacts of projected climate and land-use changes on the
42
43 141 breeding distributions of 64 non-passerine wetland bird species in Europe, based on
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45 142 distribution data collected for the first European Breeding Bird Atlas (Hagemeijer and Blair
46
47 143 1997). We advance upon previous analyses for wetland birds in Europe (Huntley *et al* 2007,
48
49 144 2008) by (i) incorporating land-use change scenarios together with climate change scenarios,
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51 145 (ii) using ensemble SDMs, and (iii) comparing predicted changes from the SDMs to the
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3 146 actual observed changes from the second European Breeding Bird Atlas (EBBA2, Keller *et al*
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5 147 2020).

7
8 148 **Methods**

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11 149 Species occurrences for 64 non-passerine wetland bird species that breed in Europe were
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13 150 obtained from the first Atlas of European Breeding Birds (Hagemeijer and Blair 1997),
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15 151 hereafter “EBBA1”, which was compiled and published by the European Bird Census
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18 152 Council (EBCC). Appendix S1: Species data and study area.

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21 153 Four climatic variables from the CHELSA database, known to have high ecological relevance
22
23 154 for bird distribution, were considered in the SDMs (Karger *et al* 2017, Karger and
24
25 155 Zimmermann 2018): 1) mean seasonal temperature during April–July (Araújo *et al* 2009), 2)
26
27 156 total seasonal precipitation during April–July (Barbet-Massin *et al* 2012), 3) seasonal
28
29 157 growing degree-days $>5^{\circ}\text{C}$ (GDD) (Barbet-Massin *et al* 2012, Newbold 2018), and 4) the
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31 158 seasonal water balance (Skov and Svenning 2004, Newbold 2018). Appendix S2:
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33 159 Environmental variables.

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38 160 Four land-use variables were considered in the SDMs: 1) “wetland habitat” (Lehner and Döll
39
40 161 2004), 2) “pasture” henceforth referred to as the “agricultural land”, 3) “forest land”, and 4)
41
42 162 “urban land” as defined by Hurtt *et al* (2019, 2020). Land-use variables were compiled for
43
44 163 1984 which was the mid-year of the 24-year period for EBBA1 (1972 to 1995, Appendix S2:
45
46 164 Environmental variables).

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50 165 For future projections, we obtained climatic variables for the future period 2061–2080
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52 166 (henceforth referred to as the “2070”) based on five Global Climate Models (GCMs), bcc-
53
54 167 csm1-1, CCSM4, GISS-E2-R, HadGEM2-AO, and MRI-CGCM3, under four representative
55
56 167 concentration pathways (RCP2.6, RCP4.5, RCP6, and RCP8.5) from CHELSA (Karger *et al*
57
58 168 2017, Karger and Zimmermann 2018). The land-use scenarios for the future period 2070
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3 170 were obtained from land-use harmonization (Hurtt *et al* 2020). The four RCPs represent
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5 171 different socioeconomic models, ranging from low (RCP2.6) to high (RCP8.5) scenarios of
6
7 172 greenhouse gas emissions (Polaina *et al* 2021). Appendix S3: Future environmental variables.

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10 173 We modeled the breeding ranges of wetland birds by fitting ensemble SDMs using four
11
12 174 commonly used presence-absence SDM algorithms (GLM, GAM, GBM, and RF) with
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14 175 default settings available within the “biomod2” R package (Thuiller *et al* 2016, R Core Team
15
16 176 2016). SDM predictive performance was evaluated using the area under the curve (AUC; a
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18 177 threshold-independent metric) (Fielding and Bell 1997) and the True Skill Statistic (TSS; a
19
20 178 threshold-dependent metric) (Allouche *et al* 2006). Appendix S4: Model performance.

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23 179 The modeled breeding ranges during the reference period 1972–1995 for EBBA1 were
24
25 180 projected into the future (2070) under four RCPs and five GCMs. To minimize the prediction
26
27 181 uncertainty due to the large variability among the GCMs, we used the median of five GCMs
28
29 182 (Goberville *et al* 2015, Cianfrani *et al* 2018, Soutan *et al* 2019). Extrapolation Detection tool
30
31 183 (ExDet) (Mesgaran *et al* 2014) was used to assess the presence of non-analog environmental
32
33 184 conditions and to determine the degree of extrapolation (Appendix S5: non-analog
34
35 185 environments and extrapolation). Last, the reference and future distribution ranges were
36
37 186 classified into suitable and unsuitable ranges using a threshold that maximizes both model
38
39 187 sensitivity and specificity (Liu *et al* 2013).

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42 188 Three metrics were used to quantify the impact of environmental changes on the dynamics of
43
44 189 breeding ranges for wetland birds: (1) percent change in the area of the breeding range, (2)
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46 190 directionality and displacement shifts for the range centroid, and (3) latitudinal shifts of the
47
48 191 northern and southern margins of the range (km/year). Changes in breeding range size were
49
50 192 measured by calculating the range expansion (number of gained pixels; G) and range
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52 193 contraction (number of lost pixels; L), and relating them to the size of the reference range
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3 194 (total number of pixels; N) using “*BIOMOD_RangeSize*” function in the “biomod2” R
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5 195 package (Thuiller *et al* 2016). Directionality and displacement shifts of the geographic range
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7 196 centroid were quantified by delineating Standard Deviation Ellipse (SDE) (Furfey 1927,
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9
10 197 Johnson and Wilson 2009) over the reference and future ranges of a given species. As such,
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12 198 the centroid of SDE was used to represent species ranges’ centroid. We quantified the
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14 199 directionality and displacement shifts in the range centroid by calculating the direction as a
15
16 200 bearing relative to true north (0°) and the linear distances respectively, between the centroids
17
18 201 of the reference and future ranges. SDE was calculated using “*calc_sde*” function
19
20 202 implemented in “*aspace*” R package (Bui *et al* 2012), while both bearing and linear distance
21
22 203 were calculated using “*bearing*” and “*distGeo*” functions, respectively, implemented in
23
24 204 “*geosphere*” R package (Hijmans 2019). It is expected that in case of expanding range size,
25
26 205 the ranges of southerly species breeding in southern Europe might move northward, whereas
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28 206 the range of northerly species breeding in northern Europe might expand southward
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31 207 Similarly, in the case of contracting range size, the ranges of southerly species would retract
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33 208 southward, whereas the ranges of northerly species would retract northward (Kujala *et al*
34
35 209 2013, Thomas and Lennon 1999). Therefore, based on the centroids of breeding ranges (i.e.
36
37 210 the centroid of SDE), we classified our species into either northerly or southerly species if the
38
39 211 breeding range’s centroid was above or below the mean latitude of the study area of 5500000
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41 212 meters, (Thomas and Lennon 1999, Zuckerberg *et al* 2009).

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44 213 For the latitudinal shifts of southerly species, we measured the linear distance between the
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46 214 northern margin at the reference period and the predicted future periods for a given species
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48 215 (Carroll *et al* 2015, Ordonez and Williams 2013). The northern margin was defined as the
49
50 216 mean value of the upper 90% latitudes (90th percentile) of the pixels that were predicted
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52 217 suitable. For northerly species, we measured the linear distance between the southern margin
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54 218 at the reference period and the predicted future periods for a given species (Carroll *et al* 2015,
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3 219 Ordonez and Williams 2013). The southern margin was defined as the mean value of the
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5 220 lower 10% latitudes (10th percentile) of the pixels that were predicted suitable.
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8 221 Shifts in the latitudinal range margins are sensitive to original range size because small
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10 222 ranges can have larger potential shift (Williams and Blois 2018), and to natural barriers
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12 223 within the species' biogeographic regions such as Arctic ocean for northerly species.
13
14 224 Therefore, to test whether a relationship exists between the predicted shifts in a range's
15
16 225 latitudinal margins and the predicted changes in range size, we applied the approach
17
18 226 developed by Thomas & Lennon (1999). We statistically estimated shifts in the southern
19
20 227 margins of the northerly species and northern margins of the southerly species as the intercept
21
22 228 of a regression line depicting the linear relationship between shifts in species range latitudinal
23
24 229 margins and the changes in range size (Thomas and Lennon 1999, Taheri *et al* 2016). The
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26 230 change in range size was calculated as \log_{10} of the proportion of the number of occupied
27
28 231 pixels in the future over the number of occupied pixels in the reference range (Brommer *et al*
29
30 232 2012, Williams and Blois 2018). The regression intercept value, the parameter of interest,
31
32 233 gives the average shift in range margins independent from changes in range size, where a
33
34 234 positive intercept indicates a northward shift in range margins (Zuckerberg *et al* 2009, Kujala
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36 235 *et al* 2013).
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43 236 **Comparing predicted changes in species range with observed changes**

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45
46 237 The second Atlas of European Breeding Birds (EBBA2) was recently published by European
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48 238 Bird Census Council (Keller *et al* 2020). EBBA2 is based on nationally collected data on
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50 239 breeding birds' distributions in Europe between 2013 and 2017 at a spatial resolution of 50 ×
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52 240 50 km grid cell and using the same methodological standards as for EBBA1. Comparisons of
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54 241 bird distributions collected during two time periods that were three decades apart (EBBA1:
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56 242 1984, EBBA2: 2015) gave us a unique opportunity to evaluate and test predictions of SDMs.
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243 Our study objective was to compare the predicted changes in range size and range centroid
244 from EBBA1 data with the observed changes (log10-transformed) calculated from EBBA2
245 data, assuming a constant rate of changes (linear) over the time.

246 We measured the displacement shifts of the range centroid by delineating SDE over EBBA1
247 and EBBA2 data of a given species. We measured the displacement shifts in the range
248 centroid by calculating the linear distances between the centroids of the observed SDE of
249 EBBA1 and SDE of EBBA2 data. The shifts in range centroids and changes in range sizes
250 were calculated over different time scales, ~30 years for the observed and ~85 years for the
251 predicted. Estimated shifts in range centroids were scaled to average annual shifts by dividing
252 the observed and the predicted shifts in range centroids by the number of years, i.e. 30 and 85
253 respectively. We ran a linear regression to quantify the relation between the observed and
254 predicted average annual shifts in range centroids. In the same way, we compared the
255 predicted changes in range size with the observed changes. The observed changes in range
256 size were calculated using “*BIOMOD_RangeSize*” function in the “*biomod2*” R package
257 (Thuiller *et al* 2016).

258 **Results**

259 We used occurrence data for 64 non-passerine wetland birds breeding in Europe with taxa
260 representing 14 families (table S1). The most species-rich families included Anatidae (24
261 species) and Scolopacidae (nine species). All ensemble SDMs showed good predictive
262 performance (TSS mean = 0.72, SD = 0.11, and AUC mean = 0.92, SD = 0.04; table S1).

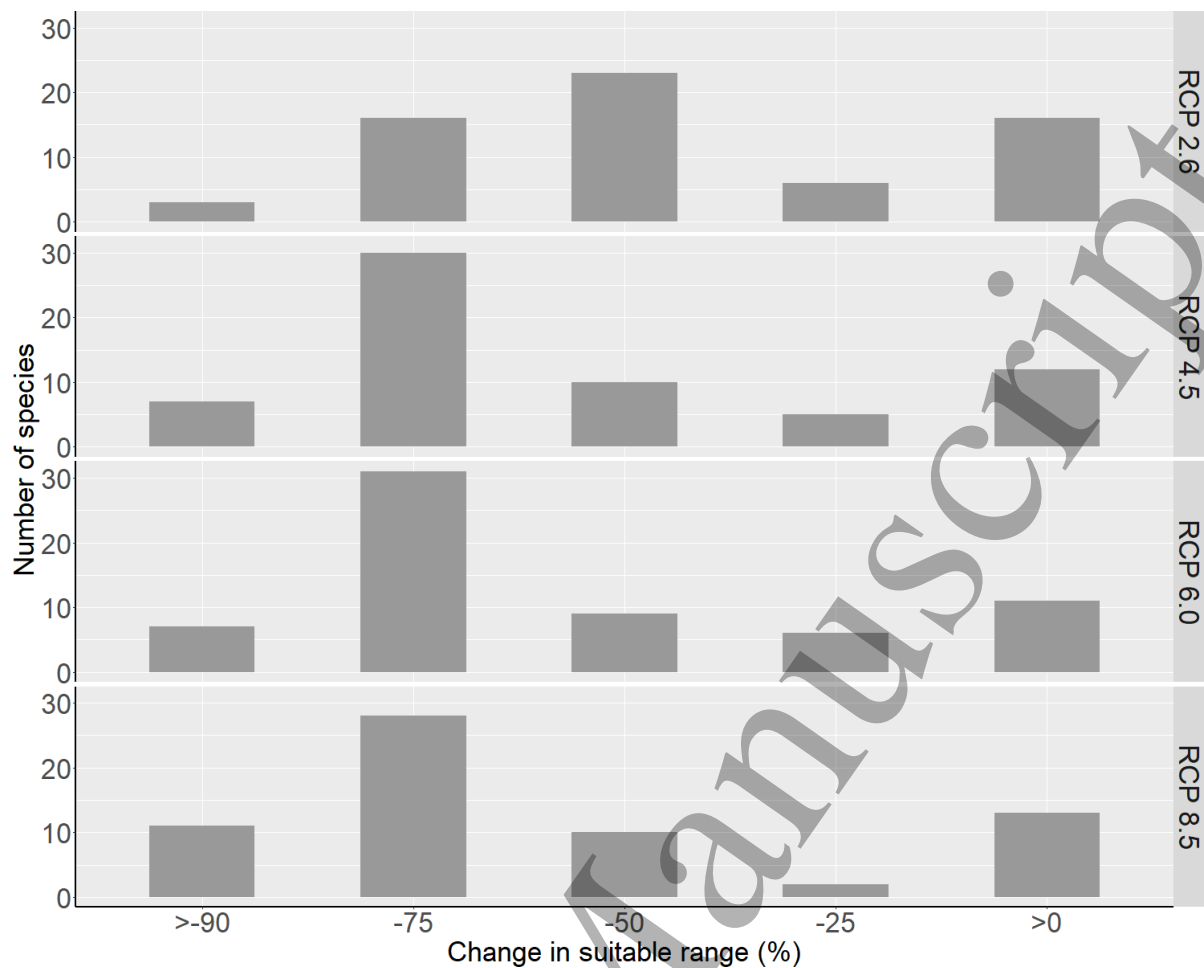
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264 **Changes in breeding range size**

265 Our ensemble models predicted significant changes in the breeding ranges for most wetland
266 birds under the projected future environmental conditions in Europe. Almost 75% of the

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3 267 species were predicted to contract their ranges, whereas ca. 20% of the species were predicted
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5 268 to expand their ranges (figure 1, figure S2, and table S2). The extent of the change in species
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7 269 range varied among species and according to the four different RCPs. For instance, ca. 25%
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10 270 and ca. 20% of the species were predicted to expand their breeding ranges by 2070 according
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12 271 to RCP 2.6 and 8.5, respectively. Four species with south-central distributions, Little Egret
13
14 272 (*Egretta garzetta*), Great White Egret (*Ardea alba*), Red-crested Pochard (*Netta rufina*), and
15
16 273 Kentish Plover (*Charadrius alexandrinus*), were predicted to markedly expand their breeding
17
18 274 ranges in the future (table S2). Other species such as Common Moorhen (*Gallinula*
19
20 275 *chloropus*) and Little Grebe (*Tachybaptus ruficollis*) were predicted to maintain their
21
22 276 reference breeding range in the future.
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27 277 Range contractions were predicted for several northerly species, whereas almost all species
28
29 278 that were predicted to expand their breeding range were southerly species (Table S2). The
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31 279 pattern of change in range size was fairly consistent among the RCPs, with only a few species
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33 280 showing an inconsistent pattern of change such as Black-crowned Night Heron (*Nycticorax*
34
35 281 *nycticorax*) and Red-throated Diver (*Gavia stellata*) (table S2).
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284 *Figure 1 The predicted change in the size of the breeding ranges under four different RCPs (2.6, 4.5, 6.0, and 8.5) in the*
 285 *future period (2070) compared to 1985. Alternative scenarios represent optimistic (RCP2.6) to pessimistic scenarios for*
 286 *emissions (RCP8.5).*

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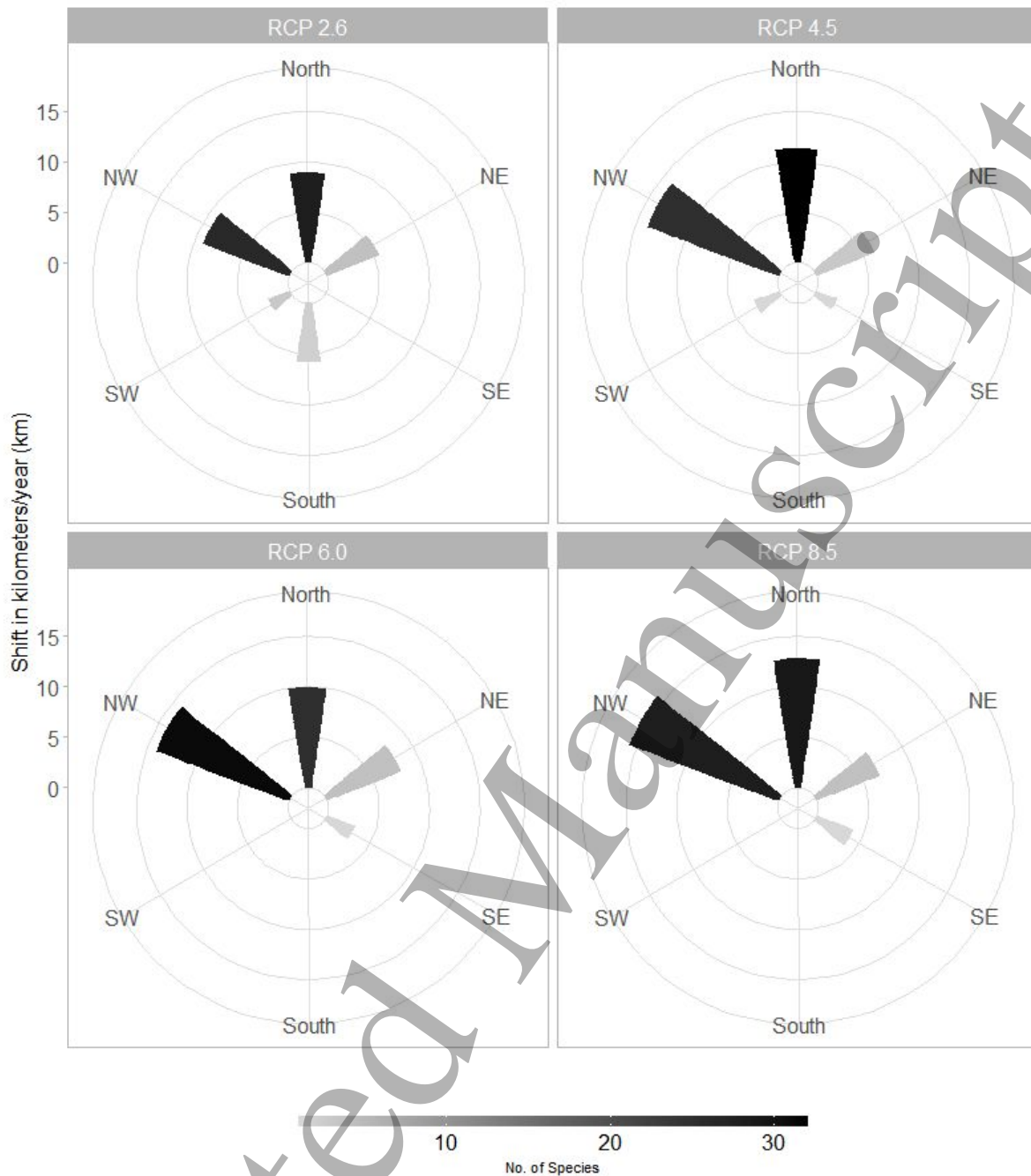
288 Shifts in centroids of breeding ranges

289 All species were predicted to shift their breeding range centroids, irrespective of the RCPs. A
 290 majority of species were predicted to shift their breeding range centroids in a northerly
 291 direction (ca. 5% NE, 45% N, and 40% NW) (figure 2 and table S3). The mean displacement
 292 shift in range centroid was predicted to be ca. 5 km/year across 64 wetland birds. Appendix
 293 S6: Shifts in breeding ranges centroids.

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296

297 *Figure 2 The predicted change in the directions of the centroid of the ranges of breeding birds. The scale bar represents the*
 298 *number of species, and the y-axis is the estimated displacement of the range centroids per year.*

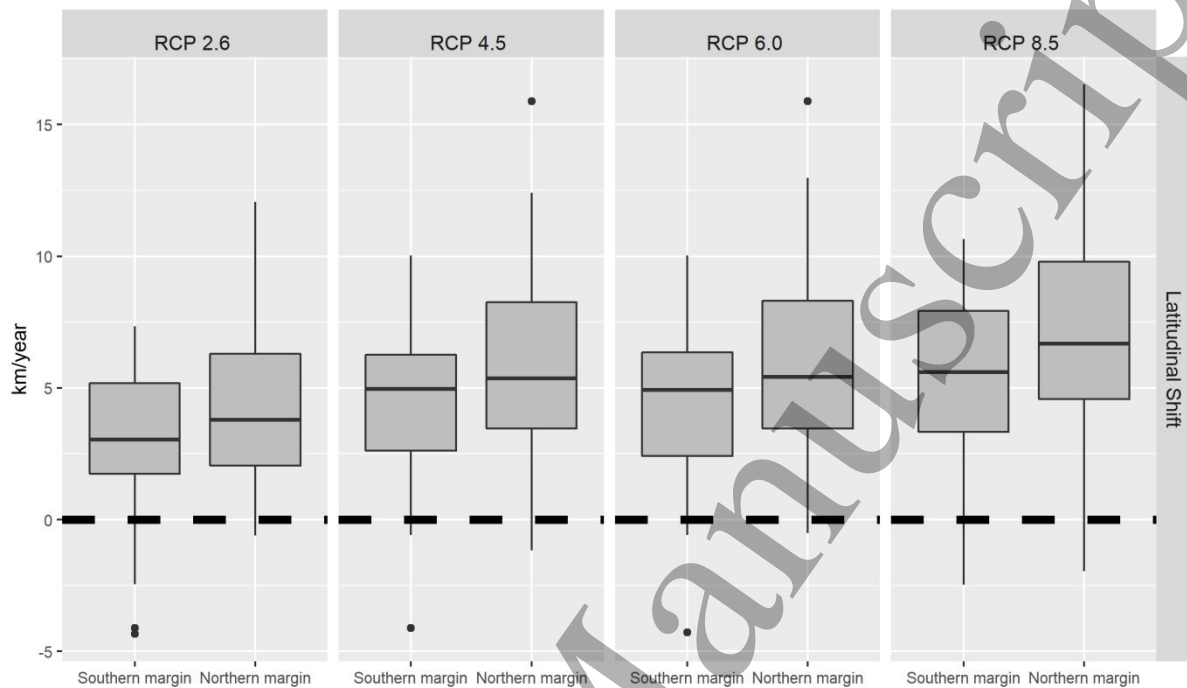
299

300 Shifts in range margins

301 Both northern and southern range margins were predicted to shift northward. However, the
 302 magnitude of margin shifts was dependent on the species. For northerly species, shifts in their
 303 southern margins varied among the RCPs, with a mean displacement shift of ca. 2 km/year

60

304 (figure 3 and table S4). For southerly species, the shifts in their northern margins varied from
 305 ca. 0 to 25 km/year depending on the RCPs with a mean shift of ca. 6 km/year (figure 3 and
 306 table 1).



307

308 *Figure 3 Predicted shifts in the southern and northern margins of breeding ranges of 64 species of wetland birds. Positive*
 309 *values above the dashed line indicate shifts toward the north. The values on the y-axis represent the annual displacement in*
 310 *range margins in km per year.*

311

312 Changes in range size were positively correlated with the predicted annual shifts in northern
 313 margins of southerly species, which suggest an increase in the number of suitable sites at
 314 northern boundaries (table 1). Changes in range size were negatively correlated with the
 315 predicted annual shifts in southern margins of northerly species, suggesting a decrease in the
 316 number of suitable sites at southern margins.

317 *Table 1 The predicted annual (km/year) latitudinal shifts of southern and northern range margins for 41 northerly*
 318 *and 23 southerly wetland bird species, respectively, as a function of the predicted change in range sizes. The*
 319 *significant positive estimate of latitudinal shift indicates a shift northward, while the negative estimate indicates a*
 320 *shift southward.*

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RCP	Parameter	Estimate	t	P	Estimate	t	P
2.6	Latitudinal Shift	4.97	7.37	0.001	2.04	2.18	0.03
	Range change	350.77	1.61	0.12	-431.03	-1.58	0.12
4.5	Latitudinal Shift	6.68	9.61	0.001	2.26	2.36	0.020
	Range change	90.93	0.45	0.65	-569.81	-2.01	0.006
6.0	Latitudinal Shift	6.56	9.37	0.001	1.36	1.32	0.19
	Range change	83.18	0.42	0.67	-708.81	3.56	0.001
8.5	Latitudinal Shift	8.51	12.97	0.001	0.39	0.36	0.72
	Range change	311.11	1.75	0.09	-881.64	-5.01	0.001
				Northern margin	Southern margin		

321

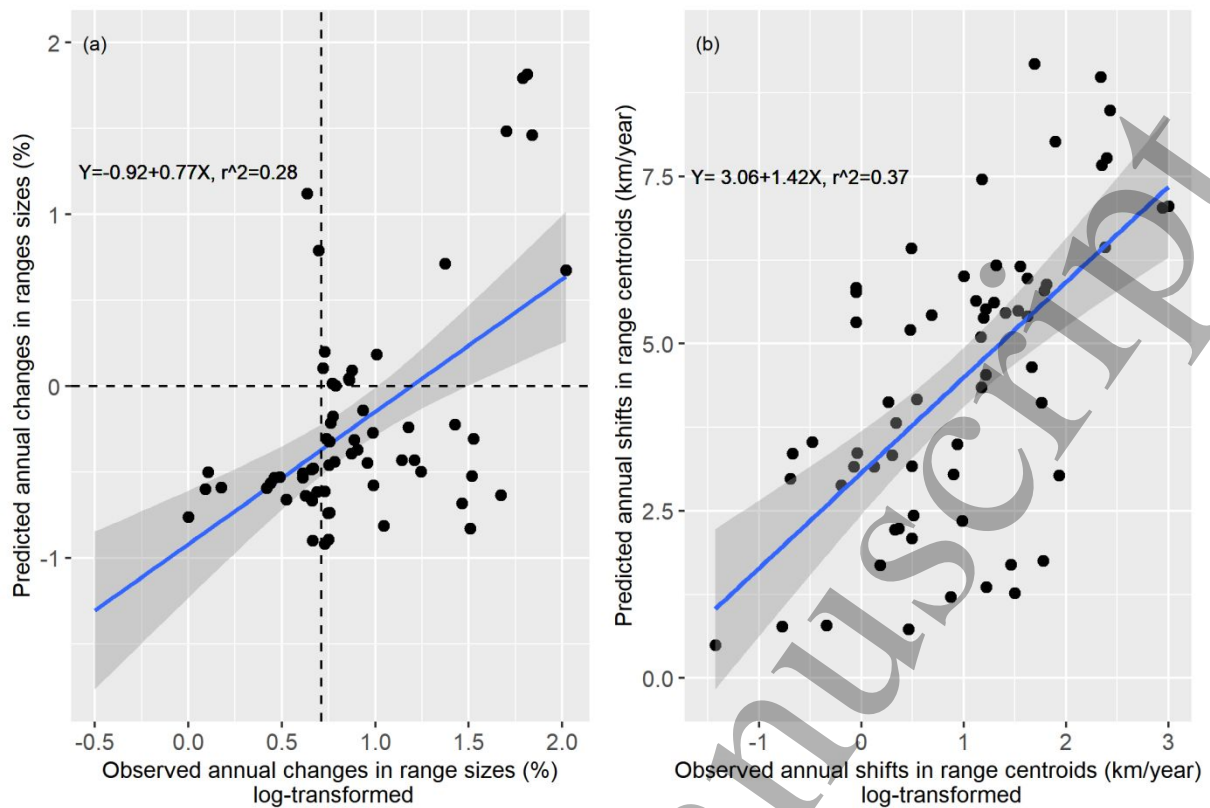
322

323 **Comparing the predicted change in species range with the observed change**

324 There was a significant positive association between the observed and the predicted annual
 325 changes in breeding range size and also the annual shifts in centroids (figure 4). The
 326 predicted contractions of breeding range sizes were in general larger than what was observed
 327 in EBBA2 (intercept= -0.29 ± 0.15). However, some species were predicted to contract their
 328 breeding ranges while they showed no change or a small increase in range such as the Tufted
 329 Duck (*Aythya fuligula*), Pochard and Whooper Swan (*Cygnus cygnus*) (figure 4(a) and table
 330 S2). The predicted shifts in range centroids were on average greater (ca. 5 km/year) than the
 331 observed ones (ca. 3.9 km/year) (intercept= 3.06 ± 0.31 ; figure 4(b) and table S3). The
 332 differences in predicted vs observed shifts were largest for species with small observed shifts
 333 in distribution (figure 4(b) and table S3).

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335

336 *Figure 4 The relationship between the predicted and the observed (log10-transformed) shifts in ranges sizes (a) and the*
 337 *predicted and observed (log10-transformed) changes in ranges centroids (b) of breeding wetland bird species in Europe.*
 338 *The solid blue line and shaded area represent the fitted value and the standard error of the fitted regression model.*

339

340 Discussion

341 The ensemble SDMs based on the expected changes in climate and land-use in the coming
 342 decades predicted significant contractions in the breeding ranges of many wetland birds,

343 while only a few species were predicted to expand their breeding ranges. In general, most
 344 species distributions, as estimated by range centroids and range margins, were predicted to

345 move northwards. The predicted shifts in range centroids were positively associated with the
 346 observed shifts in centroids over the 30 years (the 1980s–2010s) from EBBA2 data.

347 Similarly, the predicted and observed changes in breeding distribution range size were

348 positively related although some species displayed marked differences between predicted and
 349 observed changes.

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3 350 Our SDMs predicted: (i) considerable reductions in the size of the breeding ranges size
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5 351 (>50%) for many European wetland birds in the coming decades (figure 1 and table S2), (ii)
6
7 352 an average northward shift in breeding range centroids of ca. 5 km/year (figure 2 and table
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9 353 S3), and (iii) corresponding shifts in range margins with average displacement shifts of 2 and
10
11 354 6 km/year for southern range margins of northerly species and northern range margins for
12
13 355 southerly species, respectively (table 1). Our results are in line with other studies that have
14
15 356 reported shifts of breeding distributions and range size (Huntley *et al* 2007, 2008, Barbet-
16
17 357 Massin *et al* 2012, Williams and Blois 2018) and their range margins (Huang *et al* 2017,
18
19 358 Hitch and Leberg 2007, Thomas and Lennon 1999, Kujala *et al* 2013, Brommer 2004,
20
21 359 Ordonez and Williams 2013, Tayleur *et al* 2015). In reality, observed changes in range size
22
23 360 and shifts of range centroids appear generally smaller than those that predicted (Huang *et al*
24
25 361 2017, Hitch and Leberg 2007, Thomas and Lennon 1999, Brommer 2004) because species
26
27 362 ranges and abundances are responding to climate with a time lag ('climate debt' sensu
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29 363 (Devictor *et al* 2008, 2012)).

30
31 364 In our study, species with wide southerly breeding distribution such as Red-crested Pochard,
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33 365 Great White Egret, and Little Egret were among those that were predicted to expand their
34
35 366 breeding ranges in the future (table S2). The pattern of expansion for these species was also
36
37 367 supported by the observed expansion reported by EBBA2 (Keller *et al* 2020). Species with
38
39 368 broad distributions often encompass several sub-populations each with distinctive ecological
40
41 369 characteristics and dynamics (Stockwell and Peterson 2002). Furthermore, such species are
42
43 370 characterized by a wider environmental domain than they currently occupy, so they might
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45 371 benefit from new environmental conditions and, therefore, be able to expand their ranges
46
47 372 (Koschová *et al* 2014, Stockwell and Peterson 2002). A second explanation for expansion of
48
49 373 the southerly species could be that their ranges are not constrained by the continental border
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51 374 in the north (Koschová *et al* 2014).

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3 375 About 75% of the modeled bird species were predicted to contract their breeding ranges in
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5 376 Europe in the future. For some species, such as Long-tailed Duck (*Clangula hyemalis*) and
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7 377 Common Snipe (*Gallinago gallinago*), our SDMs predicted major contractions by 2070s. The
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9 378 magnitude of the predicted contractions (>50%) were consistent with results for many other
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11 379 birds at local (Andriamasimanana and Cameron 2013), regional (Virkkala *et al* 2008,
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13 380 Harrison *et al* 2003), and continental-scale (Langham *et al* 2015, Barbet-Massin *et al* 2012).
14
15 381 The contractions were partly inconsistent with the observed changes from EBBA2 (Keller *et*
16
17 382 *al* 2020) as many species including Long-tailed Duck and Common Snipe were observed to
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19 383 largely have almost the same range size in 2015 as thirty years earlier (table S2).
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24 384 Some species also show a marked opposite pattern between predicted and observed range
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26 385 changes such as Common Merganser (*Mergus merganser*) and Smew (*Mergellus albellus*)
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28 386 (figure 4(a)). Large discrepancies may have been a result of some biotic factors not
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30 387 considered in our model. For instance, over the last decades, some species have strongly
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32 388 benefitted from the increased protection and conservation, intensified farming, and milder
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34 389 winters (Keller *et al* 2020, Pavón-Jordán *et al* 2020, Gaget *et al* 2021). We focused on
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36 390 conditions during the breeding season but milder winters have benefitted the population sizes
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38 391 of several short-distance migrants that are wintering in central-north Europe (Musilová *et al*
39
40 392 2018, 2015). Positive effects of wetland protection and mild winters could be possible
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42 393 explanations for predicted decreases but observed increases in range sizes for Grey Heron
43
44 394 (*Ardea cinerea*), Common Goldeneye (*Bucephala clangula*), Smew, and Great Cormorant
45
46 395 (*Phalacrocorax carbo*) (table S2). Similarly, the divergence between the predicted expansion
47
48 396 and the observed contraction in the breeding range of Kentish Plover (table S2) could be
49
50 397 attributed to the development in coastal breeding habitats (Montalvo and Figuerola 2006),
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52 398 and changed grazing pressure at coastal grasslands and increased predator populations (Keller
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54 399 *et al* 2020). Further, we assumed a constant linear rate of changes in breeding ranges over
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3 400 time due to the lack of data that can inform a better realistic assumption. For some species,
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5 401 the environmental predictors might not be able to capture the main niche dimensions of
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7 402 species. Examples are many fish-eating species such as Goosander, Smew and Great
8
9 403 Cormorant that probably increased in numbers as a result of changed fish communities
10
11 404 (Frederiksen *et al* 2018, Østnes and Kroglund 2015), and large grazing birds such as
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13 405 Whooper Swan and Common Crane (*Grus grus*) that have increased due to changes in
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15 406 agricultural practices (Montràs-Janer *et al* 2020).

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20 407 Why are most species predicted to contract their breeding range? First, the majority of the
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22 408 species that were predicted to contract their ranges are breeding in northern Europe, and thus
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24 409 constrained by the northern continental border (Koschová *et al* 2014, Gregory *et al* 2009).
25
26 410 Second, the rate of climate change at northern latitudes could be faster as compared to that of
27
28 411 the southern latitudes (Jetz *et al* 2007, Koschová *et al* 2014).

29
30
31
32 412 The northward shift of the southern margins was mainly driven by losing suitable sites at
33
34 413 lower latitudes (significant negative range shift in table 1), while the northward shift of the
35
36 414 northern margins was driven by gaining suitable sites at higher latitudes (significant positive
37
38 415 range shift in table 1). A similar pattern has been found in several observational studies and
39
40 416 has mainly been attributed to the latitudinal temperature changes (Huang *et al* 2017, Hitch
41
42 417 and Leberg 2007, Thomas and Lennon 1999, Kujala *et al* 2013, Brommer 2004, Ordonez and
43
44 418 Williams 2013).

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48
49 419 The predicted average displacement shift of breeding range centroids (5 km/year) is
50
51 420 consistent with the average shift predicted in previous SDMs' studies (Russell *et al* 2015,
52
53 421 Huntley *et al* 2007). Although most other SDMs' studies predicting a shift in range centroids
54
55 422 suggest a shift towards the north, observational data from atlas inventories at country scale
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57 423 suggest these shifts to be smaller than predicted (ca. 1 km/year) (Brommer *et al* 2012,
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3 424 Gillings *et al* 2015, Hickling *et al* 2006, Virkkala and Lehikoinen 2014). The predicted
4
5 425 predominant northward (NW, N, and NE) shift for the centroid of the breeding range for most
6
7 426 wetland species (Figure 2) have been documented in multiple studies in North America and
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9
10 427 Europe possibly due to the general south-north latitudinal temperature gradient (Williams and
11
12 428 Blois 2018, Huang *et al* 2017, Gillings *et al* 2015, Hickling *et al* 2006). The NW shift of
13
14 429 many wetland bird species could reflect a corresponding changed patterns of precipitation
15
16
17 430 (Gillings *et al* 2015). A previous study observed that changes in precipitation patterns
18
19 431 resulted in many species undergoing westward shifts (VanDerWal *et al* 2013).
20
21
22 432 Our models probably overestimate the short-term impacts of environmental change because
23
24 433 some of the inherent uncertainties associated with SDMs. A primary source of uncertainty in
25
26
27 434 our study is the unaccounted factors such biotic interactions microclimatic conditions and
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29 435 species adaptability (Polaina *et al* 2021). A further source of uncertainty is the nature of
30
31 436 EBBA2 data, which represent the transient distributions for many species including
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33
34 437 occurrences collected from old steady-state and newly colonized sites.
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36
37 438 Our study calls for urgent intervention to preserve, manage, and restore the wetlands across
38
39 439 Europe, which requires applying conservation measures at continental and national scales.
40
41 440 We recommend to continue applying effective conservation measures such as wetland
42
43 441 restoration and creation (Kacergytė *et al* 2021). Where the economic cost for restoring the
44
45 442 natural wetlands is high, wetland creation is a potential alternative (Sebastián-González and
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47 443 Green 2016, Lehikoinen *et al* 2017). Additionally, previous studies showed that under
48
49 444 effective governance including controlling bird hunting and restoring their potential habitats,
50
51 445 wetlands can be refugia for wetland birds (Kirby *et al* 2008, Amano *et al* 2018). We
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53 446 recommend also applying spatial conservation planning, as it may inform the conservationists
54
55 447 and decision-makers where to prioritize the conservation efforts.
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3 448 **Data availability statement**
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6 449 The data that support the findings of this study are openly available at the following

7
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13

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57
58
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60

466 **References**

- 467 Allouche O, Tsoar A and Kadmon R 2006 Assessing the accuracy of species distribution models:
468 prevalence, kappa and the true skill statistic (TSS) *J. Appl. Ecol.* **43** 1223–32 Online:
469 <http://doi.wiley.com/10.1111/j.1365-2664.2006.01214.x>
- 470 Amano T, Székely T, Sandel B, Nagy S, Mundkur T, Langendoen T, Blanco D, Soykan C U and
471 Sutherland W J 2018 Successful conservation of global waterbird populations depends on
472 effective governance *Nature* **553** 199–202 Online: <http://www.nature.com/articles/nature25139>
- 473 Andriamasimanana R H and Cameron A 2013 Predicting the impacts of climate change on the
474 distribution of threatened forest-restricted birds in Madagascar *Ecol. Evol.* **3** 763–9 Online:
475 [/pmc/articles/PMC3631392/](http://pmc/articles/PMC3631392/)
- 476 Araújo M B, Thuiller W and Yoccoz N G 2009 Reopening the climate envelope reveals macroscale
477 associations with climate in European birds *Proc. Natl. Acad. Sci. U. S. A.* **106** E45–6 Online:
478 www.pnas.org/cgi/doi/10.1073/pnas.0813294106
- 479 Areias Guerreiro J, Mira A and Barbosa A M 2016 How well can models predict changes in species
480 distributions? A 13-year-old otter model revisited *Hystrix* **27** Online: [http://www.italian-journal-](http://www.italian-journal-of-mammalogy.it/article/view/11867/pdf)
481 [of-mammalogy.it/article/view/11867/pdf](http://www.italian-journal-of-mammalogy.it/article/view/11867/pdf)
- 482 Barbet-Massin M, Rome Q, Villemant C and Courchamp F 2018 Can species distribution models
483 really predict the expansion of invasive species? *PLoS One* **13** e0193085 Online:
484 <https://dx.plos.org/10.1371/journal.pone.0193085>
- 485 Barbet-Massin M, Thuiller W and Jiguet F 2012 The fate of European breeding birds under climate,
486 land-use and dispersal scenarios *Glob. Chang. Biol.* **18** 881–90 Online:
487 <http://doi.wiley.com/10.1111/j.1365-2486.2011.02552.x>
- 488 BirdLife International 2021 *European Red List of Birds* (Luxembourg) Online:
489 <http://datazone.birdlife.org/info/euroredlist2021>
- 490 Bradshaw C J A, Brook B W, Delean S, Fordham D A, Herrando-Pérez S, Cassey P, Early R,
491 Sekercioglu C H and Araújo M B 2014 Predictors of contraction and expansion of area of
492 occupancy for British birds *Proc. R. Soc. B Biol. Sci.* **281** 20140744 Online:
493 <https://royalsocietypublishing.org/doi/10.1098/rspb.2014.0744>
- 494 Brommer J E 2004 The range margins of northern birds shift polewards *Ann. Zool. Fenn.* **41** 391–7
- 495 Brommer J E, Lehikoinen A and Valkama J 2012 The Breeding Ranges of Central European and
496 Arctic Bird Species Move Poleward *PLoS One* **7** e43648 Online:
497 <https://dx.plos.org/10.1371/journal.pone.0043648>
- 498 Brun P, Kiørboe T, Licandro P and Payne M R 2016 The predictive skill of species distribution
499 models for plankton in a changing climate *Glob. Chang. Biol.* **22** 3170–81 Online:
500 <http://www.cs.princeton.edu/~schapire/maxent/>
- 501 Bui R, Buliung R N and Remmel T K 2012 aspace: A collection of functions for estimating
502 centographic statistics and computational geometries for spatial point patterns
- 503 Butt N, Possingham H P, De Los Rios C, Maggini R, Fuller R A, Maxwell S L and Watson J E M
504 2016 Challenges in assessing the vulnerability of species to climate change to inform
505 conservation actions *Biol. Conserv.* **199** 10–5
- 506 Carroll C, Lawler J J, Roberts D R and Hamann A 2015 Biotic and Climatic Velocity Identify
507 Contrasting Areas of Vulnerability to Climate Change *PLoS One* **10** e0140486 Online:
508 <https://dx.plos.org/10.1371/journal.pone.0140486>
- 509 Cashion T, Nguyen T, Brink T ten, Mook A, Palacios-Abrantes J and Roberts S M 2020 Shifting seas,

- 1
2
3 510 shifting boundaries: Dynamic marine protected area designs for a changing climate *PLoS One*
4 511 **15** e0241771 Online: <https://doi.org/10.1371/journal.pone.0241771.g001>
- 5
6 512 Cianfrani C, Broennimann O, Loy A and Guisan A 2018 More than range exposure: Global otter
7 513 vulnerability to climate change *Biol. Conserv.* **221** 103–13 Online:
8 514 <https://www.sciencedirect.com/science/article/pii/S0006320717306729#bb0310>
- 9
10 515 Csergő A M, Broennimann O, Guisan A and Buckley Y M 2020 Beyond range size: Drivers of
11 516 species' geographic range structure in European plants *bioRxiv* 2020.02.08.939819 Online:
12 517 <https://doi.org/10.1101/2020.02.08.939819>
- 13
14 518 Devictor V, Julliard R, Couvet D and Jiguet F 2008 Birds are tracking climate warming, but not fast
15 519 enough *Proc. R. Soc. B Biol. Sci.* **275** 2743–8 Online: <https://royalsocietypublishing.org/>
- 16
17 520 Devictor V, Van Swaay C, Brereton T, Brotons L, Chamberlain D, Heliölä J, Herrando S, Julliard R,
18 521 Kuussaari M, Lindström Å, Reif J, Roy D B, Schweiger O, Settele J, Stefanescu C, Van Strien
19 522 A, Van Turnhout C, Vermouzek Z, WallisDeVries M, Wynhoff I and Jiguet F 2012 Differences
20 523 in the climatic debts of birds and butterflies at a continental scale *Nat. Clim. Chang.* **2** 121–4
21 524 Online: www.nature.com/natureclimatechange
- 22
23 525 Fielding A H and Bell J F 1997 A review of methods for the assessment of prediction errors in
24 526 conservation presence/absence models *Environ. Conserv.* **24** 38–49 Online:
25 527 http://journals.cambridge.org/abstract_S0376892997000088
- 26
27 528 Frederiksen M, Korner-Nievergelt F, Marion L and Bregnballe T 2018 Where do wintering
28 529 cormorants come from? Long-term changes in the geographical origin of a migratory bird on a
29 530 continental scale ed P Stephens *J. Appl. Ecol.* **55** 2019–32 Online:
30 531 <https://onlinelibrary.wiley.com/doi/10.1111/1365-2664.13106>
- 31
32 532 Furfey P H 1927 A Note on Lefever's "Standard Deviatonal Ellipse" *Am. J. Sociol.* **33** 94–8 Online:
33 533 <https://www.journals.uchicago.edu/doi/abs/10.1086/214336>
- 34
35 534 Gaget E, Johnston A, Pavón-Jordán D, Lehikoinen A S, Sandercock B K, Soultan A, Božič L,
36 535 Clausen P, Devos K, Domsa C, Encarnaçã V, Faragó S, Fitzgerald N, Frost T, Gaudard C,
37 536 Gosztonyi L, Haas F, Hornman M, Langendoen T, Ieronymidou C, Luigujõe L, Meissner W,
38 537 Mikuska T, Molina B, Musilová Z, Paquet J, Petkov N, Portolou D, Ridzoň J, Sniauksta L,
39 538 Stpńiece A, Teufelbauer N, Wahl J, Zenatello M and Brommer J E 2021 Protected area
40 539 characteristics that help waterbirds respond to climate warming *Conserv. Biol.* Online:
41 540 <https://onlinelibrary.wiley.com/doi/10.1111/cobi.13877>
- 42
43 541 Gaget E, Le Viol I, Pavón-Jordán D, Cazalis V, Kerbirou C, Jiguet F, Popoff N, Dami L, Mondain-
44 542 Monval J Y, Defos du Rau P, Abdou W A I, Bozic L, Dakki M, Encarnaçã V M F, Erciyas-
45 543 Yavuz K, Etayeb K S, Molina B, Petkov N, Uzunova D, Zenatello M and Galewski T 2020
46 544 Assessing the effectiveness of the Ramsar Convention in preserving wintering waterbirds in the
47 545 Mediterranean *Biol. Conserv.* **243** 108485 Online:
48 546 <https://linkinghub.elsevier.com/retrieve/pii/S0006320719315332>
- 49
50 547 Gillings S, Balmer D E and Fuller R J 2015 Directionality of recent bird distribution shifts and
51 548 climate change in Great Britain *Glob. Chang. Biol.* **21** 2155–68 Online:
52 549 <http://doi.wiley.com/10.1111/gcb.12823>
- 53
54 550 Goberville E, Beaugrand G, Hautekèete N C, Piquot Y and Luczak C 2015 Uncertainties in the
55 551 projection of species distributions related to general circulation models *Ecol. Evol.* **5** 1100–16
56 552 Online: <https://onlinelibrary.wiley.com/doi/full/10.1002/ece3.1411>
- 57
58 553 Goodman R E, Lebuhn G, Seavy N E, Gardali T and Bluso-Demers J D 2012 Avian body size
59 554 changes and climate change: warming or increasing variability? *Glob. Chang. Biol.* **18** 63–73
60 555 Online: <http://doi.wiley.com/10.1111/j.1365-2486.2011.02538.x>

- 1
2
3 556 Green A J and Elmberg J 2014 Ecosystem services provided by waterbirds *Biol. Rev.* **89** 105–22
4 557 Online: <http://doi.wiley.com/10.1111/brv.12045>
- 5
6 558 Gregory R D, Willis S G, Jiguet F, Voříšek P, Klvaňová A, van Strien A, Huntley B, Collingham Y C,
7 559 Couvet D and Green R E 2009 An indicator of the impact of climatic change on European bird
8 560 populations *PLoS One* **4** e4678 Online: <https://dx.plos.org/10.1371/journal.pone.0004678>
- 9
10 561 Hagemeyer J and Blair M 1997 *The EBCC atlas of European breeding birds: Their distribution and*
11 562 *abundance* (T and A D Poyser)
- 12
13 563 Hamilton D J, Ankney C D and Bailey R C 1994 Predation of Zebra Mussels by diving ducks: An
14 564 enclosure study *Ecology* **75** 521–31 Online: <http://doi.wiley.com/10.2307/1939555>
- 15
16 565 Harrison P A, Vanhinsbergh D P, Fuller R J and Berry P M 2003 Modelling climate change impacts
17 566 on the distribution of breeding birds in Britain and Ireland *J. Nat. Conserv.* **11** 31–42
- 18
19 567 Hickling R, Roy D B, Hill J K, Fox R and Thomas C D 2006 The distributions of a wide range of
20 568 taxonomic groups are expanding polewards *Glob. Chang. Biol.* **12** 450–5 Online:
21 569 <https://onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2486.2006.01116.x>
- 22
23 570 Hijmans R J 2019 geosphere: Spherical Trigonometry Online: [https://cran.r-](https://cran.r-project.org/package=geosphere)
24 571 [project.org/package=geosphere](https://cran.r-project.org/package=geosphere)
- 25
26 572 Hitch A T and Leberg P L 2007 Breeding distributions of North American bird species moving north
27 573 as a result of climate change *Conserv. Biol.* **21** 534–9 Online:
28 574 <https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/j.1523-1739.2006.00609.x>
- 29
30 575 Hovick T J, Allred B W, McGranahan D A, Palmer M W, Dwayne Elmore R and Fuhlendorf S D
31 576 2016 Informing conservation by identifying range shift patterns across breeding habitats and
32 577 migration strategies *Biodivers. Conserv.* **25** 345–56 Online:
33 578 <https://link.springer.com/article/10.1007/s10531-016-1053-6>
- 34
35 579 Huang Q, Sauer J R and Dubayah R O 2017 Multidirectional abundance shifts among North
36 580 American birds and the relative influence of multifaceted climate factors *Glob. Chang. Biol.* **23**
37 581 3610–22 Online: <https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.13683>
- 38
39 582 Huntley B, Collingham Y C, Willis S G and Green R E 2008 Potential Impacts of Climatic Change on
40 583 European Breeding Birds *PLoS One* **3** e1439 Online:
41 584 <http://dx.plos.org/10.1371/journal.pone.0001439>
- 42
43 585 Huntley B, Green R E, Collingham Y and Willis S G 2007 *A Climatic Atlas of European Breeding*
44 586 *Birds* (Barcelona: Lynx Edicions)
- 45
46 587 Hurtt G, Chini L, Sahajpal R, Frohking S, Bodirsky B, Calvin K, Doelman J, Fisk J, Fujimori S,
47 588 Goldewijk K K, Hasegawa T, Havlik P, Heinemann A, Humpenöder F, Jungclaus J, Kaplan J,
48 589 Kennedy J, Kristzin T, Lawrence D, Lawrence P, Ma L, Mertz O, Pongratz J, Popp A, Poulter B,
49 590 Riahi K, Shevliakova E, Stehfest E, Thornton P, Tubiello F, van Vuuren D and Zhang X 2020
50 591 Harmonization of global land-use Change and management for the period 850–2100 (LUH2) for
51 592 CMIP6 *Geosci. Model Dev. Discuss.* 1–65
- 52
53 593 Hurtt G, Chini L, Sahajpal R, Frohking S, Bodirsky B L, Calvin K, Doelman J, Fisk J, Fujimori S,
54 594 Goldewijk K K, Hasegawa T, Havlik P, Heinemann A, Humpenöder F, Jungclaus J, Kaplan J,
55 595 Kristzin T, Lawrence D, Lawrence P, Mertz O, Pongratz J, Popp A, Riahi K, Shevliakova E,
56 596 Stehfest E, Thornton P, van Vuuren D and Zhang X 2019 Harmonization of global land use
57 597 change and management for the period 2015-2300
- 58
59 598 IPCC 2014 *Climate change 2014: synthesis report. Contribution of working groups I, II and III to the*
60 599 *fifth assessment report of the intergovernmental panel on climate change* ed C W Team, R K
61 600 Pachauri and L A Meyer (Geneva, Switzerland) Online: [http://www.ipcc.ch/pdf/assessment-](http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf)
62 601 [report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf)

- 1
2
3 602 Jetz W, Wilcove D S and Dobson A P 2007 Projected impacts of climate and land-use change on the
4 603 global diversity of birds *PLoS Biol.* **5** e157 Online:
5 604 <https://dx.plos.org/10.1371/journal.pbio.0050157>
6
7 605 Johnson D P and Wilson J S 2009 The socio-spatial dynamics of extreme urban heat events: The case
8 606 of heat-related deaths in Philadelphia *Appl. Geogr.* **29** 419–34
9
10 607 Kačergytė I, Arlt D, Berg Å, Žmihorski M, Knape J, Rosin Z M and Pärt T 2021 Evaluating created
11 608 wetlands for bird diversity and reproductive success *Biol. Conserv.* **257** 109084
12
13 609 Karger D N, Conrad O, Böhrer J, Kawohl T, Kreft H, Soria-Auza R W, Zimmermann N E, Linder H
14 610 P and Kessler M 2017 Climatologies at high resolution for the earth's land surface areas *Sci.*
15 611 *Data* **4** 1–20 Online: www.nature.com/scientificdata
16
17 612 Karger D N and Zimmermann N E 2018 CHELSAcruts – High resolution temperature and
18 613 precipitation timeseries for the 20th century and beyond *EnviDat*
19
20 614 Keller V, Herrando S, Voříšek P, Franch M, Kipson M, Milanese P, Martí D, Anton M, Klvaňová A,
21 615 Kalyakin M V., Bauer H-G and Foppen R P B 2020 *European Breeding Bird Atlas 2:*
22 616 *Distribution, Abundance and Change* (Barcelona: European Bird Census Council & Lynx
23 617 Edicions)
24
25 618 Kirby J S, Stattersfield A J, Butchart S H M, Evans M I, Grimmett R F A, Jones V R, O'sullivan J,
26 619 Tucker G M and Newton I 2008 Key conservation issues for migratory land- and waterbird
27 620 species on the world's major flyways *Bird Conserv. Int.* **18** S49–73 Online:
28 621 [https://www.cambridge.org/core/journals/bird-conservation-international/article/key-](https://www.cambridge.org/core/journals/bird-conservation-international/article/key-conservation-issues-for-migratory-land-and-waterbird-species-on-the-worlds-major-flyways/B6AE87A5CB971E0B9690B625E3DD9436)
29 622 [conservation-issues-for-migratory-land-and-waterbird-species-on-the-worlds-major-](https://www.cambridge.org/core/journals/bird-conservation-international/article/key-conservation-issues-for-migratory-land-and-waterbird-species-on-the-worlds-major-flyways/B6AE87A5CB971E0B9690B625E3DD9436)
30 623 [flyways/B6AE87A5CB971E0B9690B625E3DD9436](https://www.cambridge.org/core/journals/bird-conservation-international/article/key-conservation-issues-for-migratory-land-and-waterbird-species-on-the-worlds-major-flyways/B6AE87A5CB971E0B9690B625E3DD9436)
31
32 624 Koschová M, Kuda F, Hořák D and Reif J 2014 Species' ecological traits correlate with predicted
33 625 climatically-induced shifts of European breeding ranges in birds *Community Ecol.* **15** 139–46
34 626 Online: <http://www.akademai.com/doi/abs/10.1556/ComEc.15.2014.2.2>
35
36 627 Kujala H, Vepsäläinen V, Zuckerberg B and Brommer J E 2013 Range margin shifts of birds revisited
37 628 - the role of spatiotemporally varying survey effort *Glob. Chang. Biol.* **19** 420–30 Online:
38 629 <http://doi.wiley.com/10.1111/gcb.12042>
39
40 630 Langham G M, Schuetz J G, Distler T, Soykan C U and Wilsey C 2015 Conservation Status of North
41 631 American Birds in the Face of Future Climate Change *PLoS One* **10** e0135350 Online:
42 632 <https://dx.plos.org/10.1371/journal.pone.0135350>
43
44 633 Lee T M and Jetz W 2011 Unravelling the structure of species extinction risk for predictive
45 634 conservation science *Proc. R. Soc. B Biol. Sci.* **278** 1329–38 Online:
46 635 <https://royalsocietypublishing.org/doi/10.1098/rspb.2010.1877>
47
48 636 Lehikoinen P, Lehikoinen A, Mikkola-Roos M and Jaatinen K 2017 Counteracting wetland
49 637 overgrowth increases breeding and staging bird abundances *Sci. Rep.* **7** 1–11 Online:
50 638 www.nature.com/scientificreports
51
52 639 Lehner B and Döll P 2004 Development and validation of a global database of lakes, reservoirs and
53 640 wetlands *J. Hydrol.* **296** 1–22
54
55 641 Littlefield C E, McRae B H, Michalak J L, Lawler J J and Carroll C 2017 Connecting today's climates
56 642 to future climate analogs to facilitate movement of species under climate change *Conserv. Biol.*
57 643 **31** 1397–408 Online: <http://doi.wiley.com/10.1111/cobi.12938>
58
59 644 Liu C, White M and Newell G 2013 Selecting thresholds for the prediction of species occurrence with
60 645 presence-only data *J. Biogeogr.* **40** 778–89 Online: <http://doi.wiley.com/10.1111/jbi.12058>
61
62 646 Mesgaran M B, Cousens R D and Webber B L 2014 Here be dragons: a tool for quantifying novelty

- 1
2
3 647 due to covariate range and correlation change when projecting species distribution models
4 648 *Divers. Distrib.* **20** 1147–59 Online: <http://doi.wiley.com/10.1111/ddi.12209>
5
- 6 649 Montalvo T and Figuerola J 2006 The distribution and conservation of the Kentish Plover *Charadrius*
7 650 *alexandrinus* in Catalonia *Rev. Catalana d'Ornitologia* **22** 1–8
8
- 9 651 Montràs-Janer T, Knape J, Stoessel M, Nilsson L, Tombre I, Pärt T and Månsson J 2020 Spatio-
10 652 temporal patterns of crop damage caused by geese, swans and cranes—Implications for crop
11 653 damage prevention *Agric. Ecosyst. Environ.* **300** 107001 Online:
12 654 <https://linkinghub.elsevier.com/retrieve/pii/S0167880920301869>
13
- 14 655 Musilová Z, Musil P, Zouhar J, Adam M and Bejček V 2018 Importance of Natura 2000 sites for
15 656 wintering waterbirds: Low preference, species' distribution changes and carrying capacity of
16 657 Natura 2000 could fail to protect the species *Biol. Conserv.* **228** 79–88
17
- 18 658 Musilová Z, Musil P, Zouhar J and Romportl D 2015 Long-term trends, total numbers and species
19 659 richness of increasing waterbird populations at sites on the edge of their winter range: Cold-
20 660 weather refuge sites are more important than protected sites *J. Ornithol.* **156** 923–32 Online:
21 661 <https://link.springer.com/article/10.1007/s10336-015-1223-4>
22
- 23 662 Newbold T 2018 Future effects of climate and land-use change on terrestrial vertebrate community
24 663 diversity under different scenarios *Proc. R. Soc. B Biol. Sci.* **285** 20180792 Online:
25 664 <https://royalsocietypublishing.org/doi/10.1098/rspb.2018.0792>
26
- 27 665 Ordonez A and Williams J W 2013 Climatic and biotic velocities for woody taxa distributions over
28 666 the last 16 000 years in eastern North America *Ecol. Lett.* **16** 773–81 Online:
29 667 <http://doi.wiley.com/10.1111/ele.12110>
30
- 31 668 Østnes J E and Kroglund R T 2015 The establishment of a breeding population of Smew *Mergellus*
32 669 *albellus* in an atypical habitat on the Atlantic coast of Norway *Ornis Svecica* **25** 59–64 Online:
33 670 <https://journals.lub.lu.se/os/article/view/22544>
34
- 35 671 Parmesan C, Ryrholm N, Stefanescu C, Hill J K, Thomas C D, Descimon H, Huntley B, Kaila L,
36 672 Kullberg J, Tammaru T, Tennent W J, Thomas J A and Warren M 1999 Poleward shifts in
37 673 geographical ranges of butterfly species associated with regional warming *Nature* **399** 579–83
38 674 Online: www.nature.com
39
- 40 675 Pavón-Jordán D, Abdou W, Azafzaf H, Balaž M, Bino T, Borg J J, Božič L, Butchart S H M, Clausen
41 676 P, Sniakusta L, Dakki M, Devos K, Domsa C, Encarnação V, Etayeb K, Faragó S, Fox A D,
42 677 Frost T, Gaudard C, Georgiev V, Goratze I, Hornman M, Keller V, Kostiuskyn V, Langendoen
43 678 T, Ławicki Ł, Ieronymidou C, Lewis L J, Lorentsen S-H, Luigujoe L, Meissner W, Mikuska T,
44 679 Molina B, Musil P, Musilova Z, Nagy S, Natykanets V, Nilsson L, Paquet J-Y, Portolou D,
45 680 Ridzon J, Santangeli A, Sayoud S, Šćiban M, Stipnice A, Teufelbauer N, Topić G, Uzunova D,
46 681 Vizi A, Wahl J, Yavuz K E, Zenatello M and Lehikoinen A 2020 Positive impacts of important
47 682 bird and biodiversity areas on wintering waterbirds under changing temperatures throughout
48 683 Europe and North Africa *Biol. Conserv.* **246** 108549 Online:
49 684 <https://linkinghub.elsevier.com/retrieve/pii/S000632071931170X>
50
- 51 685 Pavón-Jordán D, Clausen P, Dagys M, Devos K, Encarnação V, Fox A D, Frost T, Gaudard C,
52 686 Hornman M, Keller V, Langendoen T, Ławicki Ł, Lewis L J, Lorentsen S-H, Luigujoe L,
53 687 Meissner W, Molina B, Musil P, Musilova Z, Nilsson L, Paquet J-Y, Ridzon J, Stipnice A,
54 688 Teufelbauer N, Wahl J, Zenatello M and Lehikoinen A 2019 Habitat- and species-mediated
55 689 short- and long-term distributional changes in waterbird abundance linked to variation in
56 690 European winter weather *Divers. Distrib.* **25** 225–39 Online:
57 691 <http://doi.wiley.com/10.1111/ddi.12855>
58
- 59 692 Pievani T 2014 The sixth mass extinction: Anthropocene and the human impact on biodiversity *Rend.*
60 693 *Lincei* **25** 85–93 Online: <http://link.springer.com/10.1007/s12210-013-0258-9>

- 1
2
3 694 Polaina E, Soutlan A, Pärt T and Rodriguez Recio M 2021 The future of invasive terrestrial
4 695 vertebrates in Europe under climate and land-use change *Environ. Res. Lett.* Online:
5 696 <https://iopscience.iop.org/article/10.1088/1748-9326/abe95e>
- 7 697 R Core Team 2016 R: A language and environment for statistical computing. *Vienna, Austria R*
8 698 *Found. Stat. Comput.* <http://www.R-project.org/> Online: <http://www.r-project.org/>
- 10 699 Rayfield B, James P M A, Fall A and Fortin M J 2008 Comparing static versus dynamic protected
11 700 areas in the Québec boreal forest *Biol. Conserv.* **141** 438–49
- 12 701 Reif J and Flousek J 2012 The role of species' ecological traits in climatically driven altitudinal range
13 702 shifts of central European birds *Oikos* **121** 1053–60 Online:
14 703 <http://doi.wiley.com/10.1111/j.1600-0706.2011.20008.x>
- 16 704 Russell D, Wanless S, Collingham Y, Huntley B and Hamer K 2015 Predicting Future European
17 705 Breeding Distributions of British Seabird Species under Climate Change and Unlimited/No
18 706 Dispersal Scenarios *Diversity* **7** 342–59 Online: <http://www.mdpi.com/1424-2818/7/4/342>
- 20 707 Sales L, Ribeiro B R, Chapman C A and Loyola R 2020 Multiple dimensions of climate change on
21 708 the distribution of Amazon primates *Perspect. Ecol. Conserv.* **18** 83–90
- 23 709 Sebastián-González E and Green A J 2016 Reduction of avian diversity in created versus natural and
24 710 restored wetlands *Ecography (Cop.)*. **39** 1176–84
- 26 711 Skov F and Svenning J C 2004 Potential impact of climatic change on the distribution of forest herbs
27 712 in Europe *Ecography (Cop.)*. **27** 366–80 Online:
28 713 <https://onlinelibrary.wiley.com/doi/full/10.1111/j.0906-7590.2004.03823.x>
- 29 714 Soberón J 2007 Grinnellian and Eltonian niches and geographic distributions of species *Ecol. Lett.* **10**
30 715 1115–23 Online: <http://doi.wiley.com/10.1111/j.1461-0248.2007.01107.x>
- 32 716 Sohl T L 2014 The relative impacts of climate and land-use change on conterminous united states bird
33 717 species from 2001 to 2075 *PLoS One* **9** e112251 Online:
34 718 <https://dx.plos.org/10.1371/journal.pone.0112251>
- 36 719 Soutlan A, Wikelski M and Safi K 2019 Risk of biodiversity collapse under climate change in the
37 720 Afro-Arabian region *Sci. Rep.* **9** 955 Online: [http://www.nature.com/articles/s41598-018-37851-](http://www.nature.com/articles/s41598-018-37851-6)
38 721 6
- 40 722 Stockwell D R . and Peterson A T 2002 Effects of sample size on accuracy of species distribution
41 723 models *Ecol. Modell.* **148** 1–13 Online:
42 724 <http://www.sciencedirect.com/science/article/pii/S030438000100388X>
- 44 725 Taheri S, Naimi B and Araújo M B 2016 Did British breeding birds move north in the late 20th
45 726 century? *Clim. Chang. Responses* **3** 1–5 Online:
46 727 <https://link.springer.com/articles/10.1186/s40665-016-0020-5>
- 47 728 Tayleur C, Caplat P, Massimino D, Johnston A, Jonzén N, Smith H G and Lindström Å 2015 Swedish
48 729 birds are tracking temperature but not rainfall: evidence from a decade of abundance changes
49 730 *Glob. Ecol. Biogeogr.* **24** 859–72 Online:
50 731 <https://onlinelibrary.wiley.com/doi/full/10.1111/geb.12308>
- 52 732 Teo S S 2001 Evaluation of different duck varieties for the control of the golden apple snail (*Pomacea*
53 733 *canaliculata*) in transplanted and direct seeded rice *Crop Prot.* **20** 599–604 Online:
54 734 <https://linkinghub.elsevier.com/retrieve/pii/S0261219401000291>
- 56 735 Thomas C D and Lennon J J 1999 Birds extend their ranges northwards *Nature* **399** 213–213 Online:
57 736 <https://www.nature.com/articles/20335>
- 59 737 Thuiller W, Georges D and Engler R 2016 biomod2: Ensemble platform for species distribution
60 738 modeling. *R Packag. version 3.3-13/r726*. <https://r-forge.r-project.org/projects/biomod/> Online:

- 1
2
3 739 <https://r-forge.r-project.org/projects/biomod/>
4
- 5 740 Tittensor D P, Walpole M, Hill S L L, Boyce D G, Britten G L, Burgess N D, Butchart S H M,
6 741 Leadley P W, Regan E C, Alkemade R, Baumung R, Bellard C, Bouwman L, Bowles-Newark N
7 742 J, Chenery A M, Cheung W W L, Christensen V, Cooper H D, Crowther A R, Dixon M J R,
8 743 Galli A, Gaveau V, Gregory R D, Gutierrez N L, Hirsch T L, Höft R, Januchowski-Hartley S R,
9 744 Karmann M, Krug C B, Leverington F J, Loh J, Lojenga R K, Malsch K, Marques A, Morgan D
10 745 H W, Mumby P J, Newbold T, Noonan-Mooney K, Pagad S N, Parks B C, Pereira H M,
11 746 Robertson T, Rondinini C, Santini L, Scharlemann J P W, Schindler S, Sumaila U R, Teh L S L,
12 747 Van Kolck J, Visconti P and Ye Y 2014 A mid-term analysis of progress toward international
13 748 biodiversity targets *Science* (80-.). **346** 241–4 Online: <http://science.sciencemag.org/>
- 15 749 VanDerWal J, Murphy H T, Kutt A S, Perkins G C, Bateman B L, Perry J J and Reside A E 2013
16 750 Focus on poleward shifts in species' distribution underestimates the fingerprint of climate
17 751 change *Nat. Clim. Chang.* **3** 239–43 Online: <http://www.nature.com/articles/nclimate1688>
- 19 752 Virkkala R, Heikkinen R K, Leikola N and Luoto M 2008 Projected large-scale range reductions of
20 753 northern-boreal land bird species due to climate change *Biol. Conserv.* **141** 1343–53
- 22 754 Virkkala R and Lehikoinen A 2014 Patterns of climate-induced density shifts of species: poleward
23 755 shifts faster in northern boreal birds than in southern birds *Glob. Chang. Biol.* **20** 2995–3003
24 756 Online: <http://doi.wiley.com/10.1111/gcb.12573>
- 26 757 Wang X, Kuang F, Tan K and Ma Z 2018 Population trends, threats, and conservation
27 758 recommendations for waterbirds in China *Avian Res.* **9** 14 Online:
28 759 <https://avianres.biomedcentral.com/articles/10.1186/s40657-018-0106-9>
- 29 760 Weeks B C, Willard D E, Zimova M, Ellis A A, Witynski M L, Hennen M and Winger B M 2020
30 761 Shared morphological consequences of global warming in North American migratory birds *Ecol.*
31 762 *Lett.* **23** 316–25 Online: <https://onlinelibrary.wiley.com/doi/abs/10.1111/ele.13434>
- 33 763 Williams J E and Blois J L 2018 Range shifts in response to past and future climate change: Can
34 764 climate velocities and species' dispersal capabilities explain variation in mammalian range
35 765 shifts? *J. Biogeogr.* **45** 2175–89 Online: <http://doi.wiley.com/10.1111/jbi.13395>
- 37 766 Williamson L, Hudson M, O'Connell M, Davidson N, Young R, Amano T and Székely T 2013 Areas
38 767 of high diversity for the world's inland-breeding waterbirds *Biodivers. Conserv.* **22** 1501–12
39 768 Online: <http://csntool>.
- 41 769 Zuckerberg B, Woods A M and Porter W F 2009 Poleward shifts in breeding bird distributions in
42 770 New York State *Glob. Chang. Biol.* **15** 1866–83 Online:
43 771 <https://onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2486.2009.01878.x>
- 45 772 Zurell D, Elith J and Schröder B 2012 Predicting to new environments: tools for visualizing model
46 773 behaviour and impacts on mapped distributions *Divers. Distrib.* **18** 628–34 Online:
47 774 <http://doi.wiley.com/10.1111/j.1472-4642.2012.00887.x>

48 775
49
50 776
51
52 777
53
54
55
56
57
58
59
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