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Insurance for the future? Potential avian community resilience in cities across Europe

Morelli, Federico; Benedetti, Yanina; Ibáñez-Álamo, Juan Diego; Tryjanowski, Piotr; Jokimaki, Jukka; Kaisanlahti-Jokimaki, Marja-Liisa; Pérez-Contreras, Tomás; Sprau, Philipp; Jukka, Suhonen; Yosef, Reuven; Diaz, Mario; Møller, Anders Pape

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1 **Insurance for the future? Potential avian community resilience in cities across**
2 **Europe**

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7 4 *Running head: Bird community potential resilience in European cities*

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12 6 Federico Morelli^{1*}, Yanina Benedetti¹, Juan Diego Ibáñez-Álamo², Piotr Tryjanowski³,
13 7 Jukka Jokimäki⁴, Marja-Liisa Kaisanlahti-Jokimäki⁴, Tomás Pérez-Contreras², Philipp
14 8 Sprau⁵, Jukka Suhonen⁶, Reuven Yosef^{7,8}, Mario Díaz⁹, Anders Pape Møller¹⁰

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16 9
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20
21 10 ¹ Czech University of Life Sciences Prague, Faculty of Environmental Sciences,
22 11 Department of Applied Geoinformatics and Spatial Planning, Kamýcká 129, CZ-165 00
23 12 Prague 6, Czech Republic

24
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26
27 13 ² Department of Zoology, University of Granada, Granada, Spain

28
29
30 14 ³ Institute of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71C, PL-60-
31 15 625 Poznań, Poland

32
33
34 16 ⁴ Nature Inventory and EIA-services, Arctic Centre, University of Lapland, P. O. Box 122,
35 17 FI-96101 Rovaniemi, Finland

36
37
38
39 18 ⁵ Department of Biology, Ludwig-Maximilians-University Munich, Munich, Germany

40
41 19 ⁶ Department of Biology, University of Turku, Turku, Finland

42
43
44 20 ⁷ Ben Gurion University of the Negev, P. O. Box 272, Eilat 88000, Israel

45
46
47 21 ⁸ Rabin High School, Yotam Street, Eilat 88104, Israel

48
49
50 22 ⁹ Department of Biogeography and Global Change, Museo Nacional de Ciencias Naturales
51 23 (BGC-MNCN-CSIC), E-28006 Madrid, Spain

52
53
54 24 ¹⁰ Ecologie Systématique Evolution, Université Paris-Sud, CNRS, AgroParisTech,
55 25 Université Paris-Saclay, F-91405 Orsay Cedex, France

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58 26 *Corresponding author: fmorellius@gmail.com, tel.: +420774232640

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29 **Abstract**

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30 Urbanization is affecting avian biodiversity across the planet, and potentially increasing
31 species vulnerability to climate. Identifying the resilience of urban bird communities to
32 climate change is critical for making conservation decisions. This study explores the
33 pattern in bird communities across nine European cities and examines the projected
34 impact of climate change in order to detect communities facing a higher risk of functional
35 change in the future.

36 First, generalized linear mixed models were used to explore the potential resilience of
37 urban bird communities in nine European cities, and the effects of land cover, latitude,
38 abundance of potential domesticated predators (dogs and cats), and bird species richness
39 in each trophic guild. Bird community resilience was represented by an index of functional
40 evenness, because it indicates relatively uniform functional space within the species
41 assemblages. Second, bird community resilience in each city was compared with
42 projected changes in temperature and precipitation for the year 2070 to explore potential
43 future threats to conservation.

44 The results showed that community resilience was not significantly associated with land
45 use or predator abundance. The number of granivorous and granivorous-insectivorous
46 species increases the potential resilience of the community, while the numbers of
47 insectivores, carnivores and omnivores are negatively correlated with resilience. Of the
48 nine cities, Madrid and Toledo (Spain) are projected to experience the largest change in
49 temperature and precipitation, although their bird communities are characterized by
50 relative high resilience.

51 In contrast, Rovaniemi (Finland) is projected to experience the second highest increase in
52 temperature and the bird community is characterized by low resilience. These findings
53 indicate the importance of future research on the combined effect of urbanization and
54 climate change on urban biodiversity.

55
56 **Keywords:** biotic homogenization; bird diversity; community resilience; conservation;
57 functional evenness; urbanization

59 **INTRODUCTION**

60 **Global urbanization and ecosystem transformation**

61 We are living in a new self-induced geological era, called "the Anthropocene",
62 characterized by the increasing pressure of urban development on ecosystem dynamics
63 across the entire planet (Crutzen and Stoermer 2000; Lewis and Maslin 2015). The
64 change in land-use produced by the urbanization process is one of the major drivers of
65 environmental modification, with strong and deep impacts on both climate and global
66 biodiversity (Foley et al. 2005; Grimm et al. 2008; Aronson et al. 2014). Expanded
67 urbanization leads to habitat fragmentation and degradation (Spellerberg 1998;
68 Schmiegelow and Mönkkönen 2002; Sklenicka 2016), a process which negatively impacts
69 biodiversity at different levels of organization (Crooks et al. 2004; Wilson et al. 2016).
70 Thus, the mitigation of the loss of biodiversity is partially dependent on our understanding
71 of how urbanization structures biological communities and the subsequent development of
72 wildlife management strategies that incorporate urban ecosystems (Miller and Hobbs
73 2002).

74 The effects of urbanization on biodiversity are complex and mainly negative (McKinney
75 2002; Grimm et al. 2008; Secretariat of the Convention on Biological Diversity 2012;
76 Aronson et al. 2014; Ibáñez-Álamo et al. 2016; Morelli et al. 2016). Especially when trying
77 to assess the effects of urbanization on overall biodiversity, emphasizing that approaches
78 focusing only on species richness are limited by their failure to take the ecological role of
79 species on communities into account (Safi et al. 2013). In fact, estimates of functional
80 diversity often measure variation in ecosystem functioning better than taxonomic diversity
81 measures (Petchey et al. 2004). Among the most recognized effects of urbanization on
82 species assemblage composition stands the 'biotic homogenization' of global communities
83 (Clergeau et al. 2006; McKinney 2006). Biotic homogenization consists of the range
84 expansion of cosmopolitan or generalist species and simultaneously the range contraction
85 of regional and endemic species, a process which is particularly intense in dense urban
86 settlements (Garcillán et al. 2014). Biotic homogenization was confirmed in several taxa
87 (McKinney and Lockwood 1999; La Sorte et al. 2007; Knop 2016), but has so far mostly
88 been studied in urban bird communities (Crooks et al. 2004; Devictor et al. 2007; Godet et
89 al. 2015; Ibáñez-Álamo et al. 2016; Vázquez-Reyes et al. 2017). Urbanized areas
90 (farmlands, villages and cities) can provide additional habitat or food sources, attracting

91 specific bird species (Evans et al. 2009a; Evans et al. 2009b; Tryjanowski et al. 2015;
92 Reynolds et al. 2017). However, urban bird communities are more homogeneous and
93 often characterized by the absence of specialists when compared with communities from
94 natural habitats (Jokimäki and Kaisanlahti-Jokimäki 2003; Shochat et al. 2010; Ferenc et
95 al. 2014). These differences lead to a gradual decline in the overall functional diversity of
96 species assemblages (Pauw and Louw 2012; Kang et al. 2015; Schütz and Schulze 2015),
97 potentially also reducing the capacity of such communities to resist drastic changes in land
98 use or weather. In fact, it has already been demonstrated that urban development patterns
99 and green areas within cities affect ecosystem dynamics, modifying their abilities to cope
100 with disturbance and modifying their ecological resilience (Alberti and Marzluff 2004).

101 **Functional surrogates of potential community resilience**

102 Ecological resilience is associated with the capacity of ecological systems to resist
103 invasions, climate or land use changes (Haegeman et al. 2016). This term was introduced
104 in ecology in the 1970's by Holling (1973) and has been more recently defined as “the
105 capacity of a given system to change in order to maintain the same identity” (Folke et al.
106 2010). Thus, resilience is associated with a sort of ‘elasticity’ of the system. This property
107 is associated with a relative functional redundancy of components of that system
108 (Haegeman et al. 2016). Redundant or pseudo-redundant species can be described as
109 species sharing many functional traits, belonging to the same guild or having a similar role
110 in the ecosystem (Gitay et al. 1996). Theoretically, the loss or gain of such species should
111 not strongly affect the overall ecosystem functions (Loreau 2004).

112 Some studies have suggested that indices of functional diversity such as functional
113 evenness may be useful surrogates for the resilience of communities (Mason et al. 2005;
114 Villéger et al. 2008; Lee and Martin 2017), even if in recent years some potential
115 drawbacks were raised (Ricotta et al. 2014; Legras and Gaertner 2018). These indices
116 could be used to assess the level of utilization of available resources in a given space, by
117 the species inhabiting it (Mason et al. 2005; Mouchet et al. 2010). In communities with high
118 functional evenness the resources would be more efficiently used due to a more uniform
119 distribution of the abundance of species throughout functional space defined by the
120 species traits (Lee and Martin 2017) (see a schematic exemplification in the Fig. S1,
121 ESM). In contrast, in communities with low functional evenness available resources could
122 be underexploited, making the community more susceptible to alterations, as for instance

123 biological invasions (Elton 1958; Shea and Chesson 2002). More resilient ecological
124 systems should be able to absorb larger shocks, alleviating the effects and reducing the
125 significant modifications, offering a sort of insurance for the future, facing climate change
126 scenarios (Folke et al. 2002). In this context, the characteristics of the species composing
127 each community, as for example the type of diet, acquires significant importance to
128 determine the overall resilience capacities of such a community. We can expect that
129 communities composed of many species which are similar in terms of feeding traits (e.g.
130 several omnivorous species), could be better prepared to face eventual change in land use
131 or climate, because such communities are able to respond better by adapting to
132 fluctuations in food resources. On the other hand, communities composed of several
133 species characterized by a narrow diet (e.g. exclusively frugivorous) could be associated
134 with a higher extinction risk (Terborgh and Winter 1980).

135 **Climate change scenarios and the challenge for conservation of biodiversity**

136 The effects of climate change could be an additional pressure on ecosystems, interacting
137 with land use change and fragmentation (Eglington and Pearce-Higgins 2012), for
138 example by promoting biological invasions (Opdam and Wascher 2004; Bellard et al.
139 2013). Projections suggest that in the next decades human-induced climate change is
140 expected to continue, and probably accelerate significantly in association with the global
141 emissions of heat-trapping gases (some sources for projections: for America,
142 <https://nca2014.globalchange.gov/>; for worldwide, <https://gisclimatechange.ucar.edu/>)
143 (Hulme et al. 1999; NCAR community 2012; Brown and Caldeira 2017).

144 There exists a vast amount of scientific literature focusing on the main effects of climate in
145 bird populations, mainly produced by temperature and precipitation (Huntley et al. 2008;
146 Askeyev et al. 2018; Trautmann 2018). The main effects of climate change on birds could
147 be associated with changes in distribution range of avian species, phenology and breeding
148 success, but also genetics and overall population sizes (Trautmann 2018). Briefly, the
149 main effects of temperature can be associated with variation in the body mass (Andrew et
150 al. 2018), avian timing of reproduction (Visser et al. 2009) and reproductive performance of
151 avian species (Conrey et al. 2016). Some studies have shown that extreme temperatures
152 (e.g., heat waves or drastic fall on temperatures) during the early breeding season can
153 negatively affect nesting success of grassland birds (Conrey et al. 2016; Zuckerberg et al.
154 2018). On the other hand, the main effects of precipitation on birds are associated with the

155 direct survival of adults and nesting and hatching success. For example, it was
156 demonstrated that large amounts of precipitations during the year preceding a breeding
157 season, can increase the nesting success of some birds (Zuckerberg et al. 2018).
158 However, excessive precipitations during the breeding season can reduce the nesting
159 success (Zuckerberg et al. 2018). Additionally, intense rain events are expected to reduce
160 food availability (e.g. insect resources) or directly foraging efficiency of birds (Siikämaki
161 1996). Furthermore, many of the effects of weather variables on birds are combined and
162 associated with different ecological levels (species, populations, communities) (Møller et
163 al. 2010; Skagen and Adams 2012; Stephens et al. 2016; Trautmann 2018).

164 The use of simulated scenarios to forecast the environmental implications of potential
165 climate or land use changes is a recognized tool for the development of ecological policies
166 (Princé et al. 2013). Climate change causes different ecological fingerprints (Parmesan
167 2006): Bird populations will be affected in many ways, causing ecological adaptations in
168 response to such changes (Butler and Taylor 2005; Barbet-Massin and Jetz 2015; Howard
169 et al. 2015). Among the ecological responses, a potential geographic shift and spatial re-
170 distribution of species assemblages is a critical focus for ecosystem functioning, with deep
171 implications for conservation (Barbet-Massin and Jetz 2015; Princé and Zuckerberg 2015).
172 Induced changes could also be species-specific, altering the composition of bird
173 communities, with potential effects on overall resilience. Additionally, global climate
174 change is expected to strongly affect even the local climate of cities worldwide (Lauwaet et
175 al. 2015), which constitutes important core areas for conservation of many bird species
176 (Ives et al. 2016; Jokimäki et al. 2018). In fact, recent studies have highlighted the
177 important role of cities for global or regional biodiversity conservation, by providing
178 opportunities for settlement of species (Zerbe et al. 2003; Aronson et al. 2014; Møller and
179 Díaz 2017). Cities can be characterized by a mix between global warming and the urban
180 heat island effect (Oke 1973; Kim 1992). Early identification of specific conservation
181 targets where climate can accelerate the already negative impact of urbanization should
182 be a priority in an increasingly urbanizing planet.

183 The aims of this study were (a) to explore the patterns and geographic variation in
184 resilience of urban bird communities in European cities, (b) to identify urban bird
185 communities more likely to be threatened by climate change according to future
186 projections in temperature and rainfall, and (c) to explore the characteristics of such bird

187 assemblages in terms of species traits (e.g. diet), in order to increase our understanding of
188 potential conservation concerns, and, therefore, attempts to mitigate the negative effects
189 of such changes.

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191 **METHODS**

192 **Study area, environment and collection of bird data**

193 Fieldwork was performed in nine cities, located along a large latitudinal gradient, in six
194 European countries (Fig. 1). This approach, involving different urbanized areas, is
195 particularly suitable for investigating general patterns (Ibáñez-Álamo et al. 2016). In this
196 study were included only urban areas, with multi-story buildings, single family houses,
197 roads and parks. Our classification of environments as urban (percentage of built-up area
198 >50, building density >10/ha and residential human density >10/ha) followed the
199 description made by Marzluff *et al.* (2001). It has been used in many other studies focusing
200 on urban avian ecology (Clergeau et al. 2006; Loss et al. 2009; Møller et al. 2015; Morelli
201 et al. 2016). We collected data on vegetation cover and land use composition within a
202 distance of 50 m from each survey point (Díaz et al. 2013). Land use / cover categories
203 were classified in 6 types: building (which includes residential building, built with
204 infrastructure and processing areas and roads), trees (isolated trees, tree lines and
205 patches), bushes (which includes plants from gardens), grass, bare soil, and water.

206 Data on bird species were collected during the 2016 breeding season. The surveys were
207 locally adjusted to the start of the breeding season (e.g. early April in southern Spain or
208 late May in northern Finland). Data on bird species were collected by expert ornithologists,
209 following the standardized methodology of point counts randomly selected (Bibby et al.
210 1992; Voříšek et al. 2010) within each city (ESM, Table S1). All survey points were visited
211 between 06:00 and 10:00 only during favorable weather conditions (i.e., no rain or strong
212 wind). A total of 5 minutes in early spring and 5 minutes during a second visit in late spring
213 allowed for inclusion of both early breeders and late migrants, minimizing issues related to
214 differences in the detectability of bird species (Kéry et al. 2005). During the point counts all
215 individual birds seen or heard within a 50m distance from the observer were recorded, with
216 the only exception being raptors and nocturnal species, because they are subject to a
217 different strategy of survey. The location of each sampling point was recorded with a GPS
218 to ensure that counts were made at the same points during the two surveys. For each
219 sampling point, we also calculated the abundance of mammals as the mean number of
220 dogs and cats seen within 50m during the two 5-minute point counts.

221 **Surrogate of potential resilience of bird communities**

222 The bird community in each sampling site was defined as the total number of bird species
223 recorded during the two visits. Thus, species richness was expressed as the largest
224 number of bird species of the combined data for the two surveys performed during the
225 breeding season (Magurran 2004).

226 For each sampling site or bird community, we estimated two functional diversity indices
227 which are traditionally associated with resilience of the community: Functional evenness
228 ('FEve') (Villéger et al. 2008) and the measure 'Fever' for calculating the functional
229 evenness of a species' assemblage (Ricotta et al. 2014). Both measures are based on a
230 species-trait approach, which focuses on functional aspects of biodiversity (de Bello et al.
231 2010). Both indices used in this study as surrogate for bird community resilience were
232 calculated using the feeding and breeding avian niche traits provided in Pearman et al.
233 (2014). The bird traits consists of 73 variables describing the niche of each bird species,
234 including (i) body mass, (ii) food type (14 variables), (iii) behavior used for food acquisition
235 (9 variables), (iv) substrate from which food is taken (9 variables), (v) period of day during
236 which a species are active (3 variables), and (vi) used habitats (38 variables) (Pearman et
237 al. 2014). All variables, except for body mass, are binary variables (scored as either 0 or 1)
238 (see a complete description of the used bird traits in ESM, Table S2). The functional traits
239 are associated with many different characteristics of birds including morphological,
240 physiological, and phenological attributes of species, which are related to individual fitness
241 via their effects on growth, reproduction and survival (Violle et al. 2007).

242 The functional evenness (FEve) indicate how regular is the degree to which the biomass of
243 the species assemblage is distributed in niche space to allow effective utilization of the
244 entire range of resources available (Villéger et al. 2008) and is calculated as follows:

$$\text{FEve} = \frac{\sum_{i=1}^{S-1} \min\left(\text{PEW}_{i, \frac{1}{S-1}}\right) - \frac{1}{S-1}}{1 - \frac{1}{S-1}}$$

246 where i is the species (or functional unit), S is the total species richness and PEW is the
247 partial weighted evenness.

248 The FeveR index reflects the regularity in the distribution of abundances of species,
 249 together with the evenness in their pairwise functional dissimilarities (Ricotta et al. 2014),
 250 and is calculated as follows:

$$R_U = \frac{E_U - 1/N}{1 - 1/N}$$

252 where E_U is the index of Bulla (1994) and N the number of species, calculated as follows:

$$E_U = \sum_i^N \min\{\pi_i, 1/N\}$$

254 where π_i is the relative contribution of species i to U (average community uniqueness U).

255 The average community uniqueness U is the expected dissimilarity between one individual
 256 of species i chosen at random from a given community and all other j -th species in the
 257 community, calculated as follows:

$$U = \sum_{j \neq i}^N p_i \times U_i = \sum_i^N p_i \sum_{i \neq j}^N \frac{p_j}{1 - p_i} d_{ij}$$

259 where d_{ij} is the functional dissimilarity between species i and j (with $d_{ij} = d_{ji}$ and $d_{ii} = 0$), p_i
 260 and p_j are the relative abundance of species i and j respectively, and U_i represent the
 261 expected dissimilarity between species i and all other species in the community (Ricotta et
 262 al. 2014).

263 The functional diversity indices used in this study were calculated using the 'FD' package
 264 for FEve (Laliberté et al. 2015) and the function provided in Ricotta *et al.* (2014) for FeveR.

265 Additionally, we calculated species richness for each trophic guild: Granivorous (diet
 266 containing primarily seeds and grain), insectivorous (diet containing primarily insects and
 267 other invertebrates), granivorous-insectivorous (diet containing primarily seeds, grain,
 268 insects and other invertebrates), and carnivorous and omnivorous birds. The trophic guilds
 269 were defined by crossing information on bird species from published sources (Cramp and
 270 Perrins 1994; Storchová and Hořák 2018) and the 14 food types described in Pearman et
 271 al. (2014). With the species richness per each trophic guild we estimated also the diet
 272 diversity in each community by applying the Shannon-diversity index (Shannon 1948).

273 **Climate change projection data: differences in temperature and precipitation**

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274 Data on climate change projections were obtained from NCAR GIS Program, through
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275 Climate Change Scenarios, version 2.0, 2012. URL: <https://gisclimatechange.ucar.edu/>.
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276 Data Access Date: 25/05/2018 (NCAR community 2012). The climate change scenarios
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277 have been redesigned for the Intergovernmental Panel on Climate Change (IPCC) Fifth
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278 Assessment Report. The Community Climate System Model (CCSM) as a community-
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279 wide effort led by the National Center for Atmospheric Research (NCAR, URL:
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280 <https://ncar.ucar.edu/>), and it is a key component of the National Science Foundation
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281 program on Climate Modeling, Analysis and Prediction. We used the data provided by
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282 CCSM, because they are one of the world's leading general circulation climate models,
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283 and a community wide effort led by NCAR. The data define the Representative
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284 Concentration Pathways (RCPs), which provide concentrations of atmospheric
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285 greenhouse gas (GHG) and the trajectory that is taken over time to reach those
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286 concentrations. The spatial resolution of CCSM-3 climate change projections is
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287 approximately 1.4 x 1.4 degrees, and represents a plausible alternative scenario for the
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288 future, not a prediction or forecast (Moss et al. 2008). We downloaded three projected
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289 scenarios for current and future climate change in the years comprised between 2017 and
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290 2070: scenarios RCP 4.5, 6.0 and 8.5. In order to visualize the potential climate change
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291 expected in Europe, we used the differences in annual means (raw CCSM data) between
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292 2017 and the simulated data for 2070 in a) temperature (in °Celsius) and b) amount of
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293 precipitation (in mm) in each cell provided in the CCSM data.

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294 The three different scenarios were mapped for the European continent (ESM, Fig. S2) by
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using the ArcGIS 10.1 (ESRI 2012) tool “inverse distance weighted” (IDW). The IDW is a
technique that interpolates a raster surface from several point values, taking into account
the distances among points (Lu and Wong 2008). The distance among points is uniform
across Europe and corresponds to the distance among the centroids of the cells provided
in the CCSM data (ESM, Fig. S3). This technique (IDW) is adequate to visualize the areas
more subject to potential changes in terms of both temperature and precipitation. We used
the maps produced to overlap with the cities where bird community resilience was
calculated, and then extracted the relative values of climate change expected for each city.
For visualization of data, we set the IDW on 6 different classes from the minimum to the
maximum values of delta temperature and precipitation, by using the natural breaks

305 (Jenks) classification. This classification identifies the best group similar values and
306 maximizes the differences between classes (De Smith et al. 2007).

307 Finally, in order to compare the congruence/mismatch between potential resilience of
308 urban bird communities in nine European cities and climate change scenarios, we focused
309 on the high pathway in which radiative forcing reaches 8.5 Watts per square meter (Wm^{-2})
310 by 2100 (Moss et al. 2008), because the worst scenario is the most suitable to better
311 highlight potential areas of largest changes in temperature and precipitation in the
312 continent. The main justification for this choice is supported by a recent study suggesting
313 that the worst predictions of climate change are probably the most accurate (Brown and
314 Caldeira 2017).

315 **Statistical analyses**

316 In order to investigate the strength and direction of the association between the two
317 indices of functional diversity (FEve and FeveR) we used the Spearman correlation
318 coefficient (Triola 2012). Because both indices were significantly positively correlated ($R^2 =$
319 0.55 , $p = 4.6e-12$), the subsequent analyses only focused on one of these indices. We
320 chose FEve because this variable showed a largest range if compared with FeveR in each
321 city, guarantying a better visualization of data. A linear regression was used to explore the
322 potential association between the indices of functional diversity and bird diet diversity in
323 avian communities.

324 To explore differences in avian niche traits among species of different trophic guilds, the
325 analysis of dissimilarity was used. In this procedure, a dissimilarity matrix was constructed
326 by the “Gower” dissimilarity measure among bird species, considering the 73 avian traits
327 described above. We used the function ‘daisy’ from the package ‘cluster’ in R (Maechler et
328 al. 2018). The average dissimilarity with all the 279 species in the pool was calculated for
329 each bird species. The Kruskal-Wallis and post hoc Kruskal-Dunn were used to check for
330 significant differences in species dissimilarities among the five trophic guilds. The post hoc
331 contrasts were performed using the package ‘PMCMR’ in R (Pohlert 2014).

332 We used Mantel tests to check for spatial autocorrelation of data (SAC) (Mantel 1967),
333 based on Monte Carlo permutations with 9999 randomizations to test for significance
334 (Oksanen et al. 2016). Sampling sites were treated as statistically dependent observations
335 because the values of SAC between geographic distance (km) and FEve distance among

336 sites was very low though statistically significant ($r_M = 0.048$, $n = 588$, $p = 0.001$) (Manly
337 2006). In order to alleviate SAC issues, the geographical coordinates of sampling sites
338 were introduced as covariates to incorporate spatial variation during the modeling
339 procedure (Legendre 1993; Dormann et al. 2007).

340 Generalized Linear Mixed Models (GLMMs) were used to study the patterns of bird
341 community resilience (FEve) in relation to geographical coordinates of sampling sites, land
342 use / cover composition around the point count, abundance of mammals (number of dogs
343 and cats) and bird species richness for each trophic guild (granivorous, granivorous-
344 insectivorous, insectivorous, carnivorous and omnivorous), modeled as fixed effects. In
345 order to avoid any redundancy in the modeling procedure, we checked for the potential
346 association between the index of FEve (which was estimated considering habitat, breeding
347 and feeding traits) and the Shannon index estimated based on the species richness for
348 each trophic guild by using a simple linear regression analysis. The association between
349 these two variables was not statistically significant (ESM, Fig. S4; $F = 3.2$, $df = 1$, 586 , $p >$
350 0.05), justifying the use of both during the modelling procedure. The following predictor
351 variables were too strongly correlated and thus were removed, in order to avoid
352 multicollinearity issues (Graham 2003): building (negatively and significantly correlated
353 with grass and tree), bare soil (negatively and significantly correlated to grass) and overall
354 species richness (positively correlated to species richness for each trophic guild). City was
355 included as a random effect to account for possible consistent differences among cities.
356 Models were fitted by maximum likelihood, using the package 'lme4' in R (Bates et al.
357 2014). The model selection was based on Akaike's Information Criterion (AIC) (Burnham
358 and Anderson 2002) with the package 'AICcmodavg' in R (Mazerolle 2016).

359 All statistical tests were performed with R software version 3.2.4 (R Development Core
360 Team 2019).

362 **RESULTS**

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363 **Bird community resilience in nine European cities**

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364 A total of 107 bird species were recorded at 588 point-counts distributed in nine European
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365 cities (ESM, Table S1). The complete list of species is provided in the Electronic
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366 Supplementary Material (ESM, Table S3). Species richness per point count ranged from a
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367 minimum mean of 7.52 species (min: 3, max: 12 species) in Munich to a maximum mean
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368 of 14.14 species (min: 3, max: 30 species) in Granada.

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369 Overall, the two surrogates of bird community resilience varied between a minimum of
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370 0.69 (FEve) and 0.80 (FeveR), and a maximum of 1.00 (FEve) and 0.99 (FeveR). The
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371 differences in FEve among cities were statistically significant (ANOVA: $F = 51.08$, $df = 8$,
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372 579 , $P < 2e-16$). The lower mean value of bird community resilience (FEve) was found in
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373 Munich (0.87, min: 0.69, max: 0.95), while higher mean values were found in the Spanish
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374 cities of Madrid (mean: 0.95, min: 0.90, max: 1.00), Granada (mean: 0.94, min: 0.86, max:
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375 0.99) and Toledo (mean: 0.94, min: 0.88, max: 0.98) as well as in the city of Prague
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376 (mean: 0.94, min: 0.85, max: 0.98) (Fig. 1).

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377 The values of bird community resilience (FEve) in nine European cities were not
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378 significantly correlated with the environmental characteristics around the point counts (land
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379 use / cover composition) nor with the abundance of dogs or cats (Table 1). Additionally, we
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380 did not find evidence of latitudinal or longitudinal effects on resilience (Table 1, Fig. 1). Bird
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381 community resilience was higher in cities where the relative number of granivorous or
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382 granivorous-insectivorous species was higher, while it was negatively associated with the
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383 richness of insectivorous, carnivorous and omnivorous-scavenger bird species (Table 1,
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384 Fig. 2).

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385 Overall, avian trait dissimilarity was higher in carnivorous and omnivorous species than in
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386 granivorous, granivorous-insectivorous and insectivorous birds. These differences were
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387 statistically significant (Kruskal-Wallis $\chi^2 = 43.98$, $df = 4$, $P = 2e-09$, ESM, Fig. S5).

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388 **Avian resilience and climate change scenarios**

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389 Considering the projection of climate change scenarios for Europe in the next fifty years,
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390 provided by the Intergovernmental Panel on Climate Change (IPCC) in the Fifth
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391 Assessment Report, the cities exposed to a larger change in temperatures (higher than

392 2.4°C) are the Spanish cities of Madrid, Granada and Toledo and the Finnish cities of
393 Rovaniemi and Turku (Fig. 3). On the other hand, the European cities more exposed to
394 changes in terms of average precipitation in mm are Madrid, Groningen and Poznan (Fig.
395 3). Overall, the cities less exposed to a drastic variation in terms of temperature and
396 precipitation under a high pathway climate change projection are cities from central
397 Europe such as Prague and Munich (Fig. 3, ESM, Table S4).

398 Crossing the mean values of bird community resilience for the nine European cities with
399 the values of expected delta temperature and precipitation, explored in a 3D plot, highlight
400 some potential scenarios of urban bird conservation for the next fifty years: Even if Munich
401 was the city with the lowest avian community resilience, it seems however that bird
402 communities within that city are not affected by strong climate change events, but only by
403 a relative moderate change in temperature, with temperature increases of 1.9-2.3 °C, but
404 less strong changes in precipitation when compared with other European cities (ESM, Fig.
405 S6). The Spanish cities with higher values of bird community resilience will face more
406 notorious climate change events: Madrid (with the higher bird community resilience) could
407 be affected by a relatively large change in the mean amount of monthly precipitation (110-
408 170 mm) as well as increasing temperatures around 2.4-2.8 °C (ESM, Fig. S6). Granada
409 and Toledo could face similar scenarios of increasing temperatures, but less strong
410 changes in terms of mean amount of monthly precipitation (ESM, Fig. S6). The city of
411 Prague was characterized by bird communities with relative high resilience, and
412 simultaneously not exposed to so drastic climate change events in the next fifty years
413 (ESM, Fig. S6). The Finnish city of Rovaniemi could suffer an important increase in
414 average temperatures, while their bird species assemblages are characterized by lower
415 resilience than other urban bird communities, suggesting a potential conservation problem.

417 **DISCUSSION**

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418 **Climate change scenarios in cities and bird community resilience**

419 In this study, we suggested potential future conservation concerns in urban bird
420 communities, by crossing information on a surrogate of species assemblage resilience
421 (FEve) (Mouchet et al. 2010) and the projection of scenarios facing climate change. Even
422 if we examined three different scenarios, we used the high pathway climate change
423 scenario because it could be the most plausible (Brown and Caldeira 2017).

424 Our findings provide important information about the cities that could face stronger climate
425 change events, and the capacity of their bird communities to reduce any negative impact
426 associated with them. Briefly, a high probability of climate change and simultaneously a
427 low value of bird community resilience can be interpreted as the worst scenario,
428 suggesting a potential conservation concern.

429 A higher pressure of climate change in terms of delta temperatures and delta precipitation
430 should mainly affect cities from the Southern and Northern regions of Europe. The data
431 derived from the projections made by NCAR Climate Change Scenarios (NCAR
432 community 2012) showed that cities like Granada, Madrid and Toledo in Spain and
433 Rovaniemi and Turku in Finland could suffer variation in temperatures larger than 2.6°C
434 before the year 2070 (ESM, Table S4). Additionally, Madrid and Toledo could also be
435 exposed to a significant change in the amount of monthly precipitations. Finally, Madrid
436 was also the biggest city surveyed in this study, with more than three million people (ESM,
437 Table S1). This fact is important, if we consider that the number of threatened bird species
438 could be positively associated with human population size (Pautasso and Dinetti 2009).
439 However, these two Spanish cities are characterized by species assemblages with higher
440 resilience, a fact that can offer insurance against the ability of communities to respond to
441 challenges posed by climate change. On the other hand, from the two Finnish cities,
442 Rovaniemi could constitute a potential problem for conservation in the future: This northern
443 city could face an important increase in average temperatures, while their bird
444 communities are mostly characterized by lower values of resilience within the cities used in
445 our study. Especially in the case of Rovaniemi, most species are (long)-distance migrants
446 (Schaefer et al. 2008; Saino et al. 2011) and in most cases insectivores (Fig. 2).

447 Even if all cities could be exposed to potential climate change scenarios, the cities from
448 the central part of the continent (Groningen, Munich, Poznan and Prague) are less
449 exposed to drastic changes in temperatures, when compared with the other cities studied
450 (Fig. 3), suggesting a low conservation concern of urban bird communities. This is
451 important when planning future conservation, regarding both urbanization and climate
452 change. For example, Munich was the city with the lowest mean value of resilience of
453 avian species assemblages, but considering that future scenarios suggest a relative small
454 impact due to climate change, we consider that specific conservation actions attempting to
455 promote resilience of urban bird assemblages in this city are not urgently needed. In
456 contrast, other cities with low/medium levels of resilience, like Rovaniemi, which will be
457 exposed to important increases in temperature in the future, should be the focus of
458 conservation practices or at least close monitoring schemes. The bird communities from
459 Munich were characterized by a high proportion of insectivores and simultaneously a low
460 proportion of granivorous species, when compared with the other European cities. When
461 comparing Munich with the nearby city of Prague, Czech Republic, we can highlight how
462 the risk of increase in the level of threat for bird communities in Prague could be lower,
463 because the city presents species assemblages with high values of potential resilience,
464 also being a city not subject to particular intensification of climate change.

465 Another important result to highlight from this study is the weak correlation between
466 potential resilience of urban bird communities and land use / cover composition where the
467 communities were assessed. This lack of association in our study may suggest that little
468 variation in land use / cover composition or heterogeneity in urban green areas do not
469 have a strong impact on the regularity of bird traits in functional space and how efficiently
470 the resources are utilized. A study focused on anthropized environments (farmlands)
471 showed how functional evenness of bird communities is only weakly correlated with the
472 environmental characteristics of the area (green area size, canopy heterogeneity) (Lee
473 and Martin 2017).

474 We found in the nine European cities that urban bird communities with high richness of
475 granivorous or granivorous-insectivorous species were the communities with higher
476 potential resilience. In contrast, urban bird communities with an overrated number of
477 insectivorous, carnivorous and omnivorous species were assemblages with lower potential
478 resilience. The main reason why carnivorous and omnivorous species richness was

479 negatively associated with potential community resilience could be explained by the fact
480 that those bird species were characterized by higher trait dissimilarity, when compared
481 with the entire pool of species (ESM, Fig. S5). The granivorous birds recorded in this
482 study, on the other hand, were more similar in terms of breeding and feeding traits (ESM,
483 Fig. S5). By increasing the number of species which are functionally closer, the functional
484 redundancy will rise, achieving a higher functional evenness and potential bird community
485 resilience.

486 Regarding the bird's foraging characteristics in relation to the potential resilience of
487 species assemblages, however, we consider it relevant to highlight the limitations of
488 simple traits describing the diet of a species. Further studies should also consider the fact
489 that many species are relatively plastic in terms of foraging ecology. Some species, as
490 shrikes or sparrows, can exploit different types of diet depending on the geographical
491 context and environmental conditions, being also scavengers at roadsides (Tryjanowski et
492 al. 2003; Morelli et al. 2015). The diet plasticity of bird species, also in cities, can shift their
493 main type of food between seasons. E.g. in the northern part of Europe, while most
494 species need/use protein-rich arthropods during breeding season for their nestlings, they
495 must change their diet for berries during winter, because of a lack of insects (e.g.
496 Turdidae, Sylvidae). Geographic variation in trophic plasticity of bird species could play an
497 important role in the overall potential resilience of the communities. Since specialist
498 species are considered more prone to the processes that lead to extinction than generalist
499 species (McKinney 1997; Colles et al. 2009), we can expect that a given community
500 composed of many species characterized by high ecological plasticity in terms of foraging
501 (but also behaviour or breeding) should be better adapted to eventual environmental or
502 climatic changes, because such species could respond better by adapting to different
503 types of food or other resources. Further studies could also focus on the overall level of
504 specialization of bird communities inhabiting cities (Morelli et al. 2019).

505 Finally, the fact that we did not find any evidence of latitudinal or longitudinal effects on
506 avian resilience among the nine cities could be interpreted as a confirmation of the level of
507 homogenization of urban settlements in Europe (Devictor et al. 2007).

508 **Final considerations and some remarks on the use of a surrogate of community** 509 **resilience**

510 Recent studies have provided evidence of drawbacks for the use of this functional diversity
511 index (e.g. Ricotta et al. 2014; Legras and Gaertner 2018), which is the evenness
512 component of functional diversity. Briefly, the main concerns are related to the fact that an
513 increase in FEve index values is not always synonymous with an increase in functional
514 evenness, mainly when comparing communities which differ in terms of abundance
515 distribution (Legras and Gaertner 2018). However, in the present study, we estimated the
516 FEve crossing a trait matrix with a matrix of solely presence/absence of species, therefore
517 overcoming (or at least alleviating) this potential problem. Additionally, we explicitly
518 compared the behavior of the index FEve with the new index proposed by Ricotta et al.
519 (2014), which measures the regularity in the distribution and abundance of species in
520 functional space, together with the evenness in their pairwise functional dissimilarities, to
521 ensure that in our study both could be used similarly. Moreover, any index or metric used
522 to quantify the hypothetical “resilience” of a species assemblage must be handled
523 cautiously. An index is not a direct "measure", especially because the resilience or
524 capacity to respond to an alteration depends on many (and complex) factors: period of
525 disturbance, intensity, relative plasticity of species, biotic interactions (explicit and hidden),
526 and cascade effects (Spears et al. 2015; Morelli and Tryjanowski 2016). Ecological
527 resilience was defined as a multifaceted concept (Cumming et al. 2005). Thus, we
528 consider that any index should be more efficiently used when applied mainly to
529 comparisons among sites or areas.

530 Importantly, climate change effects can interact with the distribution of bird species,
531 facilitating the expansion of invasive birds that could compete, displace and / or prey on
532 native species (Bellard et al. 2013). Therefore, this could potentially amplify the effects of
533 changes in land use, precipitation or temperature. Maintenance of the level of functional
534 redundancy in bird communities can increase the overall tolerance of such species
535 assemblages to potential scenarios of land use and climate change (Elmqvist et al. 2003).
536 Thus, the capacity of species assemblages to face and recover from extreme events (such
537 as climate or land use change) will determine their persistence.

538 In conclusion, our findings highlighted how an approach combining projections of climate
539 change scenarios and potential resilience of species assemblages (using species trait-
540 based methods), could be useful to identify in advance conservation concerns. We
541 hypothesize that the approach used in this study could also be applied to other taxa such

542 as insects and mammals. This may help establish adequate urban planning strategies for
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543 the promotion of a high diversity of communities in urban exploiter and tolerant species,
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544 increasing the level of protection of urban ecosystem functioning.
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65

551 **REFERENCES**

1
2
3 552 Alberti M, Marzluff JM (2004) Ecological resilience in urban ecosystems: Linking urban
4
5 553 patterns to human and ecological functions. *Urban Ecosyst* 7:241–265.
6
7 554 Andrew SC, Awasthy M, Griffith AD, et al (2018) Clinal variation in avian body size is
8
9 555 better explained by summer maximum temperatures during development than by cold
10
11 556 winter temperatures. *Auk* 135:206–217. doi: 10.1642/auk-17-129.1
12
13 557 Aronson MFJ, La Sorte FA, Nilon CH, et al (2014) A global analysis of the impacts of
14
15 558 urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proc R Soc*
16
17 559 *London B - Biol Sci* 281:20133330. doi: 10.1098/rspb.2013.3330
18
19 560 Askeyev O, Askeyev A, Askeyev I (2018) Recent climate change has increased forest
20
21 561 winter bird densities in East Europe. *Ecol Res* 33:445–456. doi: 10.1007/s11284-018-
22
23 562 1566-4
24
25 563 Barbet-Massin M, Jetz W (2015) The effect of range changes on the functional turnover,
26
27 564 structure and diversity of bird assemblages under future climate scenarios. *Glob*
28
29 565 *Chang Biol* 21:2917–2928. doi: 10.1111/gcb.12905
30
31 566 Bates D, Maechler M, Bolker B, Walker S (2014) lme4: Linear mixed-effects models using
32
33 567 Eigen and S4 - R Package.
34
35 568 Bellard C, Thuiller W, Leroy B, et al (2013) Will climate change promote future invasions?
36
37 569 *Glob Chang Biol* 19:3740–3748. doi: 10.1111/gcb.12344
38
39 570 Bibby CJ, Burgess ND, Hill DA (1992) *Bird Census Techniques* (Google eBook). Academic
40
41 571 Press
42
43 572 Brown PT, Caldeira K (2017) Greater future global warming inferred from Earth's recent
44
45 573 energy budget. *Nature* 552:45–50. doi: 10.1038/nature24672
46
47 574 Bulla L (1994) An index of evenness and its associated diversity measure. *Oikos* 70:167–
48
49 575 171.
50
51 576 Burnham KP, Anderson DR (2002) *Model Selection and Multimodel Inference: A Practical*
52
53 577 *Information-Theoretic Approach*, 2nd edn. Springer, Verlag, New York, NY, USA
54
55 578 Butler RW, Taylor W (2005) A review of climate change impacts on birds. *USDA For Serv*
56
57 579 *Gen Tech Rep* 191:1107–1109.
58
59 580 Clergeau P, Croci S, Jokimäki J, et al (2006) Avifauna homogenisation by urbanisation:

581 Analysis at different European latitudes. *Biol Conserv* 127:336–344. doi:
582 10.1016/j.biocon.2005.06.035
583 Colles A, Liow LH, Prinzing A (2009) Are specialists at risk under environmental change?
584 Neoecological, paleoecological and phylogenetic approaches. *Ecol Lett* 12:849–863.
585 doi: 10.1111/j.1461-0248.2009.01336.x
586 Conrey RY, Skagen SK, Yackel Adams AA, et al (2016) Extremes of heat, drought and
587 precipitation depress reproductive performance in shortgrass prairie passerines. *Ibis*
588 (Lond 1859) 158:614–629. doi: 10.1111/ibi.12373
589 Cramp S, Perrins C (1994) *The Birds of the Western Palearctic*. Oxford University Press,
590 Oxford, UK
591 Crooks KR, Suarez A V., Bolger DT (2004) Avian assemblages along a gradient of
592 urbanization in a highly fragmented landscape. *Biol Conserv* 115:451–462. doi:
593 10.1016/S0006-3207(03)00162-9
594 Crutzen PJ, Stoermer. EF (2000) The “Anthropocene.” *Glob Chang Newsl* 41:17–18.
595 Cumming GS, Barnes G, Perz S, et al (2005) An exploratory framework for the empirical
596 measurement of resilience. *Ecosystems* 8:975–987. doi: 10.1007/s10021-005-0129-z
597 de Bello F, Lavorel S, Gerhold P, et al (2010) A biodiversity monitoring framework for
598 practical conservation of grasslands and shrublands. *Biol Conserv* 143:9–17. doi:
599 10.1016/j.biocon.2009.04.022
600 De Smith MJ, Goodchild MF, Longley PA (2007) Univariate classification schemes. In:
601 *Geospatial Analysis—A Comprehensive Guide to Principles, Techniques and*
602 *Software Tools*, 2nd edn. Troubador Publishing Ltd, p 516
603 Devictor V, Julliard R, Couvet D, et al (2007) Functional homogenization effect of
604 urbanization on bird communities. *Conserv Biol* 21:741–751. doi: 10.1111/j.1523-
605 1739.2007.00671.x
606 Díaz M, Møller AP, Flensted-Jensen E, et al (2013) The Geography of Fear: A Latitudinal
607 Gradient in Anti-Predator Escape Distances of Birds across Europe. *PLoS One*
608 8:e64634. doi: 10.1371/journal.pone.0064634
609 Dormann CF, McPherson JM, Araújo MB, et al (2007) Methods to account for spatial
610 autocorrelation in the analysis of species distributional data: a review. *Ecography*

- 611 (Cop) 30:609–628. doi: 10.1111/j.2007.0906-7590.05171.x
1
- 612 Eglinton SM, Pearce-Higgins JW (2012) Disentangling the relative importance of changes
3
613 in climate and land-use intensity in driving recent bird population trends. PLoS One
5
614 7:e30407. doi: 10.1371/journal.pone.0030407
7
- 615 Elmqvist T, Folke C, Nystrom M, et al (2003) Response Diversity, Ecosystem Change, and
9
616 Resilience. *Front Ecol Environ* 1:488–494. doi: 10.2307/3868116
11
- 617 Elton CS (1958) *The Ecology of Invasions by Animals and Plants*. Methuen, London, UK.
13
- 618 ESRI (2012) *ArcGIS Desktop: Release 10.1*. Redlands, CA: Environmental Systems
14
619 Research Institute.
17
- 620 Evans KL, Gaston KJ, Frantz AC, et al (2009a) Independent colonization of multiple urban
18
621 centres by a formerly forest specialist bird species. *Proc R Soc London B - Biol Sci*
20
622 276:2403–2410.
23
- 623 Evans KL, Newson SE, Gaston KJ (2009b) Habitat influences on urban avian
24
624 assemblages. *Ibis (Lond 1859)* 151:19–39.
27
- 625 Ferenc M, Sedláček O, Fuchs R, et al (2014) Are cities different? Patterns of species
28
626 richness and beta diversity of urban bird communities and regional species
30
627 assemblages in Europe. *Glob Ecol Biogeogr* 23:479–489. doi: 10.1111/geb.12130
33
- 628 Foley JA, Defries R, Asner GP, et al (2005) Global consequences of land use. *Science*
34
629 309:570–474. doi: 10.1126/science.1111772
37
- 630 Folke C, Carpenter S, Elmqvist T, et al (2002) Resilience and sustainable development:
38
631 Building adaptive capacity in a World of transformations. *Ambio* 31:437–440.
41
- 632 Folke C, Carpenter SR, Walker B, et al (2010) Resilience Thinking: Integrating Resilience,
42
633 Adaptability and Transformability. *Ecol Soc* 15:20.
45
- 634 Garcillán PP, Dana ED, Rebman JP, Peñas J (2014) Effects of alien species on
46
635 homogenization of urban floras across continents : a tale of two mediterranean cities
48
636 on two different continents. *Plant Ecol Evol* 147:3–9. doi: 10.5091/plecevo.2014.950
51
- 637 Gitay H, Wilson JB, Lee WG (1996) Species Redundancy: A Redundant Concept? *J Ecol*
52
638 84:121–124.
55
- 639 Godet L, Gaüzère P, Jiguet F, Devictor V (2015) Dissociating several forms of
56
640 commonness in birds sheds new light on biotic homogenization. *Glob Ecol Biogeogr*
58
59

- 641 24:416–426. doi: 10.1111/geb.12266
1
- 642 Graham MH (2003) Confronting multicollinearity in ecological multiple regression. *Ecology*
3 84:2809–2815. doi: 10.1890/02-3114
643 5
- 644 Grimm NB, Foster D, Groffman P, et al (2008) The changing landscape: ecosystem
7 responses to urbanization and pollution across climatic and societal gradients. *Front*
645 *Ecol Environ* 6:264–272. doi: 10.1890/070147
9
1046 11
- 1047 Haegeman B, Arnoldi J-F, Wang S, et al (2016) Resilience, invariability, and ecological
13 stability across levels of organization. *bioRxiv* 1–15. doi: 10.1101/085852
1048 15
- 1049 Holling CS (1973) Resilience and stability of ecological systems. *Annu Rev Ecol Syst* 4:1–
17 23. doi: 10.1146/annurev.es.04.110173.000245
1050 19
- 651 Howard C, Stephens PA, Pearce-Higgins JW, et al (2015) The drivers of avian abundance:
21 patterns in the relative importance of climate and land use. *Glob Ecol Biogeogr*
2052 24:1249–1260. doi: 10.1111/geb.12377
23
2053 25
- 654 Hulme M, Mitchell J, Ingram W, et al (1999) Climate change scenarios for global impacts
27 studies. *Glob Environ Chang* 9:S3–S19. doi: 10.1016/S0959-3780(99)00015-1
2055 29
- 656 Huntley B, Collingham YC, Willis SG, Green RE (2008) Potential impacts of climatic
31 change on European breeding birds. *PLoS One* 3:e1439. doi:
3057 10.1371/journal.pone.0001439
33
3058 35
- 659 Ibáñez-Álamo JD, Rubio E, Benedetti Y, Morelli F (2016) Global loss of avian evolutionary
37 uniqueness in urban areas. *Glob Chang Biol* 23:2990–2998. doi: 10.1111/gcb.13567
3060 39
- 661 Ives CD, Lentini PE, Threlfall CG, et al (2016) Cities are hotspots for threatened species.
41 *Glob Ecol Biogeogr* 25:117–126. doi: 10.1111/geb.12404
40
662 43
- 663 Jokimäki J, Kaisanlahti-Jokimäki M-L (2003) Spatial similarity of urban bird communities: a
44 multiscale approach. *J Biogeogr* 30:1183–1193.
45
664 47
- 665 Jokimäki J, Suhonen J, Kaisanlahti-Jokimäki M-L (2018) Landscape and Urban Planning
48 Urban core areas are important for species conservation: A European-level analysis
49 of breeding bird species. *Landsc Urban Plan* 178:73–81. doi:
50
666 51
667 52
53
668 54
55
- 669 Kang W, Minor ES, Park C, Lee D (2015) Effects of habitat structure, human disturbance,
56 and habitat connectivity on urban forest bird communities. *Urban Ecosyst* 18:857–
57
670 59
60
61
62
63
64
65

671 870. doi: 10.1007/s11252-014-0433-5
1
672 Kéry M, Royle JA, Schmid H (2005) Modeling avian abundance from replicated counts
3 using binomial mixture models. *Ecol Appl* 15:1450–1461. doi: 10.1890/04-1120
673
5
674 Kim HH (1992) Urban heat island. *Int J Remote Sens* 13:2319–2336. doi:
7
675 10.1080/01431169208904271
9
10
676 Knop E (2016) Biotic homogenization of three insect groups due to urbanization. *Glob*
11
12
677 *Chang Biol* 22:228–236. doi: 10.1111/gcb.13091
13
14
678 La Sorte F a., McKinney ML, Pyšek P (2007) Compositional similarity among urban floras
15
16
679 within and across continents: Biogeographical consequences of human-mediated
17
18
680 biotic interchange. *Glob Chang Biol* 13:913–921. doi: 10.1111/j.1365-
19
20
681 2486.2007.01329.x
21
22
682 Laliberté E, Legendre P, Shipley B (2015) Measuring functional diversity (FD) from
23
24
683 multiple traits, and other tools for functional ecology: R package version 1.0-12.
25
26
684 Lauwaet D, Hooyberghs H, Maiheu B, et al (2015) Detailed Urban Heat Island Projections
27
28
685 for Cities Worldwide: Dynamical Downscaling CMIP5 Global Climate Models. *Climate*
29
30
686 3:391–415. doi: 10.3390/cli3020391
31
32
687 Lee M-B, Martin JA (2017) Avian Species and Functional Diversity in Agricultural
33
34
688 Landscapes: Does Landscape Heterogeneity Matter? *PLoS One* 12:e0170540. doi:
35
36
689 10.1371/journal.pone.0170540
37
38
690 Legendre P (1993) Spatial Autocorrelation: Trouble or New Paradigm? *Ecology* 74:1659–
39
40
691 1673.
41
42
692 Legras G, Gaertner J-C (2018) Assessing functional evenness with the FEve index: A
43
44
693 word of warning. *Ecol Indic* 90:257–260. doi: 10.1016/J.ECOLIND.2018.03.020
45
46
694 Lewis SL, Maslin MA (2015) Defining the Anthropocene. *Nature* 519:171–180. doi:
47
48
695 10.1038/nature14258
49
50
696 Loreau M (2004) Does functional redundancy exist? *Oikos* 104:606–611. doi:
51
52
697 10.1111/j.0030-1299.2004.12685.x
53
54
698 Loss SR, Ruiz MO, Brawn JD (2009) Relationships between avian diversity, neighborhood
55
56
699 age, income, and environmental characteristics of an urban landscape. *Biol Conserv*
57
700 142:2578–2585. doi: 10.1016/j.biocon.2009.06.004
59
60
61
62
63
64
65

- 701 Lu GY, Wong DW (2008) An adaptive inverse-distance weighting spatial interpolation
702 technique. *Comput Geosci* 34:1044–1055. doi: 10.1016/j.cageo.2007.07.010
703
- 703 Maechler M, Rousseeuw P, Struyf A, et al (2018) *cluster: Cluster Analysis Basics and*
704 *Extensions*. R package version 2.0.7-1.
705
- 705 Magurran A (2004) *Measuring Biological Diversity*. Blackwell Science, Oxford, UK
706
- 706 Manly BFJ (2006) *Randomization, Bootstrap and Monte Carlo Methods in Biology*, Third
707 *Edition, 3°*. Chapman and Hall/CRC, New York, NY
708
- 708 Mantel N (1967) The detection of disease clustering and a generalized regression
709 approach. *Cancer Res* 27:209–220.
710
- 710 Marzluff JM, Bowman R, Donnelly R (2001) A historical perspective on urban bird
711 research: trend, terms, and approaches. In: Marzluff JM, Bowman R, Donnelly R
712 editors (ed) *Avian Ecology and Conservation in an Urbanizing World*. Kluwer, New
713 York, NY, pp 20–47
714
- 714 Mason NWH, Mouillot D, Lee WG, Wilson JB (2005) Functional richness, functional
715 evenness and functional divergence: the primary of functional components diversity.
716 *Oikos* 111:112–118. doi: 10.1111/j.0030-1299.2005.13886.x
717
- 717 Mazerolle MJ (2016) *AICcmodavg: Model selection and multimodel inference based on*
718 *(Q)AIC(c)*. R package.
719
- 719 McKinney M (1997) Extinction vulnerability and selectivity: combining ecological and
720 paleontological views. *Annu Rev Ecol Syst* 28:495–516. doi:
721 10.1146/annurev.ecolsys.28.1.495
722
- 722 McKinney ML (2002) Urbanization, Biodiversity, and Conservation. *Bioscience* 52:883–
723 890. doi: 10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2
724
- 724 McKinney ML (2006) Urbanization as a major cause of biotic homogenization. *Biol*
725 *Conserv* 127:247–260. doi: 10.1016/j.biocon.2005.09.005
726
- 726 McKinney ML, Lockwood JL (1999) Biotic homogenization: a few winners replacing many
727 losers in the next mass extinction. *Trends Ecol Evol* 14:450–453.
728
- 728 Miller JR, Hobbs RJ (2002) Conservation where people live and work. *Conserv Biol*
729 16:330–337. doi: 10.1046/j.1523-1739.2002.00420.x
730
- 730 Møller AP, Berthold P, Fiedler W (2010) *Effects of Climate Change on Birds*. Oxford

731 University Press, Oxford, UK
1

732 Møller AP, Díaz M (2017) Avian preference for close proximity to human habitation and its
3 ecological consequences. *Curr Zool* zox073. doi: 10.1093/cz/zox073
733 5

734 Møller AP, Díaz M, Flensted-Jensen E, et al (2015) Urbanized birds have superior
7 establishment success in novel environments. *Oecologia* 178:943–950. doi:
735 10.1007/s00442-015-3268-8
9 10.1007/s00442-015-3268-8
11

737 Morelli F, Benedetti Y, Ibáñez-Álamo JD, et al (2016) Evidence of evolutionary
13 homogenization of bird communities in urban environments across Europe. *Glob Ecol*
1738 *Biogeogr* 25:1284–1293. doi: 10.1111/geb.12486
15 1739

740 Morelli F, Benedetti Y, Møller AP, Fuller RA (2019) Measuring avian specialization. *Ecol*
19 *Evol* 9:8378–8386. doi: 10.1002/ece3.5419
21 741

742 Morelli F, Bussièrè R, Gołowski A, et al (2015) Saving the best for last: Differential usage
23 of impaled prey by red-backed shrike (*Lanius collurio*) during the breeding season.
2743 *Behav Processes* 119:6–13. doi: 10.1016/j.beproc.2015.07.006
25 2744

745 Morelli F, Tryjanowski P (2016) The dark side of the “ redundancy hypothesis ” and
29 ecosystem assessment. *Ecol Complex* 28:222–229. doi:
31 10.1016/j.ecocom.2016.07.005
32 747

748 Moss RH, Nakicenovic N, O’Neill BC (2008) Towards New Scenarios for Analysis of
35 Emissions, Climate Change, Impacts, and Response Strategies. IPCC, Geneva,
3749 Switzerland
37 750

751 Mouchet MA, Villéger S, Mason NWH, Mouillot D (2010) Functional diversity measures: An
41 overview of their redundancy and their ability to discriminate community assembly
42 rules. *Funct Ecol* 24:867–876. doi: 10.1111/j.1365-2435.2010.01695.x
43 753

754 NCAR community (2012) Climate Change Scenarios, version 2.0. In: *Community Clim.*
47 *Syst. Model.* version 3.0. <http://www.cesm.ucar.edu/models/ccsm3.0/> NCAR/UCAR.
48 <https://gisclimatechange.ucar.edu/>.
49 756

757 Oke TR (1973) City size and the urban heat island. *Atmos Environ* 7:769–779. doi:
53 10.1016/0004-6981(73)90140-6
54 758

759 Oksanen J, Guillaume Blanchet F, Kindt R, et al (2016) vegan: Community Ecology
57 Package. R package version 2.3-4. 291.
58 760

- 761 Opdam P, Wascher D (2004) Climate change meets habitat fragmentation: linking
762 landscape and biogeographical scale levels in research and conservation. *Biol*
763 *Conserv* 117:285–297. doi: 10.1016/j.biocon.2003.12.008
- 764 Parmesan C (2006) Ecological and Evolutionary Responses to Recent Climate Change.
765 *Annu Rev Ecol Evol Syst* 37:637–669. doi:
766 10.1146/annurev.ecolsys.37.091305.110100
- 767 Pautasso M, Dinetti M (2009) Avian species richness, human population and protected
768 areas across Italy's regions. *Environ Conserv* 36:22–31. doi:
769 10.1017/S037689290900544X
- 770 Pauw A, Louw K (2012) Urbanization drives a reduction in functional diversity in a guild of
771 nectar-feeding birds. *Ecol Soc* 17:27. doi: 10.5751/ES-04758-170227
- 772 Pearman PB, Lavergne S, Roquet C, et al (2014) Phylogenetic patterns of climatic, habitat
773 and trophic niches in a European avian assemblage. *Glob Ecol Biogeogr* 23:414–424.
774 doi: 10.1111/geb.12127
- 775 Petchey OL, Hector A, Gaston KJ (2004) How do different measures of Functional
776 Diversity perform? *Ecology* 85:847–857. doi: 10.1890/03-0226
- 777 Pohlert T (2014) The Pairwise Multiple Comparison of Mean Ranks Package (PMCMR). R
778 package version 4.3.
- 779 Princé K, Lorrillière R, Barbet-Massin M, Jiguet F (2013) Predicting the fate of French bird
780 communities under agriculture and climate change scenarios. *Environ Sci Policy*
781 33:120–132. doi: 10.1016/j.envsci.2013.04.009
- 782 Princé K, Zuckerberg B (2015) Climate change in our backyards : the reshuffling of North
783 America ' s winter bird communities. *Glob Chang Biol* 21:572–585. doi:
784 10.1111/gcb.12740
- 785 R Development Core Team (2019) R: A language and environment for statistical
786 computing.
- 787 Reynolds SJ, Galbraith JA, Smith JA, Jones DN (2017) Garden Bird Feeding: Insights and
788 Prospects from a North-South Comparison of This Global Urban Phenomenon. *Front*
789 *Ecol Evol* 5:24. doi: 10.3389/fevo.2017.00024
- 790 Ricotta C, Bacaro G, Moretti M (2014) A new measure of functional evenness and some of

- 791 its properties. PLoS One 9:e104060. doi: 10.1371/journal.pone.0104060
1
- 792 Safi K, Armour-Marshall K, Baillie JEM, Isaac NJB (2013) Global Patterns of Evolutionary
3
793 Distinct and Globally Endangered Amphibians and Mammals. PLoS One 8:e63582.
5
794 doi: 10.1371/journal.pone.0063582
6
7
- 795 Saino N, Ambrosini R, Rubolini D, et al (2011) Climate warming, ecological mismatch at
9
1796 arrival and population decline in migratory birds. Proc R Soc B Biol Sci 278:835–842.
11
797 doi: 10.1098/rspb.2010.1778
12
13
- 1798 Schaefer HC, Jetz W, Böhning-Gaese K (2008) Impact of climate change on migratory
15
799 birds: Community reassembly versus adaptation. Glob Ecol Biogeogr 17:38–49. doi:
16
800 10.1111/j.1466-8238.2007.00341.x
17
18
- 801 Schmiegelow FKA, Mönkkönen M (2002) Habitat loss and fragmentation in dynamic
21
802 landscapes: avian perspectives from the boreal forest. Ecol Appl 12:375–389.
22
23
- 803 Schütz C, Schulze CH (2015) Functional diversity of urban bird communities: Effects of
25
804 landscape composition, green space area and vegetation cover. Ecol Evol 5:5230–
26
805 5239. doi: 10.1002/ece3.1778
27
28
- 806 Secretariat of the Convention on Biological Diversity (2012) Cities and Biodiversity
31
807 Outlook: A Global Assessment of the Links between Urbanization, Biodiversity, and
32
808 Ecosystem Services. Montreal, Canada
33
34
- 809 Shannon CE (1948) The mathematical theory of communication. Bell Syst Tech J 27:379–
37
810 423.
38
39
- 811 Shea K, Chesson P (2002) Community ecology theory as a framework for biological
41
812 invasions. Trends Ecol Evol 17:170–176. doi: 10.1016/S0169-5347(02)02495-3
42
43
- 813 Shochat E, Lerman S, Fernández-Juricic E (2010) Birds in Urban Ecosystems: Population
45
814 Dynamics, Community Structure, Biodiversity, and Conservation. In: Aitkenhead-
46
815 Peterson J, Volder A (eds) Agronomy Monograph 55. Urban Ecosystem Ecology.
47
816 Madison, WI, USA, pp 75–86
48
49
50
- 817 Siikamäki P (1996) Nestling growth and mortality of Pied Flycatchers (*Ficedula hypoleuca*)
51
818 in relation to weather and breeding effort. Ibis (Lond 1859) 138:471–478.
53
54
55
- 819 Skagen SK, Adams AAY (2012) Weather effects on avian breeding performance and
56
820 implications of climate change. Ecol Appl 22:1131–1145. doi: 10.1890/11-0291.1
57
58
59
60
61
62
63
64
65

- 821 Sklenicka P (2016) Classification of farmland ownership fragmentation as a cause of land
1
822 degradation: A review on typology, consequences, and remedies. *Land use policy*
2
823 57:694–701.
3
4
- 5
824 Spears BM, Ives SC, Angeler DG, et al (2015) Effective management of ecological
6
825 resilience - are we there yet? *J Appl Ecol* 52:1311–1315. doi: 10.1111/1365-
7
826 2664.12497
8
9
10
- 11
827 Spellerberg IFIF (1998) Ecological effects of roads and traffic: a literature review. *Glob*
12
828 *Ecol Biogeogr Lett* 7:317–333.
13
14
- 15
829 Stephens PA, Mason LR, Green RE, et al (2016) Consistent response of bird populations
16
830 to climate change on two continents. *Science* 352:84–87. doi:
17
831 10.1126/science.aac4858
18
19
20
- 21
832 Storchová L, Hořák D (2018) Life-history characteristics of European birds. *Glob Ecol*
22
833 *Biogeogr* 27:400–406. doi: 10.1111/geb.12709
23
24
- 25
834 Terborgh J, Winter B (1980) Some causes of extinction. In: Soule M, Wilcox B (eds)
26
835 *Conservation Biology: an Evolutionary-Ecological Perspective*, 1st edn. Sinauer
27
836 Associates Inc, New York, pp 119–133
28
29
30
- 31
837 Trautmann S (2018) Climate Change Impacts on Bird Species. In: Tietze DT (ed) *Bird*
32
838 *Species - How they arise, modify and vanish*, 1st edn. Springer, pp 217–234
33
34
- 35
839 Triola MF (2012) *Elementary Statistics*, 12th edn. Pearson International, London, UK
36
37
- 38
840 Tryjanowski P, Karg M, Karg J (2003) Food of the Red-backed Shrike *Lanius collurio* : a
39
841 comparison of three methods of diet analysis. *Acta Ornithol* 38:59–64.
40
41
- 42
842 Tryjanowski P, Skórka P, Sparks TH, et al (2015) Urban and rural habitats differ in number
43
843 and type of bird feeders and in bird species consuming supplementary food. *Environ*
44
844 *Sci Pollut Res* 22:15097–103. doi: 10.1007/s11356-015-4723-0
45
46
47
- 48
845 Vázquez-Reyes LDLD, Arizmendi M del CMDC, Godínez-Álvarez HO, et al (2017)
49
846 Directional effects of biotic homogenization of bird communities in Mexican seasonal
50
847 forests. *Condor* 119:275–288. doi: 10.1650/CONDOR-16-116.1
51
52
53
- 54
848 Villéger S, Mason NWH, Mouillot D (2008) New multidimensional functional diversity
55
849 indices for a multifaceted framework in functional ecology. *Ecology* 89:2290–2301.
56
850 doi: 10.1890/07-1206.1
57
58
59
60
61
62
63
64
65

851 Violle C, Navas M-LL, Vile D, et al (2007) Let the concept of trait be functional! *Oikos*
1 116:882–892. doi: 10.1111/j.0030-1299.2007.15559.x
2
3
853 Visser ME, Holleman LJM, Caro SP (2009) Temperature has a causal effect on avian
5 timing of reproduction. *Proc R Soc B Biol Sci* 276:2323–2331. doi:
854 10.1098/rspb.2009.0213
7
855 10.1098/rspb.2009.0213
8
9
1056 Voříšek P, Klvaňová A, Wotton S, Gregory RD (2010) A best practice guide for wild bird
11 monitoring schemes. Pan-European Common Bird Monitoring Scheme (PECMBS),
12 Bruxelles, Belgium
13
14
859 Wilson MC, Chen X-Y, Corlett RT, et al (2016) Habitat fragmentation and biodiversity
15 conservation: key findings and future challenges. *Landsc Ecol* 31:219–227. doi:
16 10.1007/s10980-015-0312-3
17
18
19
20
21
862 Zerbe S, Maurer U, Schmitz S, Sukopp H (2003) Biodiversity in Berlin and its potential for
22 nature conservation. *Landsc Urban Plan* 62:139–148.
23
24
25
864 Zuckerberg B, Ribic CA, McCauley LA (2018) Effects of temperature and precipitation on
26 grassland bird nesting success as mediated by patch size. *Conserv Biol* 32:872–882.
27 doi: 10.1111/cobi.13089
28
29
30
866

31
867
32
33
868

35
36
37
38
39
40
41
42
43
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