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Is research effort associated with the conservation status of European bird species?

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ABSTRACT: Research effort is critical to the success of interventions which aim to reduce declines in biodiversity and so can be considered as a conservation resource. European bird species are among the best studied and most popular groups of animals, yet 1 in 10 are currently globally threatened or near threatened, and many have been prioritised by various multilateral environmental agreements. To investigate how research effort is directed towards European bird species, and in particular whether conservation listing prompts additional research, the number of outputs from a Web of Science search related to conservation was used to develop an index of research effort for each species. This index was then analysed against a set of population, morphological, ecological and socioeconomic parameters collated from the literature, plus measures of threat level. A series of generalised linear models revealed that the most important factors in explaining the distribution of research effort amongst European bird species included 'European population size', 'potential research investment' and 'habitat type', which were linked to ease of study. Also important were the species' generation length, 1990–2000 European population trend and migration status. Research effort was not well targeted with respect to either European or global threat status, and there was little support for the suggestion that inclusion of species in legislative instruments such as Annex I of the EU Birds Directive might stimulate research. Research effort must become better prioritised to achieve the greatest net conservation benefit.

KEY WORDS: EU Birds Directive · IUCN Red List · Threatened birds · Web of Science

INTRODUCTION

Across the world, biodiversity is in decline and the ecological impact of humanity is increasing (WWF 2012). In response, governments and other organisations are taking conservation action to prevent species extinction. This is particularly true of birds, one of the best studied and most popular groups of animals; nonetheless, many species are still undergoing serious declines (BirdLife International 2013). Globally, avian extinction rates are expected to reach 1.5 species per 1000 species per year by the end of the century (Pimm et al. 2006), and in Europe 44 species are currently listed as globally threatened or near threatened (IUCN 2012).

The most effective conservation strategies vary between species due to ecological, physiological and socioeconomic differences. This means research in this field cannot necessarily be transferred between species and that species-specific studies may be needed, especially since the success of conservation actions is maximised when they are based upon scientific evidence (Sutherland et al. 2004, Williams et al. 2012).

Unfortunately, there are insufficient resources to carry out all the work necessary to halt declines in

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biodiversity, and conservation action must be directed to where it can have the greatest impact (e.g. Wilson et al. 2006, Marris 2007). Often the most threatened species are prioritised (Rodrigues et al. 2006), and improving monitoring and research is one measure, among several types of intervention, which can be taken to help reduce species' risk of extinction. We would therefore expect research effort to be correlated with threat status of species.

Knowledge gap analysis of research effort is a relatively new area of conservation science, but, since 2005, several papers have assessed whether research effort is associated with species' threat status. Two papers focussing on bird species concluded that threat status was either significantly associated with research effort (Brooks et al. 2008) or showed a clear trend (de Lima et al. 2011). Both analyses found that species classed in more globally threatened IUCN Red List categories received greater research effort than those in less threatened groups. In contrast, work on other taxonomic groups, such as Felidae (Brodie 2009) and coral reefs (Fisher et al. 2011), did not show a relationship between research effort and threat status.

Our study first investigates relationships between a series of candidate variables, each potentially relevant to the conservation of European bird species, and research effort. The analysis is then extended by running a set of models to determine which candidate variables explain most variation in research effort. Candidate variables included population, morphological, ecological and socioeconomic parameters chosen to reflect different potential influences upon the distribution of research effort across species. Some variables, such as European threat status, were expected to have an impact because they identify those species most in need of conservation action, whereas others, such as body mass, were hypothesised to be important simply because they influence the ease with which studies can be carried out. This study advances the field by including some candidate variables that have not been analysed by previous authors; for example, different measures of threat were considered alongside global IUCN Red List status. Uniquely, it also uses an index of research effort which takes into account the impact each paper may have upon the scientific community by considering the year of publication and the impact factor of the journal. Thus, our focus is on factors, especially conservation status, that may influence research effort, a contrast to previous studies (e.g. Restani & Marzluff 2002, Male & Bean 2005) which have investigated how conservation funds are distributed among threatened species.

METHODS

Data sources of candidate variables. For each species, information on a number of parameters was collated from the literature alongside details of threat status and inclusion in multilateral environmental agreements (MEAs). Much of the information is taken from the publication Birds in Europe 2 (BiE2) (BirdLife International 2004), the most up-to-date authoritative source on European bird populations. Field data for this publication were originally collected in each country by a range of experts, monitoring organisations and other regional contributors in approximately the year 2000. Therefore, where possible, data from 2000 were used for candidate variables from other sources. For the present purposes, Europe extends from Greenland, Iceland and Ireland in the west across continental Europe and western Russia as far east as the Urals and south-east to Cyprus, Turkey, Armenia and Azerbaijan.

European population size (breeding pairs). The geometric mean of minimum and maximum European population size estimates from BiE2 was calculated for each species; values ranged from 3 (brown fish owl *Ketupa zeylonensis*) to 176 635 217 (common chaffinch *Fringilla coelebs*) breeding pairs.

Percentage of global population in Europe. Taken from BiE2, these data are expressed categorically. The categories were <5% of global population breeding in Europe (e.g. shikra *Accipiter badius*), 5–24, 25–49, 50–74, 75–94, >95 and 100% (e.g. Zino's petrel *Pterodroma madeira*).

1990–2000 European population trend. In BiE2, species were classed as showing 1 of 8 population trends: stable, fluctuating, small decline, moderate decline, large decline, small increase, moderate increase and large increase. For clarity and ease of analysis in our study they were grouped together into categories of: stable, fluctuating, declining and increasing.

Potential research investment. For each species this index was calculated based on the percentage of the European population in each of the n countries of Europe (BirdLife unpubl. data) and the per capita gross domestic product (GDP) of these countries (World Bank 2012):

$$\text{Potential research investment} = 0.5\sum_{k}^{n} \begin{gathered}\text{\% of European wintering population in country } k\\ \times \text{ per capita GDP of country } k\end{gathered} + 0.5\sum_{k}^{n} \begin{gathered}\text{\% of European breeding population in country } k\\ \times \text{ per capita GDP of country } k\end{gathered} \quad (1)$$

For this index, based on the anticipation that species with a high proportion of their populations in wealthier countries may be more heavily researched, some caveats must be entered: the index assumes that 50 % of time is spent in breeding areas and 50 % in wintering areas; the data available for the percentage of the European population in each country are more accurate for breeding than wintering populations; and, if some individuals of a species spend either the breeding or winter season outside of Europe, no value is assigned for this time. For this assessment, the most recent per capita GDP data available were used, for most countries from 2011, rather than data from 2000. However, there is an almost perfect positive association between per capita GDP measurements for 2000 and 2011 ($r_S = 0.953$, $n = 201$, $p < 2.2 \times 10^{-16}$), and, therefore, conclusions drawn involving this variable are unlikely to be affected by using more recent data than for other candidate variables.

Habitat type. In BiE2, largely following Tucker & Evans (1997), species were classified according to their principal habitat into 1 of 9 categories: Mediterranean; agricultural and grassland; boreal and temperate forests; montane; tundra, mires and moorland; inland wetlands; coastal; marine; and those species associated with other habitats.

Migration status. In BiE2, species are classed into 1 of 5 migration status categories: resident species (remain in their breeding countries year round), partial migrants within Europe (migrate over very short distances in Europe, often in response to adverse weather conditions), full migrants within Europe (migrate over long distances to winter in Europe), short-distance migrants (winter just outside Europe, e.g. North Africa) and long-distance migrants (winter in sub-Saharan Africa or Asia).

Body mass. The body mass of each species (BirdLife unpubl. data) ranged from 6 g (goldcrest *Regulus regulus* and firecrest *R. ignicapilla*) to 10 735 g (mute swan *Cygnus olor*).

Generation length. The generation length of each species (BirdLife unpubl. data) was considered as the mean age of the parents of the current cohort and is calculated as:

$$\text{Generation length} = \left(\frac{1}{\text{Mean annual mortality}}\right) + \text{Age at first breeding} \tag{2}$$

Generation length ranged from 2.5 yr (Dupont's lark *Chersophilus duponti*) to 30.7 yr (northern fulmar *Fulmarus glacialis*).

Annex I. The EU Birds Directive (2009/147/EC) was adopted in 1979 to address the conservation of European birds. Species in Annex I of the Directive are those in danger of extinction, those which are rare, vulnerable to specific changes in habitat, or which require particular attention due to the specific nature of their habitat. Member States are obliged to maintain or improve the conservation status of these species by protecting their habitat. For 15 species listed in Appendix I (at the end of the present article), only certain subspecies are listed in Annex I. For our analysis these were considered full Annex I-listed species.

Species Action Plan (SAP). Species Action Plans have been drawn up for some of the bird species listed in Annex I of the EU Birds Directive. They provide an official framework for work to conserve these species and set out a series of recommendations for conservation action. For 5 species listed in Appendix 2 (at the end of the present article), only certain subspecies are listed in Annex 1. For our analysis these were considered full SAP species.

Species of European Conservation Concern (SPEC) category. Following BiE2, species are classified into 1 of 5 categories based on their global and European threat status plus the proportion of their global population in Europe. SPEC1 species are of global conservation concern (Critically Endangered [CR], Endangered [EN], Vulnerable [VU], Near Threatened [NT] or Data Deficient [DD]; see Red List section below), SPEC2 species are concentrated in Europe and have an unfavourable conservation status, SPEC3 species are not concentrated in Europe but have an unfavourable conservation status, Non-SPEC species are not concentrated in Europe and have a favourable conservation status and Non-SPEC^E species are concentrated in Europe but have a favourable conservation status.

European threat status. Following BiE2, species are classified into 1 of 8 threat categories specifically based on their status in Europe: Secure, Localised, Rare, Depleted, Declining, Vulnerable, Endangered and Critically Endangered.

Adapted 2000 global Red List status. The IUCN Red List is updated at least once a year, with the global status of birds being assessed by BirdLife International. Until 2001, there was a slightly different classification scheme to today's, which included a Lower Risk category segregated into: Least Concern, Near Threatened and Conservation Dependent. In our analysis, these former categories were adapted to match the current categories: LC, NT (containing Near Threatened and Conservation Dependent groups), VU, EN and CR, with species in the last 3 categories being termed globally threatened. Since other metrics of species status were from BiE2 and dated to approximately 2000, our analysis used the species status in 2000, modified to reflect the current classification scheme.

Measuring research effort. Between 29 October and 2 November 2012, searches for each European bird species were made in the Web of Science (WoS) ([v.5.8] Thomson Reuters 2012) within 2 databases: Science Citation Index Expanded (1900–present), which contains papers from over 8500 scientific journals, and Conference Proceedings Citation Index — Science (1990–present). Two rounds of searches were made for papers published between 1 January 1950 and 29 October 2012 using species-specific search terms within the 'topic' field. The first search was for 'common name*' OR 'scientific name' (subsequently known as the general dataset) and the second search was for 'common name*' OR 'species name' AND 'conserv*' (subsequently known as the conservation dataset).

Originally, searches were made on all 518 species of European bird. Afterwards, some species were removed from the sample. The first group, comprising ruff *Philomachus pugnax*, merlin *Falco columbarius* and rook *Corvus frugilegus*, was removed, since many hits arose because their common names were related to other topics. The next group comprised species which were missing data for any of the candidate variables (except 'habitat type' where 'unclassified' was considered a meaningful category). This left an overall sample of 426 species, which was used in all analyses unless specified otherwise. There were 40 936 papers in the conservation dataset and 72 251 in the general dataset. The list of papers for 2012 is incomplete, since searches were made part way through the year.

For reasons of practicality we did not attach differential scores to papers where a single species was studied versus those where several species were researched.

Details on each paper were downloaded and assembled in an Excel database. Inspection of the paper and journal titles in the general dataset revealed that a significant number of papers were irrelevant, so further analyses were based on the conservation dataset (henceforth the only dataset considered). Since 1970, the average proportion of papers related to conservation each year has remained relatively constant at 0.7–0.8 (data not shown), and, therefore, conclusions drawn from the conservation dataset are also likely to be applicable to the general dataset.

Besides the total number of papers published, 2 other values were used to create an index for research effort on each species. Over time there has been an increase in the number of papers published each year. A paper published in, for example, 1950 (when only 7 conservation-related papers were published) represents a greater proportion of research effort than a paper published in 2011 (when 2979 papers were published). Similarly, papers published in different journals contribute differentially to research impact. The annually published Journal Citation Report (Thomson Reuters 2012) calculates a journal impact factor for each journal, based on the number of times papers from that journal are cited relative to the number of items published in the journal. Impact factors for the journals in the conservation dataset range from 0.0043 for 'Canadian Field Naturalist' to 38.075 for 'Nature Reviews Genetics'. Twelve percent of journals had not been given a journal impact factor and were assigned an arbitrary low value of 0.1. This approach was adopted because the missing data are not randomly distributed with respect to impact factor. It is low impact journals that are especially likely to have no measured impact factor; hence, the need to assign an arbitrary and fairly low impact factor. The final index for each species was calculated by summing values across the *n* published papers for that species:

$$\text{Research effort index} = \sum_{k}^{n} \left(\frac{\begin{array}{c}\text{Journal Impact Factor of the journal}\\ \text{in which paper } k \text{ is published}\end{array}}{\begin{array}{c}\text{Total number of papers published the}\\ \text{same year as paper } k \text{ across all species}\end{array}} \right) \quad (3)$$

The metric of research effort described above, described as an adjusted research effort index, is used throughout the remainder of this paper. It is well correlated with the raw number of papers for each species ($r = 0.566$, $n = 426$, $p < 0.001$). However, there is an argument, which we acknowledge, that a paper published in, say, 2010, is likely to be as influential as one published in, say, 1960, even though the latter represents a far higher proportion of the total research output in that year, 1960. Accordingly, for the AIC (Akaike's information criterion) modelling exercise (see 'Modelling') — but only for this exercise — we also used unadjusted research effort where the denominator in Eq. (3) was 1, and not the total number of papers published in the year.

Individual analyses. The relationship between research effort and each continuous candidate variable was analysed to detect any correlations, and we also checked whether research effort differed significantly between classes of categorical variables. Non-parametric tests were used, as data for several variables were positively skewed and the assumption of a normal distribution was therefore not met. For the purposes of clarity, 'transformed adjusted (total number of papers weighted by year and journal impact factor) research effort' was used as the measure of research effort in the plotted graphs (see next section for transformation). In the univariate statistical analyses the original variable 'total number of papers weighted by year and journal impact factor' was used.

Modelling. Using the statistical software R Version 3.0.1 (R Core Team 2013) and the conservation dataset for 426 species, a series of 8192 generalised linear models (GLMs) was constructed using all possible combinations of candidate variables, including univariate models with each being included in 4096 models. GLMs were chosen as they allow both continuous and categorical variables to be used and do not assume a normal distribution of data. The index of research effort, either unadjusted or adjusted ('total number of conservation papers weighted by year and journal impact factor') as described above, was transformed for use in models using a log transformation, so that residuals approached more closely a normal distribution. One species was removed to correct for leverage, and 19 more were removed because of zero research effort in the spreadsheet. The remaining 406 transformed indices of research effort could then be used as the dependent variable in the GLMs with a Gaussian error distribution and an Identity link function.

Before modelling we checked for collinearity between explanatory variables and found that in no case was the correlation coefficient >0.7 (Appendix 3), a cut-off which is considered acceptable (Draper & Smith 1998; dss.princeton.edu/online_help/analysis/regression_intro.htm).

For each model, the AIC weight was calculated to indicate the likelihood that the model was the best within that set (Table 1). For each variable, the AIC weights of every model in which it appears were summed to give a total AIC weight (Burnham & Anderson 2002). This value indicates the relative importance of each variable in explaining the variation in research effort (see Table 2).

Table 1. The leading models (ΔAIC < 2) using (a) transformed adjusted research effort index (see 'Methods' for description of the index) and (b) transformed unadjusted research effort index. AIC: Akaike's information criterion; BiE2: Birds in Europe 2; SAP: Species Action Plans; SPEC: Species of European Conservation Concern. Note that not all components appear in the 6 best performing models

Component models	df	logLik	AIC	ΔAIC	Weight	R^2	Adjusted R^2
a)							
4/5/6/7/8/9/10	27	−785.253	1624.506	0	0.081217	0.3714	0.3299
4/5/6/7/9/10	23	−789.793	1625.586	1.080619	0.047314	0.3571	0.3219
3/4/5/6/7/8/9/10	28	−784.809	1625.618	1.111823	0.046582	0.3728	0.3296
1/4/5/6/7/8/9/10	28	−785.064	1626.129	1.623007	0.036076	0.3720	0.3288
4/5/6/7/8/9/10/12	28	−785.129	1626.257	1.751457	0.033831	0.3718	0.3286
4/5/6/7/8/10	24	−789.193	1626.387	1.880825	0.031712	0.3590	0.3221
b)							
4/5/6/7/8/9/10/12	28	−717.756	1491.511	0	0.116473	0.4064	0.3656
1/4/5/6/7/8/9/10/12	29	−717.055	1492.11	0.599172	0.086321	0.4085	0.3661
5/6/7/8/9/10/12	22	−724.543	1493.086	1.575312	0.052985	0.3862	0.3542
3/4/5/6/7/8/9/10/12	29	−717.582	1493.164	1.652817	0.050971	0.4070	0.3644
4/5/6/7/8/9/10	27	−719.599	1493.199	1.687872	0.050085	0.4001	0.3615
1/5/6/7/8/9/10/12	23	−723.636	1493.272	1.760944	0.048288	0.3889	0.3554

Component model coding

Term code	Full name	Term code	Full name
1	Annex I	8	Migration status
2	BiE2 SPEC category	9	1990–2000 European population trend
3	Body mass (g)	10	Potential research investment
4	Global population in Europe (%)	11	Red List status 2000
5	Generation length (yr)	12	SAP
6	Habitat type	13	BiE2 European threat status
7	Mean BiE2 European population size		

Table 2. Total AIC weights for models including each candidate variable were summed to give a rank of the relative importance of each variable in explaining the variation in transformed adjusted research effort index and transformed unadjusted research effort index. See Table 1 for abbreviations

Variable	Relative importance (transformed adjusted research effort)	Relative importance (transformed unadjusted research effort)
Potential research investment	1	1
Mean BiE2 European population size	1	1
Habitat type	1	1
Generation length (yr)	0.97	1
Global population in Europe (%)	0.75	0.64
1990–2000 European population trend	0.65	0.95
Migration status	0.61	0.99
Body mass (g)	0.39	0.34
SAP	0.33	0.74
Annex I	0.31	0.43
Red List status 2000	0.14	0.23
BiE2 SPEC category	0.03	0.05
BiE2 European threat status	0.02	0.09

RESULTS

There was great variation in the research effort on different species of European birds. The mean number of papers per species was 96, but this was highly skewed by the few species with a very large research effort, such as the great tit *Parus major* (2927 papers) and mallard *Anas platyrhynchos* (2878). The median number of papers per species was 27, while 19 species generated no published papers. The mean number of papers per year increased from 10.4 (1950–1954) to 2674.4 (2007–2011).

European population size (breeding pairs). Fig. 1 shows a statistically significant positive correlation between European population size and research effort ($r_S = 0.271$, n = 426, $p = 1.311 \times 10^{-8}$), although there are many species which do not fit this trend. For example, common chiffchaff *Phylloscopus collybita* has a large European population size of over 42 million breeding pairs, but our search revealed only 13 papers published.

Percentage of global population in Europe. There was a statistically significant difference in research effort between groups of species with different percentages of their global population in Europe (Fig. 2; Kruskal-Wallis $\chi^2 = 19.444$, p = 0.00348). A series of post hoc pairwise Wilcox tests was then carried out with p-values adjusted using Bonferroni corrections. Species with <5% of their global population in Europe were significantly less researched than those which have 5–24% (p = 0.0048), 25–49% (p = 0.0089), or 50–74% (p = 0.0020) of their populations in Europe.

1990–2000 Population trend. Fig. 3 shows a statistically significant difference in research effort between groups of species with different 1990–2000 European population trends (Kruskal-Wallis χ^2 = 12.305, p = 0.00641). A series of post hoc pairwise Wilcox tests was then carried out with p-values adjusted using Bonferroni corrections. Significantly more research was carried out on increasing species than on stable species (p = 0.0093).

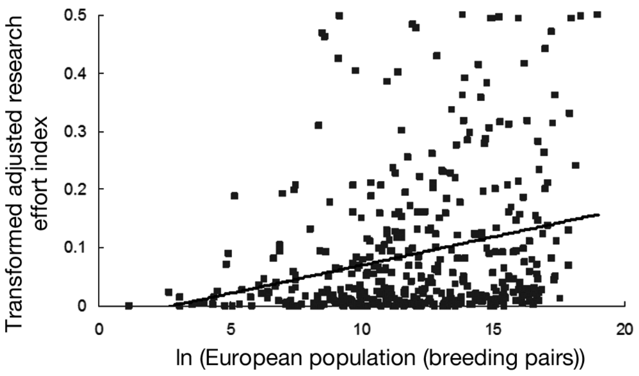

Fig. 1. Transformed adjusted research effort index (see 'Results') plotted against the natural logarithm of 'European population size (breeding pairs)'. Each point corresponds to an individual species. Solid line: r-calculated line of best fit

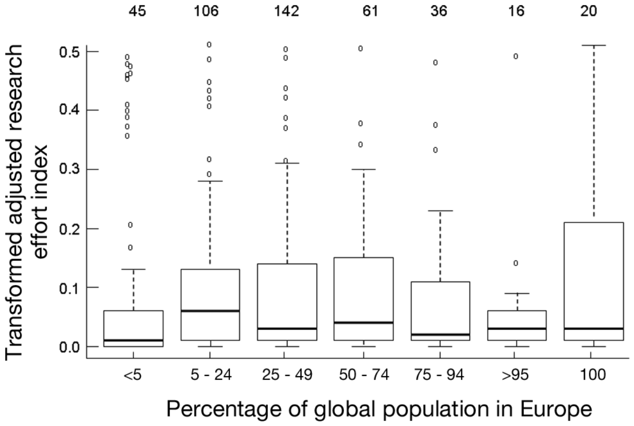

Fig. 2. Boxplot showing the distribution of transformed adjusted research effort index across species in each category of 'percentage of global population in Europe', total n = 426 (individual numbers for each category are given above the boxplots). Boxplot shows the 10th, 25th, 50th, 75th and 90th percentiles of data with open circles indicating outliers

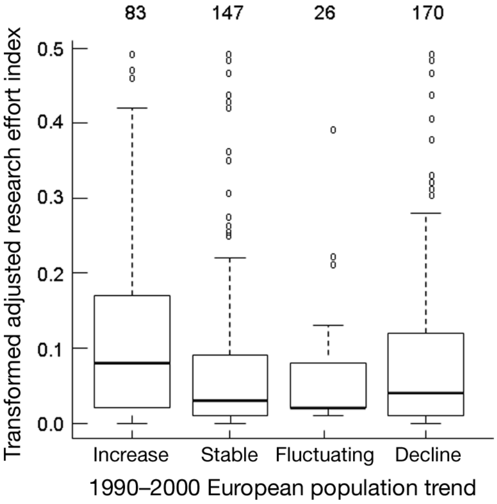

Fig. 3. Boxplot showing the distribution of transformed adjusted research effort index across species in each category of '1990–2000 European population trend', total n = 426. Boxplot description as in Fig. 2

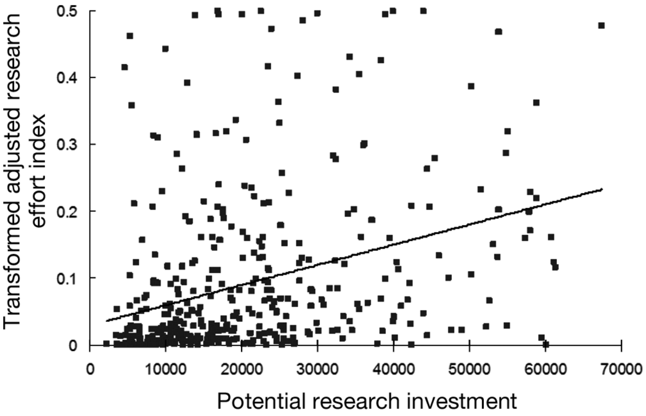

Fig. 4. Transformed adjusted research effort index plotted against potential research investment. Each point corresponds to an individual species. Solid line: r-calculated line of best fit

Potential research investment. Fig. 4 shows a statistically significant positive correlation between potential research investment and research effort ($r_S = 0.446$, n = 426, $p < 1 \times 10^{-15}$). There was also a statistically significant positive correlation when potential research investment was based only on the distribution of European populations during breeding ($r_S = 0.426$, n = 426, $p < 1 \times 10^{-15}$) or winter ($r_S = 0.387$, n = 426, $p < 1 \times 10^{-15}$) seasons.

Habitat type. Fig. 5 shows a statistically significant difference in research effort between groups of species with different habitat types (Kruskal-Wallis $\chi^2 = 74.850$, $p = 1.692 \times 10^{-12}$). Research effort was particularly low in species from 'Mediterranean', 'montane' and 'unclassified' habitats.

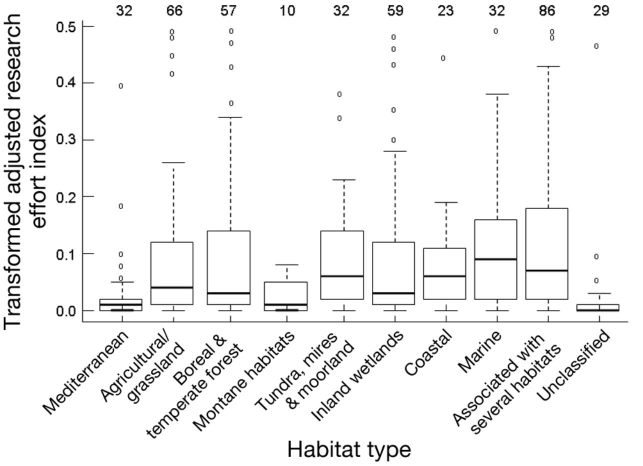

Fig. 5. Boxplot showing the distribution of transformed adjusted research effort index across species in each habitat type, total n = 426. Boxplot description as in Fig. 2

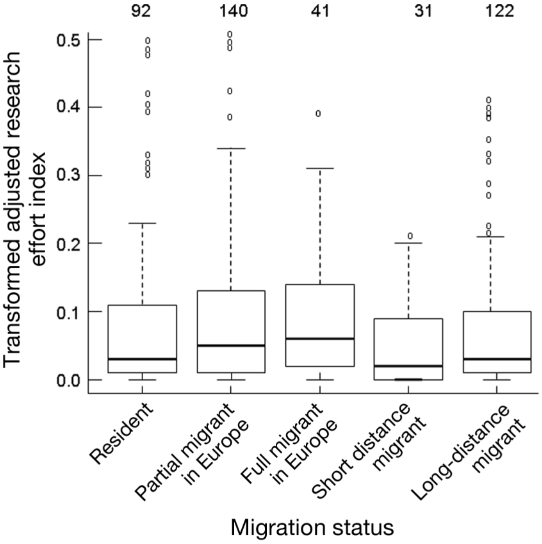

Fig. 6. Boxplot showing the distribution of transformed adjusted research effort index across species in each category of migration status, total n = 426. Boxplot description as in Fig. 2

Migration status. Fig. 6 shows a statistically significant difference in research effort between groups of species of different migration statuses (Kruskal-Wallis $\chi^2 = 16.189$, p = 0.00278). A series of post hoc pairwise Wilcox tests was then carried out with p-values adjusted using Bonferroni corrections. Statistically significant differences were found between 'full migrants within Europe' and both 'long-distance migrants' (p = 0.0057) and 'short-distance migrants' (p = 0.0163), the latter two being species which winter south of Europe.

Generation length and body mass. Fig. 7a shows a statistically significant positive correlation between generation length and research effort ($r_S = 0.293$, $n = 426$, $p = 6.833 \times 10^{-10}$), while there was also (Fig. 7b) a statistically significant positive correlation between body mass and research effort ($r_S = 0.282$, $n = 426$, $p = 3.052 \times 10^{-9}$). Notable outliers include the large-bodied species Caspian snowcock *Tetraogallus caspius* and Caucasian snowcock *T. caucasicus*, with body masses of 1.83 and 2.51 kg, respectively. Not a single paper has been published on either species.

SAP and Annex I. Fig. 8a shows no statistically significant difference in research effort between those species with or without a SAP (Kruskal-Wallis $\chi^2 = 0.059$, $p = 0.808$). There was also no statistically significant difference in research effort between species listed and those not listed in Annex I (Fig. 8b; Kruskal-Wallis $\chi^2 = 0.718$, $p = 0.397$). We also investigated whether research effort increased after species were added to Annex I, but found no evidence for such an increase (data not shown).

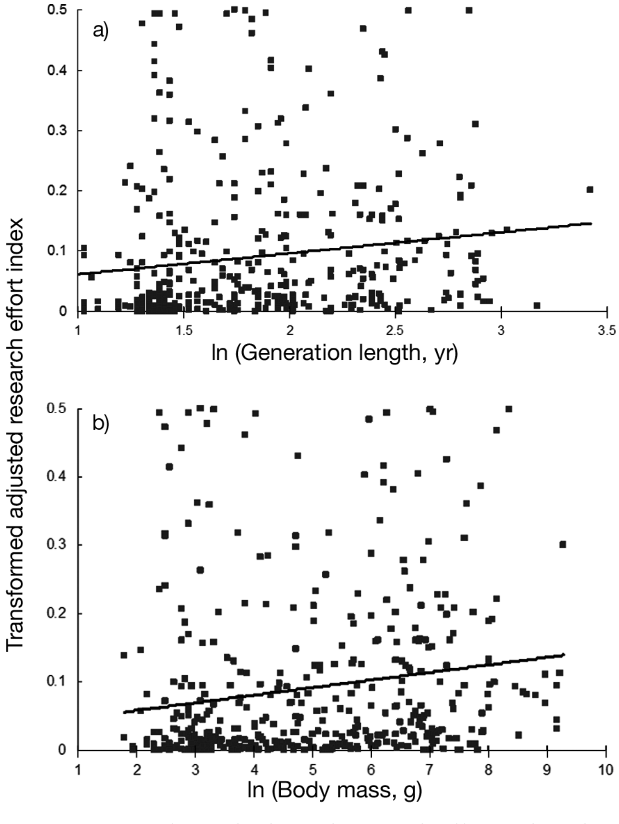

Fig. 7. (a) Transformed adjusted research effort index plotted against the natural logarithm of 'generation length (yr)'. (b) Transformed adjusted research effort index plotted against the natural logarithm of 'body mass' (g). Each point corresponds to an individual species. Solid line: r-calculated line of best fit

SPEC category and European threat status. There was no statistically significant difference in research effort either between groups of species with different SPEC categories (Fig. 9a; Kruskal-Wallis $\chi^2 = 1.801$, $p = 0.772$), or between groups of species with different European threat statuses (Fig. 9b; Kruskal-Wallis $\chi^2 = 7.962$, $p = 0.336$). Since there were small numbers of species in some of the more threatened categories, a second analysis was conducted in which species with a threat status other than secure were amalgamated into a single 'Threatened' category. There was no statistically significant difference either between groups of species in 'Secure' and 'Threatened categories' (Kruskal-Wallis $\chi^2 = 0.287$, $p = 0.592$).

Adapted 2000 global Red List status. Fig. 10 shows no statistically significant difference in research effort between species with different global Red List status (Kruskal-Wallis $\chi^2 = 3.753$, $p = 0.441$). Since

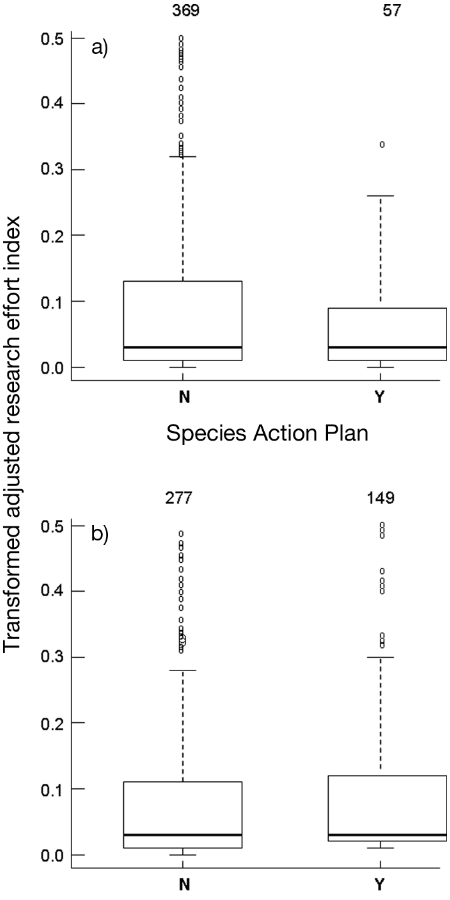

Fig. 8. Boxplots showing (a) the distribution of transformed adjusted research effort index across species with and without Species Action Plans (SAPs), total n = 426, and (b) the distribution of transformed adjusted research effort index across species according to whether they are (Y) or are not (N) on Annex I, n = 426. Boxplot description as in Fig. 2

there were very few species in the more threatened categories, a second analysis was conducted in which species with a threat status of CR, EN, or VU were amalgamated into a single 'Threatened' category. Again there was no statistically significant difference between groups of species in 'Least Concern', 'Near Threatened' and 'Threatened' categories (Kruskal-Wallis $\chi^2 = 3.753$, p = 0.441).

Modelling. Modelling showed that the factors having the greatest influence on the amount of research conducted on a species were its European population size, the potential research investment and the habitat (Tables 1 & 2). Thus, the most researched species were those that were abundant, that occupied wealthy countries and that did not use Mediterranean or montane habitats. Generation length was also important, with longer-lived species being more heavily researched. Migration status, European population trend and the percentage of the global population breeding in Europe were the next most important explanatory variables. This ranking of the key explanatory variables was almost identical for the 2 metrics of research effort used (Table 2). Meanwhile, the variables related to threat status consistently appeared to be rather unimportant in explaining research effort (Table 2); in fact, 3 variables, Red List status 2000, BiE2 SPEC category and BiE2 threat status, did not appear at all in any of the top models (Table 1).

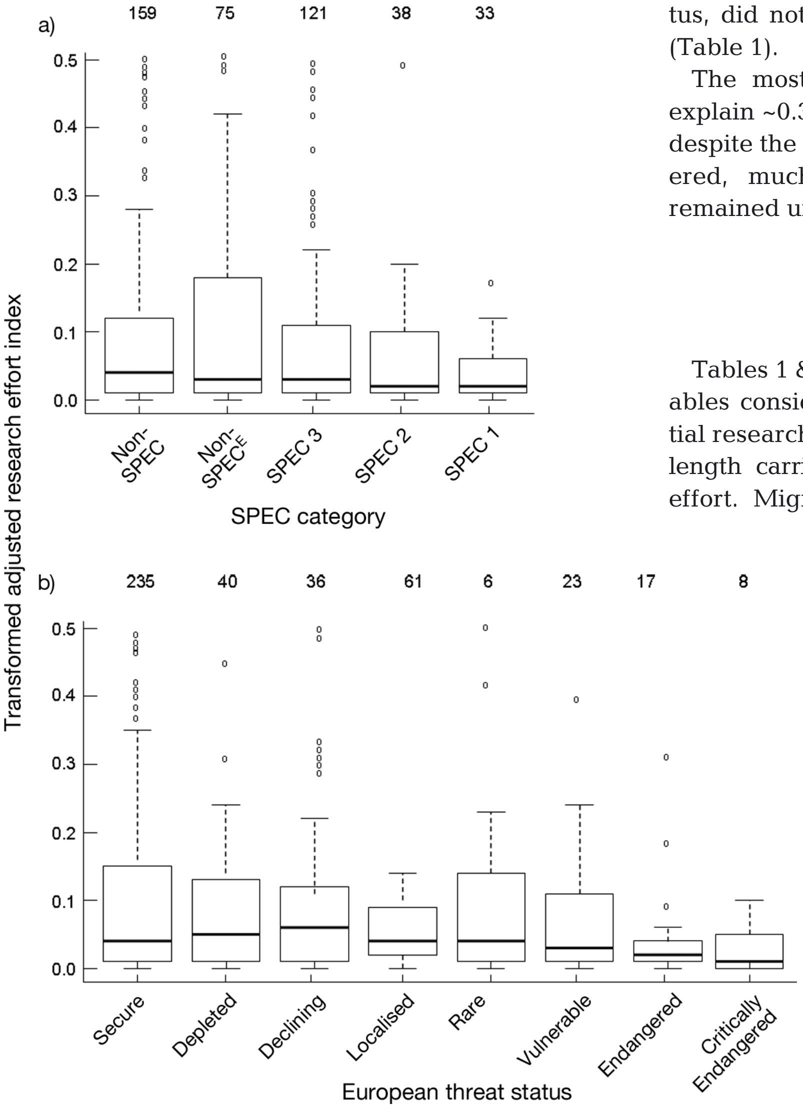

Fig. 9. Boxplots showing (a) the distribution of transformed adjusted research effort index across species within different Species of European Conservation Concern (SPEC) categories, total n = 426, and (b) the distribution of transformed adjusted research effort index for species with different European threat statuses, total n = 426. Boxplot description as in Fig. 2

The most supported models for research effort explain ~0.35 to 0.40 of the variation (Table 1). Thus, despite the wide array of candidate variables considered, much of the variation in research effort remained unexplained.

DISCUSSION

Tables 1 & 2 show that, of the set of candidate variables considered, European population size, potential research investment, habitat type and generation length carried most weight in explaining research effort. Migration status, percentage of the global population in Europe and 1990–2000 European population trend also have a moderately high relative importance, whereas variables linked to the threat status of species have a low relative importance and do not show a significant association with research effort in univariate statistical tests.

Birds with larger populations have a greater research effort, almost certainly because species with more individuals tend to be more widespread and available for research. Another explanatory factor may be that research is less stringently regulated because of such species' generally favourable conservation status (McMahon et al. 2007).

Birds which have a higher proportion of their European population in countries with a large per capita GDP have a larger research effort, as measured by our study. This supports previous studies that found GDP is posi-

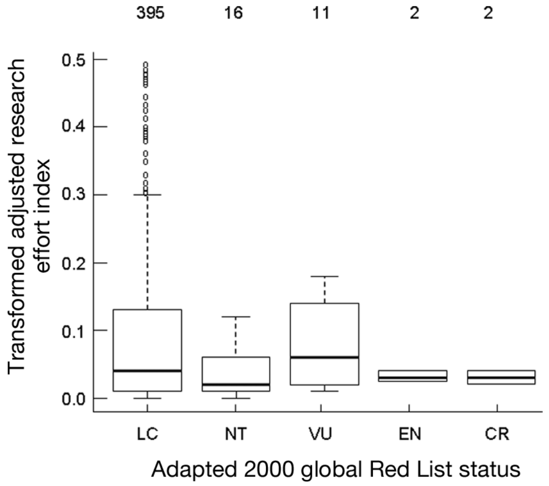

Fig. 10. Boxplot showing the distribution of transformed adjusted research effort index across species with different global Red List statuses, total n = 426. Boxplot description as in Fig. 2. LC: Least Concern; NT: Near Threatened; VU: Vulnerable; EN: Endangered; CR: Critically Endangered

tively correlated with conservation science research effort (e.g. Lawler et al. 2006, Fisher et al. 2011) and in particular those which show that research effort on European bird species is biased towards Western Europe, which has a higher per capita GDP than Eastern Europe (Baldi & Batary 2011, Tryjanowski et al. 2011). Countries with higher per capita GDPs are more likely to be able to invest in funding for conservation through government-sponsored research in universities and research institutes. Within Europe, per capita university research performance is much higher for Western European than Eastern European countries (Aghion et al. 2007). Additionally, wealthier countries are more likely to have well-resourced non-governmental organisations that undertake research. Not only must the research be undertaken, but it must also be developed to a state where it is published in peer-reviewed journals indexed by Web of Science, a process that also demands resources. However, the relationship between potential research investment and research effort is perhaps influenced by more than simple economic considerations; it may be the result of a science communication bias.

There is an overrepresentation of papers from high-income countries in peer-reviewed journals. When Fazey et al. (2005) assessed papers published in 3 well-known conservation journals in 2001, they found that only 28% of studies were from low-income countries, and similar biases have been found by other authors (e.g. Brooks et al. 2008, Brito & Oprea 2009). This may reflect differences in research effort, but it might also be because the work is not being reported in internationally accessible literature. Scientists from lower income countries face potential socioeconomic barriers to publishing research. For example, Fazey et al. (2005) interviewed conservation science academics and found that some identified the language barrier as a ‘real problem’. Conservation managers often use a surprisingly small amount of published literature when planning conservation actions (e.g. Linklater 2003, Pullin et al. 2004). It is plausible that countries with a lower GDP are still carrying out research, but publishing a smaller proportion of the results in international journals, with unpublished research being used to drive conservation actions. De Lima et al. (2011) found that the evenness in species research was lower when searches were performed in the Web of Science than in BirdLife’s library catalogue, which contains greater amounts of unpublished literature. There may therefore be less of a research effort bias amongst the literature that conservation managers are actually using than that detected in this study. Nevertheless, a communication bias is as real an issue as a research effort bias. Without exposure to peer-review within the scientific community, research cannot be critiqued and developed, leading to the possibility of ineffective or even harmful management strategies being pursued (Sutherland et al. 2004). The development of evidence-based databases such as conservationevidence.com and synopses (e.g. Williams et al. 2012) may help address this problem.

Birds with longer generation lengths and higher body masses, variables that are significantly correlated ($r_S = 0.768$, $p < 1 \times 10^{-15}$), tended to have a higher research effort. However, generation length was a better predictor than body mass (Table 2). Birds that have a low annual mortality and/or a high age at first breeding will have long generation lengths which facilitate certain long-term monitoring studies. Generation length differs significantly between birds living in different habitats (Kruskal-Wallis $\chi^2 = 112.272$, $p < 1 \times 10^{-15}$), with the generation lengths of birds in marine habitats being significantly higher than those in all other categories (as shown by a series of post hoc pairwise Wilcox tests with p-values adjusted using Bonferroni corrections). This might partly explain the high research effort for these long-lived seabirds which are the focus of many tracking studies (Burger & Shaffer 2008) and are often studied as indicators of the general health of marine ecosystems (Piatt & Sydeman 2007).

Species with a higher body mass, such as raptors, gulls, geese and ducks, had a higher research effort, supporting the findings of other studies (e.g. Brodie 2009). The relationship between body mass and habitat type was, however, more complicated than for generation length, with no clear indication that the high research effort for bigger-bodied species was being driven principally by marine species. Larger species are often easier to locate and observe, making them more accessible for research. Another possible explanation is that bigger-bodied species tend to be more charismatic (Żmihorski et al. 2013) and therefore more attractive to researchers as a result of both personal taste and increased funding availability. This bias extends into the realm of conservation action with charismatic species being more likely to be the subject of reintroduction programmes (Seddon et al. 2005), with potentially improved conservation outcomes (Brambilla et al. 2013). The result is that species which are more charismatic are likely to have a greater research effort, as found in other studies (e.g. Amori & Gippoliti 2000, Martín-López et al. 2009).

The individual analysis of habitat type revealed a trend for species from more aquatic environments to receive greater research effort (Fig. 5). This is likely to be due to ease of locating birds and carrying out studies, as waterbirds are often colonial when breeding and/or congregate outside the breeding season (Rolland et al. 1998). Further, as discussed above for marine birds, aquatic species may be studied as good ecosystem indicators (Kushlan 1993). On the other hand, birds from montane and Mediterranean habitats were relatively poorly studied, possibly for reasons of inaccessibility and relatively low GDP, respectively.

Migration status was an important factor, with species migrating within Europe and into Europe for the winter particularly well-researched (Fig. 6). Species in the latter category have a significantly higher potential research investment than others (Kruskal-Wallis $\chi^2 = 123.639$, $p < 1 \times 10^{-15}$, post hoc pairwise Wilcox tests with Bonferroni adjusted p-values show a significant difference between the 'full migrant in Europe' category and all others). This suggests that the factor's importance as a predictor comes from incorporating into models the possibility of birds spending at least part of the year in countries with relatively high GDPs, already identified as a correlate of research effort.

The 1990–2000 population trend was another important factor. Birds with population trends which have a clear direction, particularly 'increasing', have a higher research effort than those with stable or fluctuating trends. While it may be counter-intuitive that the conservation literature should focus on birds with the most favourable population trends, it is likely that this relationship is simply because those with increasing population sizes are more widespread and available.

Even with a model containing all or most of the candidate variables considered here, there is still considerable variation in research effort which is not explained. There are several other variables, such as European range size and degree of media coverage (Sutherland et al. 2011), which could also be considered in models. However, it is likely that some variation in research effort is stochastic and would never be fully explained by models. Various 'serendipitous historical events and geopolitics' can play a large role in determining which species receive most of the attention, especially as there may be positive feedback when well-received studies on a particular species encourage further research (de Lima et al. 2011).

Is research effort well targeted in relation to conservation need?

The results of this study demonstrate that European bird research effort is poorly targeted with respect to both threat status (European and global) and those species identified as of particular concern (Annex I, SAP, SPEC category). According to our dataset, fewer than 10 papers were published on 5 (22%) of the 23 species currently listed as globally threatened (global IUCN Red List status of VU, EN, or CR); these included the Endangered Zino's petrel and the red-breasted goose *Branta ruficollis* and the Critically Endangered sociable lapwing *Vanellus gregarius*. Similar knowledge gaps are seen at a European level. Fewer than 10 papers were published on 10 (30%) of the 33 species identified as of highest priority for European conservation concern in 2004 (SPEC 1). This suggests that some of the conservation management plans based on agreements for European birds, particularly SAPs which include a 'research and monitoring' component, may actually fail to generate much research.

There are a number of reasons why threatened birds may not generate much research. Our study found population size to be one of the most important factors in predicting research effort, and, by definition, threatened birds have small populations which, along with a small range size and potentially restricted habitat type, make them less available for research. It may also be that legal restrictions, designed to minimize risks to wild populations, deter researchers from working on these species, and so hamper the very conservation research necessary for their survival (McMahon et al. 2007). This result is particularly concerning, since birds are well studied compared to other taxa such as mammals (Amori & Gippoliti 2000) and amphibians (Brito 2008), where there may be an even greater research shortfall on threatened species.

It is possible that, whilst more threatened species do not attract significantly more research than less threatened species, research effort on these groups does increase once they are recognised as being of conservation concern. Previous research has shown that there is a detectable lag of over 10 yr between species being added to conservation agreements, such as Annex I, and achieving an improved conservation status (Male & Bean 2005, Donald et al. 2007). However, our study found no evidence of a similar increase in research effort, even when over 30 yr have passed.

There are some positive signs: none of the 19 species on which zero papers were produced was classed as threatened according to the IUCN global Red List of either 2000 or 2012, supporting findings that it is more likely that there will be at least 1 ouput on threatened species of birds (de Lima et al. 2011). Furthermore, Brooks et al. (2008) found that threatened species were more likely to have a single dedicated reference than non-threatened species. One specific ecological study is more likely to help design effective conservation management plans for a species than inclusion in several comparative studies. Fuller et al. (2003) investigated the impact of SAPs on the conservation of Galliformes and found that, during the implementation of their Action Plans, at least 133 research outputs were generated. Of these outputs, only 45 (34%) were papers in peer-reviewed journals. This suggests there may be information on species that is generated as a result of being recognised as a conservation concern that is not made accessible to the scientific community via peer-reviewed journals, and indeed may be difficult to access. Finally, whilst conservation research effort may not be allocated appropriately to the most threatened groups, there is evidence that it is relatively well-targeted with respect to the most harmful threats (Lawler et al. 2006).

It is important to emphasise that these results do not support a complete reallocation of research effort towards more threatened species. Insights from studies of common species are often applicable to the conservation of more threatened species. Sometimes research may pose a small risk to populations, and common species must be used as alternative models to those which are rarer. In the case of larger-bodied birds, such charismatic species are often used as 'flagship species' by conservation organisations to attract public and donor support. Research on these species can raise the organisation's profile and lead to increased funding which may then be invested into conservation actions to the benefit of a range of other species (Walpole & Leader-Williams 2002). Fundamentally, conservation is not just about preventing the extinction of threatened species, but also about maintaining the favourable status of species with healthy populations. Ideally, all species should be monitored for emerging threats and changes in population trends, and where basic ecological data are still lacking on species these gaps should be filled, particularly for threatened species.

The results on the relationship between threat status and research effort found here differ from those of other studies on birds. Brooks et al. (2008) found that non-threatened bird species had a higher mean number of papers per species than threatened species, but, amongst threatened species, research effort was greater on Critically Endangered species than on those Vulnerable or Endangered. De Lima et al. (2011) also show a clear trend, albeit non-significant, for bird species in more threatened categories to have a higher research effort.

Methodologically, our study uses a more sophisticated measure of research effort that incorporates the year and journal in which a paper is published. In addition, there is variation among orders of birds in the degree to which research effort is biased towards threatened or non-threatened species (Brito & Oprea 2009), and so the sample of birds selected for analysis is likely to have a significant impact on results. While de Lima et al. (2011) analysed data on 1321 species of restricted-range island bird species across the globe and Brooks et al. (2008) based their analysis on 50 threatened species selected at random from the 4 volumes (4–7, del Hoyo et al. 1997–2002) of 'The Handbook of the birds of the world', our work addressed an unselected group of 426 European bird species. These are very different samples, and it seems highly plausible that different trends are present in each of the groups. This highlights the need for more knowledge gap analyses to be performed on different sets of species. When the key stakeholders in the allocation of conservation funding, as well as individual researchers, are aware of the biases in research effort, where particular knowledge gaps lie and how these gaps may shift over time, there is a greater chance that research will be directed towards wherever it is most urgently needed.

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Appendix 1.

Only these subspecies of the following species are listed in Annex I of the EU Birds Directive: *Accipiter gentilis arrigonii*, *Accipiter nisus granti*, *Anser albifrons flavirostris*, *Calidris alpina schinzii*, *Certhia brachydactyla dorotheae*, *Columba palumbus azorica*, *Dendrocopus major canariensis* and *Dendrocopus major thanneri*, *Fringilla coelebs ombriosa*, *Lagopus mutus pyrenaicus* and *Lagopus mutus helveticus*, *Parus ater cypriotes*, *Perdix perdix italica* and *Perdix perdix hispaniensis*, *Phalacrocorax aristotelis desmarestii*, *Tetrao tetrix tetrix*, *Troglodytes troglodytes fridariensis*, *Uria aalge ibericus*

Appendix 2.

Action Plan or Brief Management Statement only exists for these subspecies of the following species: *Accipiter gentilis arrigonii*, *Accipiter nisus granti*, *Dendrocopus major canariensis* and *Dendrocopus major thanneri*, *Perdix perdix italica*, *Phalacrocorax aristotelis desmarestii*

Appendix 3.

Table A1. Matrix of correlation coefficients between independent variables. **Bold** values indicate Pearson correlation coefficients between continuous variables, plain text indicates Spearman rank correlation coefficients between ordered categorical variables, or between ordered categorical variables and continuous variables

	Potential research investment	European population size	Body mass	Generation length	Population trend	Percentage of global population in Europe	IUCN Red List status	European threat status
Potential research investment	**1**		**0.22**	**0.29**	0.15	0.08	0.16	0.18
European population size	**−0.03**	**1**	**−0.14**	**−0.18**	0.04	0.43	0.35	0.38
Body mass	**0.22**	**−0.14**	**1**	**0.53**	0.09	−0.14	−0.17	−0.2
Generation length	**0.29**	**−0.18**	**0.53**	**1**	0.15	−0.09	−0.18	−0.15
Population trend	0.15	0.04	0.09	0.15	1	0.04	0.02	0.55
Percentage of global population in Europe	0.08	0.43	−0.14	−0.09	0.04	1	−0.11	0.14
IUCN Red List status	0.16	0.35	−0.17	−0.18	0.02	−0.11	1	0.34
European threat status	0.18	0.38	−0.2	−0.15	0.55	0.14	0.34	1

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