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Birds and Natura 2000: a review of the scientific literature

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Review Article

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Summary

The Natura 2000 network, the pillar of biodiversity conservation in Europe, still shows some knowledge gaps after almost 30 years since its implementation. As birds are a taxonomic group that is underrepresented in the literature related to Natura 2000 compared to their importance in the EU Directives, this review investigated the characteristics of the scientific research dedicated to birds in relation to Natura 2000. This review focused on 169 peer-reviewed articles covering a period of 25 years (1995–2019). Most studies were set within single Natura 2000 site or regions within countries, and concerned terrestrial habitats, particularly wetlands. The terrestrial Mediterranean biogeographical region and marine Atlantic region had the greatest number of publications, while Spain, Italy, and France were the countries with the highest number of reviewed articles. The number of publications was correlated to Natura 2000 coverage at both country and biogeographical region level. Bird species were studied mainly at a community or single-species level and most publications studied distribution and occurrence of the bird species of interest, while very few assessed the conservation status of the species. Only a few articles set within Natura 2000 sites addressed the issues of habitat suitability for birds or the effectiveness of conservation efforts. Both Annex I and non-Annex I bird species were examined in the literature, with most species having decreasing population trends at the European scale. Future research on bird conservation and Natura 2000 should focus on marine ecosystems as well as habitats that have received less attention despite their important role in a changing future (alpine and urban types). Moreover, future studies should encompass larger spatial scales and those species for which status and trends are still not thoroughly investigated. Finally, it would be important to enhance research efforts on the conservation status and effectiveness in relation to the network.

Introduction

Global biodiversity indicators have shown worryingly negative trends and, apart from a few exceptions, there are no significant reductions in rates of decline (Butchart *et al.* 2010, Ceballos *et al.* 2015). Biodiversity change in natural ecosystems is likely to generate complicated impacts on ecosystem functioning (Duffy 2003, Hooper *et al.* 2012). It has been widely demonstrated that biodiversity loss is due to a combination of drivers, among which climate and land-use change are at the forefront (McKinney and Lockwood 1999, Chazal and Rounsevell 2009, Bálint *et al.* 2011). Anthropogenic pressure, including human-driven land cover change has led to habitat fragmentation and deterioration, which makes biodiversity conservation an even more challenging task (Fahrig 2003, Gaston *et al.* 2003, Weinzettel *et al.* 2013).

Policies are recognized as one of the main driving forces of land use change and nature conservation (Donald *et al.* 2007, Kankaanpää and Carter 2004), therefore biodiversity loss is increasingly seen as a political problem that must be solved through policy tools (Boere and Rubec 2002, Butchart *et al.* 2010). The European Union (EU) took its most concrete steps towards achieving biodiversity conservation targets through the adoption of the Habitats Directive (92/43/EEC, HD) and the Birds Directive (2009/147/EC, BD) (Beresford *et al.* 2016), which require the EU Member States to establish a comprehensive network of protected areas, the Natura 2000 network. Indeed, a key action to halt species and habitat loss is to designate areas for conservation (Margules *et al.* 1988, Albuquerque *et al.* 2013, Jackson *et al.* 2009, Pellissier *et al.* 2013, Gray *et al.* 2016). To ensure biodiversity conservation, the designation of protected areas must consider threats, opportunities, legal frameworks, and available resources (Gregory *et al.* 2005) and establish effective management approaches (Campagnaro *et al.* 2018). Accordingly, the Natura 2000 network contributes to the maintenance, and, where necessary, the restoration, of threatened habitats and species listed in the Directives (according to Article 4 of the BD and Annexes I and II of the HD). Moreover, Natura 2000 is the largest coordinated network of sites

with strong legal protection aiming to conserve biodiversity and improve connectivity at continental scale, representing a major example of nature protection (Campagnaro *et al.* 2019).

Research has demonstrated that large-scale conservation measures guarantee critical ecological processes and prevent rapid loss of diversity due to habitat fragmentation (Krauss *et al.* 2010, Poiani *et al.* 2000). In Europe, large-scale conservation is particularly challenging because the continent is characterised by a diverse array of socio-ecological systems and made up of many different countries with distinct political, social, economic, and ecological systems (Orlikowska *et al.* 2016, Campagnaro *et al.* 2019). Natura 2000 is based on an integrated conservation approach, which seeks to balance protection of habitats and species with economic, social, and cultural requirements as well as local characteristics (Article 2 (3) of the HD), and therefore allowing for a wide variety of land uses (Winter *et al.* 2014, Winkel *et al.* 2015). All these features make Natura 2000 the pillar of European Union biodiversity conservation policy.

Natura 2000 implementation does not come without flaws or hindrances (Campagnaro *et al.* 2019). These shortfalls have been examined by the 'Fitness Check' in the EC Regulatory Fitness and Performance Program (REFIT) which aimed to examine the effectiveness, efficiency, relevance, coherence, and EU added value of the HD and BD (Milieu *et al.* 2016). A wide nature protection network requires an effective monitoring and implementation programme (Balmford *et al.* 2003, Gaston *et al.* 2008, Butchart *et al.* 2010), even more so when considering the current changing environment (Brambilla *et al.* 2015). Science can further contribute to the assessment of the implementation of conservation policies since monitoring and research can fill the knowledge gaps about the effects on habitats and species (Maiorano *et al.* 2007, Kati *et al.* 2015, Winkel *et al.* 2015).

Orlikowska *et al.* (2016), through a review of the scientific literature, detected the knowledge gaps in ecological research on Natura 2000. Their findings suggest that further research should address underrepresented taxonomic groups in the literature related to Natura 2000 in comparison to their representation in the EU Nature Directives, such as birds, which are often linked to rare habitats. Indeed, Article 10 of the BD stresses the need for research as the basis for protection, management, and use of bird species and populations. Furthermore, birds have been demonstrated to be effective indicators to measure and monitor biodiversity (Gregory *et al.* 2005, Klvanova *et al.* 2009, Pellissier *et al.* 2013) and, through their responses, have provided evidence of the impacts of policies implementation and related habitats management (Kleijn *et al.* 2001, Donald *et al.* 2002, Gamero *et al.* 2017, Reif and Vermouzek 2019). Therefore, in this study we conducted a literature review to deepen our knowledge of Natura 2000 in relation to bird conservation.

The aim of our review was to provide insights into how birds have been studied within the framework of Natura 2000, from both a quantitative and qualitative point of view. We tested the representativeness of the publications in relation to temporal interest, approaches adopted, type of study, aims, coverage of habitat categories within Natura 2000, scale of investigation, biogeographical region, and distribution of bird species. Information about the targeted bird species was also recorded, mainly in relation to their taxonomic group, protection status, population trends and threat category. Such information gives a comprehensive picture of the knowledge gaps about bird conservation in EU protected areas.

Materials and Methods

Data selection criteria

Our research focused on peer-reviewed literature, since our interest was to define the level of interest and ecological research effort addressed by the academic scientific community to bird trends and status in relation to the Natura 2000 network. The articles for our review were selected through a search in the main fields (title, abstract and keywords) of both the Web of Science Core Collection™ (WoSCC) and Scopus™ databases, to retrieve consistent and accurate results (Wilson *et al.* 2007, Falagas *et al.* 2008, de Winter *et al.* 2014).

We searched the databases by inputting a query string (reported in Appendix S1 in the online supplementary material) that included the terms related to the EU Nature legislation (i.e., 'Natura 2000', 'Birds Directive' and 'Habitats Directive') in combination with the term "bird*" with all its plausible declinations or the scientific or English common names of all 193 species and subspecies protected under Annex I of the BD. Common English names were derived from EC (2019), or in cases where this was not available, from the IUCN Red List of Threatened Species database (IUCN 2017), the European Bird Portal (EBCC 2015), or the Collins Bird Guide (Svensson *et al.* 2009). We did not specify any time span for the search, because we wanted to see how the topics related to birds have been treated throughout the Natura 2000 implementation process. The search was launched on 30 November 2019, so we did not include any publication later than that date. Our analysis consequently covers articles from 1995 to 2019.

After deleting double entries, we obtained an initial set of 383 articles. From this list we removed the publications that were not relevant to topics and issues related to Natura 2000 and bird species, and that addressed areas uniquely outside of the EU. We selected a total number of 169 articles for our analysis (Appendix S2).

Data collection and analysis

The content of each paper was examined, and information was classified for several different attributes of interest (Table 1) regarding the main characteristics of the studies (research aims and strategy; year of publication), the study areas (spatial scale; jurisdiction and country; environment and habitat types; biogeographical region; elevation) and of the targeted bird species (protection under Birds Directive; taxonomic group; threat status; population trend; movement patterns of the species; area of distribution). Attributes sharing a specific focus were analysed and discussed together. Each attribute, which indicates the type of data recorded, can refer to different categories.

We computed the number of publications for every category of each attribute separately. This provided an overview of research on birds related to Natura 2000. For the attributes related to threat status and population trends of species, we computed the number of species examined in each category. In addition, to assess the interest according to each category of conservation status and trend, we computed how many times each species has been examined in the analysed articles and the numbers were then aggregated per category. When the subspecies mentioned in the analysed studies were not of European conservation concern, they were aggregated under the main species, in order to attribute a threat status category at European level as indicated by IUCN (2017).

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Table 1. Specific focus and related attributes with their categories and explanation used to analyse the reviewed papers. For description of the categories of habitat type, the codes in [] refer to the numerical codes used in the Corine land cover classification system.

Specific focus	Attributes	Categories	Description
Interest in the Topic and Research Approaches	Year of publishing	Range between 1995 and 2019	The range emerged from the search itself, since no criteria about the year of publishing were set.
	Type of research strategy	Study with qualitative/analytical approach	Describes characteristics of the population or phenomenon being studied without hypothesis testing.
		Quantitative empirical study	Focuses on current conditions; uses statistical tests and models based on empirical data.
		Modelling	Focuses on future conditions; uses simulations or modelling as an analytical tool.
		Review	Literature review.
	Research aims	Species richness	The categories have been elaborated according to the research aims of the article analysed.
		Species composition	
		Abundances	
		Distribution and occurrence	
		Use of resources	
		Habitat suitability, use and selection	
		Population trends and dynamics	
		Conservation status	
		Threats or mortality causes (vulnerability)	
		Conservation actions state of the art and assessments	
		Management and planning	
		Breeding phenology	
		Methodology application test	
Study Subjects' Characteristics	Jurisdiction of the study area	Natura 2000 site	When a non-Natura 2000 site was involved, if possible, the different legal status of protection or management was reported.
		Non-Natura 2000 site	
		Both	
	Type of environment	Terrestrial	Inland waterbodies are considered as a terrestrial environment.
		Marine	
	Elevation of the study area	High altitudes	Results were aggregated according to elevation classes (high altitudes from montane level: 900 metres above sea level, if not specified with words).
		Low altitudes	
		Not specified	
	Habitat type	Alpine/subalpine	
		Forests	Areas occupied by vegetation pattern defined as forests [31].
		Pastures and grasslands	Open lands characterized by natural or sown herbaceous species [23].
		Rural areas/Agricultural crops	Lands managed for production purposes [21, 22, 24]
		Wetlands	These can be distinguished between inland wetlands and waters and marine and coastal wetlands, according to the Ramsar Classification System for Wetland Type (Ramsar Convention Secretariat, 2013) [41, 42, 51, 521, and 522]
		Rocky areas or bare ground	Mainly covered by bare rock, sands or areas with little or no vegetation [331, 332, 333]
		Marine	Sea and ocean, pelagic environment [523]
		Shrubland	*Sclerophyllous* vegetation, transitional woodland-shrub [32]
		Artificial and urban areas	Artificial landscapes [11, 12, 13, 14]
		Other	Not possible to be categorised with categories above
		Various	When multiple habitat types were considered indistinctively

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Table 1. (*Continued*)

Specific focus	Attributes	Categories	Description
Spatial Scale and Distribution	Country/ies	Name/s of the Nation/s on which the study focused	Name(s) of the country(ies) directly concerned by the research (authors' affiliation was not considered). We used 'EU' when the whole EU territory was considered, and each single country member was accounted for too.
	Spatial scale of the study	Single site	
		Region within a country	
		Single country	
		More than one country	
		European Union (EU28)	
		Not specified	
	Biogeographical and marine region	Alpine	As defined by EEA (2020). For articles involving multiple regions, all relevant regions were recorded.
		Arctic	
		Anatolian	
		Atlantic	
		Black Sea	
		Boreal	
		Continental	
		Macaronesian	
		Mediterranean	
		Pannonian	
		Steppic	
Bird species	Bird species examined in the study	(No categories)	List of the species that were examined (specifying species, and possible subspecies)
	Ecological unit	Single species	Focuses on a single species
		Community/guild	Focuses on an assemblage of populations of several species
		Ecosystem	Focuses on living organisms in conjunction with the non-living components of their environment, interacting as a system and linked together through nutrient cycles and energy flows (Chapin *et al.*, 2002)
		NA	None of the above categories is applicable
	Protection under Birds Directive	Annex I	
		Non-Annex I	
	Taxonomic group	Bustards	The groups have been defined according to the latest update of the database on the EU bird population status as reported under Article 12 (BD) for the period 2013-2018 (version 2020)
		Cranes, rails, gallinule, and coots	
		Cuckoos	
		Ducks, geese, and swans	
		Falcons	
		Gannets and cormorants	
		Grebes	
		Hawks and eagles	
		Herons, pelicans, ibises, and spoonbills	
		Kingfishers, rollers, bee-eaters, and hoopoe	
		Loons or divers	
		Owls	
		Passerines	
		Petrels, storm-petrels, and shearwaters	

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Table 1. (*Continued*)

Specific focus	Attributes	Categories	Description
		Pheasants, partridges, and grouse	
		Pigeons and doves	
		Sandgrouse	
		Storks and flamingo	
		Swifts and nightjars	
		Waders, gulls, and auks	
		Woodpeckers	
	Threat status	Extinct (EX)	According to the IUCN Red List Categories (IUCN, 2017)
		Extinct in the Wild (EW)	
		Critically Endangered (CR)	
		Endangered (EN)	
		Vulnerable (VU)	
		Near Threatened (NT)	
		Least Concern (LC)	
		Not Evaluated (NE)	
		Unknown	
	Population trend	Increasing	According to the IUCN Red List Categories (IUCN, 2017)
		Stable	
		Decreasing	
		Unknown	
	Movement patterns of the species	Full migrants	A substantial proportion of the global or regional population makes regular or seasonal cyclical movements beyond the breeding range, with predictable timing and destinations According to the IUCN Red List Categories (IUCN, 2017)
		Altitudinal migrants	Regularly/seasonally makes cyclical movements to higher/ lower elevations with predictable timing and destinations. According to the IUCN Red List Categories (IUCN, 2017)
		Nomadic	Moves in response to resources that are sporadic in time and distribution According to the IUCN Red List Categories (IUCN, 2017)
		Not a migrant	None of those defined above According to the IUCN Red List Categories (IUCN, 2017)
		Unknown	According to the IUCN Red List Categories (IUCN, 2017)
	Distribution surface area	(No categories)	Data have been obtained from the latest update of the database on the EU birds population status as reported under Article 12 (BD) for the period 2013-2018 (version 2020).

The area covered by different Corine land cover classes in 2015 was computed from the EEA dataset (https://www.eea.europa.eu/data-and-maps/data/natura2000-clc-by-nuts). We performed a chi-squared test of independence in R software (version 3.6.2; R Development Core Team 2019) for the number of times each habitat category was considered in the analysed literature in relation with the coverage of Corine land cover classes inside Natura 2000 sites (km^2), except for 'Alpine and subalpine', 'Various' and 'Other' categories, due to a lack of correspondence with Corine land cover classes. To assess if the number of publications was proportional to the representativeness of Natura 2000 in each EU country, we considered the information available from the EEA Natura 2000 barometer table (updated to the end of 2018, published on 15 March 2019). We tested whether the number of publications per country was correlated to the number and area of Natura 2000 sites in the country, the country's total land area, and the country's Natura 2000 percentage cover over the total land area. We applied the Spearman rank correlation method since our variables were not normally distributed. The same approach was followed to assess whether the number of publications per biogeographical region was related to the total area that the region covers, the number of Natura 2000 sites and the summed area of Natura 2000 sites found within the region, as well as the percentage of the area of each biogeographical region covered by Natura 2000. We calculated the areas covered by Europe's different biogeographical regions (km^2) using EEA's 'BiogeoRegions2016' shapefile) in ArcGIS 10.8 (ESRI 2020)

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using the EEA. We calculated the area covered by Natura 2000 sites within biogeographical regions by overlapping the 'BiogeoRegions2016' shapefile with the 'Natura 2000 End 2018' shapefile.

Additionally, we assessed whether there was any correlation between the number of times a bird species was considered in literature and its distribution. To obtain the distribution area of bird species considered in the analysed literature, as well as to group the bird species according to taxon categories (see Table 1), we used data reported in the datasets from Article 12 of the BD for the period 2013-2018 (https://www.eea.europa.eu/data-and-maps/data/article-12-database-birds-directive-2009-147-ec-1). Finally, according to the categories related to the population trends and the threat status we analysed not only the number of bird species belonging to the different categories, but also the number of times bird species belonging to the different categories were examined in the analysed studies, and the average number of times each of the species belonging to the same category were examined in the articles.

Results

Interest in the topic and research approaches

The publications selected for the analysis were distributed between 1995 and 2019. According to the number of publications per year, a generally increasing attention to the topic of birds and Natura 2000 can be noted (Figure 1). Most of the articles adopted empirical/quantitative approaches (107), followed by those developing models (42), reviewing the literature (16) or implementing qualitative/analytic research methodologies (13). Few studies adopted more than one approach for their research.

The analysed literature focused mainly on distribution and occurrence of birds (86), while less than one third of the articles focused on the relationship between the habitat(s) and the bird species of interest (49) (Figure 2). Only about a quarter of the publications that set their studies in Natura 2000 sites addressed the research questions related to habitat suitability, use and

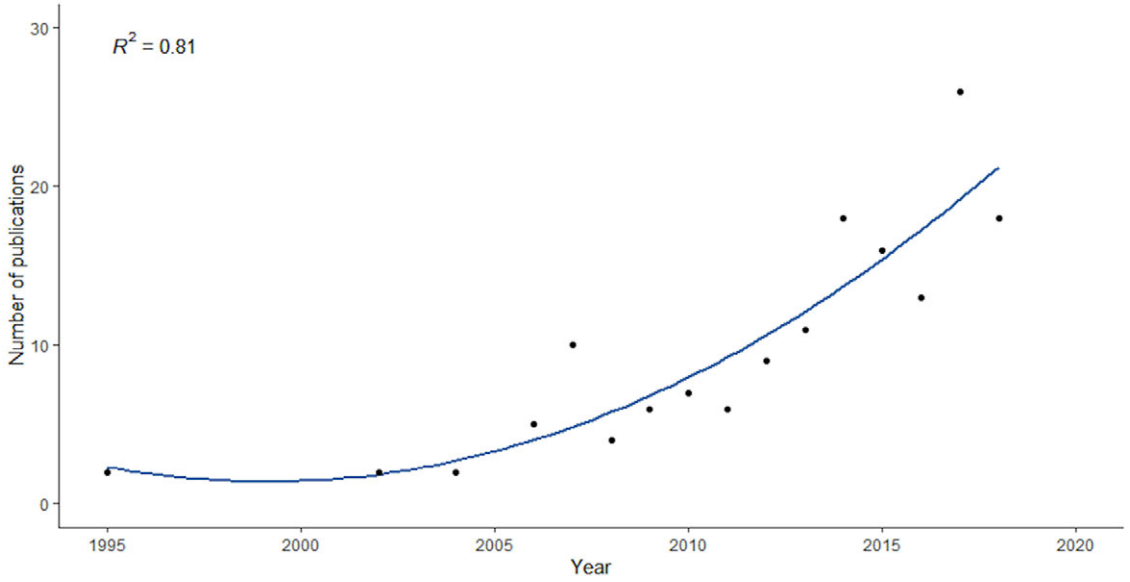

Figure 1. Number of relevant publications per year. The trend line obtained through linear modelling in blue shows an increasing trend of the publication of studies over time.

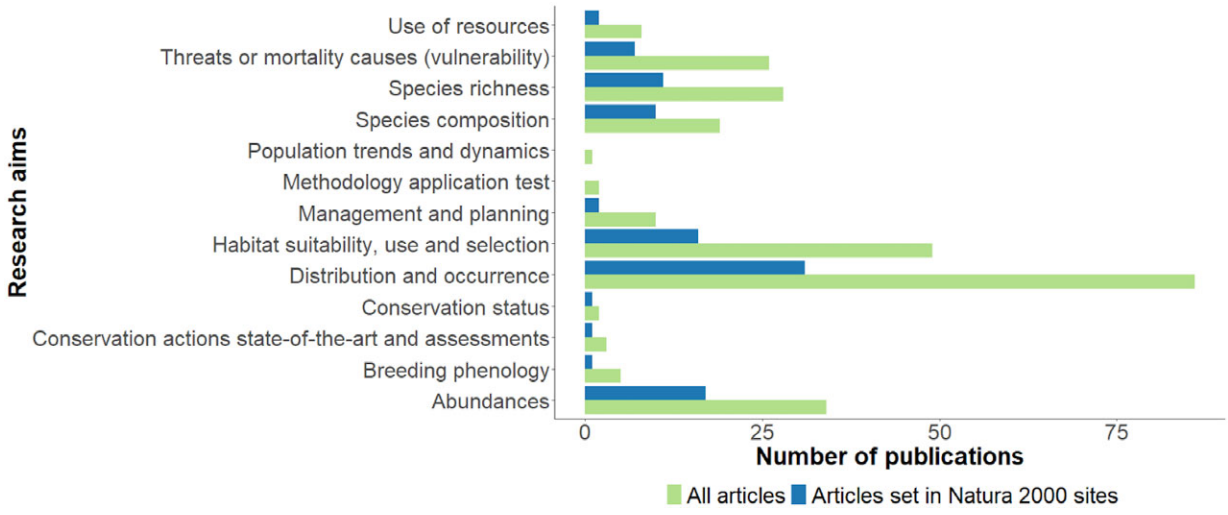

Figure 2. Number of publications in total (light green) and number of publications set in Natura 2000 sites (blue) that have addressed the listed research aims. A single publication can have addressed more than one research aim.

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selection (16 out of 67) and only one article assessed the conservation status of birds and the effectiveness of conservation measures within Natura 2000 sites.

Study subjects' characteristics

Most of the publications set their studies in Natura 2000 sites (40%), one-third considered both protected sites under Natura 2000 and unprotected areas outside Natura 2000 (33%), while others did not directly concern Natura 2000 sites (23%). Different legal status of protection was reported when the study area was not in a Natura 2000 site (4%): most of these were Important Bird Areas, National Parks, Buffer Zones, National Protected Areas, or Nature Reserves. Some articles also considered Regional Parks or Landscape Parks, while only a few mentioned Geoparks, Natural Heritage Zones, Managed Reserves, and Provincial Parks.

The majority of publications (161) focused their studies on terrestrial environments, while many fewer concerned marine environments (20). Among the studies, low elevation sites were considered more often (63 articles) than high elevation sites (36 articles), while many did not specify elevation (109).

The least reported macro-categories of habitats (Figure 3a) were urban areas, Alpine and subalpine habitats, rocky areas, and marine waters. The habitats that appeared most frequently were wetlands (70), despite the fact that their coverage in the Natura 2000 network is not among the highest. A large number of publications concerned forests, rural and agricultural areas, also grasslands and shrublands, or they focused on various habitat types not specifically defined. The cover of the habitat categories inside Natura 2000 sites varied greatly (Figure 3b) and the number of publications dedicated to a certain habitat category were not dependent on its cover in Natura 2000 sites (P-value >0.2). Regarding specifically wetlands, coastal and marine habitats and those typical of inland areas had an almost equal contribution (Figure 3c).

Spatial scale and distribution

Most publications were focused on the single-site (37%) or regional scale (corresponding to the category 'region within a country'; 27%). Articles related to single country levels were quite common (18%), while studies encompassing more than one country or the whole EU were less so (9% and 8%, respectively). Very few studies did not specify the spatial scale of focus (1%). In total 48 countries were considered in the analysed articles. The studies were mainly distributed within the EU, but some of them also involved other European or non-European countries (Figure 4). A few studies involved North African countries (Morocco, Tunisia, Algeria, Libya), Middle Eastern countries (Israel, Lebanon, Jordan, Syria), and other non-EU European countries (Albania, Montenegro, Bosnia-Herzegovina, Serbia, North Macedonia, Norway, Switzerland, Moldova, Belarus, Ukraine, Georgia). The EU country that reported the highest number of publications was Spain, which is also the 5th country in order per number of Natura 2000 sites (1,863) and the first in terms of total land area covered by the Natura 2000 network (222,420 km^2). The number of publications per country is correlated to the total extent of Natura 2000 sites within the EU Member States territory ($\rho = 0.73$; P-value < 0.001) (Table 2). Natura 2000 total cover at country level is highly correlated to the total country terrestrial area ($\rho = 0.89$; P-value < 0.001). No correlation emerged between the number of publications per country and the number of Natura 2000 sites in the country and proportion of Natura 2000 network area with respect to the total land area of the country ($\rho = 0.36$; P-value >0.1 and $\rho = -0.075$; P-value >0.5, respectively).

The terrestrial biogeographical region that reported the highest number of publications was the Mediterranean (71), while the region with least related articles (17) was Macaronesia (Figure 5). The Mediterranean region is in 4th place in terms of number of Natura 2000 sites present (4,377) and is second in terms of surface area (893,763 km^2). While Macaronesia is the smallest region (9,954 km^2), it contains more than 200 sites. The marine Atlantic region was the most studied marine region in the literature (17 times) and is also the most extensive (2,222,870 km^2) and second in terms of number of Natura 2000 sites (1,200). The marine region with the lowest number of publications (4) is Macaronesia and it follows the Atlantic one in terms of area (1,852,800 km^2). Contrary to the analysis at country level, the number of publications is highly correlated to the number of sites in each region, both terrestrial biogeographical and marine ($\rho = 0.80$; P-value < 0.001) (Table 3). The number of publications per region is not correlated to its total area ($\rho = 0.31$; P-value <0.5), while, again, the proportion of Natura 2000 site surfaces in the regional area is not correlated to the number of publications ($\rho = 0.27$; P-value <0.5).

Bird species

In total, the review covered 486 species and subspecies. These bird species have been mainly studied at community level (45%) as well as at single-species level (41%), and only a modest number of articles focused on ecosystem level (14%). The number of Annex I species and subspecies studied in the scientific literature (179) is close to the total number listed in Annex I of the EU Birds Directive (193), and Annex I species (excluding subspecies) in the analysed literature have been mentioned 169 out of 175 of them (Figure 6a and b). However, if we look at the frequency of observations for Annex I and non-Annex I (Figure 6c) in comparison to the total number of Annex I and non-Annex I species present in the EU Bird List 2018 (EC 2018) (Figure 6a), the interest in Annex I bird species was proportionally higher than that for species not of conservation concern.

The Annex I species most frequently studied in the analysed literature were Red-backed Shrike *Lanius collurio*, Western Marsh Harrier *Circus aeruginosus*, Ortolan Bunting *Emberiza ortulana*, and Woodlark *Lullula arborea*, while non-Annex I species that were most frequently reported were Black-headed Gull *Chroicocephalus ridibundus*, Skylark *Alauda arvensis*, and Buzzard *Buteo buteo*. No correlation emerged between number of publications and distribution for each species (P-value >0.5; Figure 7). The most frequently studied species have a medium-high distribution cover (Figure 7).

The Annex I species not reported in the analysed literature were Gyrfalcon *Falco rusticolus*, Scottish Crossbill *Loxia scotica*, Cyprus Wheatear *Oenanthe cypriaca*, Northern Hawk-owl *Surnia ulula*, Cyprus Warbler *Sylvia melanothorax*, and Common Buttonquail *Turnix sylvaticus*.

The taxonomic groups which report the higher figures in terms of number of species and number of times these species have been reported in the analysed literature were passerines; waders, gulls, and auks; ducks, geese, and swans; and hawks and eagles (Figure 8). Loons and divers; cuckoos; and sandgrouse were the least recorded and reported in the analysed literature.

The bird species showing decreasing population trends at EU level were the most studied and reported (Figure 9a and b). However, in general, such species have been less frequently reported in

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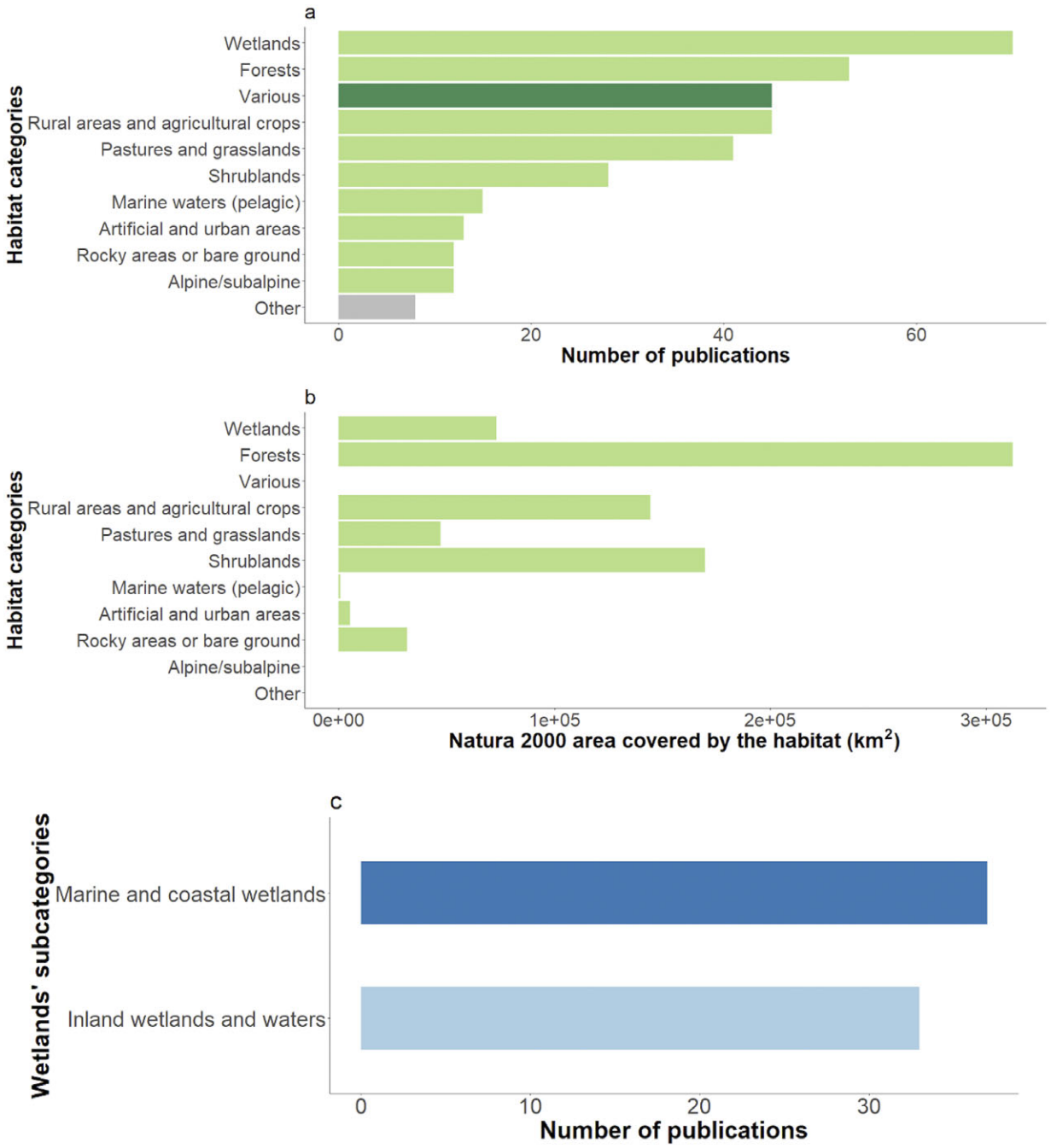

Figure 3. a) Number of times each habitat category has been considered in the analysed publications. Some articles did not specify the category of habitat, mainly because they encompassed large scales, so they were included in the 'other' category (grey). Several articles considered multiple habitats indistinctively (dark green). b) Cover of habitat categories inside Natura 2000 sites (km^2) with values computed from Corine land cover classes. The categories "Alpine/subalpine", "Various", and "Others" have no information about their cover within Natura 2000 sites. c) "Wetlands" have two sub-categories: marine inlets and transitional waters ("Marine and coastal wetlands"), and rivers, lakes, inland marshes and peatbogs ("Inland wetlands and waters"); the former has been considered more frequently in the analysed literature.

the entire analysed literature (Figure 9c). In fact, bird species with unknown or increasing population trends have been reported a higher number of times on average. Lastly, species for which population trend information is not available were less frequently considered in the analysed publications.

Among the total 472 bird species, 79% were assessed as 'Least Concern' and an additional ∽6% were 'Near Threatened' (Figure 10a). The bird species defined as threatened at European level were only ∽10% (for a total of 48 species): ∽6% 'Vulnerable', ∽3% 'Endangered', and ∽1% 'Critically Endangered'. No evaluation is available for ∽4% of the bird species. Taking the number of times that bird species belonging to the same risk category (IUCN 2017) were examined in the analysed articles, most of the observations focused on species assessed as 'Least Concern' (3,087 observations) (Figure 10b). 'Vulnerable' bird species were reported 210 times, and 'Near Threatened' species 178 times. 'Endangered' species were reported 64 times in articles, whereas 'Critically Endangered' species only 10 times. Lastly, looking at the number

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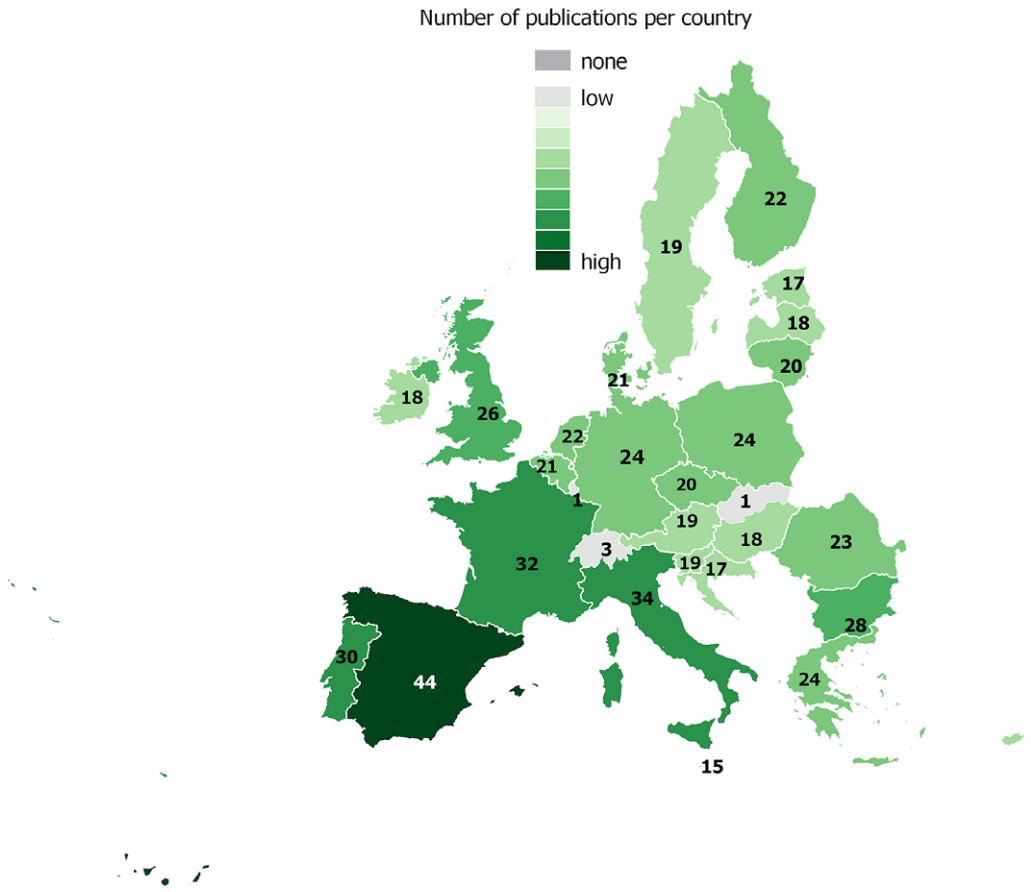

Figure 4. The EU 28 member states that were considered in the analysed articles are reported in the map. A darker green colour corresponds to a higher number of publications.

Table 2. Spearman rank correlations between the number of publications reported per country and the variables related to Natura 2000 at country level. The value of ρ Spearman's coefficient is reported.

	N° of publications				
N° of sites	0.36	N° of sites			
Country area (Km^2)	0.68	0.79	Country area (Km^2)		
Natura 2000 cover (Km^2)	0.73	0.71	0.89	Natura 2000 cover (Km^2)	
Proportion percentage (%)	−0.075	−0.079	−0.075	−0.031	Natura 2000 cover (Km^2)

of times that species belonging to the same threat level category have been reported on average, threatened species are still less reported than those which are not considered as threatened (Figure 10c). Most of the studied species (77%) are full migrants. Altitudinal migrants represent 20% of species, while the other groups of movement patterns are a negligible proportion (<2%).

Discussion

Interest in the topic and research approaches

Scientific publications on birdlife in relation to Natura 2000 have increased over the years. An initial scarcity of relevant studies on the topic might reflect the slow pace of progress in designating Natura 2000 sites, in particular SPAs, and the delayed implementation of the network in the Member States (Weber 2002, Evans 2012). Indeed, many studies on the effectiveness of Natura 2000 in conserving birds or habitats were possible only after a period of time since the designation of sites. Pellissier *et al.* (2013) suggested surveying the trends of bird populations at least 10 years after the commencement of management to measure the efficiency of Natura 2000 measures, since it was noted that there is often a lag phase between statutory protection measures and a detectable population-level response. Finally, our results confirmed that studies only started to accumulate after 2004, which coincided with the EU25 enlargement (Popescu *et al.* 2014). Interestingly, most of the studies had an empirical and quantitative approach showing the importance that these studies can have for monitoring and reporting on the status of bird populations.

Study subjects' characteristics

As expected, most of the publications focused on Natura 2000 sites. However, almost a quarter concerned sites not included in the

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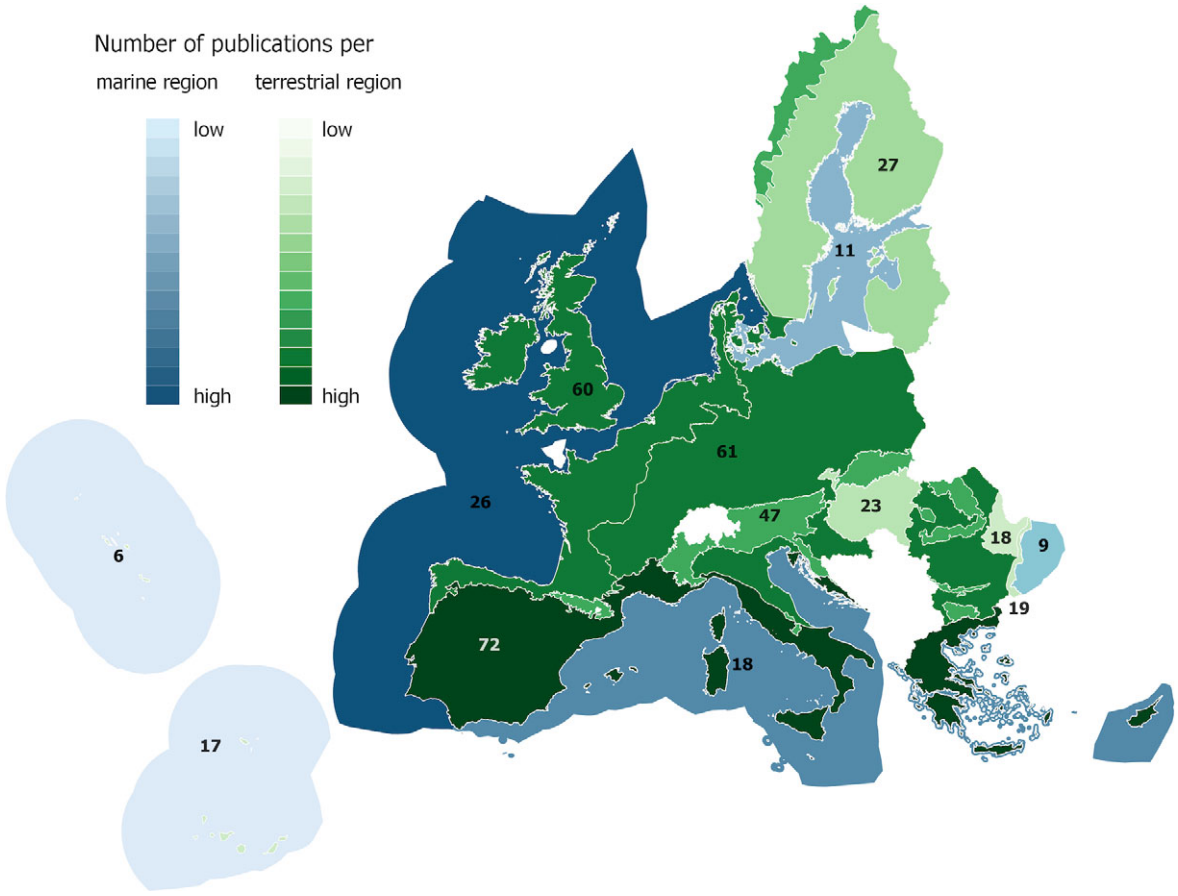

Figure 5. Number of times the regions have been considered in the analysed literature. Darker colours correspond to higher numbers of publications and vice versa.

Table 3. Spearman rank correlations between the number of publications reported per country and the variables related to Natura 2000 at country level. The value of ρ Spearman's coefficient is reported.

	N° of publications				
N° of sites	0.80	N° of sites			
Biogeographical or marine region area (Km^2)	0.31	0.58	Biogeographical or marine region area (Km^2)		
Natura 2000 cover (Km^2)	0.66	0.78	0.83	Natura 2000 cover (Km^2)	
Proportion percentage (%)	0.27	-0.16	−0.57	−0.21	Natura 2000 cover (Km^2)

Natura 2000 network. This emphasizes that the BD and HD do not relate only to protected sites but are also of importance for bird protection outside the network, since both Directives include measures for the strict protection of selected species (including all wild birds) wherever they occur. Moreover, areas with no protection constraints like rural ecosystems, play a complementary role to the surrounding natural protected areas in the conservation of bird species richness at different scales (Pino *et al.* 2000, Cai and Pettenella 2013). However, the research set in Natura 2000 sites should aim more at investigating the conservation status of birds and assessing the effectiveness of conservation efforts at different spatial scales (but see, for large scales, Donald *et al.* 2007, Popescu *et al.* 2014, Orlikowska *et al.* 2016, Sanderson *et al.* 2016, Gamero *et al.* 2017, Portaccio *et al.* 2021). An interesting result is that one third of the analysed literature considered both areas inside and outside Natura 2000 within the same study. Indeed, to assess efficiency, and efficacy of Natura 2000, it is important to evaluate the differences in terms of conservation success in comparison to areas not under protection regimes or regulated by other types of conservation efforts or land-use planning strategies (e.g. Cai and Pettenella 2013, Pellissier *et al.* 2013, Morán-López *et al.* 2020).

The analysed literature contains eight times more articles focusing on terrestrial than marine environments. Several shortfalls have been identified in the implementation of Natura 2000 in marine ecosystems (Metcalfe *et al.* 2013) and the HD Annexes have been criticized, as they were initially conceived for terrestrial and inshore

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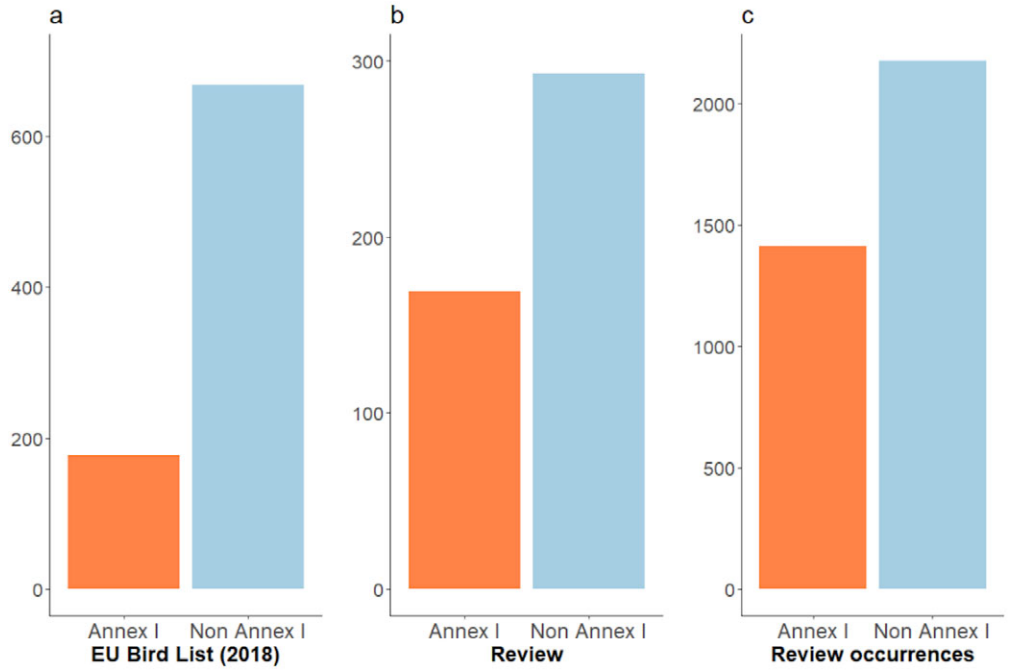

Figure 6. a) Number of species listed in the latest update of the EU Bird List, distinguishing between those included and not included in Annex I of the Birds Directive. b) Number of both Annex I and non-Annex I species recorded in the literature review. c) Number of times Annex I and non-Annex I species have been studied in the analysed articles.

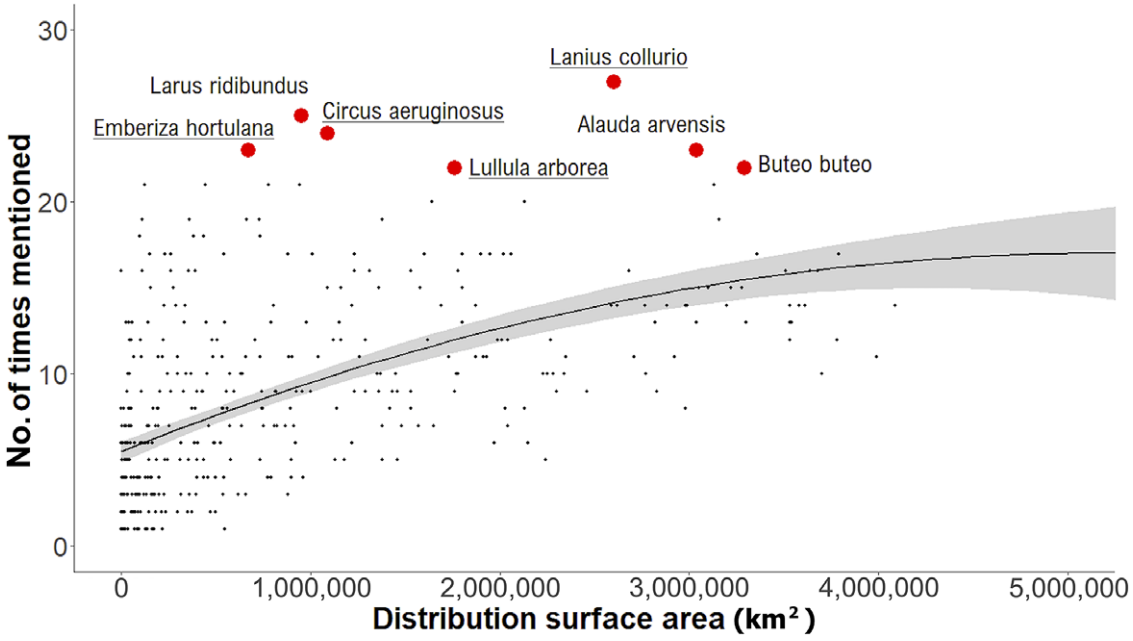

Figure 7. Correlation between the distribution (km^2) of each bird species and the number of times it has been considered in the analysed literature ($R^2 = 0.33$). Red points indicate the species that have been most frequently considered (n >21), Annex I species names are underlined.

areas (Evans 2012). Indeed, efforts are still required to identify additional marine Natura 2000 sites and implement appropriate conservation measures, since marine regions have few habitat types with good status (Milieu *et al.* 2016, EEA 2020). Seabirds are more threatened than other comparable groups of birds and their status has deteriorated faster over recent decades (Croxall *et al.* 2012, BirdLife International 2020); petrels, storm-petrels and shearwaters are in a bad or poor conservation status for 60% of the assessments, while for the remaining 40% the status is still unknown (EEA 2020). The scientific community should therefore show greater interest in such species (Furness and Camphuysen 1997).

It comes as no surprise that one of the most biologically productive habitats in the world (Gardner and Finlayson 2018), wetlands, is the most frequently studied habitat category, despite its limited cover in the Natura 2000 network. In fact, the BD can be considered as an EU response to the Ramsar Convention on Wetlands (Ramsar Convention Secretariat 2013), since Article 4.2 declares that "Member States shall pay particular attention to the

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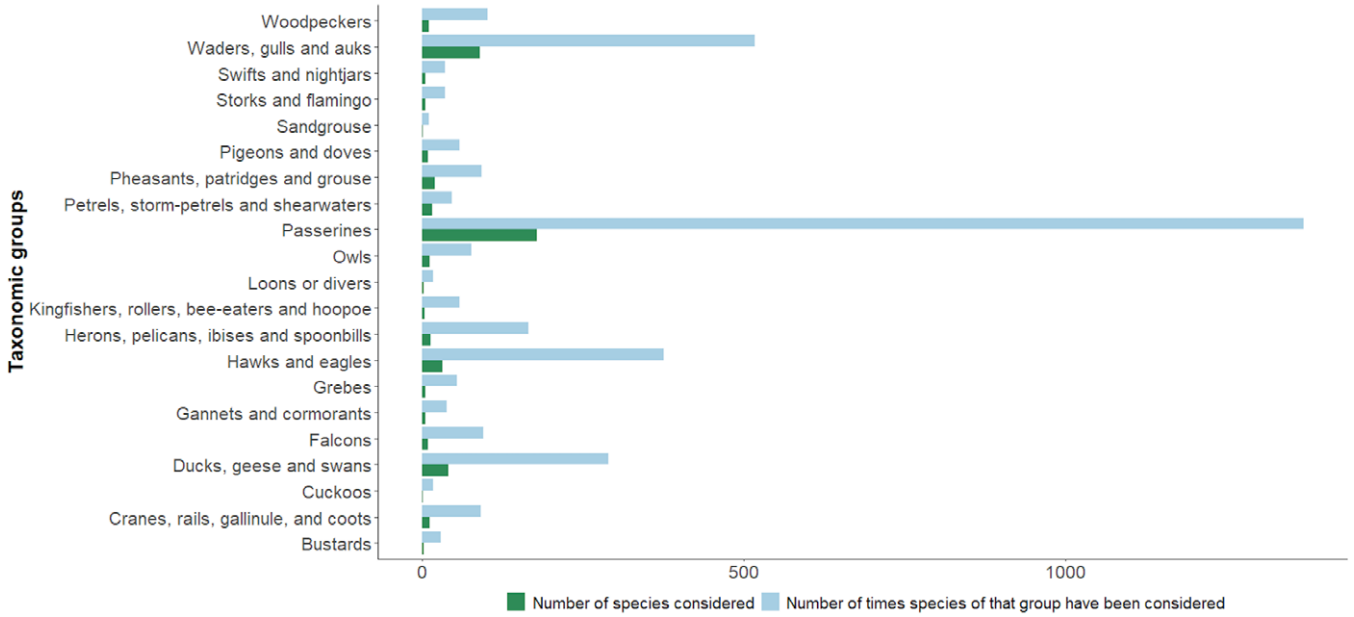

Figure 8. Bird species are grouped at the taxonomic level according to the methodology for the reporting under Article 12 of the BD. The figure shows the number of species per each taxonomic group and reported in the analysed literature (in green), and the number of times bird species belonging to the same taxonomic group have been considered in the analysed literature (light blue).

protection of wetlands and particularly to wetlands of international importance". The trend of increasing investigation on wetlands in the literature over time might be both a consequence of improved data collection technologies and methods (Davidson *et al.* 2018) but also of increased attention to the continuous decline that waterbirds had been showing at global level since the late 1980s (Butchart *et al.* 2007). Indeed, according to the BD Article 12 and HD Article 17 reports and assessments for the period 2008–2012 (EEA 2015), 31% of the bird populations associated with wetland ecosystems within the Natura 2000 network show decreasing trends; however, in the following reporting period (2013–2018), wetland bird species have reported the highest share of improving trends (EEA 2020).

By contrast, 17% of the bird species associated with forest ecosystems, the habitat category in second place for number of articles, have a deteriorating trend (EEA 2020). Forests cover approximately half of the Natura 2000 area, and they report the highest share of habitat types protected by the Annex I of the HD (EC 2015, EEA 2020). Such a wide area of forests protected under Natura 2000 give hope that the network has the potential to contribute towards mitigating – even if not halting - the overall decline of woodland birds (Pellissier *et al.* 2020). Despite forest generalists increasing, forest specialists show worrying decreasing trends (Gregory *et al.* 2007, Inger *et al.* 2014). Indeed, although forests have shown the most improving trends in the last reporting period under Article 12 of the BD, more than 80% of them in the EU are in a bad or poor conservation status, and land use changes within the Natura network show a decrease in forest cover (EEA 2020). Indeed, further research should continue to study forest birds as they are excellent habitat quality indicators (Gregory *et al.* 2003, Roberge and Angelstam 2006, BirdLife International 2020).

In general, some habitat categories could be better represented in the literature (Müller *et al.* 2018), but further research should stress better the relationship between habitats and bird species (suitability, selection, and use), as suggested by our results on the research aims of the investigated literature. Despite their limited cover in the Natura 2000 network, more attention should be given to alpine habitats, since they are generally regarded as biodiversity hotspots and function as important sources of colonizing bird species from the surrounding lowlands (Lomolino 2001, Sergio and Pedrini 2007, Manes *et al.* 2021, Trew and Maclean 2021). Since high elevation systems may be particularly vulnerable to climate change (Klanderud and Totland 2005, Scridel *et al.* 2018, Lehikoinen *et al.* 2019, Nila *et al.* 2019) and relatively few studies have focused on higher altitudes in relation to Natura 2000, further research should be conducted in such habitats.

Spatial scale and distribution

According to our results, research related to birds and Natura 2000 is mainly focused on the local scale, with most attention addressed to single study sites and regions. Certainly, the high levels of uniqueness linked to the presence of rare or endangered bird species in Natura 2000 sites (Hoffmann *et al.* 2018) and the application of small-scale planning approaches and nature protection tools contributes to EU-wide birdlife conservation (Donald *et al.* 2007, Verschuuren 2015), indicate that detailed monitoring of the outcomes at local level is essential to better understand the strengths and weaknesses of the strategies involved. However, Natura 2000 scales up conservation across nations and regions and, even if its implementation is still far from a complete interconnection of sites, the positive results are in part due to the broad and cross-national dimension of the network (Merken *et al.* 2010, Mazaris *et al.* 2013, Koschová *et al.* 2018, Campagnaro *et al.* 2019, Ferranti *et al.* 2019). It is therefore necessary to increase studies at wider scales, in order to assess the outcomes of shared conservation efforts, even more so when focusing on birds, the ranges of which are usually much larger than the areas of individual countries (Gaston *et al.* 2003) and whose populations are connected by dispersal or migration over large areas (Gilroy *et al.* 2016).

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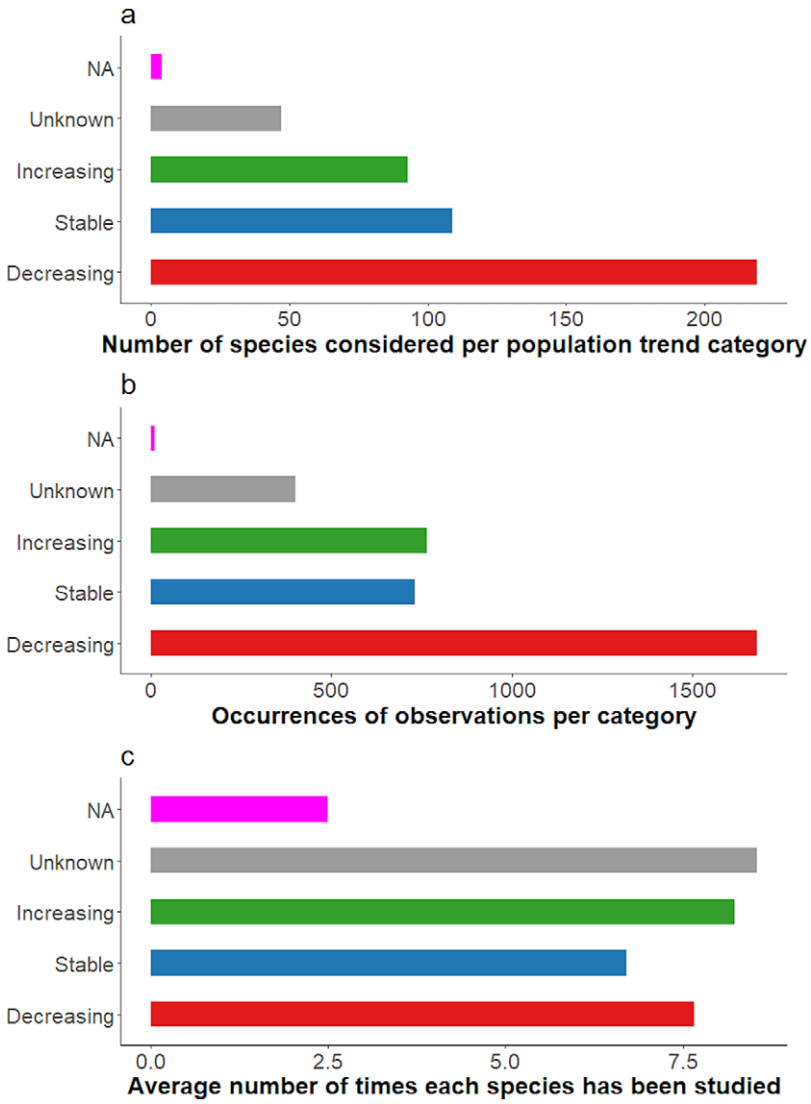

Figure 9. a) Number of bird species belonging to the different categories of population trends in Europe (IUCN 2017). b) Number of times bird species belonging to the different categories of population trends in Europe were examined in the analysed studies. c) Average number of times each of the species belonging to the same population trend category were examined in the articles.

Only one study considered non-European countries, and it involved North Africa (Gaget *et al.* 2018). Indeed, assessing, monitoring, and managing the protection of long-distance bird migrants on the breeding grounds alone may be insufficient (Sanderson *et al.* 2016), especially in view of a future scenario of climate change and habitat fragmentation (Regos *et al.* 2016, Gaüzère *et al.* 2016, Triviño *et al.* 2018, Pereira and Jordán 2017, Sándor and Domşa 2018). The countries that joined the EU most recently (e.g. Croatia in 2013), have a medium-high number of publications. Such assessments are valuable since it has emerged that Annex I species had more positive trends than non-Annex I species, with a better score in the old EU Member States (Sanderson *et al.* 2016, Koschová *et al.* 2018). Research on birds in relation to Natura 2000 should be promoted in those countries which are integrating EU legislation into national law, since only a few articles have been reported for Albania, Montenegro, North Macedonia, Serbia, and Turkey. The country with the maximum number of publications is Spain. Such a high scientific interest in studying birds could be attributable to the fact that the Iberian Peninsula is crucial for bird species following the western migratory pathway (Tellería *et al.* 2009), and it has a comparatively high proportion of endemic species as well as large proportions of many EU species' populations within its territory (EEA 2020). Spain is also the country with the greatest cover of the Natura 2000 network and significant recent increase of the SAC area (EEA 2020), confirming our results concerning the correlation between the number of articles per country and Natura 2000 related variables.

The percentage of national territory under Natura 2000 was weakly correlated with the number of total studies at country level, confirming what was already observed by Popescu *et al.* (2014). The terrestrial Mediterranean biogeographical region had the highest number of publications. Such high interest might be because, in addition to being a worldwide biodiversity hotspot (Myers *et al.* 2000), there is a clear latitudinal gradient in the number of threatened species occurring within Natura 2000 sites, with southern countries hosting most of the threatened species (Hermoso *et al.* 2019a,b,c). However, the effectiveness of Natura 2000 in the Mediterranean region is also criticized, mainly in relation to the need for

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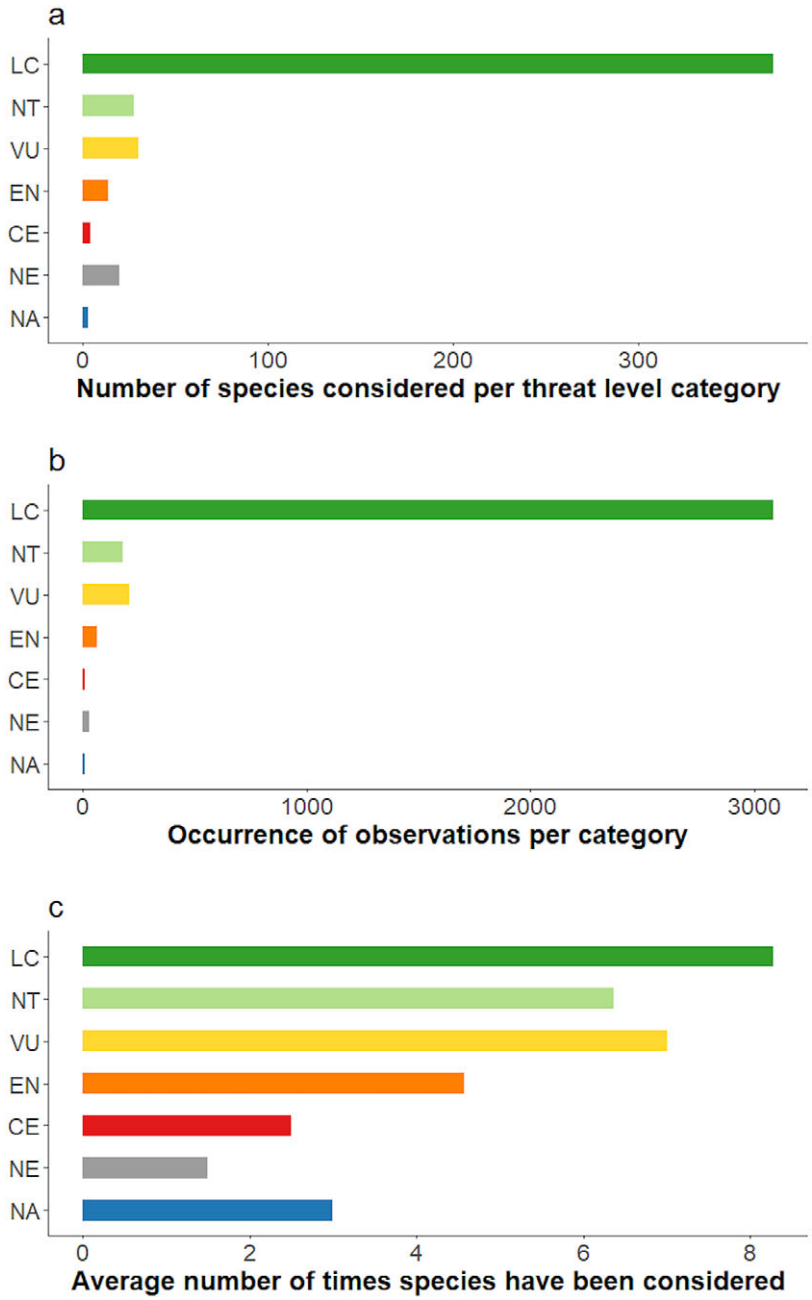

Figure 10. a) Number of bird species per risk category (IUCN 2017). b) Number of times that bird species belonging to the same risk category (IUCN 2017) were examined in the analysed articles. c) Mean number of species per review article under each category.

a systematic re-evaluation of conservation priorities (Regos *et al.* 2016) and because there are still legal shortfalls with millions of migratory birds illegally killed in most of the Mediterranean countries (Brochet *et al.* 2016). The Steppic region, which is the terrestrial region with the lowest number of related publications, stands out with 72% of habitat assessments showing a good conservation status (EEA 2020). On the contrary, both the marine and terrestrial Atlantic regions, which have been among the most reported in the analysed articles, are given some of the highest shares of decreasing trends of some wintering bird populations. A high proportion of the ecoregions that currently do not meet the 10% representation target in Natura 2000 network belong to the Atlantic biogeographical region (Müller *et al.* 2018). In general, more research related to the EU Nature Directives implementation on regions having a higher share of bird species with clearly unfavourable status, could contribute to more successful conservation outcomes for the Natura 2000 network.

Bird species

Birds have been almost equally studied at both community and species level. Ferrier and Guisan (2006) stated that community level approaches, compared to species level, allow for a greater possibility of detecting shared patterns of environmental response across rarely recorded species. Accordingly, community-level modelling can be an adequate approach to studying birds in relation to Natura

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2000 conservation measures. However, more attention to birds in relation to their host ecosystem is needed. Indeed, conservation measures and interventions implemented under Natura 2000 may locally change the structure and function of ecosystems, and, consequently, impact the bird species and communities (Battisti and Fanelli 2015). Therefore, more assessments of the relationship between a species, population or community and the related ecosystem are suggested.

Because of the heterogeneous composition of taxonomic groups, it is difficult to draw any conclusions about bird species' rate of representativeness in the scientific literature. However, it is of interest to compare our results on the interest addressed to certain groups and their population status at the EU level. For instance, falcons, that received relatively high scientific attention, have four out of 10 species with deteriorating population status and trends (EEA 2020). Therefore, more studies at the taxonomic group level might be of interest in order to assess both the quality of the environments they share and the possible pressures they are threatened by.

A single species approach must be implemented, instead, when the interest is in specific bird species or populations of conservation concern. This approach would contribute to reporting according to Article 12 of the BD, for instance, on the size and trends of individual bird species populations and distributions, including main threats and pressures affecting species (EEA 2020).

Our results show that the scientific literature frequently addressed bird species included in Annex I of the BD. The set of species currently listed in the Annexes of EU nature Directives has a wide umbrella potential (Morán-López *et al.* 2020), and Natura 2000 sites host a substantial number of birds not included in the Annexes (Trochet and Schmeller 2013, Pellissier *et al.* 2020). This is further corroborated by our review as bird species not included in the BD Annexes were also frequently studied. Indeed, it is important to deepen our knowledge on their status and ecology since common and non-threatened species play a crucial role in ecosystems and their decline could also alter the trends of threatened species (Gaston 2011).

According to our results, the category of species showing decreasing population trends is the most abundant in terms of number of species reported. However, species showing decreasing trends have been mentioned slightly less frequently than those showing increasing or unknown trends. In contrast to discrepancies between the conservation status of species between the Red List and HD assessments (Moser *et al.* 2016), Annex I and II of the BD cover the majority of threatened bird species (Trochet and Schmeller 2013, Hermoso *et al.* 2019a,b,c). Based on this, since the reviewed literature covered most of the Annex I species, it is likely that most threatened species are included. However, our results show that bird species which are not considered threatened have been studied more frequently on average than those which are threatened. This must be because 80.3% of bird species are not considered to be facing any imminent threats (IUCN 2010). Indeed, research should target threatened species aiming also to indicate appropriate conservation measures to improve their conditions.

Conclusions

This review focuses on bird taxa in relation to Natura 2000. Birds, compared to other taxa, have shown the best results in terms of conservation status, even if there are still some gaps in knowledge, monitoring, and protection (EEA 2020). Science certainly plays a major role in contributing to better implementation of the conservation policies, and our results show increasing interest in bird protection in relation to Natura 2000. Future research on birds at the European level should pay more attention to marine ecosystems, which show the highest depletion rates, as well as habitats that have received less attention (i.e. alpine and subalpine areas) but that are becoming more crucial within the perspective of climate change and habitat fragmentation (Brambilla *et al.* 2016, 2020, Lehikoinen *et al.* 2019). To ensure enhanced achievements in terms of protection of bird species, future studies should encompass large spatial scales and address not only threatened species, but also species whose status and trends are still not investigated enough. Furthermore, research should contribute to assess the conservation status of bird species and the effectiveness of biodiversity conservation efforts, while further investigation on the relationship between habitat and species is essential for the future success of environmental management for nature protection.

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