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The value of community science data to analyze long-term avian trends in understudied regions: The state of birds in Türkiye

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ABSTRACT

Recent studies have revealed concerning declines in bird populations in Europe and other parts of the world. In understudied but biodiverse regions, especially those that are located along key migratory flyways, there is an unmet need to evaluate the status of resident and migratory birdlife for avian conservation ecology. This is especially urgent at a time when recent regional studies have highlighted the scale of the decline of the European and Palearctic avifauna. Rapidly growing community science datasets may help bridge the gaps in our understanding of long-term regional avifaunal trends. In this study, we used eBird data submitted by observers in Türkiye to undertake the first long-term assessment of the state of the country's birds from 2001 to 2022. We evaluated population trends based on presence-absence data of species to determine if any birds have significantly increased or decreased in the country so far this century. We provide a list of trends for 418 bird species that had large enough sample sizes of eBird observations from Türkiye, and highlight which species have significantly declined or increased. We found that 63 species have significantly declined in detection while 120 have significantly increased during the study period. Our findings provide a baseline for the future monitoring of Türkiye's birds and help contextualize population changes of birds in Türkiye against those occurring at the continental (Palearctic) scale. Additionally, we include movement classifications for all of the bird species in this study. We also provide a framework to effectively use eBird data to assess long-term avifaunal changes at the country-level in other understudied regions. Finally, we highlight ways in which eBirders in Türkiye and elsewhere can strengthen the quality and value of community ornithology data for population assessments and avian conservation ecology.

1. Introduction

Recent studies have revealed significant declines in avian populations, particularly of migratory birds, on continental scales over the past few decades (e.g., Sanderson et al., 2006; Vickery et al., 2014; Horns and Şekercioğlu, 2018; Bauer et al., 2019; Rosenberg et al., 2019; Burns et al., 2021). These analyses, especially in Europe and North America, rely on data gathered in systematic, structured sampling projects by volunteers, such as the USGS Breeding Bird Survey (Nebel et al., 2010; Rosenberg et al., 2019; Sauer et al., 2020) and the Pan-European Common Bird Monitoring Scheme (Inger et al., 2015), that can provide data with a high degree of temporal and spatial resolution. Systematic observational data is also essential for identifying species of concern and monitoring the efficacy of conservation efforts (Ralph et al., 1995; Kleiman et al., 2000; Rosenberg et al., 2017; Sauer et al., 2020). Formal, structured surveys produce high-quality data, but can be cost-prohibitive and hard to maintain. Due to these challenges, widespread longitudinal surveys have not been conducted in most of the world for extended periods, especially in developing countries that host most of the world's biodiversity (Şekercioğlu, 2012; Seak et al., 2012; Horns et al., 2018).

More flexible forms of community science may offer a timely solution to the current long-term study deficit in many understudied regions. One of the best known and widely used community science platforms is eBird, a semi-structured effort launched in 2002 by the Cornell Lab of Ornithology, which allows birdwatchers anywhere in the world to record their bird observations (Sullivan et al., 2009; Amano et al., 2016) and submit a list of the species and number of individuals they observe

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for a specific location. Usage of eBird has steadily increased since its introduction in 2002 (Team eBird, 2021). In May 2022, Cornell reported that they had passed 1.2 billion individual bird observations from 89 million checklists submitted by almost 700 thousand birdwatchers around the world (eBird Team, 2022). This vast and growing database has already been used by scientists to help evaluate bird population trends (Clark, 2017; Walker and Taylor, 2017, 2020; Horns et al., 2018; Fink et al., 2020; Neate-Clegg et al., 2020), species' abundances and occurrences (Marki et al., 2016; Clark, 2017; Pranty and Ponzo, 2020), and conservation requirements of species (Sullivan et al., 2017; Robinson et al., 2018; Lees et al., 2021).

One understudied region in which community science data like that of eBird can be an asset in studies of birdlife is Anatolia and the rest of Türkiye (Abolafya et al., 2013). Türkiye's geographical location, varied climates, flora, and topography have contributed to an exceptional avian diversity not found in any other nation in the Western Palearctic (Şekercioğlu et al., 2011; Abolafya et al., 2013). Much of Türkiye is covered by three global biodiversity hotspots: the Mediterranean Basin, Irano-Anatolian, and the Caucasus ecoregions (Şekercioğlu et al., 2011; Abolafya et al., 2013). Bound by both the Mediterranean and the Black Sea, Türkiye hosts hundreds of resident species and is also a natural migratory corridor for birds (Şekercioğlu, 2006; Bilgin et al., 2016; Buechley et al., 2018; Phipps et al., 2019; Kittelberger et al., 2021, 2022). Türkiye is located along the intersection of three major global avian migratory flyways (Bilgin et al., 2016), linking Africa and the Middle East with Europe and Asia through the Caucasus. With 393 resident, breeding, and migratory bird species, Türkiye is ranked 90th in the world for bird species richness (BirdLife International, 2023). The number of recorded species in the country has steadily risen over the past two decades and will continue to increase as hobbyist and professional observers lead to heightened coverage of the region (Şekercioğlu et al., 2011; Abolafya et al., 2013). To date, 494 bird species have accepted records in Türkiye (eBird, 2023), including vagrants and established exotics, and this number is expected to exceed 500 in the near future (Şekercioğlu et al., 2011). Approximately 316 bird species are known to breed in the country, of which around 300 are regular breeders (Dizdaroğlu et al., 2017). There are 21 globally threatened bird species that regularly occur in Türkiye, 6% of the country's avifaunal richness (BirdLife International, 2023).

Despite Türkiye's unique location along migratory flyways and notable species richness, there is a dearth of understanding of the state of birds in the region. There has been only one long-term ongoing bird monitoring program in the country—a midwinter waterbird census first begun in 1967 on a non-annual basis and managed by international groups before being re-organized in 2002 to an annual survey run by Turkish birdwatching groups (Kirwan et al., 2008; KOSKS, 2020). The scope of this census has been limited primarily to wetlands and waterbirds, which make up roughly one third of Türkiye's bird species (Kirwan et al., 2008; BirdLife International, 2023). There have also been a few regional breeding bird atlas studies (Kirwan et al., 2008), focusing on Southeast Anatolia (Welch, 2004), Konya Basin (Eken and Magnin, 1999), and forests in the Mediterranean region (Zeydanli et al., 2005). More recently (2014–2017), the Turkish Breeding Bird Atlas was established to enhance country-wide knowledge of Türkiye's breeding species (Dizdaroğlu et al., 2017). However, these various surveys lacked the temporal resolution necessary for assessing bird population trends over time. Furthermore, there is a comparably small number of birdwatchers in Türkiye for a country of its size (Dizdaroğlu et al., 2017). As a nation that is both ornithologically understudied and at the intersection of three major global avian migratory flyways from Africa to Europe, the Middle East, and Asia (Bilgin et al., 2016; Kittelberger et al., 2022), Türkiye is a priority country for evaluating long-term avian population trends and for assessing which species need increased research and conservation attention. With over 117,000 complete checklists contributed by nearly 5000 birdwatchers (eBird, 2023), data from eBird can provide both long-term temporal trends and higher resolution spatial data (Horns et al., 2018; Neate-Clegg et al., 2020) in a manner that prior survey efforts were not able to capture.

In this study, we used eBird data submitted by observers in Türkiye to assess the state of the country's birds. We first mapped the distribution of submitted eBird checklists across the country to identify hotspots of birding effort both temporally and spatially, as well as regions that have been previously undersampled in the country. We then conducted presence-absence analyses to model population trends in a majority of Türkiye's birds, including species deemed sensitive by eBird, determining which species are increasing, decreasing, or remaining stable over the past 22 years. In particular, among the species experiencing significant changes in trends, we examine which of these are Near Threatened or threatened both globally and within Europe. Finally, we provide an overview of challenges and solutions to both working with eBird data and increasing the quality of these data, and present an approach and workflow for analyzing country-wide eBird data that can be applied by other researchers to other countries and regions anywhere in the world.

2. Materials and methods

2.1. eBird dataset and data filtering

We downloaded the complete eBird world dataset in January 2023 (ebd_prv_relDec-2022), which provided data through December 2022. Using the R package auk (Strimas-Mackey et al., 2018), we then filtered this dataset for our study. First, we restricted the full eBird dataset to observations submitted solely from Türkiye. Next, we removed observations at a taxonomic level higher than the species level, and used the function "auk_rollup" to collapse lower-level taxonomic categories (i.e., subspecies, intergrade, form) to species level (Strimas-Mackey et al., 2018). We also used the function "auk_unique" to de-duplicate records from checklists that have been shared with multiple individuals, which aims to result in a single record for each species on a group checklist (Strimas-Mackey et al., 2018). This filtering resulted in observations for 516 total species from Türkiye (including unapproved records). In order to include in our study the seven species listed in eBird as sensitive [Great Bustard (*Otis tarda*), Pin-tailed Sandgrouse (*Pterocles alchata*), Bonelli's Eagle (*Aquila fasciata*), Brown Fish-owl (*Ketupa zeylonensis*), Boreal Owl (*Aegolius funereus*), Lanner Falcon (*Falco biarmicus*), and Saker Falcon (*Falco cherrug*)], as these sensitive data are hidden from the public and not included in the main downloaded dataset, we requested from eBird the data on these species and used the same approach as above to filter this dataset.

Next, we filtered both datasets by date, focusing on the 22-year period from 2001 to 2022. We first removed species records that were not yet confirmed. Then we removed 84 species with fewer than 10 records from checklists (Neate-Clegg et al., 2020; Walker and Taylor, 2020). In order to disregard rare vagrants or infrequently encountered species in the country, we removed eight species with observations from fewer than three years during this 22-year period: Wood Duck (*Aix sponsa*), Bateleur (*Terathopius ecaudatus*), Sabine's Gull (*Xema sabini*), Glaucous Gull (*Larus hyperboreus*), Greater Hoopoe-lark (*Alaemon alaudipes*), Bar-tailed Lark (*Ammomanes cinctura*), Hume's Warbler (*Phylloscopus humei*), and Hooded Wheatear (*Oenanthe monacha*). We also removed any records from checklists that were marked as incomplete, resulting in six more species being taken out of our dataset using the previously noted observation threshold: Pectoral Sandpiper (*Calidris melanotos*), Orange-winged Parrot (*Amazona amazonica*), Red-tailed Shrike (*Lanius isabellinus*), Olive-backed Pipit (*Anthus hodgsoni*), Asian Desert Warbler (*Sylvia nana*), and Little Bunting (*Emberiza pusilla*). This finally resulted in a filtered dataset of 418 species (Appendix A) from 82,869 individual complete eBird checklists submitted across Türkiye during the study period from 2001 to 2022.

2.2. Mapping

We filtered the eBird data by the Checklist ID to identify the total number of complete checklists submitted during the study period (82,829), removing any duplicate checklists. We then classified checklists submitted between April and October as peak migration/breeding, and those between November and March as overwintering checklists.

We used ArcMap (ESRI, 2020) to plot the checklist locations on a map of Türkiye, using the associated coordinates for each individual checklist, and used the Point Density (Spatial Analyst) tool to generate a raster layer, or "heat map", giving a visual representation of the density of checklist submitted across the country. We generated four maps—one map with all the birding locations plotted as points, and three depicting the spatial distribution of: (1) all submitted checklists, (2) migration/-breeding checklists, and (3) overwintering checklists. All heat maps used the Natural Breaks (Jenks) classification method and five classes. Upper values in the map key were rounded to the nearest hundred.

2.3. Dataset

With the exception of seven species [Tundra Bean Goose (*Anser serrirostris*), Grey-headed Swamphen (*Porphyrio poliocephalus*), Hooded Crow (*Corvus cornix*), Delicate Prinia (*Prinia lepida*), Eastern Black-eared Wheatear (*Oenanthe melanoleuca*), Siberian Stonechat (*Saxicola maurus*), and European Stonechat (*Saxicola rubicola*)], avian taxonomy was based on BirdLife International (2023), which maintains its own list of the world's bird species, reviewed and adopted by the BirdLife Taxonomic Working Group (BirdLife International, 2023) and utilized by the IUCN Red List (IUCN, 2023) for species' global threat statuses. We compiled both global IUCN and European Red List statuses for each species in our dataset (BirdLife International, 2021; IUCN, 2023). Threat status for each species in our dataset consists of Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), or Regionally Extinct (RE).

Movement status for each species was compiled from BirdBase, a global dataset of avian traits (see Şekercioğlu et al., 2004; 2019 for more details) which compiles information from literature and primary sources such as Birds of the World (Cornell University, 2022). In BirdBase, movement type describes whether a bird is either a long[er]-distance migrant ("migratory"), an "altitudinal" migrant, an "irregular" migrant (nomadic, irruptive, and other irregular movements based on weather patterns and age-specific movements), or a "resident" species.

2.4. Statistical analyses

To evaluate population trends at the species level over time, we subset the complete checklist dataset by species and used the 'pivot_wider' function in the tidyr package (Wickham et al., 2023) to determine presence-absence for all species at each location in every checklist (i.e., every list contained all species for each location an observer visited: non-zero values were scored as 1, and the lack of observation for each list/species combination was scored as 0). For each species, we used a generalized linear mixed-effects model (GLMEM, family = binomial), with presence-absence as the response variable (Bates et al., 2015). Time (date) and sampling effort (duration of sampling time per checklist) were included in our model as fixed explanatory variables. Because of the nature of the repeated measures inherent in longitudinal studies, location and observer ID were included as random effects for each model. When model covariance matrices were singular, observer was removed as a random effect.

All statistical analyses (Appendix B) and graphing were conducted in R (version 4.2.2, 2022-10-31; R Core Team, 2022).

3. Results

3.1. Kernel density maps

There were 56,276 complete checklists submitted during peak migration and breeding (April to October; Fig. 1A), accounting for 68% of total submitted checklists. There were 26,553 checklists submitted during the winter months (November to March; Fig. 1B), accounting for 32% of submitted checklists. Therefore, there were more than twice as many checklists submitted across Türkiye during peak migration and breeding compared with the overwintering months (Fig. 1).

When considering the total (year-round) observations, the primary gaps (with fewest or no observations) exist in the eastern-interior portion of Türkiye (Fig. 2). During the overwintering months, there are much larger gaps in coverage, particularly in the interior and east of the country (Fig. 1B). Istanbul and Ankara, the two largest cities, show the highest density of submitted checklists in the country. Despite the bulk of eBirding occurring in cities, there is a wide distribution of checklists, indicating that most regions within the country have been sampled and have avian presence data (checklists).

3.2. eBirding trends

The number of submitted checklists by eBird users in Türkiye has increased quadratically over the past 22 years (Appendix Fig. S1), with the number of complete checklists roughly doubling over the past several years to a high of almost 14,000. Likewise, the number of incomplete checklists has also been increasing, such that the last few years have seen several thousand incomplete lists submitted (Appendix Fig. S1).

3.3. Avifaunal trends

Of the 418 bird species in our eBird dataset, there are 21 globally threatened species—1 Critically Endangered, 5 Endangered, and 15 Vulnerable bird species (BirdLife International, 2023); and 23 Near Threatened species. An additional 34 species are listed as either Near Threatened (12), Vulnerable (15), Endangered (6), or Regionally Extinct (1) in the Western Palearctic (BirdLife International, 2021). Finally, there are five Least Concern species of interest; three that are recognized as sensitive species on eBird (Bonelli's Eagle, Pin-tailed Sandgrouse, and Boreal Owl) and two that have recently expanded their range into Türkiye (Namaqua Dove *Oena capensis*, and Black-winged Kite *Elanus caeruleus*).

3.3.1. Effect of date

Among these 83 species noted above, 32 had significant changes in population trends over time (Appendix Table S1). There were 13 global and/or European Near Threatened or threatened species that underwent population declines (IUCN, 2023/ERL, 2021 designations included; Table 1): Northern Pintail (*Anas acuta*), LC/VU: $p = 0.007$ (Appendix Fig. S2A); Marbled Teal (*Marmaronetta angustirostris*), NT/VU: $p < 0.001$ (Fig. 3A); Common Pochard (*Aythya ferina*), VU/VU: $p < 0.001$ (Fig. 3B); Common Eider (*Somateria mollissima*), NT/EN: $p < 0.001$ (Fig. 3C); Red-breasted Merganser (*Mergus serrator*), LC/NT: $p = 0.042$; Common Quail (*Coturnix coturnix*), LC/NT: $p < 0.001$; Little Swift (*Apus affinis*), LC/NT: $p = 0.007$; European Turtle-Dove (*Streptopelia turtur*), VU/VU: $p < 0.001$ (Appendix Fig. S2B); Eurasian Coot (*Fulica atra*), LC/NT: $p = 0.003$; Eurasian Curlew (*Numenius arquata*), NT/NT: $p = 0.007$; Bearded Vulture (*Gypaetus barbatus*), NT/NT: $p = 0.008$ (Fig. 3D); Egyptian Vulture (*Neophron percnopterus*), EN/VU: $p < 0.001$ (Fig. 3E); and Steppe Eagle (*Aquila nipalensis*), EN/CR: $p = 0.018$ (Fig. 3F). We also found that 50 globally Least Concern species underwent significant declines in population trend over time (Appendix Table S2).

There were also 19 species among the 83 noted above that experienced significant increases (Appendix Table S1), including 12 globally

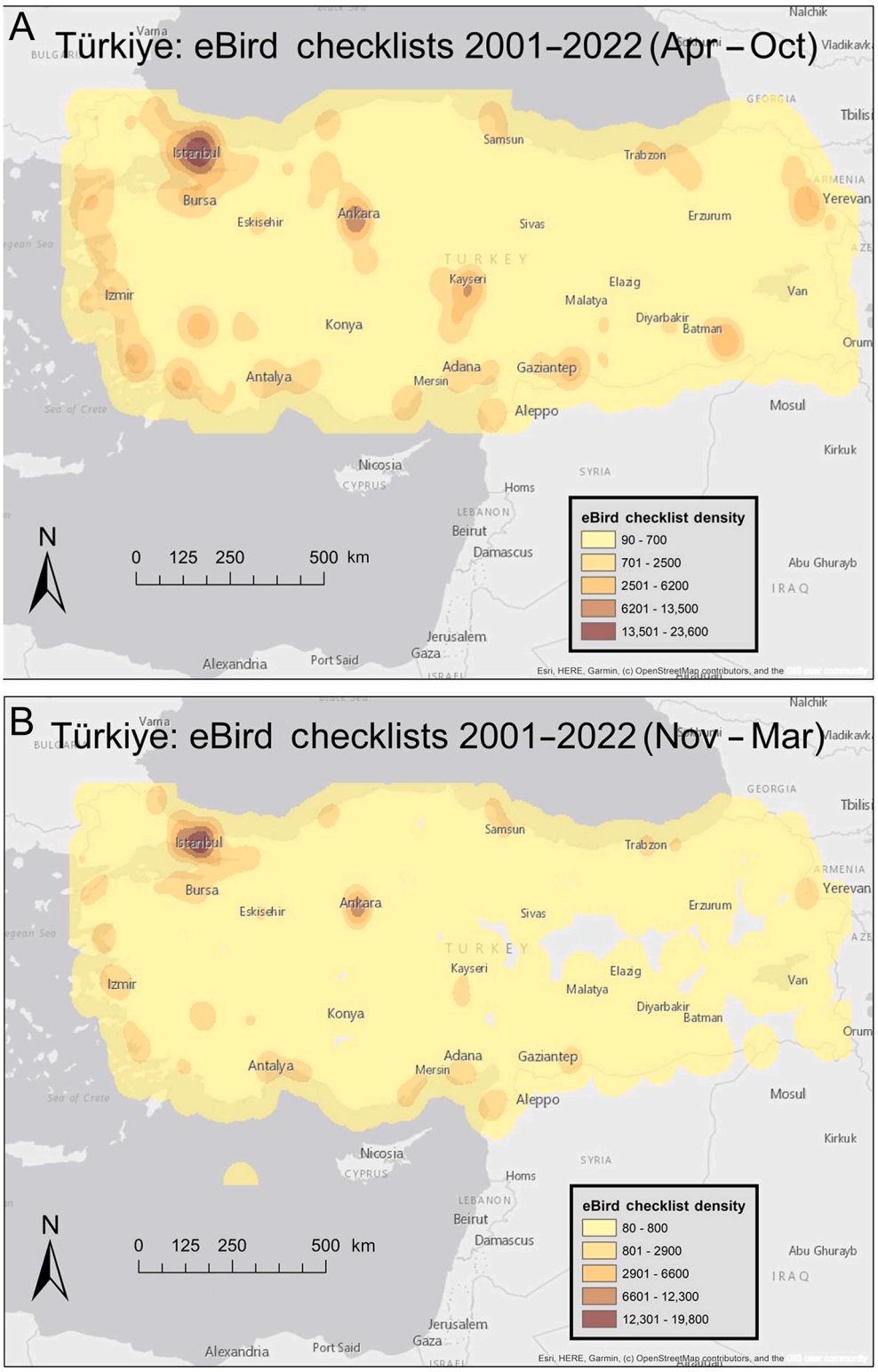


Fig. 1. A map of the kernel density of eBird observations in Türkiye between 2001 and 2022 according to time of year in which checklists were submitted to eBird. (A) Warm month checklists submitted between April and October; (B) Cold month checklists submitted between November and March. The more observations for a particular area, the warmer the color. An area with no color indicates a lack of submitted data. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

and/or European threatened species (Table 1): Lesser White-fronted Goose (*Anser erythropus*), VU/VU: $p = 0.008$ (Fig. 4A); Tundra Swan (*Cygnus columbianus*), LC/VU: $p = 0.012$ (Appendix Fig. S2C); Great Spotted Cuckoo (*Clamator glandarius*), LC/VU: $p = 0.027$ (Appendix Fig. S2D); Horned Grebe (*Podiceps auritus*), VU/NT: $p < 0.001$ (Fig. 4B); Red-wattled Lapwing (*Vanellus indicus*), LC/VU: $p = 0.003$ (Appendix Fig. S2E); Curlew Sandpiper (*Calidris ferruginea*), NT/VU: $p = 0.042$ (Appendix Fig. S2F); Slender-billed Gull (*Chroicocephalus genei*), LC/VU: $p = 0.004$ (Appendix Fig. S2G); Greater Spotted Eagle (*Clanga clanga*), VU/VU: $p < 0.001$; Eastern Imperial Eagle (*Aquila etanus*), VU/LC: $p =$

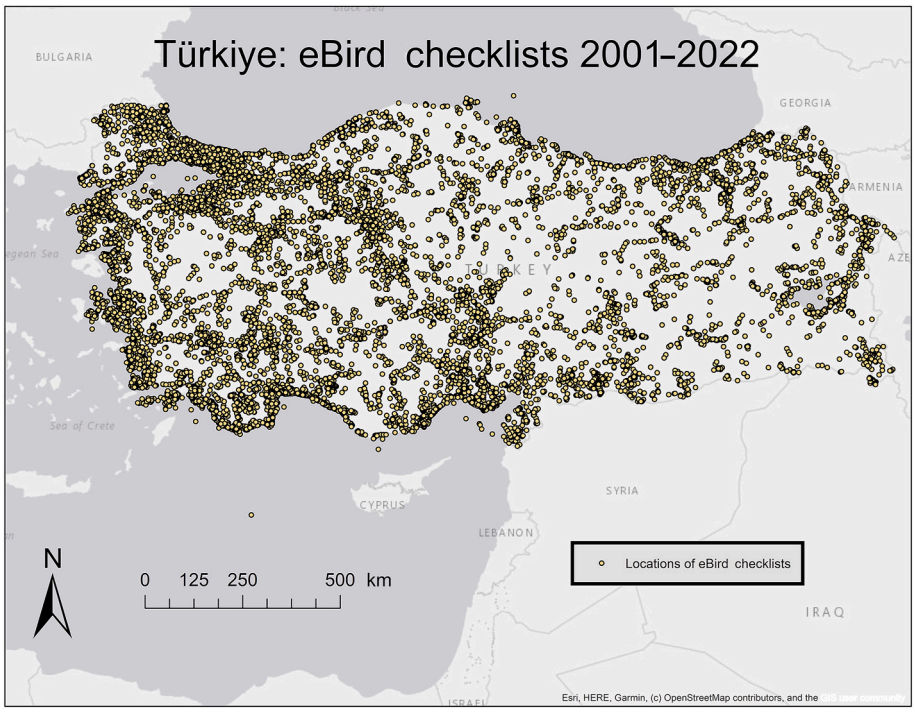


Fig. 2. A map of the location of eBird checklists submitted in Türkiye between 2001 and 2022.

Table 1
Key bird species recorded in Türkiye from eBird between 2001 and 2022 with adequate sample sizes (≥10 records and ≥3 years of observations) that underwent significant changes ($p \leq 0.05$) in presence-absence population trend, according to our GLMEM.

English name	Scientific name	Estimate	SE	*Z*	*p*	IUCN23	ERL21
Northern Pintail	*Anas acuta*	−0.310	0.115	−2.695	0.007	LC	VU
Marbled Teal	*Marmaronetta angustirostris*	−1.868	0.450	−4.148	<0.001	NT	VU
Common Pochard	*Aythya ferina*	−0.219	0.053	−4.079	<0.001	VU	VU
Common Eider	*Somateria mollissima*	−3.190	0.754	−4.231	<0.001	NT	EN
Red-breasted Merganser	*Mergus serrator*	−0.438	0.215	−2.034	0.042	LC	NT
Common Quail	*Coturnix coturnix*	−0.604	0.112	−5.382	<0.001	LC	NT
Little Swift	*Apus affinis*	−0.449	0.168	−2.677	0.007	LC	NT
European Turtle-Dove	*Streptopelia turtur*	−0.267	0.049	−5.498	<0.001	VU	VU
Eurasian Coot	*Fulica atra*	−0.197	0.067	−2.945	0.003	LC	NT
Eurasian Curlew	*Numenius arquata*	−0.208	0.077	−2.696	0.007	NT	NT
Bearded Vulture	*Gypaetus barbatus*	−0.482	0.180	−2.672	0.008	NT	NT
Egyptian Vulture	*Neophron percnopterus*	−0.496	0.105	−4.726	<0.001	EN	VU
Steppe Eagle	*Aquila nipalensis*	−0.592	0.250	−2.365	0.018	EN	CR
Lesser White-fronted Goose	*Anser erythropus*	7.047	0.001	2.648	0.008	VU	VU
Tundra Swan	*Cygnus columbianus*	0.499	0.199	2.516	0.012	LC	VU
Common Swift	*Apus apus*	0.196	0.046	4.272	<0.001	LC	NT
Great Spotted Cuckoo	*Clamator glandarius*	0.477	0.216	2.209	0.027	LC	VU
Namaqua Dove	*Oena capensis*	3.602	0.742	4.855	<0.001	LC	
Horned Grebe	*Podiceps auritus*	0.196	0.046	4.272	<0.001	VU	NT
Lesser Flamingo	*Phoeniconaias minor*	0.851	0.344	2.472	0.014	NT	
Red-wattled Lapwing	*Vanellus indicus*	5.959	1.983	3.004	0.003	LC	VU
Bar-tailed Godwit	*Limosa lapponica*	0.468	0.21	2.223	0.026	NT	LC
Ruff	*Calidris pugnax*	0.232	0.044	5.242	<0.001	LC	NT
Curlew Sandpiper	*Calidris ferruginea*	0.185	0.091	2.037	0.042	NT	VU
Slender-billed Gull	*Chroicocephalus genei*	0.163	0.057	2.849	0.004	LC	VU
Black-winged Kite	*Elanus caeruleus*	1.764	0.306	5.760	<0.001	LC	LC
Greater Spotted Eagle	*Clanga clanga*	0.644	0.125	5.149	<0.001	VU	VU
Eastern Imperial Eagle	*Aquila heliaca*	0.423	0.160	2.648	0.008	VU	LC
White-breasted Kingfisher	*Halcyon smyrnensis*	0.446	0.132	3.381	0.001	LC	VU
Pied Kingfisher	*Ceryle rudis*	0.588	0.126	4.656	<0.001	LC	VU
Alexandrine Parakeet	*Palaeornis eupatria*	1.143	0.462	2.474	0.013	NT	
Woodchat Shrike	*Lanius senator*	0.201	0.082	2.458	0.014	NT	NT

These species are either threatened (Vulnerable, Endangered) or Near Threatened globally (IUCN, 2023) and/or in Europe (BirdLife International, 2021), or notable species of interest. Species are separated into negative (Estimate < 0) and positive (Estimate > 0) trends and then listed taxonomically. SE = standard error, $Z = z$ statistic, $p = p$-value, IUCN23 = IUCN Red List Ranking in 2023, ERL21 = European Red List 2021, NT = Near Threatened, VU = Vulnerable, EN = Endangered. English and scientific names follow taxonomic classifications based on BirdLife International (2023).

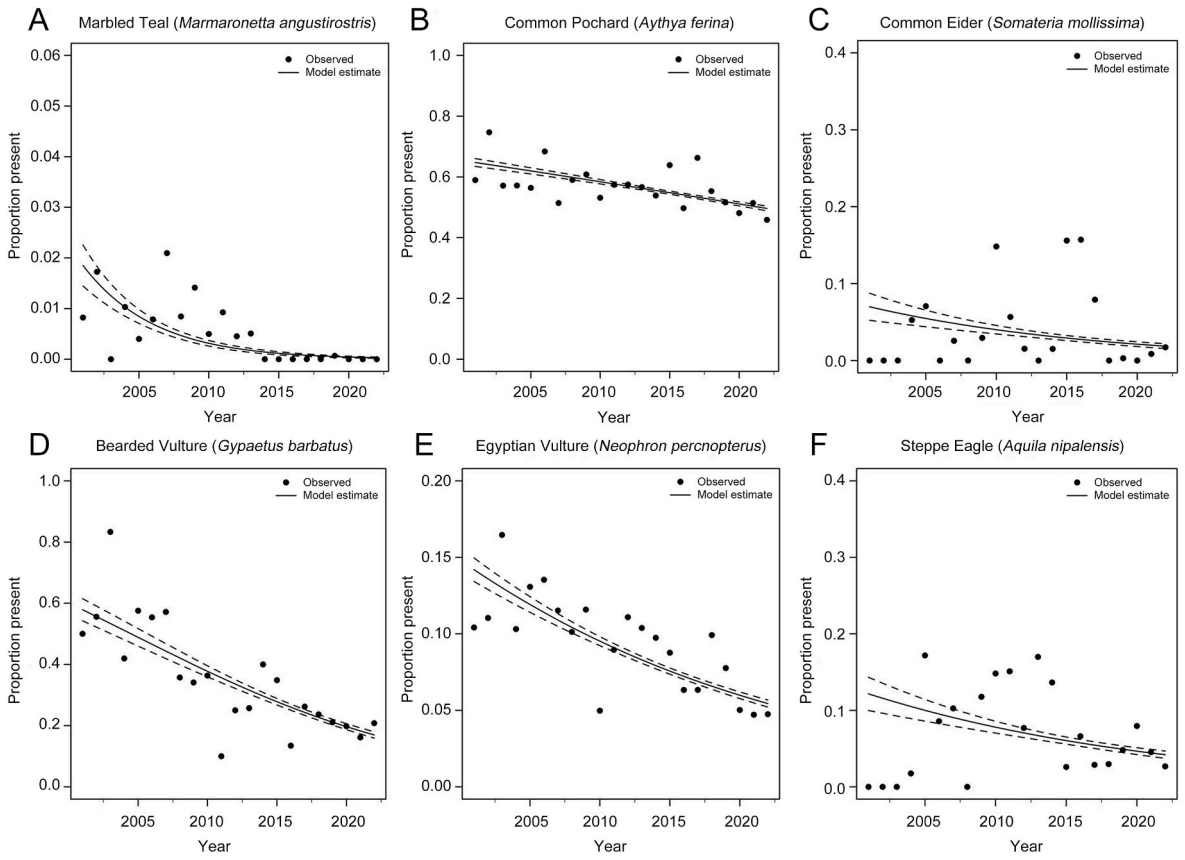


Fig. 3. The proportional trend of a species present across all sites in Türkiye as a function of time between 2001 and 2022 from complete submitted eBird checklists. These six globally Near Threatened or threatened species underwent a significant negative change ($p \leq 0.05$) in trend across the 22-year period (Table 1). (A) Marbled Teal, NT/VU; (B) Common Pochard, VU/VU; (C) Common Eider, VU/VU; (D) Bearded Vulture, NT/NT; (E) Egyptian Vulture, EN/VU; and (F) Steppe Eagle, EN/CR. The IUCN 2023/ERL 2021 threat status designations are included next to each species name above, with LC = Least Concern, NT = Near Threatened, VU = Vulnerable. Model predictions (±95% confidence intervals) are based on GLM estimates and do not depict the effects of sampling effort, observer ID, or location on the trend.

0.008 (Fig. 4C); White-breasted Kingfisher (*Halcyon smyrnensis*), LC/VU: $p = 0.001$ (Appendix Fig. S2H); Pied Kingfisher (*Ceryle rudis*), LC/VU: $p < 0.001$; and the globally Near Threatened Alexandrine Parakeet (*Palaeornis eupatria*): $p = 0.013$ (Fig. 4D), a species introduced to Türkiye. There were five other globally and/or European Near Threatened species that also experienced significant population increases relative to year (Table 1): Common Swift (*Apus apus*), Lesser Flamingo (*Phoeniconaias minor*), Bar-tailed Godwit (*Limosa lapponica*), Ruff (*Calidris pugnax*), and Woodchat Shrike (*Lanius senator*). Namaqua Dove and Black-winged Kite, both Least Concern species, also experienced a significant positive population trend: both had a $p < 0.001$ (Table 1; Fig. 4E and F). Finally, there were 101 other Least Concern species that had a significant increase in population trend over time (Appendix Table S2).

The seven species designated as sensitive by eBird did not undergo any significant changes in population during the 22-year period (Appendix Table S1): Pin-tailed Sandgrouse, LC/LC; Great Bustard, VU/LC; Bonelli's Eagle, LC/LC; Brown Fish-owl, LC/EN; Boreal Owl, LC/LC; Lanner Falcon, LC/NT; and Saker Falcon, EN/EN. The following species listed as Endangered or Critically Endangered either globally and/or in Europe also did not undergo any significant changes (Appendix Table S1): White-headed Duck (*Oxyura leucocephala*), EN/VU; Black-bellied Sandgrouse (*Pterocles orientalis*), LC/EN; Demoiselle Crane (*Anthropoides virgo*), LC/EN; Northern Bald Ibis (*Geronticus eremita*), EN/RE; Sociable Lapwing (*Vanellus gregarious*), CR/CR; Parasitic Jaeger (*Stercorarius parasiticus*), LC/EN; Pallid Scops-owl (*Otus brucei*), LC/EN; and Desert Lark (*Ammomanes deserti*), LC/EN. There were an additional 19 Vulnerable species (8 globally and 11 only in Europe) that did not undergo significant population trends during the study period (Appendix Table S1). All of these species can therefore be viewed as having relatively stable populations during the study period.

3.3.2. Effect of duration

There were also 31 listed (Near Threatened or threatened) species that had significant presence-absence trends due to the effect of sampling duration (i.e., birding effort). Three of these species experienced declines in detection with effort (Appendix Table S1), meaning that fewer birds were detected with more birding time: Lesser White-fronted Goose, VU/VU: $p < 0.001$; Cinereous Vulture (*Aegypius monachus*), NT/LC: $p = 0.018$; and Bearded Vulture, NT/NT: $p = 0.009$. The other Near Threatened or threatened species that experienced increases in population with more effort (Appendix Table S1), meaning more birds were detected with additional time birding, consisted of: Ferruginous Duck (*Aythya nyroca*), NT/LC; Tufted Duck (*Aythya fuligula*), LC/NT; Common Pochard, VU/VU; Horned Grebe, VU/NT; Common Quail, LC/NT; Common Swift, LC/NT; Little Swift, LC/NT; European Turtle-Dove, VU/VU; Yelkouan Shearwater (*Puffinus yelkouan*), VU/VU; Cream-colored Courser (*Cursorius cursor*), LC/NT; Northern Lapwing (*Vanellus vanellus*), NT/VU; Black-tailed Godwit (*Limosa limosa*), NT/NT; Common Redshank (*Tringa etanus*), LC/VU; Curlew Sandpiper, NT/VU; Broad-billed Sandpiper (*Calidris falcinellus*), LC/VU; Ruff, LC/NT; Common Snipe (*Gallinago gallinago*), LC/VU; Great Snipe (*Gallinago media*), NT/LC; Black-legged Kittiwake (*Rissa tridactyla*),VU/VU; Slender-billed Gull, LC/VU; Egyptian Vulture, EN/VU; Pallid Harrier (*Circus macrourus*), NT/LC; White-breasted Kingfisher, LC/VU; Pied Kingfisher, LC/VU; Red-footed Falcon (*Falco vespertinus*), VU/VU; Iraq Babbler (*Argya altirostris*), LC/NT; Woodchat Shrike, NT/NT; and Desert Lark, LC/EN.

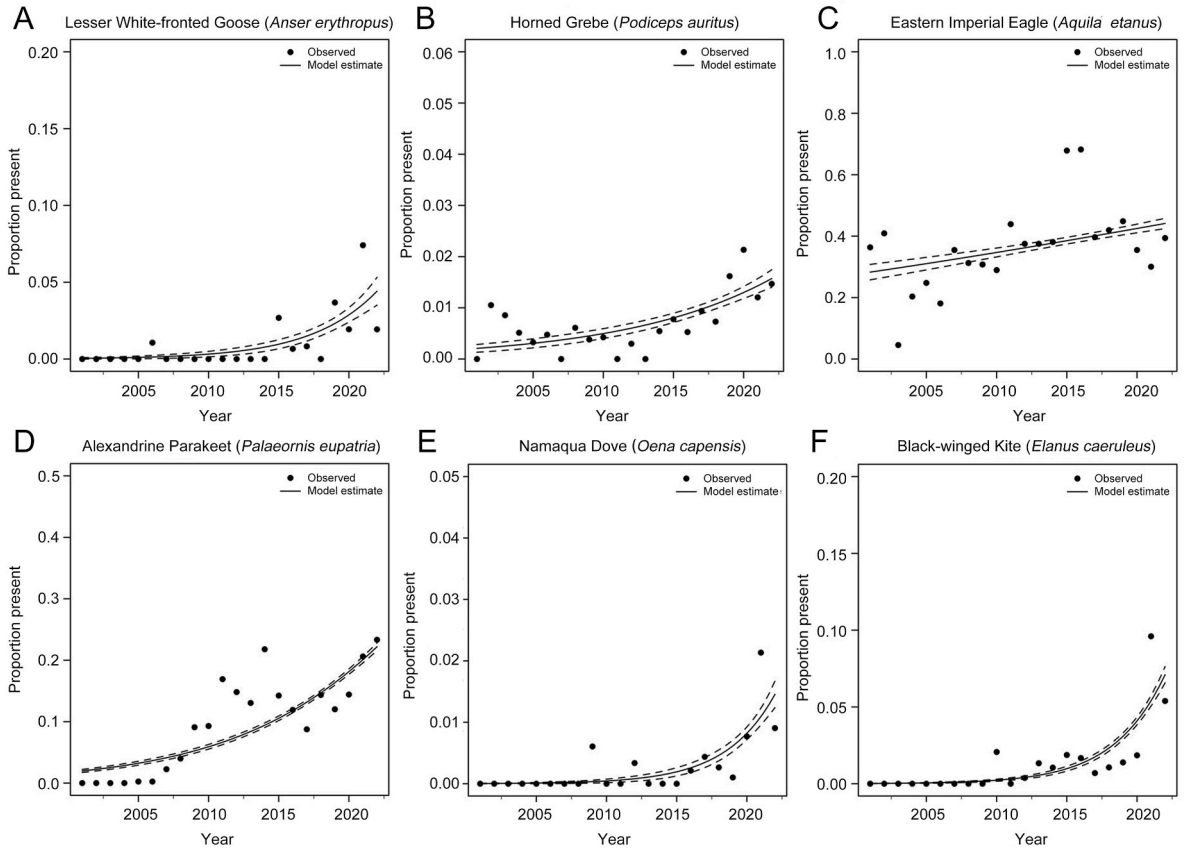


Fig. 4. The proportional trend of a species present across all sites in Türkiye as a function of time between 2001 and 2022 from complete submitted eBird checklists. These six species underwent a significant positive change ($p \leq 0.05$) in trend across the 22-year period (Greater Spotted Eagle is not included here because the GLM for these figures does not include random effects dealing with repeated measures of location and observer, which results in a misleading graphical trend) (Table 1). (A) Lesser White-fronted Goose, VU/VU; (B) Horned Grebe, VU/NT; (C) Eastern Imperial Eagle, VU/LC; (D) Alexandrine Parakeet, NT/; (E) Namaqua Dove, LC/; and (F) Black-winged Kite, LC/LC. Model predictions (±95% confidence intervals) are based on GLM estimates and do not depict the effects of sampling effort, observer ID, or location on the trend.

Furthermore, we found that 236 Least Concern species experienced significant trends due to sampling duration, with 12 species undergoing a negative trend and 224 species a positive trend (Appendix A).

3.3.3. Movement trends

Among the Turkish bird species in this study, there are 35 species (8%) classified as year-round resident and 383 species (92%) that undergo some degree of movement (Appendix B). Within this latter group, 305 species (80%) are predominantly longer-distance migrants (aka "migratory"), 33 (9%) undergo altitudinal migration, and 15 (4%) are irregular migrants (Appendix B). All seven of the threatened species with decreasing population trends over time are migratory, while the six declining Near Threatened species consist of five migratory birds and one resident species. The declining Least Concern species comprise of 43 migratory birds, 6 altitudinal migrants, and 1 irregular migrant. Among the species with increasing population trends, 90 (75%) are migratory, 9 (7%) are altitudinal migrants, 6 (5%) are irregular migrants, and 15 (13%) are resident species. For the species that experienced no population trend, 190 (81%) are migratory, 18 (8%) are altitudinal migrants, 8 (3%) are irregular migrants, and 19 (8%) are resident species.

Using a Fisher's Exact Test, we found no significant difference between resident and non-resident species that experienced population declines ($p = 0.151$). However, we did find a significant difference between these two groups for species whose populations increased ($p = 0.006$). We found that none of the resident species have declined during our study period, while 6.8% of birds that migrate have declined. Contrastingly, we found a significant increase in the proportion of resident species being present within Türkiye, with 34.3% of residents increasing while only 14.5% of non-residents increasing. We found that within birds that migrate, there was no difference among the three different movement types ($p = 0.917$).

4. Discussion

Our study represents the first long-term country-wide assessment of bird detection trends in Türkiye. We provide a comprehensive examination of country-level trends of 418 species of avifauna over the past 22 years in Türkiye, with a focus on which species are significantly increasing or decreasing. We found that 183 species (44% of Türkiye's birds in this study) have experienced significant changes in their Türkiye populations between 2001 and 2022 (Appendix A), with 63 species (15%) declining and 120 species (29%) increasing, based on presence-absence data. Among species that declined, 40% of birds have globally declining populations while 22% have globally increasing populations. Among birds that increased, 47% of birds are globally declining while 20% are globally increasing (Appendix A). We found that resident species in general are not experiencing population declines, in contrast to species that undertake long-distance or altitudinal migrations, many of which are declining. These results highlight the need for heightened conservation attention on species that migrate in Türkiye, and the region as a whole, especially since a majority of the species in our study undertake some type of migration. Of note though, while prior research may have shown a greater percentage of birds in Türkiye decreasing (BirdLife International, 2004), this discrepancy from our study is likely due to different criteria used to calculate avian population trends; in our analyses, we looked at changes in occupancy over time.

Many of Türkiye's declining bird species are highly dependent on wetlands. Long-distance migratory species disproportionately utilize wetlands as stopover sites during their migrations (Murray et al., 2018; Blount et al., 2021; Donnelly et al., 2021). Waterfowl, grebes, shorebirds, and other wetland obligates also use wetlands for breeding and overwintering as well as migratory stopover sites (Murray et al., 2018; Blount et al., 2021; Donnelly et al., 2021). Like much of the world, there is a long history of heavy anthropogenic pressures on the limited freshwater resources in Türkiye, which is accelerating the degradation, desiccation, and destruction of wetlands (Ataol and Onmuş, 2021; Shelton, 2023). While Türkiye has hundreds of wetlands, including 135 that are classified as "wetlands of international significance" (GDNCNP, 2010), the country has lost millions of hectares of its natural wetlands over the past century (Nivet and Frazier, 2004). Between 1911 and 2014, over 30% of Türkiye's natural wetlands disappeared (Ataol and Onmuş, 2021; Shelton, 2023). During the same period, dam building campaigns expanded and Türkiye went from having no major dams in the 1920's to more than 750 dams today (Ataol and Onmuş, 2021). Although the reservoirs created by these dams have increased the total available freshwater surface area, the artificial wetlands they have created are far less functional than the natural riparian wetland habitats they have destroyed (Ataol and Onmuş, 2021). In the early and mid-20th century, wetlands were intentionally drained to mitigate malaria outbreaks and create land for agriculture (Nivet and Frazier, 2004). Eventually, in response to the growing local and global recognition of the economic, cultural, and ecological value of wetlands, Türkiye signed the Ramsar Convention in 1994 (Ataol and Onmuş, 2021). However, unsuccessful enforcement of the wetland law has allowed unfettered water diversions for agriculture that continue to shrink and dry Türkiye's wetlands (Ataol and Onmuş, 2021). Furthermore, the exclusion of riparian and coastal areas from wetland conservation zoning in 2010, the increasing circumvention of the Environmental Impact Assessment process, and a major push to double Türkiye's dams and hydroelectric power plants by 2023 (Şekercioğlu et al., 2011b) have accelerated the destruction of Türkiye's wetlands in the past decade. Between 2016 and 2023, several globally recognized Important Bird Areas (IBAs), including Lake Akşehir, Lake Kuyucuk, and Lake Tuz, have completely dried due to water diversions for agriculture (Shelton, 2023).

Climate change is also contributing to and exacerbating wetland decline (Dervisoglu, 2022), but it appears to be secondary to unsustainable water practices. A recent study examining global changes in lake water storage (LWS) showed that more than 50% of lakes >100 km^2 have decreased LWS over the past three decades (Yao et al., 2023). In Türkiye, the study showed that natural lakes are shrinking and attribute the shrinkage to changes in precipitation and runoff. However, the lack of statistically significant changes in precipitation across most of Türkiye's watershed basins coupled with the increase in LWS in reservoirs may indicate that the magnitude of decreasing runoff reaching natural lakes and wetlands has more to do with upstream diversions than climate driven changes in the precipitation regime, as field work at Lake Kuyucuk of Kars has documented (Unpublished data from the authors; Ataol and Onmuş, 2021; Shelton, 2023; Yao et al., 2023).

4.1. Species-specific changes

Nine of the species that significantly declined across Türkiye are globally threatened or Near Threatened with extinction (Table 1). Three of these species are waterfowl: Marbled Teal, Common Pochard, and Common Eider (Fig. 3A, B, C). While Common Pochard is still abundant across the country, the same cannot be said for the other two species. Though Common Eider was never a widespread species in Türkiye or present in large numbers, our study indicates that this species has undergone a steep decline (Fig. 3C); there have been only two sightings of this species in the country in 2023 as of July (eBird, 2023). This species is reportedly close to meeting the requirements for being listed as globally threatened (BirdLife International, 2023), and in Europe the species is expected to have declined by over 50% across three generations by 2033 due to factors such as predation, diseases, and food shortages (BirdLife International, 2021). The decline of Marbled Teal on the other hand is even more alarming. This Vulnerable duck has been a species of concern across the Palearctic for years, declining through much of its range due to habitat loss (Tucker et al., 1994; Green, 1998; Chaudhry et al., 2019; BirdLife International, 2023). In Türkiye, this species used to regularly occur (Green, 1998), but our study indicates that this species is almost completely extirpated from the country, with only three eBird records since 2014 (Fig. 3A) through 2023 (two of which have occurred in 2023 and are therefore not include in the eBird dataset of complete years used in this study; eBird, 2023). There is limited recent published research on populations of Marbled Teal in the Middle East (Green, 1998; Abed et al., 2014), so our study provides important documentation of the long-term decline of this species in this region. We recommend that multi-year surveys be conducted in other countries in the Middle East to assess the status of this teal elsewhere in the region. In areas where this species still occurs, there should be a focus on conserving wetlands using previously documented habitat requirements for this species (Green, 1998).

Another taxonomic group that has a relatively large number of declining globally threatened or Near Threatened species in the region is raptors. Like waterfowl, three raptor species fall into this category: Bearded Vulture, Egyptian Vulture, and Steppe Eagle (Fig. 3D, E, F), with the latter two being the two most imperiled bird species to have declined across Türkiye this century. Raptors are one of the most threatened group of birds in the world, with Old World vultures in particular facing some of the most significant declines (Buechley et al., 2018, 2022). Egyptian Vulture faces a large range of threats across its range, including a variety of poisoning, persecution, electrocution, reduced food availability, and mortalities from wind farms (Sanz-Aguilar et al., 2015; Velevski et al., 2015; Freitas et al., 2020). Bearded Vulture is susceptible to similar threats, including poisoning, persecution, disturbance, changes in food availability and livestock practices, and collisions with powerlines and wind farms (BirdLife International, 2023). In Türkiye, increases in grazing pressure and human presences in montane regions has led to habitat degradation for Bearded Vulture (BirdLife International, 2023). Steppe Eagles are declining due to several key reasons: the loss of habitat resulting from the conversion of steppe into agricultural land, direct persecution, electrocution from powerlines, and vulnerability to wind farms (Sharma et al., 2014; Shobrak et al., 2022; BirdLife International, 2023).

The other two globally notable and significantly decreasing bird species in Türkiye this century (Table 1; Appendix Figs. S2A and B) are European Turtle-dove (Appendix Fig. S2B), due to habitat modification and hunting pressure (Marx et al., 2016; Fisher et al., 2018; LORMÉE et al., 2020; Moreno-Zarate et al., 2020); and Eurasian Curlew, due to habitat loss and fragmentation as well as increased predation and reduced breeding success due to human pressures (Viana et al., 2023). Additionally, we found significant negative declines in four species that are currently globally Least Concern but listed as either Near Threatened or Vulnerable in Europe: Northern Pintail (Appendix Fig. S2A), Common Quail, Little Swift, and Eurasian Coot (Table 1; BirdLife International, 2021). All of these European and globally threatened or Near Threatened species should receive heightened and prioritized conservation attention, monitoring, and surveying in Türkiye, such as nation-wide censuses targeting these species and/or mapping of historical and current distributions of these birds (e.g., Green and Navarro, 1997; Chaudhry et al., 2019; Ouassou et al., 2021).

In contrast, we found that only six globally Near Threatened or threatened (Vulnerable) species had increased than decreased in detection in Türkiye during the study period (Table 1). Two of these birds are waterbirds that were somewhat rare in the country to begin with (Lesser White-fronted Goose and Horned Grebe; Fig. 4A and B), two are raptors (Greater Spotted Eagle and Eastern Imperial Eagle; Fig. 4C), one is a wader (Curlew Sandpiper; Appendix Fig. S2E), and the other is

Alexandrine Parakeet. The increase in the globally Near Threatened Alexandrine Parakeet (Fig. 4D), an introduced and invasive species in Türkiye, can be attributed to the growing population in urban areas, mostly in the greater Istanbul area (eBird, 2023). There were seven other species that are Vulnerable in Europe that increased (Table 1), of which six species are associated with wetlands. Besides these positive trends for threatened or Near Threatened species, there were eleven species that are globally threatened with extinction that did not experience a significant change in detection during the 22-year period (Appendix Table S1), including three globally Endangered or Critically Endangered species: White-headed Duck, Northern Bald Ibis, and Sociable Lapwing. Finally, all of the species designated as "sensitive" by eBird in Türkiye did not undergo a significant population change.

Of note among the Least Concern species that experienced significant population trends are two other species that have expanded their ranges and naturally become established within Türkiye since 2001, possibly due to climate change (Abolafya et al., 2013), and now breed in Anatolia: Namaqua Dove and Black-winged Kite (Fig. 4E and F). We can expect these species and others that were unrecorded on eBird before our study period to continue to undergo positive trends in the future, as both exotic and natural birds become more established and expand their range and numbers, and as continued growth in the number of birdwatchers in the region (Appendix Fig. S1) leads to more records of vagrant species due to heightened birding effort as well as an increase in spatial and temporal coverage of birds in the country.

4.2. Quality and analytical approaches to eBird data

Contributions from eBirders can be utilized to better understand spatial and temporal changes in avian abundance and long-term population trends (e.g., Walker and Taylor, 2017; Horns et al., 2018; Fink et al., 2020; Neate-Clegg et al., 2020), especially species that are not well-represented in bird monitoring efforts (Walker and Taylor, 2020). While uneven sampling intensity among submitted eBird checklists can be accounted for when analyzing the data (Walker and Taylor, 2017, 2020; Horns et al., 2018; Neate-Clegg et al., 2020), some aspects of population changes or bird occurrences may not be fully captured or represented in the eBird data. For example, part of the Caucasian population of Velvet Scoter (*Melanitta fusca*) once bred at high elevation, deep lakes in eastern Türkiye (Kirwan et al., 2008; Paposhvili, 2018), but this alpine breeding population has completely disappeared from Türkiye within the past decade (Şekercioğlu et al., 2018; Boyla et al., 2019). However, the extirpation of this breeding scoter population in Türkiye is not yet significantly detectable by eBird in our detection analyses, as the remaining Caucasian birds that still breed in Georgia winter along the coast of Türkiye in the Black Sea (Paposhvili, 2018)—there have been no detections of this species inland from 2008 to 2023 (eBird, 2023).

One solution to addressing some of these eBird data issues is to have increased birding effort in areas that are undersampled spatially and temporally. As is common with many community science projects, sampling is heavily biased toward urban locations. Looking at submitted eBird checklists in Türkiye over the past 22 years, we can see rural areas are still lacking in coverage, specifically parts of eastern Türkiye (Figs. 1 and 2). The spatial heterogeneity leads to a bias favoring the detection of more metropolitan species. However, birders that travel for rarer species with narrow ranges may offset this urban-centric spatial bias to some degree. We also found that there are half as many checklists submitted in Türkiye during the overwintering months than during breeding and migration (Fig. 1), with large gaps across the eastern half of the country and other interior regions. This undersampling in the winter can reduce detections of waterfowl and other birds that migrate to the country during this time period. Likewise, our study demonstrates the importance of sampling effort in population trends, with duration of birding having a significant effect on 16 species that are Near Threatened or threatened globally and/or in Europe (Appendix A), including: one globally endangered species (Egyptian Vulture), 6 globally Vulnerable species (Common Pochard, Horned Grebe, European Turtle-Dove, Yelkouan Shearwater, Black-legged Kittiwake, and Red-footed Falcon), and one species Endangered in Europe (Desert Lark). In most cases, increased birding duration led to more individuals of a species seen, with notable avian groups that benefitted including waterfowl, tubenoses, raptors, shorebirds, and gulls. Knowing for which taxa increased duration of bird checklists is important can help inform censuses and point counts in the future that including birds in these specific functional groups.

In another example of intensity of spatial sampling, Blyth's Reed-warbler (*Acrocephalus dumetorum*) was only first recorded in Türkiye in 2007 on eBird, and there were a total of nine confirmed observations submitted through 2020, with an additional nine submitted between 2021 and 2023. This is likely a result of both undersampling in habitats this species should occur in (most records come from the Aras River Ornithological Station in northeastern Türkiye (Horns et al., 2016), where five individuals of this cryptic species were ringed during autumn 2021 alone; unpublished data from the authors) and some birders not submitting their observations to eBird, particularly those at ringing stations where the identification of cryptic species such as Blyth's Reed-warbler can be more easily confirmed in hand. We recommend that ringing stations, as well as groups and researchers conducting censuses of species (such as wetland surveys and point counts) strive to submit their sightings to eBird to further complement and add to the sightings of these species from the general public.

Perhaps most importantly, though, is a need to have more accurate and detailed data being submitted by birdwatchers. From the 22 years of data we analyzed, it is clear that many eBirders in Türkiye tend to select "X" to note that a species is present (31% of observations) rather than counting and providing as accurate a tally of individuals of a species as possible. This can severely limit the ability of researchers to be able to evaluate avian population trends and hamper efforts to conduct abundance analyses. While it is possible to replace all "X's" in the dataset with a number, the breadth of species diversity across which "X" counts would need to be replaced (many checklists had an "X" count for every species on the list) means that any selected replacement number would be an overcount for some species and an undercount for others. We recommend that eBirders in Türkiye and elsewhere strive to count or provide a best estimate of the number of individuals of a species present, when possible, rather than simply selecting "X".

Finally, in this study we provide a framework for assessing long-term avifaunal trends at the regional-level using country-wide eBird data (see Materials and methods; Appendix B). Working with such large and extensive eBird datasets can be computationally intensive, with a specific workflow necessary. We have therefore made our general R script for our study available (Appendix B) so that others, especially those seeking to address potential data analysis issues, may utilize our workflow for their own research. This approach can be used and modified by other researchers and applied to any country in the world, especially those in understudied regions like Türkiye that lack other more standardized, established bird monitoring programs. The analytical approach that we have employed in this study will enable timely, cost-effective analyses using pre-existing community science data that will both provide information on trends in various bird communities and help inform current conservation efforts and needs.

5. Conclusion

In understudied but biodiverse regions, particularly those that are located along key migratory flyways, it is important to evaluate the status of both resident and migratory birdlife (Kittelberger et al., 2021). This is extremely pertinent at a time when there are ongoing long-term and large-scale declines in avian biodiversity across entire regions and continents (e.g., Robbins et al., 1989; Sanderson et al., 2006; Bauer et al., 2019; Rosenberg et al., 2019; Neate-Clegg et al., 2020; Burns et al.,

2021). Recent regional studies have highlighted the scale of the decline of avifauna on the European continent (Inger et al., 2015; Burns et al., 2021). For example, since 1980 there has been close to a 20% decline in breeding birds across the European Union, resulting in a net loss of potentially over 600 million individual birds in the past four decades in the EU (Burns et al., 2021). Studies have also spotlighted the precipitous declines of Afro-Palearctic migrants and have described the factors resulting in these population trends at breeding but especially wintering grounds (Sanderson et al., 2006; Vickery et al., 2014; Walther and Huettmann, 2021), showing a need for cross-country and cross-continental partnerships and coordination to address this plight of regional biodiversity. Consequently, we demonstrate that resident species in Türkiye are proportionately faring better than species that migrate, which has important complications for avian conservation. We likewise provide the first list of movement statuses for all of the birds in Türkiye in this study (Appendix B), designating whether species migrate or are resident while also specifying the type of migration that species may undertake.

With such significant declines occurring in Europe and the western Palearctic, we can expect that declines of similar magnitudes have likely also been occurring in Türkiye and the Middle East as a whole, since many European and Afro-Palearctic species also range through this region. Our list of species that have undergone significant changes (Table 1; Appendix Table S1) as well as our population trends for most bird species occurring in Türkiye (Appendix A) can therefore help serve as a baseline upon which future monitoring of these birds can occur. Future surveys of Türkiye's birdlife will provide a more detailed picture of the current state of these birds in the country, and the region as a whole, and help us better understand the longer-term trajectories of the populations for these species, especially threatened species that are currently undergoing notable significant declines. The framework we provide in this study can be utilized to assess the trends in the populations of most bird species that live in other biodiverse but understudied parts of the world. Additionally, we examine sampling effort of eBirder community scientists in Türkiye and note which regions of the country are still under-sampled, particularly at different times of the year (Fig. 1). This knowledge can also help inform future bird surveys, help fill in knowledge gaps, and provide a clearer understanding of the state of birds in the region.

Ethics statement

Not applicable.

CRediT authorship contribution statement

Kyle D. Kittelberger: Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing. **Colby J. Tanner:** Data curation, Methodology, Software, Writing - original draft, Writing - review & editing. **Nikolas D. Orton:** Data curation, Software, Formal analysis, Writing - original draft, Writing - review & editing. **Çağan Hakkı Şekercioğlu:** Conceptualization, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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