AVIAN CONSERVATION & ECOLOGY

VOLUME 15, ISSUE 2, ARTICLE 18

Boland, C. R. J., and B. O. Burwell. 2020. Ranking and mapping the high conservation priority bird species of Saudi Arabia. *Avian Conservation and Ecology* 15(2):18. https://doi.org/10.5751/ACE-01705-150218

Research Paper

Ranking and mapping the high conservation priority bird species of Saudi Arabia

Christopher R. J. Boland[1] *and Bruce O. Burwell*[2]
[1]Environmental Protection Department, Saudi Aramco, [2]Operational Excellence Department, Saudi Aramco

ABSTRACT. One of the challenges facing conservation biologists and land managers is to determine which species in the biota should receive conservation priority. This is particularly challenging in regions with comparatively little baseline ecological data, such as the Arabian Peninsula. Here we create a list of high conservation priority species for the birds of Saudi Arabia using objective criteria. In total, 102 of Saudi Arabia's 401 regularly occurring bird species were assigned as high conservation priority. We then rank the conservation priority of these species based on their threatened status, population trend, national distribution and abundance, level of national responsibility, endemicity, and evolutionary distinctiveness. We use GIS to map the locations of high conservation priority species, revealing that most occur in the Kingdom's southwest (in the Asir Mountains and foothills, Tihama coastal plains, and Red Sea coastline). A wide array of threats is impacting Saudi Arabia's highest conservation priority birds, particularly overhunting, alpine habitat fragmentation and degradation, Allee effects, secondary poisoning, and persecution. The methodology that we developed could be easily applied to other taxa and in other countries to help identify and rank high conservation species in other regions with limited baseline data.

Classement et cartographie des espèces d'oiseaux dont la conservation est hautement prioritaire en Arabie saoudite

RÉSUMÉ. L'un des défis que doivent relever les biologistes de la conservation et les gestionnaires des terres consiste à déterminer quelles espèces du biote doivent être priorisées pour leur conservation. Cet exercice est particulièrement difficile dans les régions où les données écologiques de base sont relativement peu nombreuses, comme la péninsule arabique. Dans le présent article, nous avons établi une liste d'espèces prioritaires pour la conservation des oiseaux d'Arabie saoudite à partir de critères objectifs. En tout, 102 des 401 espèces d'oiseaux régulièrement présentes en Arabie Saoudite ont été classées comme hautement prioritaires pour leur conservation. Nous avons ensuite classé la priorité de ces espèces en fonction de leur statut de menace, de la tendance de leur population, de leur répartition et de leur abondance nationales, du niveau de responsabilité nationale, de leur endémicité et de leur caractère distinctif sur le plan de l'évolution. Nous avons utilisé le SIG pour cartographier leur présence, révélant que la plupart de ces espèces prioritaires se trouvent dans le sud-ouest du Royaume (dans les montagnes et les contreforts de l'Asir, les plaines côtières de Tihama et le littoral de la mer Rouge). Un large éventail de menaces pèse sur les oiseaux à priorité élevée de conservation en Arabie saoudite, notamment la chasse excessive, la fragmentation et la dégradation de l'habitat alpin, les effets de bordure, l'empoisonnement secondaire et la persécution. La méthodologie que nous avons élaborée pourrait facilement être appliquée à d'autres taxons et dans d'autres pays pour aider les responsables à identifier et à classer les espèces dont la conservation est prioritaire et où les données de base sont limitées.

Key Words: *Asir Magpie; Asir Mountains; conservation priority; GIS; Saudi Arabia; threatened species*

INTRODUCTION

Global biodiversity is experiencing an extinction rate a thousand times greater than the natural background rate (Pimm et al. 1995, Barnosky et al. 2011), and yet the resources currently made available for conservation are insufficient to prevent the impending loss of much of the world's threatened biodiversity (James et al. 2001). Therefore conservation agencies must prioritize which species receive active protection and which miss out, a concept known as conservation triage (Vane-Wright et al. 1991, Bottrill et al. 2008).

National conservation prioritization systems often vary greatly in what attributes are used, and how these attributes are scored and weighted (Schmeller et al. 2008, Le Berre et al. 2019). Most schemes score species based on extinction risk plus other measures of conservation importance, such as degree of endemicity, phylogenetic uniqueness, cost effectiveness, likelihood of success, and cultural, economic, or flagship value (e.g., Avery et al. 1995, Rodríguez et al. 2004, Gauthier et al. 2010, Seoane et al. 2011, Vieira da Silva et al. 2016). Ideally, these prioritization schemes are effective at drawing attention to high conservation priority species, helping conservation agencies make rational decisions, and ultimately conserving biodiversity.

Here we develop a simple and objective method for ranking the national conservation priority of vertebrate species using the birds of Saudi Arabia as a case study, a country with comparatively little baseline data, ecological research, or extant conservation programs (Meyer et al. 2015). There has been one previous

Address of Correspondent: Christopher R. J. Boland, PO Box 1697, Saudi Aramco, Dhahran , Saudi Arabia, 31311, christopher.boland@aramco.com

attempt to prioritize Saudi Arabia's biodiversity. In 2003 the former National Commission for Wildlife Conservation and Development (NCWCD) produced a list of High Conservation Priority taxa (NCWCD 2003). However that list is now out of date and incomplete because of recent taxonomic revisions, revised global conservation assessments, new regional conservation assessments (Symes et al. 2015), substantially greater understanding of species distribution and abundance within Saudi Arabia (Jennings 2010, Boland and Alsuhaibany 2020), and a broader understanding of conservation prioritization principles in general (Wilson et al. 2006, 2009, Redding et al. 2008, Fischer et al. 2011, Jetz et al. 2014). Thus a new and updated list of high conservation priority species is warranted.

Our objectives are to (i) create an updated high conservation priority list of the birds of Saudi Arabia using objective criteria, (ii) develop a method to rank those species using quantifiable conservation attributes that could be repeated for other taxa or in other countries, and (iii) use GIS to identify locations of especially high conservation priority in Saudi Arabia. The aim of the updated list is to increase public awareness of the Kingdom's highest priority birds, encourage developers, industries, and private landowners to implement appropriate mitigation measures to avoid impacting species of highest conservation priority, and help inform the optimal allocation of limited conservation resources.

METHODS

Ranking the high conservation priority species

To compile the list of high conservation priority species we assessed all 401 bird species recorded with confidence in Saudi Arabia (Boland and Alsuhaibany 2020). Species were regarded as high conservation priority if they met one or more of the following three criteria. First, species were deemed high conservation priority if they are globally or regionally vulnerable, endangered, critically endangered, regionally extinct, or reintroduced (Symes et al. 2015, IUCN 2020). Second, species were deemed high conservation priority if they are regionally endemic (i.e., they occur entirely within the Arabian Peninsula south of Saudi Arabia's northern border, allowing for vagrant sightings) or near endemic (where more than 95% of their range occurs within the Arabian Peninsula), or contain regionally endemic subspecies (as per del Hoyo et al. 2020). Finally, we deemed species as high conservation priority if more than 50% of their global population occurs within Saudi Arabia at some stage during the year. For resident species, we conservatively estimated the proportion of the global population occurring in Saudi Arabia based on global distribution maps, assuming species have a homogenous distribution within their range. For migratory species, the percentage of the global population that is likely to pass through or winter in the Kingdom was estimated based upon the position of Saudi Arabia in relation to the breeding and wintering ranges, assuming species migrate in a direct route between their breeding and nonbreeding ranges (as depicted in del Hoyo et al. 2020).

To rank the high conservation priority species we applied a weighted scoring system based on measurable aspects of conservation significance as shown in Table 1. For each high conservation priority species, we scored the following attributes: global conservation status, regional conservation status, global population trend, regional population trend, percentage of global population occurring in Saudi Arabia, level of endemicity, national abundance, area of occurrence, and evolutionary distinctiveness. Our scoring approach for each attribute is outlined in turn below.

First, species with poorer conservation statuses were scored higher, as were species with decreasing populations and species with a greater percentage of the global population occurring in Saudi Arabia (Table 1). Species that are endemic to the Arabian Peninsula were scored higher than species that are near endemic, which in turn were scored higher than species that contain endemic subspecies. Populations that are not endemic or near endemic to the Arabian Peninsula were scored 0 (Table 1).

To score the abundance of breeding species within Saudi Arabia, the estimated number of breeding pairs (from Boland and Alsuhaibany 2020) was assigned a score out of 10 (see Table 1). Species with lower breeding abundances were scored higher. Former breeding species that are now possibly extinct within the Kingdom, namely, Arabian Bustard (*Ardeotis arabs*), Bateleur (*Terathopius ecaudatus*), and Bearded Vulture (*Gypaetus barbatus*), were treated as breeding species and given the maximum score. For nonbreeding birds, the relative abundance of each species (from Boland and Alsuhaibany 2020) was assigned a score out of 10 (see Table 1). Scarcer species were scored higher than more abundant species. Nonbreeding species that are both passage migrants and winter visitors had their abundance scores for these traits averaged. Species that have both a breeding and nonbreeding range within Saudi Arabia had their nonbreeding abundance scores excluded.

To score the area of occurrence within Saudi Arabia for each species, first we used ArcGIS 10.6.1 (ESRI 2018) to create GIS polygons from published breeding, wintering, and passage range maps (Boland and Alsuhaibany 2020). The percentage of Saudi Arabia's land area occupied by each species was then calculated using GIS and scored as per Table 1. Breeding ranges were scored out of 10, whereas wintering and passage ranges were each scored out of 5. Species that have both a breeding and nonbreeding range within Saudi Arabia had their nonbreeding range scores excluded. Species that are confined to a smaller area within Saudi Arabia scored higher.

Finally, evolutionary distinctiveness was scored out of 10 on three attributes of equal weight: (i) the number of species in the genera globally, (ii) the number of species in the family globally, and (iii) the number of species in the genera within Saudi Arabia (del Hoyo et al. 2020, Boland and Alsuhaibany 2020). Species that are more evolutionarily distinct scored higher (Table 1).

The scoring system was applied with the following caveats. Regional conservation status and trend had not been reported for 12 of the species included in the final list (see Table 2); therefore we scored the regional status as per its global status and the regional trend as "unknown." The regional population trend for Arabian Lark (*Eremalauda eremodites*) was scored as decreasing because of the dearth of recent sightings (Boland and Alsuhaibany 2020) although it is listed as stable by the IUCN

(Symes et al. 2015). The Arabian Spotted Eagle-Owl (*Bubo africanus milesi*) is treated as a "probable regional endemic" (Boland and Alsuhaibany 2020, Holt et al. 2020), and was assigned a score of 7.5, whereas a recognized endemic species would score 10. Finally, we assigned the Steppe Whimbrel (*Numenius phaeopus alboaxillaris*) as critically endangered regionally with an unknown population trend. Because the Steppe Whimbrel is a subspecies, it was assigned a score of 5 for its critical status, whereas a critically endangered full species would score 10.

Table 1. The scoring system used to rank high conservation priority species. Figures in parentheses show the maximum score for each attribute.

Attribute	Classification	Score
Global attributes [20]		
Global conservation status	Critically endangered	10
	Endangered	7.5
	Vulnerable	5
	Near threatened	2.5
	Least concern	0
Global population trend	Decreasing	10
	Stable or unknown	5
	Increasing	0
Regional attributes [20]		
Regional conservation status	Reintroduced	10
	Critically endangered	10
	Endangered	7.5
	Vulnerable	5
	Near threatened	2.5
	Least concern	0
Regional population trend	Decreasing	10
	Possibly decreasing	7.5
	Stable or unknown	5
	Possibly increasing	2.5
	Increasing	0
National attributes [40]		
Breeding pairs	Possibly extinct	10
	1–9	9
	10–99	8
	100–499	7
	500–999	6
	1000–4999	5
	5000–9999	4
	10,000–19,999	3
	20,000–99,999	2
	100,000–299,999	1
	300,000 or more	0
Nonbreeding abundance	Possibly extinct	10
	Extremely rare	8
	Rare	6
	Scarce	4
	Uncommon	2
	Common or Abundant	0
Breeding or nonbreeding area [% of Saudi Arabia]	0.5 or less	10
	1	9
	2	8
	etc.	...
	7	3
	8	2
	9	1
	10 or more	0
% of global population in Saudi Arabia	100	20
	90	18
	80	16
	etc.	...
	10	2
	1	0.2
Level of endemicity [10]		
Endemic species status	Regional endemic	10
	Near endemic	7.5
	Probable endemic	7.5
Endemic subspecies status	Regional endemic	5
	Near endemic	2.5
Evolutionary distinctiveness [10]		
Number of species in the genus	1	3.3
	2–5	2.5
	6–10	1.7
	11–20	0.8
	21 or more	0
Number of species in the family	1	3.3
	2–5	2.5
	6–10	1.7
	11–20	0.8
	21 or more	0
Number of species in the genus in Saudi Arabia	1	3.3
	2–5	2.5
	6–10	1.7
	11–20	0.8
	21 or more	0
	Maximum	100

Mapping the high conservation priority species

We mapped the summed conservation priority scores for all 102 high conservation priority species using ArcGIS 10.6.1 (ESRI 2018). The range maps of all high conservation priority species were clipped according to each species' elevation limits (as reported in Boland and Alsuhaibany 2020). Each range layer was converted to a raster format using the conservation priority score as its attribute value. Each species' individual raster layers were combined using weighted sum where each layer was given a weighting factor of 1. In other words, the range maps for each species were overlain, and the sum of conservation priority scores for each species at each point in the Kingdom was mapped. We used the SETNULL function to identify which points contained either the maximum or the minimum summed conservation priority scores for all species. We then used the Locate Region Tool to identify which 100-km^2 patches contained either the maximum or the minimum average summed conservation priority scores.

RESULTS

Ranking the high conservation priority species

A total of 102 species made the list of high conservation priority taxa (Table 2). Seventeen species were included because of their global threatened conservation status, while 29 species were included because they have been assessed as regionally threatened (Symes et al. 2015), including 10 species that were already on the list on account of their international conservation status. Twenty species met the criteria for inclusion on the list because of their regional endemic status: 15 species are fully

Table 2. Saudi Arabia's high conservation priority bird species.
Key: [†]included on NCWCD List; [‡]nonbreeding species; [§]regional status and trend had not been assessed; [¶]species-specific caveat (see methods).
Status: score [CR = critically endangered; EN = endangered; VU = vulnerable; NT = near threatened; LC = least concern]; Trend: score [DE = decreasing; PD = possibly decreasing; ST = stable; PI = possibly increasing; IN = increasing; UN = unknown]; Area = area of occurrence within Saudi Arabia: score [% of Saudi Arabia]; Abundance: score [estimated number of breeding pairs for breeding species or relative abundance for nonbreeding species]; Global population: score [percentage of global population that occurs within Saudi Arabia during the year]; Endemicity: score [EA = Endemic to Arabia; NE = near endemic to Arabia; PE = probably endemic to Arabia; WS = widespread species (not endemic); ES = endemic subspecies; NS = near endemic subspecies; Distinctness: score [number of species in the genera - number of species in the family - number of species in the genera within Saudi Arabia].

Rank	Species	Score	Global Status	Global Trend	Regional Status	Regional Trend	Area	Abundance	Global Population	Endemicity	Distinctness
1	Asir Magpie[†] *Pica asirensis*	87.8	7.5 [EN]	10 [DE]	7.5 [EN]	10 [DE]	10 [0.2]	7 [130]	20 [100]	10 [EA]	5.8 [5-130-1]
2	Basra Reed-Warbler *Acrocephalus griseldis*	62.0	7.5 [EN]	5 [ST]	7.5 [EN]	5 [UN]	10 [0.2]	9 [8]	18 [90]	0 [WS]	0 [37-54-7]
3	Socotra Cormorant[†] *Phalacrocorax nigrogularis*	61.6	5 [VU]	10 [DE]	5 [VU]	10 [DE]	9 [1]	2 [35,000]	6.4 [32]	10 [EA]	4.2 [11-35-1]
4	Arabian Woodpecker[†] *Dendropicos dorae*	60.8	2.5 [NT]	10 [DE]	2.5 [NT]	10 [DE]	3 [7]	4 [5500]	14.6 [73]	10 [EA]	4.2 [17-254-1]
5	Yemen Warbler[†] *Sylvia buryi*	60.2	2.5 [NT]	10 [DE]	2.5 [NT]	10 [DE]	10 [0.1]	4 [5000]	11.2 [56]	10 [EA]	0 [30-69-13]
6	Asian Houbara[†] *Chlamydotis macqueenii*	59.8	5 [VU]	10 [DE]	10 [CR]	10 [DE]	8 [2]	8 [30]	3 [15]	0 [WS]	5.8 [2-26-1]
7	Yemen Thrush[†] *Turdus menachensis*	59.0	2.5 [NT]	10 [DE]	2.5 [NT]	10 [DE]	10 [0.3]	4 [5000]	10 [50]	10 [EA]	0 [87-176-6]
8	Arabian Grosbeak[†] *Rhynchostruthus percivali*	58.8	2.5 [NT]	10 [DE]	2.5 [NT]	10 [DE]	8 [2]	6 [500]	4 [20]	10 [EA]	5.8 [3-211-1]
9	Arabian Bustard[†] *Ardeotis arabs*	58.3	2.5 [NT]	10 [DE]	10 [CR]	10 [DE]	10 [0]	10 [0]	0 [0]	0 [WS]	5.8 [2-26-1]
10	Northern Bald Ibis[†‡] *Geronticus eremita*	52.3	7.5 [EN]	5 [ST]	10 [CR]	10 [DE]	4 [8]	10 [PE]	0 [0]	0 [WS]	5.8 [2-34-1]
11	Bearded Vulture[†] *Gypaetus barbatus*	51.7	2.5 [NT]	10 [DE]	5 [VU]	7.5 [PD]	10 [0]	10 [0]	0 [0]	0 [WS]	6.7 [1-248-1]
12	Sooty Falcon[†] *Falco concolor*	51.5	5 [VU]	10 [DE]	7.5 [EN]	10 [DE]	2 [8]	7 [300]	10 [50]	0 [WS]	0 [39-64-7]
13	Crab Plover[†] *Dromas ardeola*	51.0	0 [LC]	5 [ST]	5 [VU]	10 [DE]	6 [4]	5 [1,400]	10 [50]	0 [WS]	10 [1-1-1]
14	Common Ostrich[†] *Struthio camelus*	50.5	0 [LC]	10 [DE]	10 [RE]	5 [ST]	9 [1]	8 [80]	0.2 [1]	0 [WS]	8.3 [2-2-1]
15	Lappet-faced Vulture[†] *Torgos tracheliotos*	49.7	7.5 [EN]	10 [DE]	5 [VU]	7.5 [PD]	0 [33]	6 [500]	2 [10]	5 [ES]	6.7 [1-248-1]
16	Arabian Waxbill[†] *Estrilda rufibarba*	49.6	0 [LC]	10 [DE]	0 [LC]	10 [DE]	8 [2]	4 [5,000]	3.4 [17]	10 [EA]	4.2 [16-141-1]
17	Tawny Eagle *Aquila rapax*	48.7	5 [VU]	10 [DE]	7.5 [EN]	10 [DE]	8 [2]	7 [100]	0.4 [2]	0 [WS]	0.8 [11-248-6]
18	Arabian Lark[¶] *Eremalauda eremodites*	48.3	0 [LC]	5 [ST]	0 [LC]	10 [DE]	0 [58]	3 [17,000]	17 [85]	7.5 [NE]	5.8 [2-92-1]
19	Cinereous Bunting[‡] *Emberiza cineracea*	47.5	2.5 [NT]	10 [DE]	0 [LC]	5 [UN]	10 [0.1]	6 [RA]	14 [70]	0 [WS]	0 [44-44-7]
20	Philby's Partridge[†] *Alectoris philbyi*	47.3	0 [LC]	5 [ST]	0 [LC]	5 [ST]	9 [1]	3 [15,000]	12 [60]	10 [EA]	3.3 [7-182-3]
21	Collared Kingfisher[†] *Todiramphus chloris*	47.2	0 [LC]	10 [DE]	7.5 [EN]	10 [DE]	9 [1]	7 [300]	0.4 [2]	0 [WS]	3-3 [25-119-1]
22	Red-billed Tropicbird *Phaethon aethereus*	47.2	0 [LC]	10 [DE]	0 [LC]	7.5 [PD]	8 [2]	8 [50]	0.4 [2]	5 [ES]	8.3 [3-3-1]
23	Sociable Lapwing[‡§] *Vanellus gregarious*	47.0	10 [CR]	10 [DE]	10 [CR]	5 [UN]	4 [2-47]	6 [RA]	2 [10]	0 [WS]	0 [24-71-5]
24	Bateleur[§] *Terathopius ecaudatus*	46.7	2.5 [NT]	10 [DE]	2.5 [NT]	5 [UN]	10 [0]	10 [0]	0 [0]	0 [WS]	6.7 [1-248-1]
25	Egyptian Vulture *Neophron percnopterus*	46.2	7.5 [EN]	10 [DE]	5 [VU]	10 [DE]	1 [9]	5 [1000]	1 [5]	0 [WS]	6.7 [1-248-1]
26	European Goldfinch *Carduelis carduelis*	45.7	0 [LC]	10 [DE]	7.5 [EN]	10 [DE]	7 [3]	5 [2000]	0.4 [2]	0 [WS]	5.8 [4-211-1]
27	Great Knot[‡§] *Calidris tenuirostris*	45.7	7.5 [EN]	10 [DE]	7.5 [EN]	5 [UN]	9.5 [0.2-1]	6 [RA]	0.2 [1]	0 [WS]	0 [24-91-8]
28	Yemen Linnet *Linaria yemenensis*	45.0	0 [LC]	5 [ST]	0 [LC]	5 [ST]	9 [1]	1 [100,000]	10 [50]	10 [EA]	5 [4-211-2]
29	Helmeted Guineafowl[†] *Numida meleagris*	44.5	0 [LC]	5 [ST]	5 [VU]	10 [DE]	10 [0.5]	6 [500]	0.2 [1]	0 [WS]	8.3 [1-8-1]

(con'd)

30	Arabian Serin[†] *Crithagra rothschildi*	44.5	0 [LC]	5 [ST]	0 [LC]	5 [ST]	8 [2]	1 [260,000]	13 [65]	10 [EA]	2.5 [25-211-2]
31	African Olive-Pigeon *Columba arquatrix*	43.2	0 [LC]	10 [DE]	7.5 [EN]	5 [ST]	10 [0.1]	8 [75]	1 [5]	0 [WS]	1.7 [35-350-3]
32	Hamerkop *Scopus umbretta*	42.4	0 [LC]	5 [ST]	5 [VU]	10 [DE]	7 [3]	5 [1,500]	0.4 [2]	0 [WS]	10 [1-1-1]
33	Steppe Whimbrel[‡§¶] *Numenius p. alboaxillaris*	42.2	0 [LC]	10 [DE]	5 [CR] SS	5 [UN]	4 [2-100]	8 [ER]	6 [30]	0 [WS]	4.2 [8-91-2]
34	Greater Spotted Eagle[†‡§] *Clanga clanga*	41.8	5 [VU]	10 [DE]	5 [VU]	5 [UN]	8 [2]	2 [UC]	1 [5]	0 [WS]	5.8 [3-248-1]
35	Pink-backed Pelican[†] *Pelecanus rufescens*	41.8	0 [LC]	5 [ST]	5 [VU]	10 [DE]	8 [2]	7 [400]	1 [5]	0 [WS]	5.8 [8-8-2]
36	Tristram's Starling *Onychognathus tristramii*	40.7	0 [LC]	5 [ST]	0 [LC]	5 [ST]	10 [0.2]	2 [35,000]	7 [35]	7.5 [NE]	4.2 [11-123-1]
37	Arabian Scops-Owl *Otus pamelae*	40.1	0 [LC]	5 [ST]	0 [LC]	5 [ST]	6 [4]	3 [14,000]	9.4 [47]	10 [EA]	1.7 [53-222-3]
38	(Arabian) Spotted Eagle-Owl[¶] *Bubo africanus milesi*	39.8	0 [LC]	5 [ST]	0 [LC]	5 [ST]	5 [5]	6 [800]	8 [40]	7.5 [PE]	3.3 [18-222-2]
39	Buff-breasted Wheatear *Oenanthe bottae*	39.6	0 [LC]	5 [ST]	0 [LC]	5 [ST]	10 [0.1]	3 [13,000]	6.6 [33]	10 [EA]	0 [28-335-14]
40	Saker Falcon[†‡] *Falco cherrug*	39.5	7.5 [EN]	10 [DE]	10 [CR]	5 [UN]	0 [100-100]	6 [RA]	1 [5]	0 [WS]	0 [39-64-7]
41	Harlequin Quail[§] *Coturnix delegorguei*	38.9	0 [LC]	5 [ST]	2.5 [NT]	5 [UN]	10 [0.5]	7 [300]	0.2 [1]	5 [ES]	4.2 [6-187-2]
42	Yemen Serin[†] *Crithagra menachensis*	38.5	0 [LC]	5 [ST]	0 [LC]	5 [ST]	9 [1]	2 [25,000]	5 [25]	10 [EA]	2.5 [25-211-2]
43	Lanner Falcon[†] *Falco biarmicus*	38.4	0 [LC]	0 [IN]	10 [CR]	10 [DE]	10 [0]	8 [50]	0.4 [2]	0 [WS]	0 [39-64-7]
44	Short-toed Snake-Eagle *Circaetus gallicus*	38.0	0 [LC]	5 [ST]	5 [VU]	5 [ST]	9 [1]	7 [120]	2 [10]	0 [WS]	5 [6-248-1]
45	Arabian Sunbird *Cinnyris hellmayri*	35.5	0 [LC]	5 [ST]	0 [LC]	5 [ST]	2 [8]	1 [250,000]	10 [50]	10 [EA]	2.5 [58-147-2]
46	Pale Sparrow *Carpospiza brachydactyla*	35.2	0 [LC]	5 [ST]	0 [LC]	2.5 [IN?]	0 [19]	5 [2000]	16 [80]	0 [WS]	6.7 [1-43-1]
47	Black-winged Kite *Elanus caeruleus*	35.0	0 [LC]	5 [ST]	5 [VU]	0 [IN]	10 [0.5]	9 [3]	0.2 [1]	0 [WS]	5.8 [4-248-1]
48	Dark Chanting-Goshawk *Melierax metabates*	35.0	0 [LC]	5 [ST]	0 [LC]	5 [ST]	8 [2]	6 [750]	0.2 [1]	5 [ES]	5.8 [3-248-1]
49	Brown Woodland-warbler *Phylloscopus umbrovirens*	35.0	0 [LC]	5 [ST]	0 [LC]	10 [DE]	9 [1]	2 [40,000]	4 [20]	5 [ES]	0 [78-78-6]
50	Caspian Plover[‡§] *Charadrius asiaticus*	35.0	0 [LC]	10 [DE]	0 [LC]	5 [UN]	0 [48]	4 [SC]	16 [80]	0 [WS]	0 [33-71-6]
51	Sand Partridge *Ammoperdix heyi*	35.0	0 [LC]	5 [ST]	0 [LC]	10 [DE]	0 [48]	0 [530,000]	10 [50]	5 [ES]	5 [2-187-2]
52	Arabian Partridge[†] *Alectoris melanocephala*	34.9	0 [LC]	5 [ST]	0 [LC]	5 [ST]	3 [7]	1 [150,000]	7.5 [38]	10 [EA]	3.3 [7-182-3]
53	Steppe Eagle[‡§] *Aquila nipalensis*	34.8	7.5 [EN]	10 [DE]	7.5 [EN]	5 [UN]	0 [100-100]	0 [CO]	4 [20]	0 [WS]	0.8 [11-248-6]
54	Rufous-capped Lark *Calandrella eremica*	34.2	0 [LC]	5 [UN]	0 [LC]	5 [ST]	9 [1]	2 [25,000]	4 [20]	5 [ES]	4.2 [6-92-2]
55	Goliath Heron *Ardea goliath*	32.5	0 [LC]	5 [ST]	7.5 [EN]	5 [UN]	6 [4]	8 [60]	0.2 [1]	0 [WS]	0.8 [14-64-5]
56	Horsfield's Bushlark *Mirafra javanica*	32.0	0 [LC]	5 [ST]	0 [LC]	2.5 [PI]	9 [1]	7 [200]	0.2 [1]	5 [ES]	3.3 [24-92-1]
57	Hypocolius[‡] *Hypocolius ampelinus*	32.0	0 [LC]	5 [UN]	0 [LC]	5 [ST]	0 [50]	0 [CO]	12 [60]	0 [WS]	10 [1-1-1]
58	Common Pochard[‡§] *Aythya ferina*	31.9	5 [VU]	10 [DE]	5 [VU]	5 [UN]	0 [63-100]	4 [SC]	0.4 [2]	0 [WS]	2.5 [12-165-3]
59	Arabian Golden Sparrow[†] *Passer euchlorus*	31.7	0 [LC]	5 [ST]	0 [LC]	5 [ST]	8 [2]	2 [25,000]	10 [50]	0 [WS]	1.7 [28-43-3]
60	Griffon Vulture[‡] *Gyps fulvus*	31.7	0 [LC]	0 [IN]	7.5 [EN]	10 [DE]	2 [8]	5 [2500]	3 [15]	0 [WS]	4.2 [8-248-2]
61	Egyptian Nightjar[‡] *Caprimulgus aegyptius*	31.5	0 [LC]	10 [DE]	0 [LC]	5 [ST]	2.5 [5-52]	2 [UC]	12 [60]	0 [WS]	0 [38-98-5]
62	Sinai Rosefinch *Carpodacus synoicus*	31.5	0 [LC]	5 [ST]	0 [LC]	5 [ST]	3 [7]	4 [5000]	12 [60]	0 [WS]	2.5 [25-211-2]
63	African Paradise-Flycatcher *Terpsiphone viridis*	31.4	0 [LC]	5 [ST]	0 [LC]	5 [ST]	7 [3]	5 [1500]	0.2 [1]	5 [ES]	4.2 [17-105-1]
64	African Pipit *Anthus cinnamomeus*	31.2	0 [LC]	5 [ST]	0 [LC]	5 [ST]	9 [1]	7 [100]	0.2 [1]	5 [ES]	0 [41-67-7]
65	Brown Noddy[†] *Anous stolidus*	31.0	0 [LC]	5 [ST]	0 [LC]	5 [UN]	6 [4]	4 [7200]	0.2 [1]	5 [ES]	5.8 [5-100-1]
66	White-eyed Gull[†] *Larus leucophthalmus*	31.0	0 [LC]	5 [ST]	0 [LC]	5 [ST]	4 [6]	5 [3000]	12 [60]	0 [WS]	0 [29-33-7]

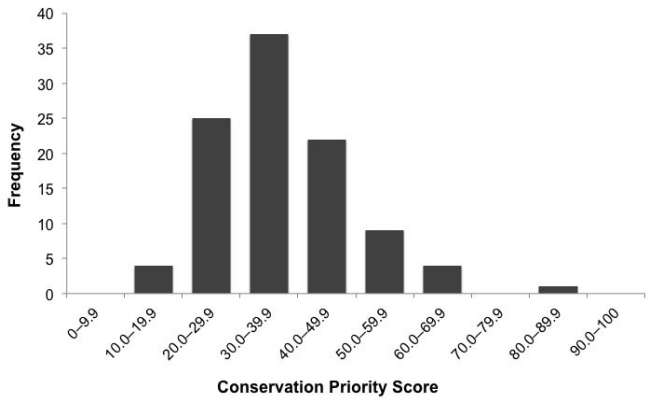
(con'd)

67	Black-crowned Tchagra *Tchagra senegalus*	30.5	0 [LC]	5 [ST]	0 [LC]	2.5 [IN?]	7 [3]	5 [2000]	0.2 [1]	5 [ES]	5.8 [4-48-1]
68	Golden Eagle *Aquila chrysaetos*	30.5	0 [LC]	5 [ST]	7.5 [EN]	10 [DE]	0 [12]	7 [200]	0.2 [1]	0 [WS]	0.8 [11-248-6]
69	Grey-headed Kingfisher *Halcyon leucocephala*	30.5	0 [LC]	5 [ST]	0 [LC]	5 [UN]	7 [3]	5 [1500]	0.2 [1]	5 [ES]	3.3 [12-120-2]
70	Kurdish Wheatear‡ *Oenanthe xanthoprymna*	30.5	0 [LC]	5 [ST]	0 [LC]	5 [UN]	2.5 [5-100]	6 [RA]	12 [60]	0 [WS]	0 [28-335-14]
71	Upcher's Warbler† *Hippolais languida*	30.2	0 [LC]	5 [ST]	0 [LC]	5 [ST]	0 [100]	2 [UC]	14 [70]	0 [WS]	4.2 [4-54-3]
72	Arabian Warbler *Sylvia leucomelaena*	30.0	0 [LC]	10 [DE]	0 [LC]	5 [ST]	0 [13]	2 [65,000]	8 [40]	5 [ES]	0 [30-69-13]
73	Mourning Wheatear† *Oenanthe lugens*	30.0	0 [LC]	5 [ST]	0 [LC]	10 [DE]	0 [14]	0 [445,000]	10 [50]	5 [ES]	0 [28-335-14]
74	Common Stonechat *Saxicola torquatus*	29.7	0 [LC]	5 [ST]	0 [LC]	5 [ST]	8 [2]	3 [20,000]	0.4 [2]	5 [ES]	3.3 [11-335-2]
75	Streaked Scrub-Warbler *Scotocerca inquieta*	29.7	0 [LC]	10 [DE]	0 [LC]	5 [ST]	0 [43]	0 [300,000]	3 [15]	5 [ES]	6.7 [1-37-1]
76	Arabian Babbler *Argya squamiceps*	29.5	0 [LC]	0 [IN]	0 [LC]	0 [IN]	0 [37]	2 [75,000]	10 [50]	7.5 [NE]	5 [9-148-1]
77	Desert Tawny Owl† *Strix hadorami*	29.2	0 [LC]	5 [ST]	0 [LC]	5 [ST]	0 [19]	5 [1800]	10 [50]	0 [WS]	4.2 [17-222-1]
78	Little Rock-Thrush *Monticola rufocinereus*	29.0	0 [LC]	5 [ST]	0 [LC]	2.5 [PI]	9 [1]	3 [12,500]	2 [10]	5 [ES]	2.5 [14-335-3]
79	Red-tailed Shrike‡ *Lanius phoenicuroides*	29.0	0 [LC]	5 [ST]	0 [LC]	5 [ST]	3 [4-100]	0 [CO]	16 [80]	0 [WS]	0 [29-33-7]
80	Eastern Imperial Eagle†‡§ *Aquila heliaca*	28.8	5 [VU]	10 [DE]	5 [VU]	5 [UN]	0 [49]	2 [UC]	1 [5]	0 [WS]	0.8 [11-248-6]
81	Nubian Nightjar *Caprimulgus nubicus*	28.5	0 [LC]	10 [DE]	0 [LC]	5 [ST]	5 [5]	5 [2400]	1 [5]	2.5 [NS]	0 [38-98-5]
82	Black-bellied Sandgrouse‡ *Pterocles orientalis*	28.4	0 [LC]	10 [DE]	7.5 [EN]	5 [UN]	0 [22]	4 [SC]	0.2 [1]	0 [WS]	1.7 [14-16-6]
83	Abyssinian White-eye *Zosterops abyssinicus*	28.3	0 [LC]	5 [UN]	0 [LC]	5 [ST]	6 [4]	1 [200,000]	3 [15]	5 [ES]	3.3 [49-135-1]
84	European Turtle-Dove *Streptopelia turtur*	27.8	5 [VU]	10 [DE]	0 [LC]	5 [UN]	0 [26]	5 [1600]	2 [10]	0 [WS]	0.8 [15-350-5]
85	Verreaux's Eagle† *Aquila verreauxii*	27.7	0 [LC]	5 [ST]	7.5 [EN]	0 [IN]	6 [4]	8 [25]	0.4 [2]	0 [WS]	0.8 [11-248-6]
86	Crested Lark *Galerida cristata*	26.0	0 [LC]	10 [DE]	0 [LC]	5 [ST]	0 [82]	0 [4,000,000]	1 [5]	5 [ES]	5 [6-92-1]
87	Ménétries's Warbler‡ *Sylvia mystacea*	26.0	0 [LC]	5 [ST]	0 [LC]	5 [UN]	0 [43-100]	2 [UC]	14 [70]	0 [WS]	0 [30-69-13]
88	Arabian Green Bee-eater *Merops cyanophrys*	25.3	0 [LC]	0 [IN]	0 [LC]	0 [IN]	0 [36]	2 [75,000]	10 [50]	7.5 [NE]	0.8 [28-31-4]
89	Levant Sparrowhawk‡§ *Accipiter brevipes*	24.8	0 [LC]	5 [ST]	0 [LC]	5 [UN]	0 [24]	4 [SC]	10 [50]	0 [WS]	0.8 [48-248-4]
90	Long-billed Pipit *Anthus similis*	24.4	0 [LC]	5 [ST]	0 [LC]	5 [ST]	6 [4]	3 [20,000]	0.4 [2]	5 [ES]	0 [41-67-7]
91	Fan-tailed Raven *Corvus rhipidurus*	24.2	0 [LC]	10 [DE]	0 [LC]	5 [ST]	0 [38]	2 [90,000]	3 [15]	2.5 [NS]	1.7 [43-130-3]
92	Chestnut-bellied Sandgrouse† *Pterocles exustus*	24.1	0 [LC]	5 [ST]	0 [LC]	5 [ST]	4 [6]	3 [20,000]	0.4 [2]	5 [ES]	1.7 [14-16-6]
93	Pied Wheatear‡§ *Oenanthe pleschanka*	22.0	0 [LC]	5 [ST]	0 [LC]	5 [UN]	0 [100]	0 [CO]	12 [60]	0 [WS]	0 [28-335-14]
94	Graceful Prinia *Prinia gracilis*	21.3	0 [LC]	5 [ST]	0 [LC]	5 [ST]	0 [27]	2 [45,000]	1 [5]	5 [ES]	3.3 [26-161-1]
95	Cinnamon-breasted Bunting *Emberiza tahapisi*	21.2	0 [LC]	5 [ST]	0 [LC]	5 [ST]	6 [4]	0 [350,000]	0.2 [1]	5 [ES]	0 [44-44-7]
96	Peregrine Falcon† *Falco peregrinus*	21.2	0 [LC]	5 [ST]	7.5 [EN]	2.5 [PI]	0 [29]	6 [500]	0.2 [1]	0 [WS]	0 [39-64-7]
97	House Sparrow *Passer domesticus hufufae*	20.2	0 [LC]	10 [DE]	0 [LC]	2.5 [PI]	0 [78]	0 [4,000,000]	1 [5]	5 [ES]	1.7 [28-43-3]
98	Isabelline Wheatear† *Oenanthe isabellina*	20.0	0 [LC]	5 [ST]	0 [LC]	5 [ST]	0 [100-100]	0 [CO]	10 [50]	0 [WS]	0 [28-335-14]
99	Black Scrub-Robin *Cercotrichas podobe*	15.5	0 [LC]	5 [ST]	0 [LC]	0 [IN]	0 [42]	1 [250,000]	2 [10]	2.5 [NS]	5 [5-335-2]
100	White-crowned Wheatear *Oenanthe leucopyga*	15.5	0 [LC]	5 [ST]	0 [LC]	5 [ST]	0 [49]	0 [300,000]	3 [15]	2.5 [NS]	0 [28-335-14]
101	Blackstart *Oenanthe melanura*	14.0	0 [LC]	5 [ST]	0 [LC]	0 [IN]	0 [41]	0 [900,000]	4 [20]	5 [ES]	0 [28-335-14]
102	White-spectacled Bulbul *Pycnonotus xanthopygos*	12.5	0 [LC]	0 [IN]	0 [LC]	0 [IN]	0 [33]	0 [1,500,000]	10 [50]	0 [WS]	2.5 [41-157-2]

endemic to the region, four are near endemic, and one (Arabian Spotted Eagle-Owl) is probably endemic to the Arabian Peninsula. Thirty-four species contain subspecies that are endemic (n = 30 species) or near endemic (n = 4 species) to the Arabian Peninsula (Table 2). Thirty-three species were included because more than 50% of the global population is likely to occur

in Saudi Arabia. Finally the Whimbrel (*Numenius phaeopus*) made the list because of the critically endangered status of the subspecies "Steppe Whimbrel." The final list consists of 81 breeding species and 21 nonbreeding species. The overall conservation scores of the 102 high conservation priority species ranged from a high of 87.8 (out of a possible 100) for the Asir Magpie (*Pica asirensis*) to a low of 12.5 for the White-spectacled Bulbul (*Pycnonotus xanthopygos*; Fig. 1, Table 2).

Fig. 1. Frequency histogram of the conservation priority scores for all 102 high conservation priority bird species in Saudi Arabia.



Mapping the high conservation priority species

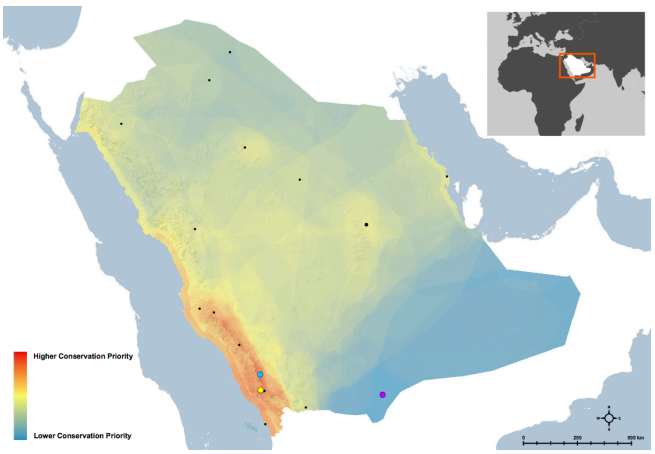
Higher concentrations of high conservation priority species are located in the Asir Mountains and foothills in southwestern Saudi Arabia (Fig. 2), followed by the Red Sea coast, and the Tihama coastal plains (between the Red Sea coast and the Asir Mountains). The point with the highest high conservation priority score was 18 km WNW of Abha city (18.251406°N, 42.344104° E) in the vicinity of Jabal Sawda' just inside the Asir National Park. The 100-km² patch with the highest average conservation priority score was between Tanumah and Al-Ithnayn in the Asir Mountains, not within any existing protected area. The lowest concentrations of high conservation priority species occurred in the Rub' al-Khali, Great Nafud, and Ad-Dahna deserts. The location with the lowest overall score was in the Rub' al-Khali along the Yemen border around Sharorah (around 17.583333°N, 47.416666°E) and the surrounding area comprised the 100-km² patch with the lowest average conservation priority score (Fig. 2).

DISCUSSION

Ranking the high conservation priority species

Our analysis has more than doubled the number of high conservation priority bird species in Saudi Arabia from 49 in 2003 when the first list was developed (NCWCD 2003) to 102 in 2020. This significant increase is due to a better understanding of bird distribution and abundance, revised taxonomy, revised global assessments, and new regional assessments since the NCWCD produced their list in 2003. We then developed a relatively objective scoring system to rank Saudi Arabia's high conservation priority species to help draw attention to key species both within the Kingdom and the Arabian Peninsula in general.

Fig. 2. Heat map of the summed conservation scores for all high conservation priority bird species per location across Saudi Arabia. Locations with higher summed conservation priority scores are depicted in redder colors, whereas locations with lower scores are shown in bluer colors. The yellow circle denotes the individual point with the highest summed conservation priority score. The blue circle represents the 100-km² patch with the highest average summed conservation priority scores. The purple circle represents both the point with the lowest summed conservation priority score and the 100-km² patch with the lowest average summed conservation priority scores. Black dots represent provincial capitals.



There is no standardized method for ranking national conservation priorities for birds or any other taxa. Most prioritization schemes rank species according to extinction risk along with various measures of species value, such as degree of national responsibility, endemicity, evolutionary distinctiveness, and social significance (Schmeller et al. 2008, Le Berre et al. 2019). We discuss our approach to each of these criteria below.

To assess each species' extinction risk, we scored conservation status and population trend at both the regional and global levels using IUCN Red List data (Symes et al. 2015, IUCN 2020). To measure national extinction risk, we quantified and scored each species' area of occurrence and relative abundance. Species that are restricted to a smaller area and/or in lower densities are typically more prone to impacts from deleterious environmental changes and catastrophic or stochastic events and therefore scored higher.

To measure Saudi Arabia's level of responsibility for each species, birds were scored according to their levels of endemicity and the proportion of the global population that occurs within the Kingdom at some stage during the year. The latter is an estimate of the contribution of the local population to the global survival of the species and as such is an important indicator of a species' conservation risk within a given nation (Schmeller et al. 2008, 2014, Kukkala et al. 2019).

Each species was scored for its degree of evolutionary distinctiveness, which is a gauge of a species' isolation on its phylogenetic tree and thus a measure of its contribution to the total evolutionary history of its clade (Bennett et al. 2014, Jetz et al. 2014). This is an important consideration in conservation because the loss of a species in an old, monotypic, or species-poor clade would result in a greater loss of biodiversity than that of a young species with many close relatives (Isaac et al. 2007). Our scoring system also included a measure of distinctiveness within Saudi Arabia to prioritize species that contribute to phylogenetic diversity within the Kingdom.

Several prioritization schemes include social attributes such as cultural significance as a measure for determining conservation priority (e.g., Mace et al. 2007, Vieira da Silva et al. 2016); however this attribute was not included in our analysis because of its intrinsically subjective nature. Certainly some species have particular cultural relevance in Saudi Arabia and the Arabian Peninsula in general. For example, Saker (*Falco cherrug*), Lanner (*F. biarmicus*), and Peregrine Falcons (*F. peregrinus*) as well as Golden Eagles (*Aquila chrysaetos*) are widely esteemed for their use in traditional falconry, and to a lesser extent so are Asian Houbara (*Chlamydotis macqueenii*), Arabian Bustard, Common Quail (*Coturnix coturnix*), and Eurasian Thick-knee (*Burhinus oedicnemus*) for their use as quarry. The long history of falconry in Arabia underpinned UNESCO's decision in 2012 to inscribe falconry on the list of humanity's Intangible Cultural Heritage. But is the traditional use of trained birds a sufficient reason to elevate a species conservation priority over other species, which may be in dire need of protection? Indeed some could take exception to elevating the status of falcons on the basis that for generations they have been used to kill other birds, including species that are now critically endangered (Asian Houbara) or possibly extinct (Arabian Bustard) in the region. Certainly conservation biologists and land managers would be wise to highlight a bird's cultural value when garnering support to protect a high conservation priority species (Bowen-Jones and Entwistle 2002, Jepson and Barua 2015). However, using cultural value to rank a species' conservation priority against another species is wrought with subjectivity.

Other conservation prioritization schemes have used subjective criteria to rank birds very effectively, such as a species' value as a flagship, umbrella, or indicator species (Lambeck 1997, Simberloff 1998, Lindenmayer et al. 2000, Roberge et al. 2008, McGowan et al. 2020), or its scientific value, beauty, or charisma (Mace and Hudson 1999, Small 2011, Ducarme et al. 2013). However, because there are no data available for these attributes within Saudi Arabia they were excluded from our analysis.

Our scoring system gives higher overall scores to species that (i) have a poorer global conservation status and trend, (ii) have a poorer regional conservation status and trend, (iii) have lower numbers of breeding, or wintering and migrating birds within Saudi Arabia, (iv) have a greater proportion of the global population in or passing through Saudi Arabia, (v) occur within a smaller portion of Saudi Arabia, (vi) are regionally endemic, and (vii) have fewer species within their genera and family. The worst-case scenario (a species that is critically endangered and decreasing both globally and regionally, endemic to Saudi Arabia but possibly extinct, and the only member of its genera and family) would score the maximum score of 100. Conversely the best-case scenario (a species that is of least concern and increasing both globally and regionally, with more than 300,000 breeding pairs in the Kingdom, is not endemic to Arabia, comprises less than 1% of the global population, and is a member of a family and genus with dozens of species) would score 0.

Unlike most other prioritization schemes, our methodology considers both breeding and nonbreeding species. Overall, the list includes 81 breeding species, which represents 37% of the 219 species that have been recorded breeding in the Kingdom (Boland and Alsuhaibany 2020). The nine highest conservation priority species all breed within Saudi Arabia, while the highest ranked nonbreeding species is the Northern Bald Ibis (*Geronticus eremita*; 10). Regional endemic species fill nine of the top 20 rankings (including six of the top eight).

The Asir Magpie was ranked as the bird species of highest conservation priority within Saudi Arabia, by a considerable margin. Its high ranking is due to its endangered status (both globally and regionally), its small and decreasing population size (perhaps 100 pairs), small range (around 3000 km^2), and the fact that its global population occurs entirely within the Kingdom. The Asir Magpie's ranking underlines the need to mount an urgent conservation program to protect and restore the species, which to date has received almost no specific conservation effort (Boland and Alsuhaibany 2020). It is the Kingdom's only nationally endemic bird, occurs within Arabia's only endemic biodiversity hotspot (Conservation International 2020), and has rich potential to be the national bird of Saudi Arabia.

Our ranking system also draws attention to the importance of Saudi Arabia to the conservation of the globally endangered Basra Reed-Warbler (*Acrocephalus griseldis*), which ranked second according to our methodology. More than 90% of the global population is likely to pass through the Kingdom on migration each year, while perhaps 10 pairs breed in spring along the Riyadh River (an artificial wetland). As far as we are aware, this species has not received any conservation attention within Saudi Arabia and was not included in the original NCWCD list of high conservation priority species in 2003. Other species that were not included in the 2003 list that nonetheless ranked among the 20 highest conservation priority birds are the Tawny Eagle (*Aquila rapax*; 17), Arabian Lark (*Eremalauda eremodites*; 18), and Cinereous Bunting (*Emberiza cineracea*; 19).

Three of the 10 highest ranked species are in imminent danger of extinction within Saudi Arabia: Asian Houbara (6), Arabian Bustard (9), and Northern Bald Ibis (10); indeed the latter two may already be extinct within the Kingdom. As noted, the Asir Magpie (1) appears to be in significant peril as well, while the Common Ostrich (*Struthio camelus*; 15) went extinct across Arabia in the 20th century and has since been reintroduced into fenced areas within the Kingdom. Therefore our scoring system identified some of the more obvious species of conservation concern, as well as species that tend to be overlooked (such as the Basra Reed-Warbler, Tawny Eagle, Arabian Lark, and Cinereous Bunting). Of the 20 highest ranked species only the Asian Houbara (6) has received much or any conservation attention within Saudi Arabia (e.g., Islam et al. 2013, Nabi et al. 2019).

Our ranking system draws attention to high conservation priority species within Saudi Arabia. Agencies, private landowners, and industries responsible for biodiversity conservation can use this list (and Fig. 2) to help inform overall conservation priorities within the Kingdom. Certainly other factors need to be incorporated in a conservation decision matrix, such as the cost of species' management, the likelihood that management intervention will succeed, habitat vulnerability, and the urgency of species decline (McCarthy et al. 2008, Joseph et al. 2009). Nonetheless, this list provides an important starting point for conservation agencies.

Limitations of the species prioritization system

Although we have attempted to create an objective, empirical measure of species conservation priority, there is nonetheless some subjectivity inherent in the scoring system. For example, one criterion for inclusion on the high conservation priority list is whether 50% or more of a species' global population occurs within Saudi Arabia at some stage during the year. However, that threshold could be lowered to, say, 30%. Ultimately a somewhat pragmatic decision was made to set the threshold at 50%. Incidentally, lowering the threshold to 30% would add an extra 26 species to the lower end of list; but it is unlikely that species-specific conservation actions would be taken on species ranked so far down the list.

Another limitation in our scoring system (which applies to most prioritization systems) is the subjective weighting applied to various attributes. For example, should regional conservation status be given more or less weight than global conservation status in a national prioritization scheme? Regional and global statuses are neither completely independent nor dependent on one another to a consistent extent across species (Wells et al. 2010), which perhaps weakens the scoring system. For this reason we ranked global and regional statuses equally. Similarly, is the number of breeding pairs of a resident species as important as abundance for a migratory species (which is the approach we took here)? Ultimately the weighting system is arbitrary but applies equally to all species.

In addition, we estimated the percentage of the global population that occurs within Saudi Arabia based on species range maps under the assumption that species are distributed uniformly across their range. This assumption is obviously flawed: for instance, traditional staging sites are essential for the survival of migratory species, but these are not distributed uniformly within or between countries; some species may forage over vast areas whereas others (such as wetland birds) might utilize only a small fraction of their range map; some migratory species may avoid flying over Saudi Arabia entirely, others may prefer it, and so on. Likewise, there was no attempt to account for variation in geographic marginality within a species range. For example, some parts of a species' range may be of more conservation value than others: central parts of a range or isolated outposts might secure future refugia, genetic diversity, and/or evolutionary potential (Schnittler and Günther 1999, Kukkala et al. 2019). However, in the absence of these data, which could take decades to acquire, this scoring system serves as a reasonably objective method for quickly ranking the conservation priorities of birds in poorly studied regions.

Mapping the high conservation priority species

Our GIS analysis revealed that the areas of highest conservation priority occur in the southwest of Saudi Arabia, particularly in the Asir Mountains and west into the Asir foothills, Tihama coastal plains, and Red Sea coast (Fig. 2). This result remained consistent regardless of whether the total count of high conservation priority species was mapped or the overall conservation scores for each species was summed and mapped. The Asir Mountains contain 16 of the 20 Arabian endemic, near endemic, or "probably endemic" species that occur within Saudi Arabia, and the greatest bird diversity in the Kingdom (Boland and Alsuhaibany 2020). Furthermore, Saudi Arabia's only nationally endemic bird species (and the species of highest conservation priority), the Asir Magpie, is entirely confined to these mountains. Conversely, the extreme desert regions of Saudi Arabia (the Rub' al-Khali, Great Nafud, and ad-Dahna deserts) contained the lowest number of high conservation priority species and the lowest summed conservation priority scores in the Kingdom. Not surprisingly, these hyper-arid regions also contain the lowest number of breeding species in Saudi Arabia (Boland and Alsuhaibany 2020). These results suggest that in order to protect Saudi Arabia's highest conservation priority bird species, conservation agencies and landowners should increase protection efforts in the southwestern regions of the Kingdom, particularly the highlands.

Threats to Saudi Arabia's high conservation priority species

Because of this ranking system we are now able to assess the threatening processes impacting the highest conservation priority species in Saudi Arabia (Table 3). Although very little conservation research has been devoted to the birds of Saudi Arabia, our preliminary analysis indicates that a wide variety of threats are impacting Saudi Arabia's highest conservation priority birds, particularly hunting, alpine habitat loss / degradation, Allee effects on small populations, secondary poisoning, and persecution, along with numerous other impacts (Table 3). Conservation programs targeted at reducing the impacts of hunting, and protecting and restoring habitat in the Asir Mountains are clearly urgent priorities. We recommend developing species-specific recovery plans for the 20 highest conservation priority bird species in Saudi Arabia.

CONCLUSION

We developed a species conservation prioritization system to rank the birds of Saudi Arabia that is transparent and can be readily applied to other vertebrate taxa and in other regions, including those with limited baseline data about species' national distributions and abundances. The methodology should be applied to all vertebrate taxa and countries within the Arabian Peninsula as a means of informing regional conservation efforts. As the largest country in the Arabian Peninsula, the efforts of Saudi Arabia are likely to be pivotal to the conservation outcomes for all birds listed as high conservation priority species.

Table 3. Key threatening processes for the 20 highest conservation priority bird species in Saudi Arabia.

Rank	Species	Score	Key threats within Saudi Arabia	References
1	Asir Magpie *Pica asirensis*	87.8	Alpine habitat loss / degradation, Allee effects	Babbington 2016, Boland and Burwell 2020
2	Basra Reed-Warbler *Acrocephalus griseldis*	62.0	Hunting	Brochet et al. 2019
3	Socotra Cormorant *Phalacrocorax nigrogularis*	61.6	Island habitat degradation, introduced predators	Whelan et al. 2018, Khan et al. 2019
4	Arabian Woodpecker *Dendropicos dorae*	60.8	Alpine habitat loss / degradation	Jennings 2010, Boland and Alsuhaibany 2020
5	Yemen Warbler *Sylvia buryi*	60.2	Alpine habitat loss / degradation	Jennings 2010, Boland and Alsuhaibany 2020
6	Asian Houbara *Chlamydotis macqueenii*	59.8	Hunting	Tourenq et al. 2005, Brochet et al. 2019, Nabi et al. 2019
7	Yemen Thrush *Turdus menachensis*	59.0	Alpine habitat loss / degradation	Jennings 2010, Boland and Alsuhaibany 2020
8	Arabian Grosbeak *Rhynchostruthus percivali*	58.8	Alpine habitat loss / degradation	Jennings 2010, Boland and Alsuhaibany 2020
9	Arabian Bustard *Ardeotis arabs*	58.3	Allee effects, hunting	Brochet et al. 2019, Boland and Alsuhaibany 2020
10	Northern Bald Ibis *Geronticus eremita*	52.3	Allee effects, hunting	Lindsell et al. 2009, Serra et al. 2011, Brochet et al. 2019
11	Bearded Vulture *Gypaetus barbatus*	51.7	Secondary poisoning, persecution	Ogada et al. 2012, Plaza et al. 2019
12	Sooty Falcon *Falco concolor*	51.5	Trapping, substandard falconry practices, hunting	Gaucher et al. 1995, McGrady et al. 2016, Brochet et al. 2019
13	Crab Plover *Dromas ardeola*	51.0	Human disturbance, egg collection, introduced predators	Almalki et al. 2014
14	Common Ostrich *Struthio camelus*	50.5	Drought, hunting, Allee effects	Islam et al. 2008
15	Lappet-faced Vulture *Torgos tracheliotos*	49.7	Secondary poisoning, persecution, nest disturbance	Shobrak 2003, Ogada et al. 2012, Plaza et al. 2019
16	Arabian Waxbill *Estrilda rufibarba*	49.6	Alpine and foothills habitat loss / degradation	Jennings 2010, Boland and Alsuhaibany 2020
17	Tawny Eagle *Aquila rapax*	48.7	Secondary poisoning, hunting, persecution	Brown 1991, Brochet et al. 2019
18	Arabian Lark *Eremalauda eremodites*	48.3	Desert habitat loss / degradation, hunting	Brochet et al. 2019, Boland and Alsuhaibany 2020
19	Cinereous Bunting *Emberiza cineracea*	47.5	Hunting	Brochet et al. 2019
20	Philby's Partridge *Alectoris philbyi*	47.3	Alpine habitat loss / degradation, hunting	Brochet et al. 2019, Boland and Alsuhaibany 2020

Responses to this article can be read online at:
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Acknowledgments:

We thank Saudi Aramco for its ongoing commitment to conserving biodiversity and two anonymous reviewers for comments on a previous version of the manuscript.

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Editor-in-Chief: Keith A.Hobson
Subject Editor: Marc-André Villard

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