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Research Article

Ranking and mapping Saudi Arabia's high conservation priority terrestrial vertebrates

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ABSTRACT

Globally, the resources devoted to biodiversity conservation are insufficient to prevent biodiversity loss, forcing conservation agencies to prioritize which species receive active protection. Accordingly, we developed an objective method for prioritizing the terrestrial vertebrates of Saudi Arabia, a country with limited baseline ecological data and limited conservation effort. Ninety-seven species were regarded as High Conservation Priority on the basis that they are listed as globally or regionally threatened and/or have more than 50% of their range within Saudi Arabia. We then scored these 97 species according to measures of extinction risk, level of endemicity, national responsibility, and phylogenetic distinctness to create a ranked list of High Conservation Priority species. The ten highest conservation priority species in Saudi Arabia are all freshwater fish or small reptiles, with the highest ranked species being the critically endangered Arabian Bream *Acanthobrama hadiyahensis*. We developed GIS heat maps of the summed conservation priority scores for the 97 High Conservation Priority species, which reveal the Asir Mountains as the highest conservation priority area within the Kingdom. The method we developed can be used on any group of species in any geographic area and can be easily revised as additional data arise.

Key words: species prioritization, conservation triage, habitat modeling, Arabian Bream, Asir Mountains

INTRODUCTION

Global biodiversity is undergoing an extinction rate a thousand times greater than the natural background rate, thus heralding the onset of the Anthropocene, an epoch in which species loss constitutes the sixth major global extinction event (Pimm *et al*., 1995; Barnosky *et al*., 2011; Ceballos *et al*., 2015). Compounding this crisis, the resources currently made available for conservation are insufficient to prevent the impending loss of much of the world's threatened biodiversity (McCarthy *et al*., 2012). As a result, conservation agencies must prioritize biota so that scarce resources can be allocated efficiently in order to conserve as many species as possible for as long as possible—a concept known as 'conservation triage', 'conservation hospice', or 'the agony of choice' (Vane-Wright, Humphries & Williams, 1991; Bottrill *et al*., 2008; Peterson, Bruskotter, & Rodriguez, 2020).

The Kingdom of Saudi Arabia is not immune to this biodiversity crisis. According to the IUCN Red List of Threatened Species, 147 species in Saudi Arabia are near threatened, 113 are vulnerable, 40 are endangered, 16 are critically endangered, three are regionally extinct (Asiatic Wild Ass *Equus hemionus*, Cheetah *Acinonyx jubatus*, and Lion *Panthera leo*), one (the Arabian Oryx *Oryx leucoryx*) was extinct in the wild (but has since been reintroduced), and one (the regionally endemic Saudi Gazelle *Gazella saudiya*) is globally extinct (IUCN, 2021). Of the 21 extant endemic species in the Kingdom, only one is listed as least concern, and none are stable or increasing (IUCN, 2021). To make matters worse, comparatively little baseline data, ecological research, or extant conservation programs exist within the Kingdom (Meyer *et al*., 2015). Clearly an empirical method for prioritizing Saudi Arabia's imperiled biodiversity is urgently required.

Accordingly, we recently developed a species prioritization scheme for Saudi Arabia's 488 bird species (Boland & Burwell, 2020a). Here we attempt to develop a prioritization scheme for the Kingdom's terrestrial vertebrate fauna (amphibians, freshwater fish, mammals and reptiles). The only previous attempt to prioritize Saudi Arabia's terrestrial vertebrates was in 2003 when the now defunct National Commission for Wildlife Conservation and Development (NCWCD) produced a list of High Conservation Priority taxa. The NCWCD list included species that were regionally or globally threatened, endemic or near endemic to Arabia, dependent upon Saudi Arabia for their conservation, and/or deemed to be of ecological, economic, cultural or flagship importance. However, the NCWCD list is now out of date as a result of taxonomic revision, the discovery of several new species within Saudi Arabia, updated global and regional conservation assessments (Mallon & Budd, 2011; Cox *et al*., 2012; Harrison, Cox & Tognelli, 2015; IUCN, 2021), and a better understanding of conservation prioritization principles in general (e.g, Redding *et al*., 2008; Wilson, Carwardine, & Possingham, 2009; Fischer *et al*., 2011; Jetz *et al*., 2014). Furthermore, the NCWCD did not attempt to rank the conservation priority of the species within their list.

Therefore, the purpose of our study is to (i) develop an updated and objective list of Saudi Arabia's High Conservation Priority terrestrial vertebrate species,

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(ii) rank those species using quantifiable conservation attributes, and (iii) use geographic information system (GIS) to map the relative conservation priority for every point in the Kingdom. There is no standardized method for determining national conservation priorities (reviewed in Le Berre *et al*., 2019). Typically, prioritization schemes categorize species using some measure of extinction risk, along with other factors such as level of endemicity, national responsibility (Schmeller *et al*., 2014), phylogenetic distinctness (Collen *et al*., 2011), cultural, aesthetic, economic, flagship or keystone value (Fitzpatrick *et al*., 2007; McGowan *et al*., 2020), public appeal (Vieira da Silva *et al*., 2016), or the cost of implementing conservation actions versus likelihood of success (Joseph, Maloney & Possingham, 2009). In this study, we use empirical criteria related to extinction risk, endemicity, national responsibility, and phylogenetic distinctness. We do not use subjective measures such as cultural or aesthetic value, or other measures for which data do not currently exist—such as cost, likelihood of success, or economic, flagship or keystone value. We attempt to develop an empirical method that could be applied consistently to any group of species, in any geographic area, and that can be regularly revised as more data are gathered.

Our overall objective is to increase public awareness of the taxa of greatest conservation importance to the kingdom, encourage developers, industries and landowners to implement appropriate mitigation measures to ensure the protection of species of highest conservation priority, and contribute to the optimal allocation of limited conservation resources within Saudi Arabia.

MATERIALS AND METHODS

Identifying the High Conservation Priority species

To identify Saudi Arabia's High Conservation Priority species, we assessed all terrestrial vertebrate species (amphibians, freshwater fish, mammals and reptiles) recorded in the Kingdom. We regarded a species as being of High Conservation Priority nationally if it met one or more of the following criteria: (i) it is globally threatened (vulnerable, endangered, critically endangered, regionally extinct, or reintroduced: IUCN, 2021), (ii) regionally threatened (Mallon & Budd, 2011; Cox *et al*., 2012; Harrison *et al*., 2015; IUCN, 2021), and/or (iii) at least 50% of the global range occurs in Saudi Arabia.

We obtained range maps for each species of mammal, amphibian and reptile from published sources (IUCN, 2021; Nilson & Rastegar-Pouyani, 2007; Petzold *et al*., 2014; Šmíd *et al*., 2017a, b, Bates & Broadley, 2018). Range maps were digitized using ArcGIS 10.6.1 (ESRI, 2018) and then clipped according to the published elevation range limits for each species. Because there are no published range maps for Saudi Arabia's freshwater fish species, we created range maps using point location data presented in Hamidan & Shobrak's (2019) comprehensive review of all freshwater fish locations recorded in Saudi Arabia since 1977. Each reported location was buffered by 2000 m (to allow for any potential lack of precision with older records). We used ArcGIS to select all of the watersheds that intersected the buffered points. We created a drainage network using the elevation model and used the Flow Direction tool to create a layer depicting the direction of flow for each cell. We used the Flow Accumulation tool to calculate the accumulated flow for each downslope cell. This layer was segmented into drainage patterns using the Con tool, which performed a conditional operation on the data to maintain the upper values representing the drainage network. The Set Null tool was applied to eliminate lower drainage network values (below 5). We used the Stream Order tool to assign a numeric order to links in the stream network. The Stream To Feature tool converted the raster data to a linear feature. The intersections of the drainage network were converted to point features. Using the Watershed tool, sub-basins were created using the intersections of the drainage networks. This process enabled us to develop accurate maps of the known watersheds used by each freshwater fish species in the Kingdom.

Ranking the High Conservation Priority species

To rank Saudi Arabia's High Conservation Priority species, we applied a weighted scoring system based on measurable aspects of conservation importance as shown in Table 1. The scoring system was designed to have a maximum score of 100 (highest conservation priority) and a minimum score of 0 (lowest conservation priority). Our scoring approach for each attribute is outlined below.

First, species with a poorer global conservation status were scored higher, with a maximum score of 10 (Table 1). Data deficient that have been recorded extremely rarely (less than five occasions) and from only one or two localities were assigned a score of 10—the same score assigned to critically endangered species. Data deficient species that occur in a large range (exceeding 10,000 km^2) and have been recorded in multiple localities were assigned a score of 5 for their global status—the same score applied to vulnerable species. Second, species with a poorer regional conservation status were scored higher, with a maximum score of 10 (Table 1). For species that have no assigned regional status, we applied the global conservation status to the regional conservation status score.

Third, species with decreasing populations were scored higher (10) than populations that are stable (5) or increasing (0) (Table 1). Species with an unknown global population trend scored 6.7 for this attribute, while species with an unknown regional population trend scored 7.3 (which are the average scores for species with known global and regional trends, respectively, and more or less equivalent to species that are 'probably decreasing').

Fourth, species with a greater percentage of the global range occurring in Saudi Arabia scored higher, with a maximum score of 20 (Table 1). We used ArcGIS to digitize published range maps for each species and calculate the percentage of each species' global range that occurs in the Kingdom.

Fifth, species with a more restricted range within Saudi Arabia were scored higher (to a maximum of 10). To calculate each species' area of occurrence within the Kingdom, we used ArcGIS to determine the percentage of Saudi Arabia's land area occupied by each species and scored as per Table 1. Species that occur across 10% or more of Saudi Arabia scored 0.

Sixth, species that are endemic to the Arabian Peninsula were scored higher (10) than species that are near endemic (7.5), whereas widespread species that are neither endemic or near endemic scored 0 (Table 1).

Finally, species that are more evolutionary distinct were scored higher, with a maximum score of 20. Evolutionary distinctness was measured using 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 extant within Saudi Arabia (Table 1). To measure evolutionary distinctness, we used the taxonomies provided in IUCN (2021) for mammals and amphibians, the Reptile Database (Uetz, Freed & Hošek, 2021) for reptiles, and Fish Base (Froese & Pauly, 2019) for freshwater fish.

Mapping the High Conservation Priority species

To map the locations of high conservation priority areas within Saudi Arabia, we used ArcGIS to convert each species' range layer to a raster format using its conservation priority score as its attribute value. All 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 Set Null tool to identify which points in the Kingdom 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 contain either the maximum or the minimum average summed conservation priority scores.

RESULTS

In total, 97 species made the list of High Conservation Priority taxa (Table 2), consisting of 55 reptile species, 29 mammal species, eight freshwater fish species, and five amphibian species. Ten species were included because they are globally threatened. Ten species are regionally threatened. Ten species are endemic to Saudi Arabia; another 37 species are endemic to the Arabian Peninsula, and 19 others are near endemic to the Arabian Peninsula. Sixty-four species have 50% or more of their global range in Saudi Arabia. Many species met multiple criteria for inclusion on the list.

The overall conservation priority scores of the 97 High Conservation Priority species ranged from a high of 88.3 for the Arabian Bream to a low of 20.0 for the Libyan Jird (Figure 1; Table 2).

The areas containing the highest summed conservation priority scores for amphibians, freshwater fish, and mammals were all found in the Asir Mountains, while the area with the highest summed conservation priority score for reptiles was found in Al Jawf in the vicinity of Al Khanafa Wildlife Sanctuary (Figure 2; Table 3). The lowest conservation priority area for reptiles is north of Najran city in Najran Province, and for mammals west of Medina city in Al Medina Province. Amphibians and fish are absent from the majority of Saudi Arabia and therefore scored zero across large swathes of the Kingdom (Figure 2).

DISCUSSION

Identifying Saudi Arabia's High Conservation Priority species

Our study classified 97 terrestrial vertebrate species as High Conservation Priority in Saudi Arabia. The only previous attempt to identify Saudi Arabia's High Conservation Priority terrestrial vertebrate species was by

Table 1. The scoring system used to rank High Conservation Priority terrestrial vertebrate 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	Increasing	10
	Unknown	6.7
	Stable	5
	Increasing	0
Regional attributes [20]		
Regional conservation status	Critically endangered	10
	Endangered	7.5
	Vulnerable	5
	Near threatened	2.5
	Least concern	0
Regional population trend	Increasing	10
	Unknown	7.3
	Stable	5
	Increasing	0
National attributes [30]		
Proportion of global population	100	20
	90	18
	80	16
	etc.	…
	10	2
	1	0.2
Area of occurrence [% of Saudi Arabia]	0.5 or less	10
	1	9
	2	8
	3	7
	etc.	…
	7	3
	8	2
	9	1
	10 or more	0
Level of endemicity [10]		
Endemic species status	Regional endemic	10
	Near endemic	7.5
	Not endemic	0
Evolutionary distinctiveness [20]		
Number of species in the genus	1	6.7
	2-5	5
	6-10	3.3
	11-20	1.7
	21 or more	0
Number of species in the family	1	6.7
	2-10	5
	11-50	3.3
	50-100	1.7
	101 or more	0
Number of species in the genus in Saudi Arabia	1	6.7
	2-5	5
	6-10	3.3
	11-20	1.7
	21 or more	0
	Maximum	**100**

Table 2. Saudi Arabia's High Conservation Priority terrestrial vertebrate species.
Key: Status: CR = critically endangered; EN = endangered; VU = vulnerable; NT = near threatened; LC = least concern [score]; Trend: DE = decreasing; ST = stable; IN = increasing; UN = unknown [score]; Area = area of occurrence within Saudi Arabia: % of Saudi Arabia [score]; Global population: percentage of global population that occurs within Saudi Arabia [score]; Endemicity: AP = Endemic to Arabia; NE = near endemic to Arabia; WS = widespread species / not endemic [score]; Distinctness: number of species in the genera - number of species in the family - number of species in the genera within Saudi Arabia [score]. * = Not included on NCWCD list, # = Regional conservation status was assigned from global conservation status.

Rank	Species	Score	Taxa	Global Status	Global Trend	Regional Status	Regional Trend	SA Area	Global Population	Endemicity	Distinctness
1	Arabian Bream *Acanthobrama hadiyahensis*	88.3	Fish	CR [10]	DE [10]	CR [10]	DE [10]	0.1 [9.9]	100 [20]	SA [10]	11-3160-1 [8.3]
2	Arabian Himri *Carasobarbus apoensis*	84.8	Fish	EN [7.5]	DE [10]	EN [7.5]	DE [10]	0.2 [9.8]	100 [20]	SA [10]	10-3160-1 [10]
3	Gasperetti's Leafnose Snake * *Lytorhynchus gasperetti*	81.2	Reptile	DD / CR [10]	UN [6.7]	DD / CR [10]	UN [7.3]	1.1 [8.9]	100 [20]	SA [10]	6-1982-2 [8.3]
4	Leviton's Cylindrical Skink *Chalcides levitoni*	80.5	Reptile	DD / CR [10]	UN [6.7]	DD / CR [10]	UN [7.3]	0.2 [9.8]	100 [20]	SA [10]	32-1709-1 [6.7]
5	Sarso Island Racer * *Coluber insulanus*	77.3	Reptile	DD / CR [10]	UN [6.7]	DD / CR [10]	UN [7.3]	0.0 [10]	100 [20]	SA [10]	27-1982-7 [3.3]
6	Saudi Sand Gecko * *Tropiocolotes wolf-gangboehmei*	75.5	Reptile	DD / EN [7.5]	UN [6.7]	DD / EN [7.5]	UN [7.3]	0.2 [9.8]	100 [20]	SA [10]	12-1356-2 [6.7]
7	Asir Garra *Garra buettikeri*	72.1	Fish	VU [5]	DE [10]	VU [5]	DE [10]	0.4 [9.6]	100 [20]	AP [7.5]	146-3160-3 [5]
8	Alfaraj's Gecko * *Hemidactylus alfaraji*	71.9	Reptile	DD / EN [7.5]	UN [6.7]	DD / EN [7.5]	UN [7.3]	0.4 [9.6]	100 [20]	SA [10]	164-1356-7 [3.3]
9	Arabian Lotak *Cyprinion mhalense*	67.9	Fish	LC [0]	DE [10]	LC [0]	DE [10]	0.4 [9.6]	100 [20]	SA [10]	9-3160-2 [8.3]
10	Asir Gecko * *Hemidactylus asirensis*	65.6	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	1.7 [8.3]	100 [20]	SA [10]	164-1356-7 [3.3]
11	Saudi Arabian Sand Lizard * *Mesalina saudiarabica*	65.5	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	3.5 [6.5]	100 [20]	SA [10]	19-350-6 [5]
12	Yemeni Mouse * *Myomyscus yemeni*	62.9	Mammal	DD [5]	UN [6.7]	DD [5]	UN [7.3]	2.3 [7.7]	60 [12]	AP [7.5]	4-788-1 [11.7]
13	Mount Elba Snake-eyed Lizard * *Ophisops elbaensis*	61.4	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	1.6 [8.4]	70 [14]	NE [5]	10-350-1 [10]
14	Saudi Fringe-fingered Lizard * *Acanthodactylus gongrorhynchatus*	60.5	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	0.7 [9.3]	90 [18]	AP [7.5]	44-350-11 [1.7]
15	Arabian Gazelle *Gazella arabica*	59.9	Mammal	VU [5]	DE [10]	VU [5]	DE [10]	6.3 [3.7]	60 [12]	AP [7.5]	11-141-2 [6.7]
16	Bearded Turtle * *Pelomedusa barbata*	59.5	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	2.0 [8]	50 [10]	AP [7.5]	10-27-1 [10]
17	Arabian Egg-eater * *Dasypeltis arabica*	59.2	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	0.6 [9.4]	50 [10]	AP [7.5]	16-1982-1 [8.3]
18	Arabian Oryx *Oryx leucoryx*	59.9	Mammal	VU [5]	ST [5]	VU [5]	ST [5]	0.8 [9.2]	70 [14]	NE [5]	4-141-1 [11.7]
19	Arabian Sand Lizard * *Mesalina arnoldi*	57.6	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	0.9 [9.1]	60 [12]	AP [7.5]	19-350-6 [5]
20	Leopard *Panthera pardus*	55.9	Mammal	VU [5]	DE [10]	CR [10]	DE [10]	1.8 [8.2]	5 [1]	WS [0]	5-38-1 [11.7]
21	Nubian Ibex # *Capra nubiana*	55.3	Mammal	VU [5]	DE [10]	VU [5]	DE [10]	2.7 [7.3]	40 [8]	WS [0]	9-141-1 [10]
22	Mountain Gecko * *Hemidactylus montanus*	54.1	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	0.8 [9.2]	50 [10]	AP [7.5]	164-1356-7 [3.3]
23	Spiny-tailed Lizard *Uromastyx aegyptia*	53.7	Reptile	VU [5]	DE [10]	VU [5]	DE [10]	90.4 [0]	60 [12]	NE [5]	15-530-2 [6.7]
24	Arabian Garra *Garra tibanica*	52.4	Fish	LC [0]	DE [10]	LC [0]	DE [10]	0.1 [9.9]	50 [10]	AP [7.5]	146-3160-3 [5]
25	Gulf Short-fingered Gecko * *Pseudoceramodactylus khobarensis*	51.8	Reptile	LC [0]	DE [10]	LC [0]	DE [10]	0.6 [9.4]	20 [4]	NE [5]	1-1356-1 [13.3]
26	Yemen Monitor *Varanus yemenensis*	50.3	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	0.2 [9.8]	20 [4]	AP [7.5]	83-83-2 [5]
27	Desert Pipistrelle * *Pipistrellus ariel*	50.0	Mammal	DD [5]	UN [6.7]	DD [5]	UN [7.3]	8.0 [2]	70 [14]	NE [5]	39-438-2 [5]
28	Hadramaut Lotak *Cyprinion acinaces*	49.6	Fish	LC [0]	UN [6.7]	LC [0]	UN [7.3]	0.2 [9.8]	50 [10]	AP [7.5]	9-3160-2 [8.3]
29	Striped Hyaena *Hyaena hyaena*	49.3	Mammal	NT [2.5]	DE [10]	EN [7.5]	DE [10]	57.7 [0]	5 [1]	WS [0]	1-4-1 [18.3]
30	Arabian Shabout *Arabibarbus arabicus*	49.1	Fish	LC [0]	ST [5]	LC [0]	ST [5]	0.0 [10]	50 [10]	AP [7.5]	3-3160-1 [11.7]

Table 2 continued

31	Arabian Sand Gazelle [#] *Gazella marica*	48.7	Mammal	VU [5]	DE [10]	VU [5]	DE [10]	80.5 [0]	60 [12]	WS [0]	11-141-2 [6.7]
32	Hejaz Gecko * *Hemidactylus granosus*	48.3	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	19.7 [0]	80 [16]	NE [5]	164-1356-7 [3.3]
33	Rub' al-Khali Agama * *Trapelus jayakari*	48.2	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	14.3 [0]	50 [10]	AP [7.5]	13-530-4 [6.7]
34	King Jird * *Meriones rex*	47.4	Mammal	LC [0]	UN [6.7]	LC [0]	UN [7.3]	2.8 [7.2]	60 [12]	AP [7.5]	17-788-4 [6.7]
35	Yemen Rock Gecko * *Pristurus saada*	47.3	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	1.5 [8.5]	70 [14]	AP [7.5]	26-228-6 [3.3]
36	Arabian Tree Frog *[#] *Hyla felixarabica*	49.7	Amphibi-an	DD [5]	UN [6.7]	DD [5]	UN [7.3]	1.1 [8.9]	30 [6]	WS [0]	15-643-1 [8.3]
37	Aden Garra *Garra sahilia*	46.4	Fish	LC [0]	UN [6.7]	LC [0]	UN [7.3]	0.1 [9.9]	50 [10]	AP [7.5]	146-3160-3 [5]
38	Arabian Jird * *Meriones arimalius*	46.2	Mammal	LC [0]	UN [6.7]	LC [0]	UN [7.3]	11.6 [0]	90 [18]	AP [7.5]	17-788-4 [6.7]
39	Saudi Rock Gecko * *Pristurus popovi*	45.9	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	1.0 [9]	60 [12]	AP [7.5]	26-228-6 [3.3]
40	Zarudnyi's Worm Lizard * *Diplometopon zarudnyi*	45.7	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	26.5 [0]	70 [14]	NE [5]	1-6-1 [16.7]
41	Arabian Skittering Frog *Euphlyctis ehrenbergii*	45.6	Amphibi-an	LC [0]	ST [5]	LC [0]	ST [5]	3.6 [6.4]	50 [10]	AP [7.5]	4-160-1 [11.7]
42	Large Aden Gerbil * *Gerbillus poecilops*	45.6	Mammal	LC [0]	UN [6.7]	LC [0]	UN [7.3]	2.9 [7.1]	60 [12]	AP [7.5]	48-788-5 [5]
43	Ornate Mastigure *Uromastyx ornate*	44.2	Reptile	LC [0]	DE [10]	LC [0]	DE [10]	6.5 [3.5]	70 [14]	WS [0]	15-530-2 [6.7]
44	Veiled Chameleon *Chamaeleo calyptratus*	43.3	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	0.8 [9.2]	50 [10]	AP [7.5]	14-217-2 [6.7]
45	Neumann's Orangetail Lizard * *Philochortus neumanni*	43.1	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	0.4 [9.6]	10 [2]	AP [7.5]	7-350-1 [10]
46	African Straw-coloured Fruit-bat *Eidolon helvum*	42.8	Mammal	NT [2.5]	DE [10]	NT [2.5]	UN [7.3]	1.3 [8.7]	1 [0.2]	WS [0]	2-38-1 [11.7]
47	Arabian Skink * *Scincus hemprichii*	42.8	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	0.7 [9.3]	10 [2]	AP [7.5]	4-1709-3 [10]
48	Desert Cobra *Walterinnesia aegyptia*	42.0	Reptile	LC [0]	DE [10]	LC [0]	DE [10]	10.4 [0]	60 [12]	WS [0]	2-382-2 [10]
49	Tilbury's fringe-fingered lizard * *Acanthodactylus tilburyi*	41.8	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	0.9 [9.1]	80 [16]	NE [5]	44-350-11 [1.7]
50	Arabian Viper * *Echis borkini*	41.5	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	0.6 [9.4]	20 [4]	AP [7.5]	12-362-2 [6.7]
51	Yemen Short-fingered Gecko * *Stenodactylus yemenensis*	41.4	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	0.7 [9.3]	20 [4]	AP [7.5]	11-1356-4 [6.7]
52	Balletto's Toad *Sclerophrys tihamica*	40.8	Amphibi-an	LC [0]	ST [5]	LC [0]	ST [5]	1.7 [8.3]	50 [10]	AP [7.5]	45-556-2 [5]
53	Arabian Small-Scaled Bur-rowing Asp *Atractaspis andersonii*	40.5	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	6.0 [4]	50 [10]	AP [7.5]	22-69-2 [5]
54	Elegant Racer * *Platyceps elegantissimus*	40.3	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	29.8 [0]	90 [18]	NE [5]	27-1982-7 [3.3]
55	Arabian cobra *Naja arabica*	40.3	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	7.9 [2.1]	50 [10]	AP [7.5]	33-382-1 [6.7]
56	Arabian Horned Viper * *Cerastes gasperettii*	39.0	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	90.4 [0]	70 [14]	NE [5]	4-362-2 [10]
57	Sinai Banded Racer * *Platyceps sinai*	38.3	Reptile	NT [2.5]	UN [6.7]	NT [2.5]	UN [7.3]	0.0 [10]	5 [1]	NE [5]	27-1982-7 [3.3]
58	Desert Black Snake * *Walterinnesia morgani*	38.0	Reptile	VU [5]	UN [6.7]	VU [5]	UN [7.3]	23.4 [0]	20 [4]	WS [0]	2-382-2 [10]
59	Haas' fringe-fingered lizard * *Acanthodactylus haasi*	37.2	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	2.0 [8]	30 [6]	AP [7.5]	44-350-11 [1.7]
60	Honey Badger *Mellivora capensis*	36.8	Mammal	LC [0]	DE [10]	NT [2.5]	DE [10]	85.1 [0]	5 [1]	WS [0]	1-64-1 [13.3]
61	Mole Viper * *Atractaspis engaddensis*	36.5	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	9.5 [0.5]	80 [16]	NE [5]	22-69-2 [5]
62	Anderson's Rock Agama * *Acanthocercus adramitanus*	36.3	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	1.8 [8.2]	20 [4]	AP [7.5]	13-530-2 [6.7]
63	Variable Racer * *Platyceps variabilis*	36.3	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	0.6 [9.4]	10 [2]	AP [7.5]	27-1982-7 [3.3]
64	Arabian Web-footed Sand Gecko * *Stenodactylus arabicus*	36.2	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	18.1 [0]	60 [12]	AP [7.5]	11-1356-4 [6.7]
65	Asir Rock Agama *Acanthocercus yemensis*	36.2	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	0.0 [10]	10	AP [7.5]	13-530-2 [6.7]

Table 2 continued

66	Middle Eastern Short-fingered Gecko * *Stenodactylus doriae*	35.7	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	99.5 [0]	70 [14]	NE [5]	11-1356-4 [6.7]
67	Hardy's Fringe-fingered Lizard * *Acanthodactylus hardyi*	35.7	Reptile	DD [5]	UN [6.7]	DD [5]	UN [7.3]	22.7 [0]	50 [10]	WS [0]	44-350-11 [1.7]
68	Arabian Toad *Sclerophrys arabica*	35.5	Amphibi-an	LC [0]	ST [5]	LC [0]	ST [5]	7.0 [3]	50 [10]	AP [7.5]	45-556-2 [5]
69	Caspian Terrapin *Mauremys caspica*	35.1	Reptile	LC [0]	ST [5]	VU [5]	UN [7.3]	2.4 [7.6]	1 [0.2]	WS [0]	9-71-1 [10]
70	Arabian Sandfish * *Scincus mitranus*	35.0	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	71.5 [0]	50 [10]	NE [5]	4-1709-3 [10]
71	Hadramaut Sand Lizard * *Mesalina adramitana*	34.5	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	10.9 [0]	40 [8]	AP [7.5]	19-350-6 [5]
72	Yellow-spotted Agama * *Trapelus flavimaculatus*	34.2	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	50.4 [0]	50 [10]	AP [7.5]	13-530-4 [6.7]
73	Cheesman's Gerbil * *Gerbillus cheesmani*	34.0	Mammal	LC [0]	ST [5]	LC [0]	ST [5]	32.3 [0]	70 [14]	NE [5]	48-788-5 [5]
74	Arabian Toad-headed Agama * *Phrynocephalus arabicus*	34.0	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	70.2 [0]	70 [14]	NE [5]	30-530-3 [5]
75	Dhofar Toad *Duttaphrynus dhufarensis*	33.9	Amphibi-an	LC [0]	ST [5]	LC [0]	ST [5]	4.3 [5.7]	20 [4]	AP [7.5]	21-556-1 [6.7]
76	Slevin's Sand Gecko * *Stenodactylus slevini*	33.7	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	47.3 [0]	60 [12]	NE [5]	11-1356-4 [6.7]
77	Golden Spiny Mouse *# *Acomys russatus*	33.0	Mammal	LC [0]	UN [6.7]	LC [0]	UN [7.3]	18.6 [0]	70 [14]	WS [0]	21-788-2 [5]
78	Indian Grey Mongoose * *Herpestes edwardsii*	32.2	Mammal	LC [0]	ST [5]	DD [5]	UN [7.3]	2.2 [7.8]	2 [0.4]	WS [0]	15-35-2 [6.7]
79	Greater Mouse-tailed Bat *# *Rhinopoma microphyllum*	31.7	Mammal	LC [0]	ST [5]	LC [0]	UN [7.3]	2.6 [7.4]	2 [0.4]	WS [0]	6-6-3 [11.7]
80	Rock Hyrax # *Procavia capensis*	31.6	Mammal	LC [0]	ST [5]	LC [0]	UN [7.3]	24.4 [0]	5 [1]	WS [0]	1-5-1 [18.3]
81	Grey wolf *Canis lupus*	31.2	Mammal	LC [0]	ST [5]	EN [7.5]	DE [10]	100 [0]	2 [0.4]	WS [0]	8-38-2 [8.3]
82	Sand Cat *Felis margarita*	31.2	Mammal	LC [0]	UN [6.7]	NT [2.5]	DE [10]	21.7 [0]	10 [2]	WS [0]	5-38-2 [10]
83	Arabian Spiny Mouse *# *Acomys dimidiatus*	31.0	Mammal	LC [0]	UN [6.7]	LC [0]	UN [7.3]	23.9 [0]	60 [12]	WS [0]	21-788-2 [5]
84	Schmidt's Fringe-fingered Lizard * *Acanthodactylus schmidti*	30.7	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	64.5 [0]	70 [14]	NE [5]	44-350-11 [1.7]
85	Fat Sand Rat *# *Psammomys obesus*	30.0	Mammal	LC [0]	ST [5]	LC [0]	UN [7.3]	53.6 [0]	30 [6]	WS [0]	2-788-1 [11.7]
86	Cape Long-eared Bat *# *Nycteris thebaica*	29.0	Mammal	LC [0]	UN [6.7]	LC [0]	UN [7.3]	5.4 [4.6]	2 [0.4]	WS [0]	16-16-1 [10]
87	Blanford's Fox *Vulpes cana*	28.7	Mammal	LC [0]	ST [5]	VU [5]	DE [10]	21.2 [0]	10 [2]	WS [0]	12-38-3 [6.7]
88	Arabian Sand Boa *Eryx jayakari*	28.7	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	72.4 [0]	60 [12]	WS [0]	13-65-2 [6.7]
89	Horny-scaled Agama *Trapelus ruderatus*	28.7	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	37.4 [0]	60 [12]	WS [0]	13-530-4 [6.7]
90	Snake-tailed Fringe-fingered Lizard * *Acanthodactylus opheodurus*	26.7	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	43.2 [0]	50 [10]	NE [5]	44-350-11 [1.7]
91	Pale Agama * *Trapelus agnetae*	26.7	Reptile	LC [0]	ST [5]	LC [0]	ST [5]	12.6 [0]	50 [10]	WS [0]	13-530-4 [6.7]
92	Arabian Cat Snake *Telescopus dhara*	26.3	Reptile	LC [0]	UN [6.7]	LC [0]	UN [7.3]	39.5 [0]	20 [4]	WS [0]	14-1982-1 [8.3]
93	Cape Hare # *Lepus capensis*	25.7	Mammal	LC [0]	DE [10]	LC [0]	UN [7.3]	8.6 [1.4]	2 [0.4]	WS [0]	32-66-1 [6.7]
94	Wagner's Gerbil *# *Gerbillus dasyurus*	25.0	Mammal	LC [0]	ST [5]	LC [0]	ST [5]	29.2 [0]	50 [10]	WS [0]	48-788-5 [5]
95	Sundevall's Jird *# *Meriones crassus*	24.7	Mammal	LC [0]	UN [6.7]	LC [0]	UN [7.3]	73.0 [0]	20 [4]	WS [0]	17-788-4 [6.7]
96	Rüppell's Fox *Vulpes rueppellii*	23.7	Mammal	LC [0]	ST [5]	LC [0]	DE [10]	84.1 [0]	10 [2]	WS [0]	12-38-3 [6.7]
97	Libyan Jird *# *Meriones libycus*	20.0	Mammal	LC [0]	ST [5]	LC [0]	UN [7.3]	36.8 [0]	5 [1]	WS [0]	17-788-4 [6.7]

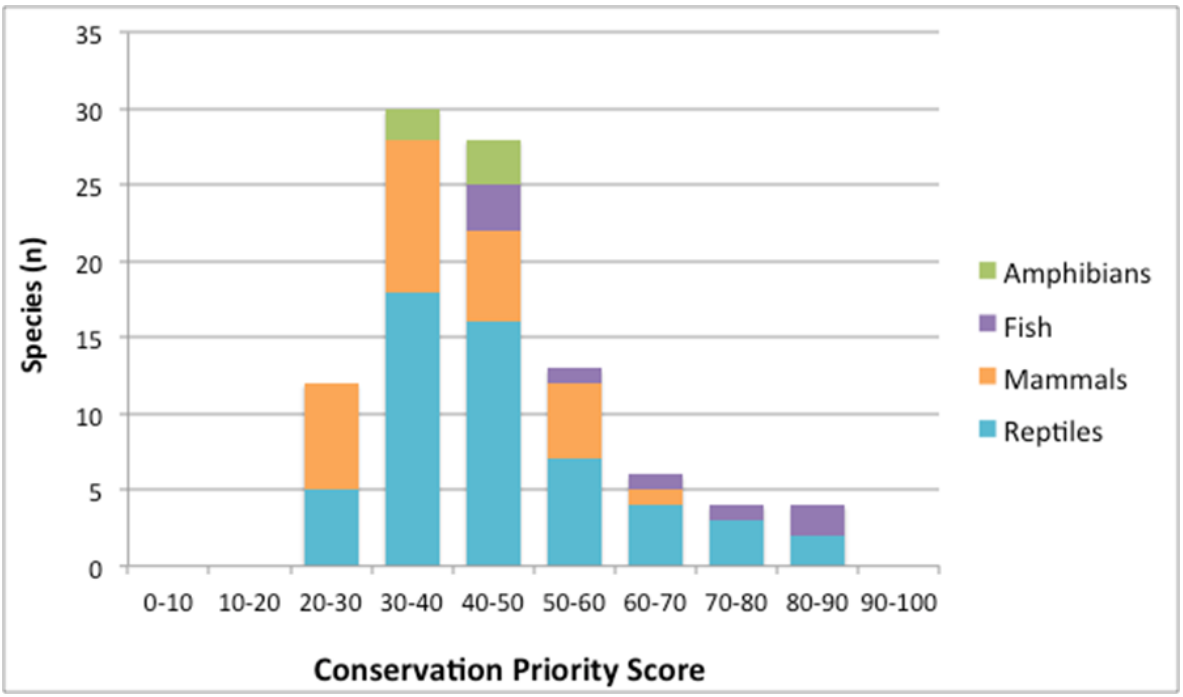

Figure 1. Frequency histogram of the conservation priority scores for the 97 high conservation priority terrestrial vertebrate species in Saudi Arabia.

Table 3. Locations of lowest and highest summed conservation priority scores for each vertebrate phylum in Saudi Arabia.

Phylum	Lowest conservation priority			Highest conservation priority		
	Summed Score	Latitude	Longitude	Summed Score	Latitude	Longitude
Mammals	34	24.660618	41.703005	486.5	18.833380	41.947112
Reptiles	0	18.481795	43.813968	862.4	17.651629	42.602138
Fish	0	Widespread	Widespread	224.8	20.434120	41.268504
Amphibians	0	Widespread	Widespread	187.3	18.446919	42.173909
Birds [a]	533	18.060095	47.436028	2194.63	18.251406	42.344104

[a] Boland & Burwell, 2020a

the NCWCD in 2003, which listed 69 terrestrial species as High Conservation Priority. Of these 69 species, only 39 (57%) met our criteria for inclusion on the High Conservation Priority list. Thus our analysis indicates that (i) 30 species on the NCWCD list are not High Conservation Priority, and (ii) an additional 58 species not listed by the former NCWCD are High Conservation Priority. Accordingly, we recommend that Saudi Arabia's conservation agencies and land managers adjust the focus of conservation effort towards the species on the updated list.

There are two key areas of difference between the High Conservation Priority lists made by our study and the former NCWCD. First, our study almost doubles the number of reptiles regarded as High Conservation Priority species (Table 4), primarily due to recent discoveries of several new species. Second, the NCWCD scheme appears to have been inadvertently biased against small mammals. For example, while the NCWCD list contained only two mammal species weighing less than 100 g (both bats), our empirical prioritization method lists 13 mammal species that weigh less than 100 g (three bats and ten rodents). Conservation and research bias in favor of animals with large body size is well documented (Tensen, 2018; dos Santos *et al*., 2020). This bias may be related to the higher cultural profile (Frynta *et al*., 2013) or greater extinction risk (Schipper *et al*., 2008) of larger animals. By using a purely objective methodology, we have been able to eliminate subconscious preferences.

Using similar methodology, Boland & Burwell (2020a) classified 102 of Saudi Arabia's 488 native bird species as High Conservation Priority. Thus 199 vertebrate species (102 birds, 55 reptiles, 29 mammals, eight freshwater fish, and five amphibian species) should now be regarded as High Conservation Priority to the Kingdom (Table 4). A similar methodology now needs to be applied to the Kingdom's marine vertebrates.

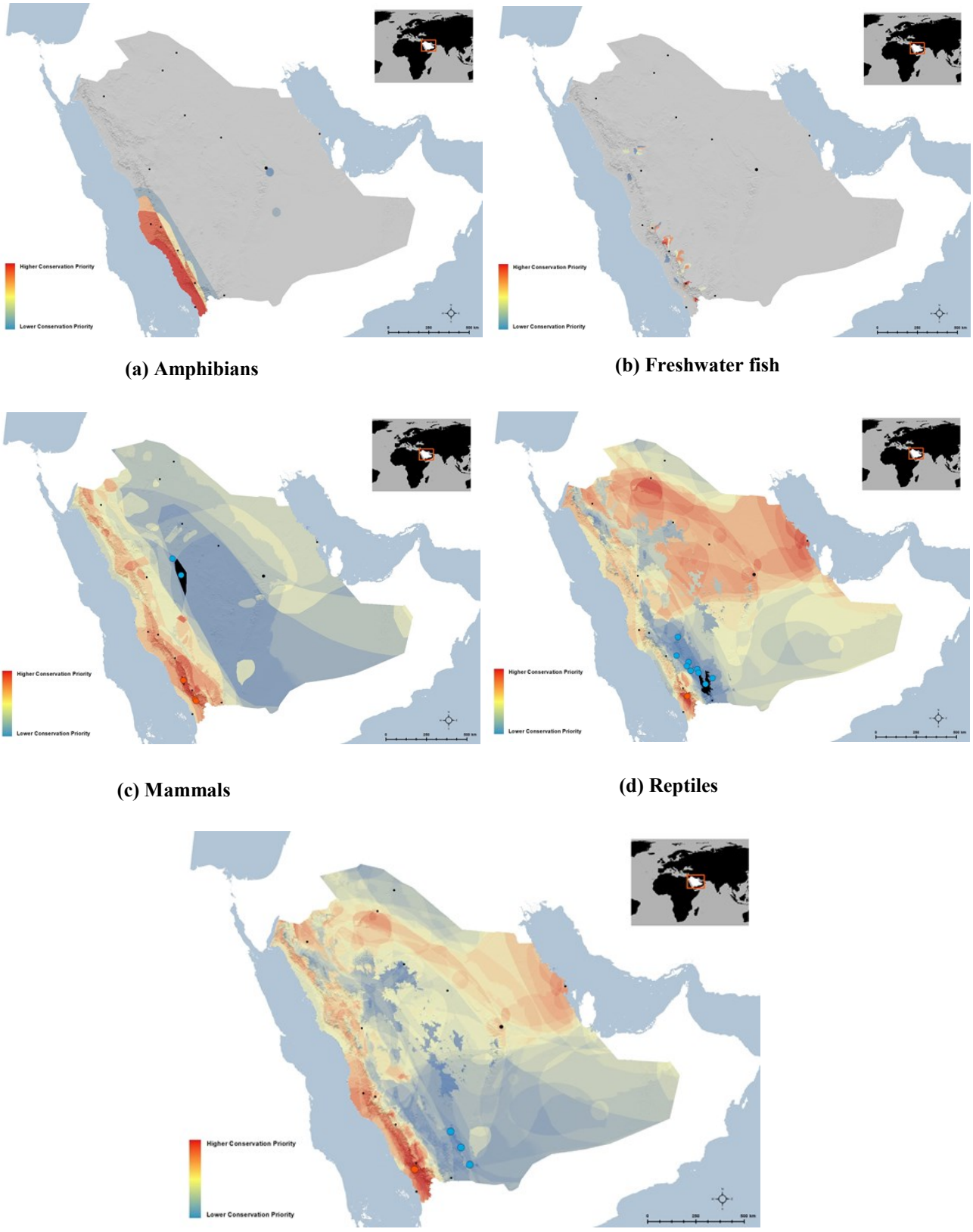

Figure 2. Heat maps of the summed conservation priority scores for each point within Saudi Arabia for (a) amphibians, (b) freshwater fish, (c) mammals, (d) reptiles, and (e) combined. Redder colors indicate areas of higher conservation priority; bluer colors represent areas of lower conservation priority; grey zones indicate areas of zero conservation priority for those taxa. Block dots indicate provincial capitals.

Table 4. Comparison between the numbers of High Conservation Priority (HCP) species in the NCWCD 2003 assessment and the present study

Phylum	Terrestrial species recorded in Saudi Arabia (n)	HCP species – NCWCD 2003 n (% of phylum)	Number of HCP species – this study n (% of phylum)	Number of HCP species included in both studies (n)
Amphibians	7[a]	7 (100)	5 (71)	4
Freshwater fish	8[b]	8 (100)	8 (100)	8
Mammals	75-80[c]	25 (31-33)	29 (36-39)	14
Reptiles	91-112[d]	29 (26-32)	55 (49-60)	12
Birds	488[e]	49 (10)	102[f] (21)	36
Total	670-696	118 (17-18)	199 (29-30)	74

[a] Aloufi *et al*., 2019; IUCN, 2021; [b] Freyhof *et al*., 2015; Hamidan & Shobrak, 2019; IUCN, 2021; [c] Harrison, 1991; Mallon & Budd, 2011; IUCN, 2021; [d] Cox *et al*., 2012; Aloufi *et al*., 2019; [e] Boland & Alsuhaibany, 2020; [f] Boland & Burwell, 2020a

Ranking Saudi Arabia's High Conservation Priority species

Our scoring system ranked the critically endangered Arabian Bream as the highest conservation priority terrestrial vertebrate species in Saudi Arabia. This freshwater fish species was discovered several decades ago at two locations, Wadi Hadiyah (near Hadiyah) and Ain Aljmyma (northwest of Khaybar) in 1977 and 1981, respectively (Coad, Alkahem & Behnke, 1983). But it was not recorded again until 2014 when two individuals were collected from Qusaiba'a Dam in the Al-Thamad area of Khaybar (Hamidan & Aloufi, 2014). It has not been reported since. This species scored very highly because it is critically endangered, decreasing, endemic to Saudi Arabia, has a tiny known range, and is the only member of its genus in the Kingdom. Despite its top conservation priority, almost nobody in Saudi Arabia is aware of its existence, it is essentially unstudied, and as far as we are aware no species-specific conservation action has been directed towards it. Its very small known range and its lack of public profile mean that this species is at great risk of extinction due to water extraction, introduced species, pollution, habitat loss, drought and other threats (Freyhof *et al*., 2015). The Arabian Bream's top ranking underlines the need to mount an urgent conservation program to study and protect the species.

Indeed, several of the highest conservation priority species appear at risk of imminent extinction if indeed they have not already succumbed. For example, Gasperetti's Leafnose Snake (3) was first described in 1977 at Khasawiyah in the southern Asir but has since been recorded from only one other site nearby (Egan, 2007). Leviton's Cylindrical Skink (4) is known from only one location in the far southwest at Khasawiyah (Aloufi *et al*., 2019). Meanwhile, the Sarso Island Racer (5) has not been reported since it was discovered in 1964 from a single specimen in the Farasan archipelago in the Red Sea (Masseti, 2014; Masseti, Marchi & Chiozzi, 2015). Again, these species do not appear to be the focus of any specific conservation or research effort. Dedicated surveys to confirm their existence would be most valuable.

The 11 highest ranked species (and 16 of the top 20) are either freshwater fish or small reptiles—none of which seem to have received direct conservation effort to date. Conversely, the Arabian Oryx (18) has received the most research and conservation effort for any species in the Arabian Peninsula. Considerable conservation effort has also been directed to the Arabian Gazelle (15), Arabian Leopard (20), and Nubian Ibex (21). Thus, there has been a clear bias towards large-bodied mammals when allocating conservation resources and research effort within the Kingdom. While a focus on larger, charismatic species may help garner public support for conservation efforts (Brodie, 2009; Frynta *et al*., 2013), it may unintentionally divert limited conservation resources away from taxa in greater need of funding and protection—including species that may only need a small amount of funding to ensure their survival.

Using an empirical methodology allows conservation agencies to eliminate subconscious biases when allocating resources and effort. For example, our methodology ranked the Grey Wolf (81) and Sand Cat (82) quite low down on the list, which may come as a surprise to some. However, both species are widespread, listed as least concern globally, and only around 10% and 2%, respectively, of their global populations occur within Saudi Arabia (Table 2). Thus, they scored relatively poorly according to our methodology. Conversely, despite being scored as the highest conservation priority mammal (12), the Yemeni Mouse has not received any reported conservation or research effort.

This scoring methodology may also help conservation agencies when deliberating whether or not to embark on a reintroduction program. At least four terrestrial vertebrate species are extinct within Saudi Arabia: the regionally extinct Asiatic Wild Ass, Cheetah, and Lion, and the globally extinct Saudi Gazelle, which was endemic to Saudi Arabia, Kuwait and Yemen. These species were excluded from the analysis; but if a small population of each species was either reintroduced or somehow discovered in Saudi Arabia, they would score (and rank) as follows: Saudi Gazelle 82.2 (3), Cheetah 58.7 (18), Lion 56.9 (20), and Asiatic Wild Ass 51.8 (25). Our study suggests, for example, that there are 24 species that should receive conservation attention before a reintroduction program was

considered for the Asiatic Wild Ass. This also underscores what a tragedy it was to lose the Saudi Gazelle to extinction several decades ago.

Five species in the top 20 have been described only within the last decade, namely Saudi Sand Gecko (6), Alfaraj's Gecko (8), Asir Gecko (10), Saudi Arabian Sand Lizard (11), and Arabian Sand Lizard (19). Each of these species appears to have a very limited distribution, despite reasonably extensive search efforts. With targeted surveys, it should be possible to greatly increase our understanding of the distribution and abundance of these data deficient species, which could in turn significantly alter their conservation priority score and ranking. This, of course, is one of the advantages of using an empirical scoring system—it can be easily updated on the basis of additional data. The challenge is for conservation agencies to be nimble enough to adapt to changing priorities in the face of such new data.

Limitations

While the scoring system used to rank the High Conservation Priority species was designed to be as objective as possible, it nonetheless has some shortcomings. For example, regional population status has not been reported for 14 of the 97 High Conservation Priority species. In these cases, we simply assigned the global conservation status to the species' regional status. Although this is not ideal, global status is a good predictor of regional status: the regional conservation status is the same as the global conservation status for 94% (78/83) of High Conservation Priority species for which we have complete data. However, for the five species in which regional status differs from global status, regional status is invariably the poorer. Thus, our scoring system may be slightly biased against those 14 species with unknown regional status. Based on our understanding, two of those 14 species may be regionally more threatened than their global status suggests, namely the Cape Hare and the Nubian Ibex. The Cape Hare is listed as least concern globally; however, anecdotal reports imply that the Arabian population has undergone a significant decline in distribution and abundance in recent years. If we had scored it as near threatened, then the Cape Hare would have moved up three places to 90th. Similarly, Nubian Ibex is globally vulnerable, but is perhaps regionally endangered. If we made this adjustment, the ibex would move up one place to 20th. This suggests that if there is a bias against these 14 species then the impacts on the overall conservation rankings are likely to be relatively minor.

Global and regional population trend is unknown for 20 and 52 of the High Conservation Priority species, respectively, which reflects the paucity of knowledge about Arabia's terrestrial vertebrates. In these cases, we simply gave the species the mean scores for these criteria for species with complete data (6.7 for global trend and 7.3 for regional trend). Again, this is less than ideal and could bias the results. For instance, species with an unknown population status may be more likely to be decreasing within Arabia (their unknown population trend may be a symptom of their ever-dwindling population size). In the absence of complete data, assigning the mean scores for these attributes seems a reasonable solution.

Another potential shortcoming of our method relates to the differing quality of data between taxa. For example, we needed to develop our own range maps for the freshwater fish species, but used published range maps for the other taxa. However, it is unlikely that this drastically altered the output since our freshwater fish range maps would need to be orders of magnitude larger to significantly change each species' priority ranking. The reasonably extensive surveys conducted by Hamidan & Shobrak (2019) suggest it is unlikely that any of the Kingdom's freshwater fish species has a particularly large range, and that gives us confidence that our range maps are realistic.

Further, the comparatively limited genetic research conducted within the Kingdom could mean that endemic species diversity is underestimated, particularly for isolated amphibian and reptile populations. For example, several potential new reptile species have been discovered in Saudi Arabia in the last ten years (Badiane *et al*., 2014; Metallinou *et al*., 2015; Garcia-Porta *et al*., 2017; Sindaco *et al*., 2018; Tamar *et al*., 2019). These species were not included in the analysis as they are not fully accepted species and there is simply insufficient published data to score them. However, if these taxa were indeed distinct species, they would rank very highly given their endemic status and apparently limited distribution.

While we have attempted to create an objective scoring methodology, we nonetheless needed to make some pragmatic decisions regarding the thresholds for inclusion and the weighting of attributes (cf. Boland & Burwell, 2020a). For instance, we considered species as being of High Conservation Priority if 50% or more of the global population occurs within Saudi Arabia. Some could argue that the threshold for inclusion should be higher, while others might prefer a lower threshold. Ultimately a pragmatic decision was made to set the threshold at 50%.

In addition, we estimated the percentage of the global population that occurs within Saudi Arabia based on species range maps on the obviously weak assumption that species are distributed uniformly across their range. Likewise, we made no attempt to account for variation in conservation value within a species' range (cf. Schnittler & Günther, 1999; Kukkala *et al*., 2019). However, since these data do not exist in Saudi Arabia and could take decades to attain, our method serves as a reasonably objective scoring system for ranking the conservation priorities of vertebrates within the Kingdom and in other poorly studied regions.

Mapping Saudi Arabia's High Conservation Priority species

Our spatial analyses indicate that the highest conservation priority areas for amphibians, freshwater fish, mammals and reptiles all occur in the southern Asir Mountains (Figure 2). The Asir Mountains also contain the highest conservation priority area for birds (Boland & Burwell, 2020a). The fact that the Asir Mountains represent the highest conservation priority area in Saudi Arabia is not surprising given this is the most diverse ecosystem in the Kingdom and Arabia's only endemic biodiversity hotspot (Conservation International, 2021). The highest conservation priority species of amphibian (Arabian Tree Frog), mammal (Yemeni Mouse), reptile (Gasperetti's Leafnose Snake), and bird (Asir Magpie: Boland & Burwell, 2020a,b) each occurs in the southern

Table 5. Likely key threatening processes for the 20 highest conservation priority terrestrial vertebrate species in Saudi Arabia.

Rank	Species	Key threats within Saudi Arabia
1	Arabian Bream *Acanthobrama hadiyahensis*	Water extraction, impoundment, introduced species, stream pollution, habitat loss, drought [a]
2	Arabian Himri *Carasobarbus apoensis*	Water extraction, impoundment, introduced species, stream pollution, habitat loss, drought [a]
3	Gasperetti's Leafnose Snake *Lytorhynchus gasperetti*	Habitat loss, habitat fragmentation, habitat degradation, overgrazing, Allee effects [b]
4	Leviton's Cylindrical Skink *Chalcides levitoni*	Habitat loss, habitat fragmentation, habitat degradation, overgrazing, Allee effects [b]
5	Sarso Island Racer *Coluber insulanus*	Habitat loss, habitat degradation, overgrazing, Allee effects, persecution [b]
6	Saudi Sand Gecko *Tropiocolotes wolfgangboehmei*	Habitat loss, habitat fragmentation, habitat degradation [b]
7	Asir Garra *Garra buettikeri*	Water extraction, impoundment, introduced species, stream pollution, habitat loss, drought [a]
8	Alfaraj's Gecko *Hemidactylus alfaraji*	Habitat loss, habitat fragmentation, habitat degradation, overgrazing, climate change [b]
9	Arabian Lotak *Cyprinion mhalense*	Water extraction, impoundment, introduced species, stream pollution, habitat loss, drought [a]
10	Asir Gecko *Hemidactylus asirensis*	Habitat loss, habitat fragmentation, habitat degradation, overgrazing [b]
11	Saudi Arabian Sand Lizard *Mesalina saudiarabica*	Habitat loss, habitat fragmentation, habitat degradation [b]
12	Yemeni Mouse *Myomyscus yemeni*	Habitat loss, habitat fragmentation, habitat degradation, mesopredator release
13	Mount Elba Snake-eyed Lizard *Ophisops elbaensis*	Habitat loss, habitat fragmentation, habitat degradation, climate change [b]
14	Saudi Fringe-fingered Lizard *Acanthodactylus gongrorhynchatus*	Allee effects, habitat loss, habitat fragmentation, habitat degradation, climate change [b]
15	Arabian Gazelle *Gazella arabica*	Habitat fragmentation, poaching, hunting, lack of genetic diversity, captive stress [d]
16	Bearded Turtle *Pelomedusa barbata*	Water extraction, impoundment, introduced species, stream pollution, habitat loss [b]
17	Arabian Egg-eater *Dasypeltis arabica*	Habitat loss, habitat fragmentation, habitat degradation, overgrazing, persecution [b]
18	Arabian Oryx *Oryx leucoryx*	Poaching, hunting, lack of genetic diversity [c]
19	Arabian Sand Lizard *Mesalina arnoldi*	Habitat loss, habitat fragmentation, habitat degradation [b]
20	Leopard *Panthera pardus*	Habitat fragmentation, poisoning, hunting, lack of genetic diversity, Allee effects, persecution [e]

[a] Freyhof *et al*., 2015; Hamidan & Shobrak, 2019; [b] Cox *et al*., 2012; Aloufi *et al*., 2019; [c] Islam, Ismail & Boug, 2011 [d] Soares *et al*., 2014; Al Jahdhami *et al*., 2017; Svizzero, 2019; [e] Mallon & Budd, 2011; Islam *et al*., 2018

Asir Mountains, while the highest conservation priority freshwater fish (Arabian Bream) is found in the Hezaj Mountains to the north. These heat maps should help conservation agencies when designating and managing protected areas, as well as land managers and industries when determining appropriate biodiversity avoidance, mitigation, restoration, or offsetting measures.

Protecting Saudi Arabia's High Conservation Priority species

As a result of our ranking system, we are now able to assess the threatening processes impacting the highest conservation priority terrestrial vertebrate species in Saudi Arabia. Our preliminary evaluation suggests that a broad array of threats is likely to be impacting Saudi Arabia's highest conservation priority species (Table 5). The most obvious threatening processes include alpine habitat loss, fragmentation and degradation, water extraction, overgrazing, poaching, and persecution, alongside numerous other threats. However, so little research has been conducted on the majority of these species that specific threats cannot be confidently identified in most cases. For most species, particularly the species with a conservation status listed as data deficient, an obvious priority action is to conduct targeted surveys and basic research to fill those data gaps.

In conclusion, we have developed an empirical methodology to rank the conservation priority of every terrestrial vertebrate species in Saudi Arabia. None of the 97 High Conservation Priority species are

increasing regionally or globally, which suggests that current conservation actions are not sufficient to protect the Kingdom's imperiled wildlife. We recommend that conservation agencies develop and implement species-specific recovery plans for each of the 20 highest conservation priority vertebrate species in Saudi Arabia. Species-specific surveys are needed to determine the population status and trend for numerous high-ranking data deficient species in Saudi Arabia. Further, conservation programs that protect and restore critical habitat in the Asir Mountains and other high conservation priority areas are urgently needed.

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REFERENCES

Al Jahdhami, M. H., Al Bulushi, S., Al Rawahi, H., Al Fazari, W., Al Amri, A., Al Owaisi, A., Al Rubaiey, S., Al Abdulasalam, Z., Al Ghafri, M., Yadav, S. and Al Rahbi, S. 2017. The status of Arabian Gazelles Gazella arabica (Mammalia: Cetartiodactyla: Bovidae) in Al Wusta Wildlife Reserve and Ras Ash Shajar Nature Reserve, Oman. Journal of Threatened Taxa 9(7): 10369-10373.

Aloufi, A. A., Amr, Z. S., Abu Baker, M. A. and Hamidan, N. 2019. Diversity and conservation of terrestrial, freshwater and marine reptiles and amphibians in Saudi Arabia. Amphibian and Reptile Conservation 13(2): 181-202.

Badiane, A., Garcia-Porta, J., Cervenka, J., Kratochvıl, L., Sindaco, R., Robinson, M. D. and Carranza, S. 2014. Phylogenetic relationships of semaphore geckos (Squamata: Sphaerodactylidae: Pristurus) with an assessment of the taxonomy of *Pristurus rupestris*. Zootaxa 3885: 33-58.

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O., Swartz, B., Quental, T. B., Marshall, C., McGuire, J. L., Lindsey, E. L., Maguire, K. C. and Mersey, B. 2011. Has the Earth's sixth mass extinction already arrived? Nature 471(7336): 51-57.

Bates, M. F. and Broadley, D. G. 2018. A revision of the egg-eating snakes of the genus *Dasypeltis* Wagler (Squamata: Colubridae: Colubrinae) in north-eastern Africa and south-western Arabia, with descriptions of three new species. Indago 34(1): 1 -95.

Boland, C. R. J. and Burwell, B. O. 2020a. Ranking and mapping the high conservation priority bird species of Saudi Arabia. Avian Conservation and Ecology: 15(2).

Boland, C. R. J. and Burwell, B. O. 2020b. Habitat modelling reveals extreme habitat fragmentation in the endangered and declining Asir Magpie, *Pica asirensis*, Saudi Arabia's only endemic bird (Aves: Passeriformes). Zoology in the Middle East 66(4): 283-294.

Bottrill, M. C., Joseph, L. N., Carwardine, J., Bode, M., Cook, C., Game, E. T., Grantham, H., Kark, S., Linke, S., McDonald-Madden, E. and Pressey, R. L. 2008. Is conservation triage just smart decision making? Trends in Ecology and Evolution 23 (12): 649-654.

Brodie, J. F. 2009. Is research effort allocated efficiently for conservation? Felidae as a global case study. Biodiversity and Conservation 18(11): 2927-2939.

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M. and Palmer, T. M. 2015. Accelerated modern human-induced species losses: Entering the sixth mass extinction. Science Advances 1(5): e1400253.

Coad, B. W, Alkahem, H. F. and Behnke, R. J. 1983. *Acanthobrama hadiyahensis*, a new species of cyprinid fish from Saudi Arabia. Publications in Natural Sciences, National Museums of Canada 2: 1-6.

Collen, B., Turvey, S. T., Waterman, C., Meredith, H. M., Kuhn, T. S., Baillie, J. E. and Isaac, N. J. 2011. Investing in evolutionary history: implementing a phylogenetic approach for mammal conservation. Philosophical Transactions of the Royal Society B: Biological Sciences 366(1578): 2611-2622.

Conservation International 2021. Critical ecosystem partnership fund. Biodiversity hotspots. www.cepf.net/our-work/biodiversity-hotspots. Cited 22 June 2021.

Cox, N., Mallon, D., Bowles, P., Els, J. and Tognelli, M. 2012. The Conservation Status and Distribution of Reptiles of the Arabian Peninsula. IUCN. Gland, Switzerland & Cambridge, and the Environment and Protected Areas Authority, Abu Dhabi.

dos Santos, J. W., Correia, R. A., Malhado, A. C., Campos-Silva, J. V., Teles, D., Jepson, P. and Ladle, R. J. 2020. Drivers of taxonomic bias in conservation research: a global analysis of terrestrial mammals. Animal Conservation 23(6): 679-688.

Egan, D. 2007. Snakes of Arabia: A Field Guide to the Snakes of the Arabian Peninsula and its Shores. Motivate, Dubai.

Environmental Systems Research Institute (ESRI) 2018. ArcGIS Desktop Release 10.6.1. Environmental Systems Research Institute, Redlands, California.

Fischer, A., Bednar-Friedl, B., Langers, F., Dobrovodská, M., Geamana, N., Skogen, K. and Dumortier, M. 2011. Universal criteria for species conservation priorities? Findings from a survey of public views across Europe. Biological Conservation 144(3): 998-1007.

Fitzpatrick, U. N. A., Murray, T. E., Paxton, R. J. and Brown, M. J. 2007. Building on IUCN regional red lists to produce lists of species of conservation priority: a model with Irish bees. Conservation Biology 21(5): 1324-1332.

Freyhof, J., Hamidan, N. A., Feulner, G. R. and Harrison, I. 2015. The status and distribution of freshwater fishes of the Arabian Peninsula. Pp. 16-29. In Status and Distribution of Freshwater Biodiversity in the Arabian Peninsula. (eds García, N., Harrison, I., Cox, N. and Tognelli, M. F. IUCN, Gland, Cambridge, and Arlington.

Froese, R. and Pauly, D. (eds). 2019. FishBase Version 12/2019. www. Fishbase.org. Cited 22 June 2021.

Frynta, D., Šimková, O., Lišková, S. and Landová, E. 2013. Mammalian collection on Noah's ark: the effects of beauty, brain and body size. PloS one 8 (5): e63110.

Garcia-Porta, J., Simó-Riudalbas, M., Robinson, M. and Carranza, S. 2017. Diversification in arid mountains: biogeography and cryptic diversity of *Pristurus rupestris rupestris* in Arabia. Journal of Biogeography 44(8): 1694-1704.

Gvoždík, V., Moravec, J., Klütsch, C. and Kotlík, P. 2010. Phylogeography of the Middle Eastern tree frogs (Hyla, Hylidae, Amphibia) as inferred from nuclear and mitochondrial DNA variation, with a description of a new species. Molecular Phylogenetics and Evolution 55(3): 1146-1166.

Hamidan, N. A. F. and Shobrak, M. 2019. An Update on Freshwater Fishes of Saudi Arabia. Journal of Biological Sciences 12(4): 495-502.

Hamidan, N. and Aloufi, A. A. 2014. Rediscovery of *Acanthobrama hadiyahensis* (Cyprinidae) in Saudi Arabia. Journal of Fish Biology 84(4): 1179-1184.

Harrison, D. 1991. Mammals of Arabia. Harrison Zoological Museum, Sevenoaks.

Harrison, I., Cox, N. and Tognelli, M. F. 2015. The Status and Distribution of Freshwater Biodiversity in the Arabian Peninsula. IUCN, Gland, Cambridge, & Arlington.

Islam, M. Z., Ismail, K. and Boug, A. 2011. Restoration of the endangered Arabian Oryx *Oryx leucoryx*, Pallas 1766 in Saudi Arabia: lessons learnt from the twenty years of re-introduction in arid fenced and unfenced protected areas: (Mammalia: Artiodactyla). Zoology in the Middle East 54(3): 125-140.

Islam, M. Z., M., Boug, A., Judas, J. and As-Shehri, A. 2018. Conservation challenges for the Arabian Leopard (*Panthera pardus nimr*) in the Western Highlands of Arabia. Biodiversity 19: 188-197.

IUCN 2021. The IUCN red list of threatened species. Version 2021-3. www.iucnredlist.org Cited 22 June 2021.

Jetz, W., Thomas, G. H., Joy, J. B., Redding, D. W., Hartmann, K. and Mooers, A. O. 2014. Global distribution and conservation of evolutionary distinctness in birds. Current Biology 24(9): 919-930.

Joseph, L. N., Maloney, R. F. and Possingham, H. P. 2009. Optimal allocation of resources among threatened species: a project prioritization protocol. Conservation Biology 23(2): 328-338.

Kukkala, A., Maiorano, L., Thuiller, W. and Arponen, A. 2019. Identifying national responsibility species based on spatial conservation prioritization. Biological Conservation 236: 411-419.

Le Berre, M., Noble, V., Pires, M., Médail, F. and Diademe, K. 2019. How to hierarchize species to determine priorities for conservation action? A critical analysis. Biodiversity and Conservation 28(12): 3051-3071.

Mallon, D. and Budd, K. 2011. Regional Red List Status of Carnivores in the Arabian Peninsula. IUCN, Gland, Cambridge, & Arlington, Cambridge, and Environment and Protected Areas Authority, Sharjah.

Masseti, M. 2014. Herpetological enigmas from the Arabian seas, with particular reference to the Sarso Island racer, *Platyceps insularis* Mertens, 1965 (Farasan archipelago, Saudi Arabia). In Scripta Herpetologica: Studies on Amphibians and Reptiles in Honour of Benedetto Lanza. (eds Capula, M. and Corti, C.). Edizioni Belvedere, Latina.

Masseti, M., De Marchi, G. and Chiozzi, G. 2015. Forbidden islands. The absence of endemics among the insular non-volant terrestrial mammalian fauna of the Red Sea. Natural History Sciences 2(2): 101-130.

McCarthy, D. P., Donald, P. F., Scharlemann, J. P., Buchanan, G. M., Balmford, A., Green, J. M., Bennun, L. A., Burgess, N. D., Fishpool, L. D., Garnett, S. T. and Leonard, D. L. 2012. Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. Science 338(6109): 946-949.

McGowan, J., Beaumont, L. J., Smith, R. J., Chauvenet, A. L., Harcourt, R., Atkinson, S. C., Mittermeier, J. C., Esperon-Rodriguez, M., Baumgartner, J.B., Beattie, A. and Dudaniec, R. Y. 2020. Conservation prioritization can resolve the flagship species conundrum. Nature Communications 11(1): 1-7.

Metallinou, M., Červenka, J., Crochet, P. A., Kratochvíl, L., Wilms, T., Geniez, P., Shobrak, M. Y., Brito, J. C. and Carranza, S. 2015. Species on the rocks: Systematics and biogeography of the rock-dwelling *Ptyodactylus* geckos (Squamata: Phyllodactylidae) in North Africa and Arabia. Molecular Phylogenetics and Evolution 85: 208-220.

Meyer, C., Kreft, H., Guralnick, R. and Jetz, W. 2015. Global priorities for an effective information basis of biodiversity distributions. Nature Communications 6(1): 1-8.

NCWCD 2003. First Saudi Arabian National Report on the Convention on Biological Diversity. National Commission for Wildlife Conservation and Development, Riyadh.

Nilson, G. and Rastegar-Pouyani, N. 2007. *Walterinnesia aegyptia* Lataste, 1887 (Ophidia: Elapidae) and the status of *Naja morgani* Mocquard 1905. Russian Journal of Herpetology 14(1): 7-14.

Peterson, M. N., Bruskotter, J. T. and Rodriguez, S. L. 2020. Conservation hospice: A better metaphor for the conservation and care of terminal species. Frontiers in Ecology and Evolution 8: 143.

Petzold, A., Vargas-Ramirez, M., Kehlmaier, C., Vamberger, M., Branch, W. R., Du Preez, L., Hofmeyr, M. D., Meyer, L., Schleicher, A., Široký, P. and Fritz, U. 2014. A revision of African helmeted terrapins (Testudines: Pelomedusidae: Pelomedusa), with descriptions of six new species. Zootaxa 3795(5): 523-548.

Pimm, S. L., Russell, G. J., Gittleman, J. L. and Brooks, T. M. 1995. The future of biodiversity. Science 269(5222): 347-350.

Redding, D. W., Hartmann, K., Mimoto, A., Bokal, D., DeVos, M. and Mooers, A. Ø. 2008. Evolutionarily distinctive species often capture more phylogenetic diversity than expected. Journal of Theoretical Biology 251(4): 606-615.

Schipper, J., Chanson, J. S., Chiozza, F., Cox, N. A., Hoffmann, M., Katariya, V., Lamoreux, J., Rodrigues, A. S., Stuart, S. N., Temple, H. J. and Baillie, J. 2008. The status of the world's land and marine mammals: diversity, threat, and knowledge. Science 322(5899): 225-230.

Schmeller, D. S., Evans, D., Lin, Y. P. and Henle, K. 2014. The national responsibility approach to setting conservation priorities—recommendations for its use. Journal of Nature Conservation 22(4): 349-357.

Schnittler, M. and Günther, K. F. 1999. Central European vascular plants requiring priority conservation measures–an analysis from national Red Lists and distribution maps. Biodiversity and Conservation 8(7): 891-925.

Sindaco, R., Simo-Riudalbas, M., Sacchi, R. and Carranza, S. 2018. Systematics of the *Mesalina guttulata* species complex (Squamata: Lacertidae) from Arabia with the description of two new species. Zootaxa 4429(3): 513-547.

Šmíd, J., Shobrak, M., Wilms, T., Joger, U. and Carranza, S. 2017a. Endemic diversification in the mountains: genetic, morphological, and geographical differentiation of the *Hemidactylus* geckos in southwestern Arabia. Organisms Diversity and Evolution 17(1): 267-285.

Šmíd, J., Moravec, J., Gvoždík, V., Štundl, J., Frynta, D., Lymberakis, P., Kapli, P., Wilms, T., Schmitz, A., Shobrak, M. and Yousefkhani, S. H. 2017b. Cutting the Gordian Knot: Phylogenetic and ecological diversification of the *Mesalina brevirostris* species complex (Squamata, Lacertidae). Zoologica Scripta 46(6): 649-664.

Soares, J. F., Pereira, H., Desta, F. S., Sandouka, M. and Macasero, W. 2015. Causes of mortality of captive Arabian gazelles (*Gazella arabica*) at King Khalid Wildlife Research Centre, Kingdom of Saudi Arabia, from 1988 to 2011. Journal of Zoo and Wildlife Medicine 46(1): 1-8.

Svizzero, S. 2019. Issues and Challenges in the Conservation of the Goitered Gazelle (*Gazella subgutturosa*; Güldenstädt, 1780). International Journal of Zoological Research 3: 1-9.

Tamar, K., Chirio, L., Shobrak, M., Busais, S. and Carranza, S. 2019. Using multilocus approach to uncover cryptic diversity within *Pseudotrapelus* lizards from Saudi Arabia. Saudi Journal of Biological Sciences 26(7): 1442-1449.

Tensen, L. 2018. Biases in wildlife and conservation research, using felids and canids as a case study. Global Ecology and Conservation 15: e00423.

Uetz, P., Freed, P. and Hošek, J. (eds) 2021. The reptile database. www.reptile-database.org. Cited 18 June 2021.

Vane-Wright, R. I., Humphries, C. J. and Williams, P. H. 1991. What to protect? Systematics and the agony of choice. Biological Conservation 55(3): 235-254.

Vieira da Silva, C., Madureira, L., Costa, J. L. and Santos, J. L. 2016. Using public preferences to weight species prioritization criteria in conservation decision making: a case study to explore potential strengths and weaknesses. Society and Natural Resources 29(12): 1517-1532.

Wilson, K. A., Carwardine, J. and Possingham, H. P. 2009. Setting conservation priorities. Annals of the New York Academy of Sciences 1162(1): 237-264.