



Prioritizing Conservation: Vulnerability Assessment of Pakistan's Threatened Species Using SAVS

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ABSTRACT

Vulnerability assessment is the key tool for selecting targets in order to prioritize conservation requirements and define management measures. The SAVS (system for assessing vulnerability of species) technique, which employs a simple questionnaire based on 22 predictive criteria that converts scores indicating a species' reaction to climate change into scores indicating resilience or vulnerability, was used in this study to assess the vulnerability of Pakistan's threatened species. In Pakistan, a total of 1108 species can be found including birds, mammals, reptiles and amphibians. Out of 1108, approximately 80 species may be threatened according to the IUCN (International Union for Conservation of Nature) red list of threatened species of Flora and Fauna. Out of 80, there are 43 birds, 24 mammals and 13 reptiles. Among these species, fifty species (62.5%) are vulnerable (VU), twenty species (25%) are endangered (EN) and ten species (12.5%) are critically endangered (CR). Field surveys, published studies, reports, and expert knowledge was utilized to identify suitable response options for each question. The overall vulnerability score is scaled from -20 (most resilient) to +20 (most susceptible). According to the scores, gharial (*Gavialis gangeticus*) (CR), Indian skimmer (*Rynchops albicollis*) (EN), Egyptian vulture (*Neophron percnopterus*) (EN), Asian woolly-necked stork (*Ciconia episcopus*) (VU) and tawny eagle *Aquila rapax* (VU) are top priority species for conservation with overall vulnerability value of 11.67, 11.53, 11.53, 10.77 and 10.77, respectively with 0, 5, 5, 5, 0 uncertainty scores. As a starting point, these conservation efforts can be made for these species on priority basis followed by the management actions for other threatened species.

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Authors' Contribution

ZA and RA conceptualized the study. ZA, RA and UA made the assessments and filled the questionnaires. RA and ZA assembled the dataset. RA drafted the manuscript. FM and ZA reviewed and improved the manuscript.

Key words

Vulnerability assessment, Climate change, SAVS, Threatened species, Conservation, Management

INTRODUCTION

Species and ecosystems are at different levels of susceptibility to the impacts of climate change across the globe. Due to the expected increase in the mean global temperature and increasing frequency and intensity of extreme climate events, threat rates for many ecosystems are expected to steepen for the most parts (IPCC, 2022). Assessing the vulnerability of threatened species is important because it helps prioritize conservation efforts and

resources. By understanding the threats a species faces and how susceptible it is to them, conservationists can determine which species are most in need of protection and allocate resources accordingly (Harper *et al.*, 2022). Thorough assessment of species and ecosystem impacts from human activities is essential for effective conservation and management (Butt *et al.*, 2022). This information can also guide the development of effective management strategies and conservation plans to help ensure the survival of these species in the long term. Additionally, regularly assessing the vulnerability of threatened species can provide important data for monitoring the effectiveness of conservation measures and identifying when additional actions may be necessary (Simmonds *et al.*, 2020).

Global warming is the key challenge of our time with regard to preserving nature. The impacts of climate change are getting more and more evident, from flooded coastal wetlands and dehydrated prairie potholes to ice caps melting (Albouy *et al.*, 2020). These effects of climate transformation will profoundly alter our capacity to preserve aquatic and terrestrial species and their habitats.

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The ecological effects of climate change do not stand alone, but interact with and intensify current pressures on nature. Knowing the connections will be essential in developing successful conservation strategies (Habibullah *et al.*, 2022). In this era of climate change, we must not only tackle the ecological issues of the past, but also look ahead and be ready to face the future's uncertainties. Vulnerability assessments can give us an understanding of which species and systems are likely to decline and which are likely to flourish (Glick *et al.*, 2011).

It is not possible to have a single, ideal procedure for vulnerability assessment that would fit all contexts. Rather, the design and execution of an assessment should depend on a thorough comprehension of the user requirements, the decision-making processes it will support, and the resources available; such as time, data, money and expert knowledge (Bagne *et al.*, 2011). Vulnerability analyses or risk of extinction assessments are useful for selecting objectives and arranging conservation requirements so that management practices, or adaptation policies, can be organized in efficient manner (Patt *et al.*, 2009). Valuation that also reveals how species and their habitats are altered by expected fluctuations allow directors to create new strategies and evaluate present management processes in terms of anticipated future circumstances (Füssel and Klein, 2008; Glick *et al.*, 2011).

According to the intergovernmental panel on climate change (IPCC), vulnerability is a function of sensitivity to a specific change in climate, exposure to these alterations and capacity of adaptation to these processes (IPCC, 2007). Sensitivity is the degree that how a species may be impacted by the climate change. Exposure is the measurement of how much change in climatic conditions and associated impact a species may experience. Adaptive capacity is defined as the opportunities that may be used to cope with sensitivity and exposure (Kovach *et al.*, 2019). Exposure and sensitivity to the climatic changes leads to determination of the potential impact. To understand the potential consequences (vulnerability) needs further attention of the species ability to cope with the possible impacts (adaptive capacity) (Glick *et al.*, 2011).

This paper uses a system for assessing vulnerability of species (SAVS) tool that can decipher how prone and to what degree species can be impacted by climate change. The SAVS assesses the comparative vulnerability or stability of vertebrate species to climate change. Created for administrators, the SAVS is a simple to use approach that employs 22 predictive indicators to generate vulnerability scores. The user scores the species characteristics connecting to potential of being vulnerable or resilient based on projections for the area. The SAVS gives a system for incorporating fresh information into the

climate change assessment process, producing six scores: An overall score, representing the level of being vulnerable or resilient, four categorical scores (habitat, physiology, phenology, and biotic interactions) indicating the root of vulnerability and uncertainty scores, which shows user confidence in the expected response (Bagne *et al.*, 2011). The main objective of this study was to prioritize the species for protection and conservation.

MATERIALS AND METHODS

The current research was carried out to assess the vulnerability of threatened species in Pakistan. A list of birds, mammals, reptiles and amphibians was compiled using published literature and books, mainly, Birds of Pakistan (Roberts, 1991, 1992; Mirza and Wasiq, 2007; Grimmett *et al.*, 2008), Mammals of Pakistan (Roberts, 1997), amphibians and reptiles of Pakistan (Khan, 2006) and published literature. Moreover, the compiled list was checked and reviewed by the wildlife experts with more than thirty years of field experience. According to the compiled list, 1108 species inhabit Pakistan either as year-round residents, summer breeders, winter migrants or passage migrants. The status of each species was obtained from IUCN red list (<https://www.iucnredlist.org/>). Out of 1108, approximately 80 species were globally threatened. Although regional conservation status can be different from global IUCN status, yet as a starting point, these eighty species were considered for the current research. Among these, 10 species are marine. Considering the assessment criteria applicability, marine species were excluded in SAVS analysis.

Study area

In Pakistan, approximately 80 species are threatened which are distributed in different habitats. The study area covers all representative habitats including water bodies, settlements, bare rocks/gravel, shrublands, grasslands, forests and deserts across Pakistan.

Geographical position

Pakistan has an area of 882,000 km² (Baig and Ahmed, 2007) between latitude 24° and 37° North and longitude 61° and 78° East (Fig. 1). The elevation ranges from sea level to almost 8000 meters above sea level.

System for assessing vulnerability of species

The SAVS tool is used to identify the relative vulnerability of vertebrates to climatic changes. It is an easily applicable tool that contains 22 predictive criteria based questionnaire to formulate the vulnerability scores (Bagne *et al.*, 2011). The questionnaire is given in

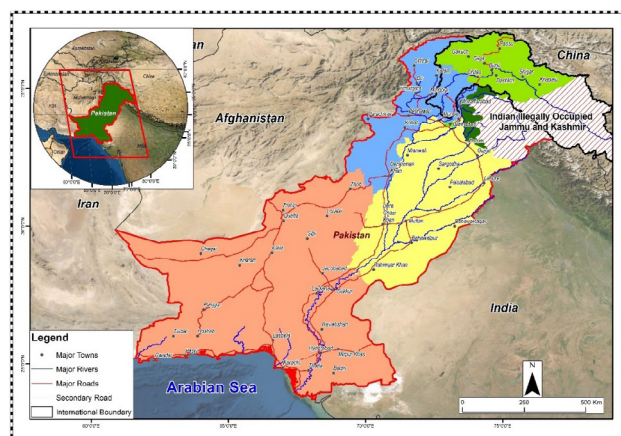


Fig. 1. Map of Pakistan.

Table I. The criteria used in SAVS tool (Bagne *et al.*, 2011).

Factor and criteria	Vulnerability component
Habitat	
H1. Breeding habitat area and distribution	Exposure, sensitivity
H1. Non-breeding habitat area and distribution	Exposure, sensitivity
H1. Habitat components required for breeding	Exposure, sensitivity
H1. Habitat components required outside breeding	Exposure, sensitivity
H1. Habitat quality	Exposure, sensitivity
H1. Ability to colonize new areas	Adaptive capacity
H1. Reliance on migratory or transitional habitats	Sensitivity
Physiology	
PS1. Physiological thresholds capacity	Sensitivity, adaptive
PS1. Sex ratio related to temperature	Sensitivity
PS1. Exposure to weather-related disturbance	Sensitivity, exposure
PS1. Changes to daily activity period	Sensitivity, adaptive capacity
PS1. Survival during resource fluctuation	Adaptive capacity
PS1. Energy requirements	Sensitivity
Phenology	
PH1. Mismatch potential: Cues	Sensitivity
PH1. Mismatch potential: Event timing	Sensitivity
PH1. Mismatch potential: Proximity	Sensitivity
PH1. Resilience to timing mismatch capacity	Sensitivity, adaptive
Biotic interactions	
I1. Food resources	Exposure, sensitivity
I2. Predators	Exposure, sensitivity
I3. Symbionts	Exposure, sensitivity
I4. Disease	Exposure, sensitivity
I5. Competitors	Exposure, sensitivity

Supplementary Table SI. In SAVS, each element or category (habitat, physiology, phenology, and biotic interaction) is scaled to a range of -5 to +5, and the total vulnerability score is scaled from -20 (most resilient) to +20 (most susceptible). The factors, criteria and vulnerability components (exposure, sensitivity and adaptive capacity) used in SAVS tool are given in Table I.

Frequent published studies, reports, field surveys and expert knowledge was utilized to identify suitable response options for each question. The field surveys of different areas in Pakistan were conducted from May 2017 to December 2022. Moreover, climate projections (temperature and precipitation) for the target region were acquired from Pakistan Meteorological Department (Figs. 2 and 3).

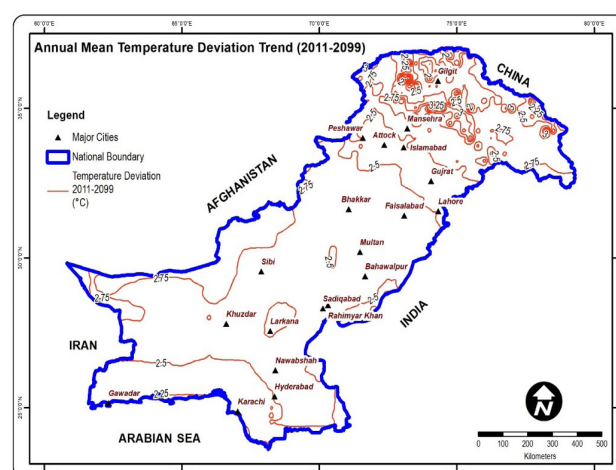


Fig. 2. Annual mean temperature trend.

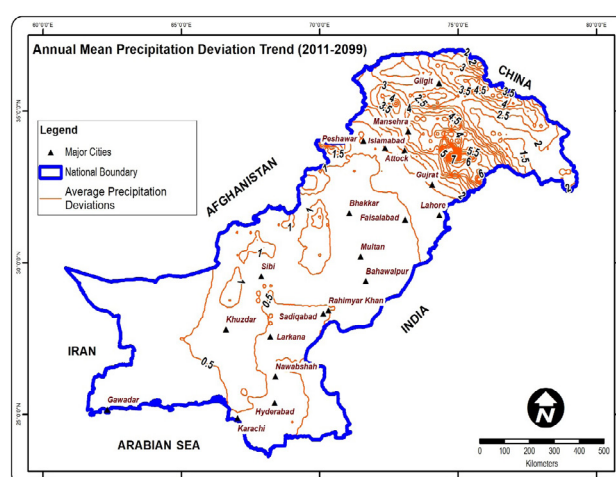


Fig. 3. Annual mean precipitation trend.

RESULTS

The current research was carried out to assess the vulnerability of Pakistan's threatened species. According to IUCN red list, there are eighty threatened species out of total 1108 species of birds, mammals, reptiles and amphibians in Pakistan (IUCN, 2022). Out of 80, there

are 43 birds, 24 mammals and 13 reptiles (Table II). Out of these, five mammals are five reptiles are marine. There are three sub-categories under threatened, i.e., vulnerable (VU), endangered (EN) and critically endangered (CR). Among threatened species in Pakistan, 62.5% (50 species) are VU, 25% (20 species) are EN and 12.5% (10 species) are CR.

Table II. List of threatened species across Pakistan.

Order/ Family	Species	IUCN status*	Trend	Occurrence**
BIRDS				
Order: Galliformes				
Family: Phasianidae	1 Western tragopan (<i>Tragopan melanocephalus</i>)	VU	Decreasing	YRR
	2 Cheer pheasant (<i>Catreus wallichii</i>)	VU	Decreasing	YRR
Order: Anseriformes				
Family: Anatidae	3 White-headed duck (<i>Oxyura leucocephala</i>)	EN	Decreasing	WM
	4 Marbled duck (<i>Marmaronetta angustirostris</i>)	VU	Decreasing	WM
	5 Common pochard (<i>Aythya ferina</i>)	VU	Decreasing	WM
	6 Lesser white-fronted goose (<i>Anser erythropus</i>)	VU	Decreasing	NA
	7 Baer's pochard (<i>Aythya baeri</i>)	CR	Decreasing	NA
	8 Long-tailed duck (<i>Clangula hyemalis</i>)	VU	Decreasing	NA
Order: Columbiformes				
Family: Columbidae	9 Yellow-eyed pigeon (<i>Columba eversmanni</i>)	VU	Decreasing	PM/WM
	10 European turtle dove (<i>Streptopelia turtur</i>)	VU	Decreasing	PM
Order: Otidiformes				
Family: Otididae	11 Great Indian bustard (<i>Ardeotis nigriceps</i>)	CR	Decreasing	WM
	12 Macqueen's bustard (<i>Chlamydotis macqueenii</i>)	VU	Decreasing	WM/PM
	13 Lesser florican (<i>Sypheotides indica</i>)	EN	Decreasing	SB
	14 Houbara bustard (<i>Chlamydotis undulata</i>)	VU	Decreasing	NA
	15 Great bustard (<i>Otis tarda</i>)	VU	Decreasing	NA
Order: Gruiformes				
Family: Gruidae	16 Sarus crane (<i>Grus antigone</i>)	VU	Decreasing	NA
	17 Siberian crane (<i>Leucogeranus leucogeranus</i>)	CR	Decreasing	NA
Order: Charadriiformes				
Family: Scolopacidae	18 Great knot (<i>Calidris tenuirostris</i>)	EN	Decreasing	WM
Family: Charadriidae	19 Sociable lapwing (<i>Vanellus gregarius</i>)	CR	Decreasing	PM/WM
Family: Laridae	20 Indian skimmer (<i>Rynchops albicollis</i>)	VU	Decreasing	SB
	21 Black-bellied tern (<i>Sterna acuticauda</i>)	EN	Decreasing	WM/YRR
Order: Accipitriformes				
Family: Accipitridae	22 Pallas's Fish eagle (<i>Haliaeetus leucoryphus</i>)	EN	Decreasing	YRR
	23 Egyptian vulture (<i>Neophron percnopterus</i>)	EN	Decreasing	SB/YRR
	24 White-rumped vulture (<i>Gyps bengalensis</i>)	CR	Decreasing	YRR
	25 Indian vulture (<i>Gyps indicus</i>)	CR	Decreasing	WM/YRR

Table continues on next pages.....

Order/ Family	Species	IUCN status*	Trend	Occurrence**
	26 Greater spotted eagle (<i>Aquila clanga</i>)	VU	Decreasing	WM
	27 Tawny eagle (<i>Aquila rapax</i>)	VU	Decreasing	YRR
	28 Steppe eagle (<i>Aquila nipalensis</i>)	EN	Decreasing	WM
	29 Imperial eagle (<i>Aquila heliaca</i>)	VU	Decreasing	WM/YRR
	30 Red-headed vulture (<i>Sarcogyps calvus</i>)	CR	Decreasing	NA
	31 Indian spotted eagle (<i>Aquila hastata</i>)	VU	Decreasing	NA
Order: Passeriformes				
Family: Laniidae	32 Southern grey shrike (<i>Lanius meridionalis</i>)	VU	Decreasing	SB/YRR
Family: Muscicapidae	33 Kashmir flycatcher (<i>Ficedula subrubra</i>)	VU	Decreasing	SB
	34 Stoliczka's bushchat (<i>Saxicola macrorhyncha</i>)	VU	Decreasing	NA
Family: Leiothrichidae	35 Jerdon's babbler (<i>Chrysomma altirostre</i>)	VU	Decreasing	YRR
Family: Locustellidae	36 Bristled grassbird (<i>Chaetornis striatus</i>)	VU	Decreasing	NA
Family: Emberizidae	37 Yellow-breasted bunting (<i>Emberiza aureola</i>)	CR	Decreasing	NA
Order: Ciconiiformes				
Family: Ciconiidae	38 Woolly-necked stork (<i>Ciconia episcopus</i>)	VU	Decreasing	NA
	39 Greater adjutant (<i>Leptoptilos dubius</i>)	EN	Decreasing	NA
Order: Falconiformes				
Family: Falconidae	40 Sooty falcon (<i>Falco concolor</i>)	VU	Decreasing	SB
	41 Saker falcon (<i>Falco cherrug</i>)	EN	Decreasing	WM
Order: Strigiformes				
Family: Strigidae	42 Snowy owl (<i>Nyctea scandiaca</i>)	VU	Decreasing	NA
Order: Podicipediformes				
Family: Podicipedidae	43 Horned grebe (<i>Podiceps auratus</i>)	VU	Decreasing	NA
MAMMALS				
Order: Pholidota				
Family: Manidae	44 Indian pangolin (<i>Manis crassicaudata</i>)	EN	Decreasing	NA
Order: Carnivora				
Family: Canidae	45 Indian wild dog (<i>Cuon alpinus</i>)	EN	Decreasing	NA
Family: Ursidae	46 Asiatic black bear (<i>Ursus thibetanus</i>)	VU	Decreasing	NA
Family: Mustelidae	47 Marbled polecat (<i>Vormela peregusna</i>)	VU	Decreasing	NA
	48 Indian otter (<i>Lutrogale perspicillata</i>)	VU	Decreasing	NA
Family: Felidae	49 Fishing cat (<i>Prionailurus viverrinus</i>)	VU	Decreasing	NA
	50 Common leopard (<i>Panthera pardus</i>)	VU	Decreasing	NA
	51 Snow leopard (<i>Panthera uncia</i>)	VU	Decreasing	NA
	52 Cheetah (<i>Acinonyx jubatus</i>)	VU	Decreasing	NA
Order: Cetartiodactyla				
Family: Moschidae	53 Himalayan musk deer (<i>Moschus chrysogaster</i>)	EN	Decreasing	NA
Family: Cervidae	54 Swamp deer (<i>Cervus duvauceli</i>)	VU	Decreasing	NA
	55 Hog deer (<i>Axis porcinus</i>)	EN	Decreasing	NA
Family: Bovidae	56 Goitered gazelle (<i>Gazella subgutturosa</i>)	VU	Decreasing	NA
	57 Wild goat (<i>Capra aegagrus</i>)	VU	Decreasing	NA

Table continues on next pages.....

Order/ Family	Species	IUCN status*	Trend	Occurrence**
	58 Afghan urial (<i>Ovis vignei cycloceros</i>)	VU	Decreasing	NA
Family: Platanistidae	59 Indus dolphin (<i>Platanista minor</i>)	EN	Unknown	NA
Order: Rodentia				
Family: Suidae	60 Woolly flying squirrel (<i>Eupetaurus cinereus</i>)	EN	Unknown	NA
Order: Artiodactyla				
Family: Balaenopteridae	61 Fin whale (<i>Balaenoptera physalus</i>)	VU	Increasing	NA
	62 Blue whale (<i>Balaenoptera musculus</i>)	EN	Increasing	NA
Family: Phocoenidae	63 Finless porpoise (<i>Neophocaena phocaenoides</i>)	VU	Decreasing	NA
Family: Delphinidae	64 Plumbeous dolphin (<i>Sousa plumbea</i>)	EN	Decreasing	NA
Family: Bovidae	65 Shapu (<i>Ovis vignei vignei</i>)	VU	Decreasing	NA
	66 Punjab urial (<i>Ovis vignei punjabensis</i>)	VU	Decreasing	NA
Order: Sirenia				
Family: Dugongidae	67 Dugong (<i>Dugong dugon</i>)	VU	Decreasing	NA
REPTILES				
Order: Crocodylia				
Family: Crocodylidae	68 The mugger (<i>Crocodylus palustris</i>)	VU	Stable	NA
	69 Gharial (<i>Gavialis gangeticus</i>)	CR	Increasing	NA
Order: Testudines				
Family: Geoemydidae	70 Common river turtle (<i>Hardella thurjii</i>)	VU	NA	NA
Family: Trionychidae	71 Indian soft-shell (<i>Aspideretes gangeticus</i>)	VU	NA	NA
	72 Narrow-head soft-shell (<i>Chitra indica</i>)	EN	NA	NA
	73 Peacock soft-shell (<i>Aspideretes hurum</i>)	VU	NA	NA
Family: Testudinidae	74 Star tortoise (<i>Geochelone elegans</i>)	VU	Decreasing	NA
Family: Geoemydidae	75 Yellow-spotted mud turtle (<i>Geoclemys hamiltonii</i>)	EN	Decreasing	NA
Family: Cheloniidae	76 Loggerhead sea turtle (<i>Caretta caretta</i>)	VU	Decreasing	NA
	77 Green sea turtle (<i>Chelonia mydas</i>)	EN	Decreasing	NA
	78 Hawksbill turtle (<i>Eretmochelys imbricata</i>)	CR	Decreasing	NA
	79 Olive ridley (<i>Lepidochelys olivacea</i>)	VU	Decreasing	NA
Family: Dermochelyidae	80 Leatherback sea turtle (<i>Dermochelys coriacea</i>)	VU	Decreasing	NA

*VU, vulnerable; EN, endangered; CR, critically endangered; **YRR, year-round resident; WM, winter migrant; SB, summer breeder; PM, passage migrant; NA, not available.

The results of SAVS revealed that gharial (*Gavialis gangeticus*) (CR), Indian skimmer (*Rynchops albicollis*) (EN), Egyptian vulture (*Neophron percnopterus*) (EN), Woolly-necked stork (*Ciconia episcopus*) and tawny eagle (*Aquila rapax*) (VU) are top priority species for conservation with overall vulnerability value of 11.67, 11.53, 10.77, 10.77 and 10.77, respectively with 0, 5, 5, 5, 0 uncertainty scores. Moreover, the most resilient species included goitered gazelle (*Gazella subgutturosa*) (VU), Indian pangolin (*Manis crassicaudata*) (EN), European turtle dove (*Streptopelia turtur*) (VU) and wild goat (*Capra aegagrus*) (VU) with vulnerability values of

2.3, 3.06, 3.49 and 3.97, respectively having 9, 9, 5 and 18 score of uncertainty (Supplementary Table S11). The uncertainty value is important to consider as it refers to lack of information.

Birds

Among birds, 25 (58%) species are vulnerable while nine (21%) species are endangered and nine (21%) are critically endangered. According to SAVS tool, Indian skimmer, Egyptian vulture, woolly-necked stork, tawny eagle (*Aquila rapax*) and Kashmir flycatcher (*Ficedula subrubra*) are top priority species with overall 11.67,

11.53, 10.77, 10.77 and 10.77 vulnerability score, respectively. The most resilient avian species included European turtle dove (*Streptopelia turtur*), yellow-eyed pigeon (*Columba eversmanni*), steppe eagle (*Aquila nipalensis*), Indian spotted eagle (*Aquila hastata*), greater adjutant (*Leptoptilos dubius*) having overall score of 3.97, 5.93, 5.93, 6.99 and 7.89, respectively. The uncertainty values for these species are 18, 18, 0, 5 and 0, respectively (Supplementary Table SIII).

Yellow-eyed pigeon and European turtle dove have the highest uncertainty values (18) that makes them good candidates for future research.

Mammals

Among mammals, 16 (67%) species are vulnerable while eight (33%) are endangered. As per SAVS scores, fishing cat (*Prionailurus viverrinus*), Indus dolphin (*Platanista minor*), Himalayan musk deer (*Moschus chrysogaster*), woolly flying squirrel (*Eupetaurus cinereus*) and Shapu (*Ovis vignei vignei*) are the top priority species for conservation having maximum vulnerability scores of 9.09, 8.95, 8.8, 8.8 and 8.8, respectively among mammals (Supplementary Table SIV). The uncertainty values for these species are 14, 14, 9, 9 and 14. Fishing cat has the highest uncertainty values of 14 among mammals making it priority candidate for further research.

Reptiles

Among reptiles, eight (62%) species are vulnerable while three (23%) are endangered and two (15%) species were critically endangered. Among reptiles, gharial (11.67) can be prioritized for conservation efforts followed by peacock soft-shell turtle (*Aspideretes hurum*) with vulnerability score of 10.62 and uncertainty value of 9. The mugger crocodile (*Crocodylus palustris*), common river turtle (*Hardella thurjii*) and Indian soft-shell turtle (*Aspideretes gangeticus*) have the vulnerability score of 9.71 with uncertainty values of five, five and nine (Supplementary Table SV). Peacock soft-shell turtle and Indian soft-shell turtle have the highest uncertainty score (09) making these species top candidates for future research among reptiles.

DISCUSSION

Birds

Among 266 (60.4%) bird species are vulnerable while nine (21%) species are endangered and eight (18.6%) are critically endangered. According to SAVS tool, Indian skimmer is at the top of the list for the species needing conservation actions. The species is native to India, Bangladesh, Pakistan Myanmar, Vietnam and Nepal

(Bird Life International, 2016). In 2014, the species was listed as “VU” due to rapid decline in population due to extensive degradation of lowland lakes and rivers (Bird Life International, 2014), but now it is globally endangered (IUCN, 2022). The major threats to the species reported in Bangladesh are human disturbances such as, fishing and cattle grazing (Mohsanin, 2014; Thompson *et al.*, 2018). A few records of its presence can be found in published literature in Pakistan. Altaf *et al.* (2018) reported five individuals in selected wetlands of Punjab between 2013 and 2014 while Ali *et al.* (2018) recorded 15 individuals at district Badin, Sindh between 2015 and 2016. Its presence at Khararo creek and Keenjhar Lake was reported by Hassan *et al.* (2020).

Egyptian Vulture is also one of the important species that requires conservation actions. Despite the fact that the species has been designated as endangered on the IUCN red list owing to fast population reduction since 2007, scientific data on the species' population trends in Pakistan is limited. The presence of maximum 84 individuals was recorded at Poonch river Mahasheer National Park from 2013 to 2019 by Ahmad *et al.* (2021) while 121 individuals were recorded between 2013 and 2014 in the same area (Kabir *et al.*, 2019). Its presence was reported in different areas of Pakistan, such as, Korangi and Phitti creek, Sindh (Khan *et al.*, 2018), Gawadar coast, Baluchistan between 2017 and 2018 (Gabol *et al.*, 2018), Laddo Jo Tarh, Thaaari Jo Tarh and Bjar Jo Tarh between 2006 to 2010, but the area is being impacted by environmental hazards as a result of large-scale development operations, primarily owing to Thar coal mining in the vicinity (Ghalib *et al.*, 2013). Moreover, human disturbance is a crucial element influencing the Egyptian vulture's breeding performance. This is especially essential in places with a high population density. If disturbance occurs during important times of breeding, the combined impact of meteorological conditions (e.g., exposure and/or shielding, Ceballos and Donazar, 1988) and nest degradation may be greater (Zuberogitia *et al.*, 2008). Moreover, diclofenac was the prime cause of decline in vulture's population but it was banned in 2006 in Pakistan, India and Nepal and it should be banned in other regions along flyways used by these vultures (Oppel *et al.*, 2021). Other activities, such as, deforestation, fires, over grazing and destruction of sources that act as habitat for migratory species are making environment less suitable for migratory species (Umar *et al.*, 2018).

Woolly-necked stork is also at priority species. The species has a wide distribution in south Asia and Africa but its population is declining in southeast Asia according to predictive models (Gula, 2020; Sundar, 2020). This species can be considered as ignored because there is no

published article available concerning the conservation of the species in Pakistan from the recent past. However, the species was studied in detail in India recently and its population is found to be stable in the said region. Based on recent evidences, the status of species has been upgraded from vulnerable to near threatened (Mahale, 2022) but its population is still decreasing globally (IUCN, 2022). However, its conservation status in Pakistan is not clear. As it appears that its habitat in Pakistan is deteriorating, it is essential to investigate this species in order to fill in the gaps and for conservation efforts.

Tawny eagle is a resident species of Pakistan and its presence was reported at different locations of Pakistan such as, Keenjhar Lake by Hassan *et al.* (2020), Korangi and Phitti creek, Sindh (Khan *et al.*, 2018) and Chotiari Reservoir, Sindh between 2006 to 2009 (Rais *et al.*, 2011). Climate change and habitat degradation are the main threats to this species.

As far as climate change is concerned, an increase in temperature and precipitation events is expected by the end of the century with sharp increase in temperature after 2050. According to representative concentration pathways (RCP) 8.5, increase in temperature can be around 4-6°C. Similarly, sharp precipitation events are also expected (Pakistan Meteorological Department, 2015). According to Habibullah *et al.* (2019) increase in precipitation can have an impact on threatened birds but no effect is expected on mammals and reptiles.

Mammals

Among mammals, 16 (67%) species are vulnerable while eight (33%) are endangered. As per SAVS scores, Fishing cat can be prioritized for conservation actions. It has been believed that the fishing cat, may have disappeared from Pakistan since the IUCN Red List's latest assessment of this species in 2010 (Zubairi and Naidu, 2016) but a few records of its presence were found from Chotiari Reservoir in Sindh in 2012 (Islam *et al.*, 2015). It is ecologically significant felid species and being known to be a marker of the health of wetland ecosystems (Mukherjee *et al.*, 2016). It is believed that Fishing cat frequently visits marsh and swampy environments in general. The rising pace of wetland shrinking and its conversion to grassland make the species more susceptible to extinction (Mishra, 2013). The major causes of wetland degradation in Pakistan include over harvesting of wild resources, industrial and urban pollution, forest clearing, agricultural expansion and infrastructure developments (Khan and Arshad, 2014). Different anthropogenic factors, including retaliation, habitat degradation (both coastal and inland wetlands (Phosri *et al.*, 2021), human conflicts (Timilsina *et al.*, 2021) and road-kills pose a threat to

these cats (Mishra *et al.*, 2021). An extensive behavioral and ecological research of fishing cats is required for the species conservation.

Indus dolphin is also an important species that require conservation being second top priority species in the vulnerability assessment list in the current study and one of the most threatened cetaceans in the world (Waqas *et al.*, 2012). It is endemic in Pakistan and some studies and conservation efforts are already going on for this species especially by world wide fund for nature (WWF) Pakistan. In Pakistan, six irrigation barrages on the Indus River have divided its population into five subpopulations (Waqas *et al.*, 2012; Braulik *et al.*, 2015) and 1450 individuals were recorded there in 2011 (Braulik *et al.*, 2015). The Indus Dolphin Reserve is located between the Guddu and Sukkur barrages and contains the largest population of this species; however, this area only covers a small portion of its former range (Waqas *et al.*, 2012). In fact, their overall habitat has been reduced by 80 percent as a result of fragmentation (Braulik *et al.*, 2015), as well as illegal fishing, water contamination, and getting stranded in irrigation canals. These threats pose a serious risk to the Indus dolphin population, as well as the potential for inbreeding due to their limited numbers in the reserve. Although, according to 2001 and 2006 population surveys, its population was increasing but after 2010 flood, its mortality increased significantly with the highest number of mortalities (45) in 2011 (Waqas *et al.*, 2012). However, the number of individuals had increased to 1987 according to the latest survey conducted by WWF in 2017 to 2018. According to WWF, the threat to the species still persists (Mahmood, 2022).

Himalayan musk deer is also one of the species of concern, which are shot in order to obtain the musk pod present in mature males. The high value of musk has provided an incentive for illicit musk deer hunting (Khan *et al.*, 2006). A total of 31 individuals were recorded in Machiara National Park, Azad Jammu and Kashmir in 2006 (Qamar *et al.*, 2008). Around 224 to 363 individuals were reported by Abbas *et al.* (2015) in Gilgit Baltistan. The main threats to Himalayan musk deer include habitat degradation caused by fuel wood collection, lopping for browse feed, livestock grazing, grass and hay cutting, mushroom and medicinal plant harvesting (Qamar *et al.*, 2008), seasonal home construction, and deforestation (Qureshi *et al.*, 2013).

Woolly flying squirrel is one of the least recorded mammals in the world (Oshida *et al.*, 2005; Qamar *et al.*, 2012) and one of the important species that can be prioritized for conservation according to the current study. Its presence was reported in Neelum valley, Azad Jammu and Kashmir in 2011. Habitat degradation and livestock

grazing are considered as major threats to this species (Qamar *et al.*, 2012). Very limited information is available for its current distribution in Pakistan. Lack of information for its distribution, behavior and ecology makes this species one of the important candidates for future research and conservation actions.

Reptiles

Among reptiles, gharial can be prioritized for conservation efforts according to current assessments. it was presumed to be locally extinct in Pakistan (Whitaker and Basu, 1983) but according to Khan and Baig (1988) its number has decreased to an alarming stage. Recently Khalid *et al.* (2024) reported the rediscovery of gharial in Sutlej River as during the surveys conducted by WWF, 17 out of 20 locals confirmed its presence. Gharial faces numerous threats to its survival, primarily due to habitat loss and degradation, as well as human activities such as fishing, sand mining, and infrastructure development that alter river ecosystems (Stevenson and Whitaker, 2010).

Peacock soft-shell turtle is second in the species conservation priority list. Fourteen individuals were observed in different tributaries of Indus River between 2007 to 2008 (Sarwar *et al.*, 2015). In 2015, 1035 individuals were recorded in seven districts of Sindh while hunting and trading were reported as major threats (Khan *et al.*, 2018). Moreover, it is used to purify blood and utilized in different Chinese medicines (Beatty *et al.*, 2001) while its meat is used by non-Muslim communities (Ali *et al.*, 2017) that can be the reasons for its decline.

The mugger is also one of the important reptile species in Pakistan. About 1016 individuals were recorded in Sindh in 2015 (Khan *et al.*, 2018a). Rahim *et al.* (2018) observed a decline in the population of Mugger crocodile in the Dasht River, noting 25 individuals compared to 99 individuals recorded in 2007-2008. No recent records are available for the species. Moreover, Rais *et al.* (2012) reported four individuals of Indian soft-shell turtle in North Punjab between 2010 to 2011. Only a few records are available for the presence of threatened reptiles. This group requires ample field-based research and conservation measures for their protection.

CONCLUSION

The research underscores the critical conservation needs of Pakistan's threatened species, highlighting that a significant proportion of birds, mammals, and reptiles face varying levels of vulnerability. Prioritizing species such as the gharial, Indian skimmer, and fishing cat is essential due to their high vulnerability scores and notable uncertainty in data, indicating a pressing need for further research.

The findings also reveal that species with the highest uncertainty, like the yellow-eyed pigeon and peacock soft-shell, are crucial targets for future studies to better understand their conservation status. Overall, targeted conservation efforts and enhanced research are imperative to address the gaps in knowledge and effectively protect Pakistan's endangered wildlife.

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Supplementary material

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Statement of conflict of interest

The authors have declared no conflict of interest.

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