

IMPERILED

THE ENCYCLOPEDIA OF CONSERVATION

Editors in Chief

Dominick A. DellaSala

Michael I. Goldstein



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IMPERILED: THE ENCYCLOPEDIA OF CONSERVATION

VOLUME 1

Imperiled Species

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Mike Goldstein is a planner and biologist for the US Forest Service in Juneau, Alaska. Mike has worked on many applied research and management questions across terrestrial and aquatic systems, addressing pesticides, dispersed recreation, development, timber harvest, and other forms of resource extraction and conservation. Mike was a principal architect and editor of Elsevier's major reference work *Earth Systems and Environmental Sciences*. Besides this book, *Imperiled: The Encyclopedia of Conservation*, Mike has also served as Co-Editor-in-Chief of the *Encyclopedia of the Anthropocene* and the *Encyclopedia of the World's Biomes*. In his spare time, Mike enjoys skiing, traveling, fishing, camping in remote places, and teaching his three young adult children the joys of life.

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Mark J. Costello is an ecologist with a longtime interest in biodiversity and biogeography from local to global scales, particularly in marine and freshwater ecosystems, and applications in conservation and aquaculture. He is a professor at Nord University (Norway). Born in Ireland, he studied in Galway and Cork, followed by postdocs at the Marine Biological Association in Plymouth England, and the Scottish Office and Napier University in Scotland. He became a lecturer in Trinity College University of Dublin, Managing Director of EcoServe (an environmental consulting company in Ireland), and Executive Director of the Huntsman Marine Science Centre, Canada. He has supervised over 60 MSc and PhD students and published over 240 peer-reviewed papers. Driven by a lifetime fascination with nature, he is especially pleased to have pioneered a new field of “ocean biodiversity informatics” and, in that, played leadership roles in the development of useful world databases that list and map biodiversity across land and sea.



Dominic DiPaolo

Dominic DiPaolo is the owner of Native Ecosystems, an ecological consulting company specializing in special status plant, bryophyte, and lichen surveys; native plant propagation; ecological landscape planning; and GIS mapping. Until recently, he worked with the National Park Service’s Inventory and Monitoring Program and Southern Oregon University, completing vegetation classifications and maps of Crater Lake National Park, Lava Beds National Monument, and Oregon Caves National Monument and Preserve. He currently resides in Ashland, Oregon, USA.



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Scott Elias received both an undergraduate degree and a PhD in Environmental Biology at the University of Colorado, Boulder. Following postdoctoral fellowships in Canada and Switzerland he returned to the Institute of Arctic and Alpine Research at the University of Colorado, where he pursued research in Quaternary paleoenvironments from 1982 to 2000. In 2000 he took a lectureship in Quaternary Science in the Geography Department of Royal Holloway, University of London, where he became Professor of Quaternary Science in 2007. He has served as editor-in-chief of the first and second editions of the *Encyclopedia of Quaternary Science*, published by Elsevier. In 2012 he became editor-in-chief of the online Reference Module in Earth Systems and Environmental Sciences. Scott’s research has focused mainly on the reconstruction of Late Pleistocene environments from the Alaska, the Rocky Mountains, and the American Southwest. He retired from Royal Holloway in 2017 and returned to Colorado, where he continues his research in paleoenvironments and his editorial duties.



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John Quinn holds a PhD in Applied Ecology from the University of Nebraska-Lincoln. He currently is an Associate Professor of Biology at Furman University. His research and teaching emphasize concerns related to biodiversity conservation and sustainability at local and global extents. Currently his research focus is on how multifunctional landscapes and soundscapes can be managed to conserve biodiversity and enhance ecosystem services and the governance tools to reach community goals.



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Dr Nejem Raheem is an Associate Professor of Economics at Emerson College in Boston, MA, USA. He has worked on ecosystem service issues for nearly 20 years, starting with examining how irrigators manage for ecosystem service production in northern New Mexico, and how to incorporate ecosystem service impacts into federal land management projects in the US arctic and Canadian subarctic. Some of the chapters in this volume draw on his experience working with NOAA staff to integrate indigenous perspectives into ecosystem service-based marine management in the Western Pacific. He has recently published work based in the Galápagos Islands and the US West. He teaches classes on ecological and behavioral economics as well as marine conservation and “regular” economics. He is an avid guitarist and open water rower as well as a hiker and cook. He lives in Boston with his wife, his old dog, and his two cats.



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John Vilella is a Senior Botanist at Siskiyou Biosurvey. He has thirteen years' experience consulting as a botanist and mycologist on BLM and Forest Service lands in Oregon, Washington, Alaska, and California. During this time, he has been responsible for training and leading surveys crews, producing and editing paperwork, and coordinating field work. John has worked on a variety of different types of projects including timber and rangeland management, dam relicensing, and ecological research. He is an expert knowledge of the Pacific Northwest fungi, bryophyte, and lichen flora, with expertise in crustose lichens. He has also worked in the academic field using his botanical expertise to instruct for several colleges and nonprofit educational organizations.

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IMPERILED: THE ENCYCLOPEDIA OF CONSERVATION

Dominick A DellaSala and Michael I Goldstein

Conservation is sometimes perceived as stopping everything cold, as holding whooping cranes in higher esteem than people. It is up to science to spread the understanding that the choice is not between wild places or people, it is between a rich or an impoverished existence for Man.

Thomas Lovejoy.

We live in a challenging time for life on Earth. An estimated one-million species face imminent extinction (IPBES, 2019) as Earth enters the sixth mass extinction event (Barnosky et al., 2011). UN Secretary General António Guterres, upon reading the latest dire climate projections of the Intergovernmental Panel on Climate Change (IPCC, 2021), issued a “code red emergency,” as greenhouse gas emissions (GHGs), currently at 417 ppm CO₂, push ecosystems and the climate beyond limits. In reading these dire projections, thousands of scientists sounded the alarm about the escalating climate and biodiversity crises. Meanwhile, scientists have been monitoring a massive ice sheet, roughly the size of Florida and dubbed the “doomsday glacier,” because it is perilously close to calving off the Antarctic mainland, eventually causing calamitous sea level rise.

The climate and biodiversity crises are intertwined consequences of what many are calling the *Anthropocene*, loosely defined as the age of humanity’s escalating ecological footprint (DellaSala and Goldstein, 2018). Consequently, nearly every wild area from pole to pole has been altered by human actions (Ibisch et al., 2016). Such widespread losses constrain the adaptive capacity of Nature and people, changing options for future generations.

The scale of global ecosystem loss is astounding and immense. Consider, half of the world’s identified biodiversity hotspots (where biodiversity is highly concentrated and found nowhere else—endemic) have just 3–10 percent intact vegetation remaining (Sloan et al., 2014). Global deforestation rates, equal to 27 football fields of forests lost every minute of every day are contributing to unprecedented extinctions and nearly a quarter of total GHGs. Coral reefs and mangroves (Greenwood, 2015), nursery grounds for the world’s only commercial animal protein, wild fish, and kelp forests, also a critical source of marine “blue carbon” (Filbee-Dexter and Wernberg, 2020), are in rapid decline.

As of 2012, four of nine planetary boundaries (global processes) are at or have exceeded tipping points, as large-scale processes like the climate and biosphere begin their downward spiral (Barnosky et al., 2012; Steffen et al., 2015). In sum, Nature is in retreat with over 40% of the Earth’s lands mass vulnerable (Barber et al., 2020) and nearly a quarter of planet’s net primary productivity (NPP) consumed by just one species—humans (Haberl et al., 2007). As the human population continues to increase—even at a slower rate—the biological machinery of life on Earth, NPP, is increasingly sequestered by more humans.

And we are all in this together. There are major consequences of these actions. Some 60% of basic ecosystem services, like clean air and potable water, have been greatly impaired (MEA, 2005). Our very health and ability to withstand global pandemics may depend on what’s left of Nature to insulate us from new viral strains and zoonotic disease transfer (Ripple et al., 2022). The more we delay action, the greater the consequences to future generations. Those consequences are felt disproportionately by poverty-stricken communities and People of

Color (United Nations, 2016). We must decide whether we want a planet teeming with life or a future apocalyptic climate with *Mad Max* like consequences (based on the 1979 movie). Simply put, there are two choices we face: by default, the planet self-corrects with dire consequences to all of us; or, hopefully, we change direction guided by a well-informed citizenry with renewed compassion for the millions of species we share this planet with.

Notably, the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES) emphasizes transformative change is required to save Nature and the planet. That means fundamental, system-wide shifts across technological, economic, and social factors, including paradigms, goals, and values (Barber et al., 2020). The IPCC/IPBES Joint Working Group similarly states that both the climate and biodiversity crises must be solved together as one integrated system (Barber et al., 2020). Further, according to Barber et al. (2020), ineffective actions to combat climate change, our current path, are harming Nature and the climate at our own peril. What happens in the decade(s) ahead could very well decide the fate of humanity and the planet for generations to come and whether we persist as the only known life force in the distant cosmos.

We should preserve every scrap of biodiversity as priceless while we learn to use it and come to understand what it means to humanity.

E.O. Wilson.

Over the past five years, we published a series of three books with Elsevier, housed in the Reference Module on Earth Systems and Environmental Sciences, that we hope will become the go-to series for those seeking much of the relevant science on biodiversity. They are *The Encyclopedia of the Anthropocene*, a global synthesis cataloguing the impact of humanity's ecological footprint related to climate change, biodiversity, contaminants, geology, energy, and ethics (DellaSala and Goldstein, 2018), *The Encyclopedia of The World's Biomes*, a global synthesis of biomes cataloguing biodiversity, anthropogenic stressors, changing climatic conditions, and conservation strategies (Goldstein and DellaSala, 2020), and this book, *Imperiled: The Encyclopedia of Conservation*.

Imperiled: The Encyclopedia of Conservation provides a global synthesis of rare and at-risk species and ecosystems across terrestrial, freshwater, and marine environments. As the *Imperiled* chapters show, what remains of Nature is our saving grace. The wellsprings of terrestrial, freshwater, and marine life are climate control centers and thusly natural climate solutions (Griscom et al., 2017). Intact ecosystems provide natural pharmaceuticals that can inoculate us from future pandemics (Ripple et al., 2022) and contain the building blocks for adaptations to forthcoming changes. In Nature, variety is the spice of life. Saving biodiversity, from gene pools to species, ecosystems, ecoregions, and biomes is in everyone's best interest as we show in the three volumes.

We thank Elsevier and the many natural resource scientists and managers who participated in helping make this set of reference books available.

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DEDICATION

While we developed this book, *Imperiled: The Encyclopedia of Conservation*, the world was in a crisis with the COVID-19 pandemic. And, while we all were battling our way through the turmoil and unrest and facing the mortality of the virus, efforts to protect nature continued.

We lost four heroes over the past couple of years, eminent scientists in conservation biology and practice:

- Georgina Mace, a Dame of the Most Excellent Order of the British Empire, died in 2020. She was the force behind the IUCN Red List of Species that has been the foundation of conservation policy since 1996, and her work helped form the biodiversity portions of the 2005 Millennium Ecosystems Assessment, items that provided the foundation for much of what we highlighted from the IUCN Species Survival Commission in these chapters.
- Thomas Lovejoy, known as the *Godfather of Biodiversity*, died in 2021. He proposed the first debt-for-nature swap to enhance conservation and protections, helped highlight forest fragmentation as a detriment to biodiversity, and founded the Amazon Biodiversity Center.
- Edward O. Wilson, known as *Darwin's Natural Heir*, the *Ant Man*, and the *Father of Biodiversity*, died in 2021. As he taught at Harvard, he published several prominent books that created space for the field of sociobiology to take root and grow. As E.O. Wilson said, "We should preserve every scrap of biodiversity as priceless while we learn to use it and come to understand what it means to humanity."
- Richard Leakey, known as a swashbuckling, pugnacious real-life Indiana Jones, died in 2022. He produced some of the most groundbreaking anthropological and paleontological finds of the 20th century, including the book *The Making of Mankind* which was later aired on the BBC. He then became a pioneering conservationist leading Kenya's Wildlife Service where he ruthlessly pursued poachers and publicly burned seized ivory.

There has also been a growing realization of the shocking statistics on death and injuries to people on the front line of nature conservation, notably Wildlife Rangers and Fisheries Observers. There are problems with poor job conditions, hazardous work assignments, and lack of insurance and medical treatment. For example, between 2002 and 2017, more than 1,500 people across 50 countries were murdered in retaliation for protecting land, water, forests, and other natural resources. The annual death toll doubled over that 15-year period, and the killings tended to take place in countries with high levels of corruption and weak rule of law (Nuwer, R., 2019. Environmental activists have higher death rates than some soldiers. *Scientific American*). In 2020, at least 225 land and environmental defenders were killed and many more attacked and threatened. More than two-thirds of the deaths occurred in Latin America, much of which is rapidly developing within a context of weak governance, extreme inequality, and political instability (Clynes, T. 2021. The violent cost of conservation. *Audubon Magazine*). And, despite making up only 5% of the world's population, more than 30% of all the fatal attacks targeted Indigenous people in 2020.

We dedicate this book, *Imperiled: The Encyclopedia of Conservation*, to the fascinating world of biodiversity that we live in, to Georgina Mace, Thomas Lovejoy, Edward O. Wilson, Richard Leakey for opening our eyes, and to the front-line people serving every day who have been injured or lost their lives while in service to conservation and preservation of the natural world.

Sincerely,
The Editors
Mike Goldstein, Dominick DellaSala,
Mark John Costello, Dominic DiPaolo, Scott Elias,
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Imperiled Vertebrates

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Abstract

Imperiled: The Encyclopedia of Conservation takes a broad look at the impact of humanity's expanding ecological footprint on the world's biota, broken down by species and systems. This section on Imperiled Vertebrates takes a closer look at certain vertebrate taxa from across the world's geography and biomes. Papers in this section provide an overview of species biology and ecology, conservation status, stressors, and conservation measures.

Introduction

Imperiled: The Encyclopedia of Conservation (DellaSala and Goldstein, 2022) takes a broad look at the impact of humanity's expanding ecological footprint on the world's biota, broken down by freshwater, marine, and terrestrial species and systems. The book also highlights ecosystem services and provides a section on conservation case studies. In all, the goal of *Imperiled: The Encyclopedia of Conservation* is to further document the scope and effects of the human footprint on the world's biota – picking up on the themes developed in the *Encyclopedia of the Anthropocene* (DellaSala and Goldstein, 2018) and as described in the *Encyclopedia of the World's Biomes* (Goldstein and DellaSala, 2020).

Vertebrates are animals with backbones or spinal columns, including mammals, birds, reptiles, amphibians, and fishes. The term 'imperiled' refers to something in a state of peril, i.e., something put at risk of being harmed, injured, or destroyed. In the context of species, this materializes as population declines, geographic range contractions, and increased risks of extinction. Articles detailing *Imperiled Vertebrate* taxa are found in most sections of this encyclopedia. This section contains 33 papers on terrestrial vertebrates from across the world. An additional 15 vertebrate papers mentioned here are found in the sections concerning ecosystem services and conservation case studies. The freshwater (Suring, 2022) and marine ecosystems sections (Costello, 2022) contain another 30 vertebrate papers not discussed here. Invertebrates, plants, and fungi are covered in other sections. When soliciting papers, I tried to ensure broad coverage of vertebrate taxa, although the number of threatened species (for example, over 14,616 mammals, birds, reptiles, amphibians, see Table 1) was simply too large to allow a comprehensive approach. Consequently, many interesting species are not included.

The papers herein provide a biological and ecological overview of species or larger taxonomic units, followed by discussion of their conservation status, stressors faced by the species and populations, and notable conservation measures and priorities taken to protect or restore the species. The aim is to provide an overview of examples of rare and imperiled terrestrial species of the world.

Biodiversity, endemism, rarity, and imperilment

Evidence has mounted that the Earth's terrestrial vertebrate fauna continues to change quickly. Extinction rates have been hotly debated and contested, concerning both the magnitude of and the reasons for the changes. With approximately 9,000 vertebrate species exhibiting declining populations, the threat of extensive extirpation of populations and species extinctions is real (see summary in Ceballos et al., 2020). The current decline in the world's biota has been called the sixth mass extinction and the current rates of extinction are greater than the estimated rates of the five previous mass extinctions (Ceballos et al., 2015). However, it should be noted that such comparisons are based on different taxa, greatly different timescales, and from different causes of extinction (Costello et al., 2013; Costello, 2019).

The term 'endemism' refers to a species found in a single defined geographic location, such as an island, mountain range, country, or other defined zone (Costello et al., 2020; Manes et al., 2022). One established zone of high endemism is Madagascar (Rowe and

Table 1 Number of vertebrate species listed as ‘*Threatened*’ by the IUCN in each major taxonomic group by generalized geographic location and overall, as adapted from the IUCN statistics page (2021–2023) <https://www.iucnredlist.org/statistics>.

Geographic Area	Mammals	Birds	Reptiles	Amphibians	Total
North Asia	56	98	11	0	165
East Asia	156	280	108	204	748
South & Southeast Asia	893	828	692	352	2,765
Oceania	212	386	308	81	987
Antarctic	10	35	7 ^a	0	52
Europe	246	470	75	36	827
North Africa	89	90	46	5	230
Sub-Saharan Africa	1093	1,110	558	409	3,170
West & Central Asia	274	443	184	21	922
North America	64	118	44	57	283
Mesoamerica	178	183	264	547	1,172
Caribbean Islands	83	143	401	184	811
South America	424	747	400	913	2,484
Total # of Species	3,778	4,931	3,098	2,809	14,616

^aAntarctic occurrence mapping includes the French Southern Territories

Donohue, 2022). For instance, all lemurs are restricted to this island, with over 100 unique endemic species (Fig. 1). In many areas, vertebrate endemism is linked to vascular plant endemism (Kier et al., 2009). Based on this pattern, biodiversity hotspots have been a target for conservation for several years. A defining work by Conservation International identified 36 geographic hotspots that are both biologically rich and facing severe threats, thereby identifying areas that are crucial for conservation (Fig. 2). These areas are also high in endemism.

We often use the word ‘*rare*’ to describe things that are unusually good or remarkable, or things not found in large numbers and consequently of interest or value. However, it should be noted that the concept of rarity is generally scale and interest dependent. Think of the diamond for which a market was created to enhance the social construct they were rare and thus deemed a higher value; the truth is that diamonds actually number among the most common gems. In a natural system, rarity is implied by species distribution and abundance. Species are considered rare if their numbers are small, or the area they occupy is small compared to other ecologically comparable species. While it is not always the case, imperilment generally implies that human actions play a role in a species demise. A species may be imperiled due to its restricted range, having very few populations or occurrences, or showing steep population loss or habitat declines or severe threats. In this volume, we address imperilment more so than rarity.

Cross-reference to many of the imperiled vertebrates in this book

Multiple taxa

1. Introduction: Imperiled Vertebrates (this paper).
2. Global biodiversity rich spots (Manes et al., 2022).
3. Reliability of global status for local imperiled populations (Meyer et al., 2022b).
4. Imperiled vertebrates of the Galápagos (Jiménez-Uzcátegui, 2022).



Fig. 1 The ringtailed lemur, *Lemur catta*, is Madagascar’s iconic lemur species. Photographed by M.E. Donohue in Anja Special Reserve, Madagascar (Rowe and Donohue, 2022).

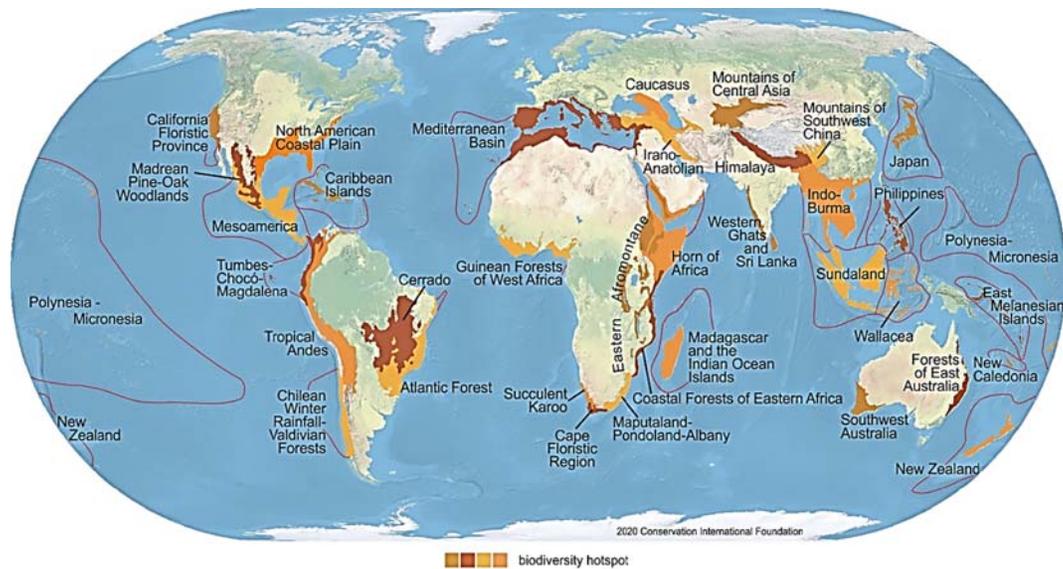


Fig. 2 Conservation International defines 36 biodiversity hotspots showing geographic areas that are both biologically rich and deeply threatened, thereby identifying areas that are crucial for conservation (see <https://www.conservation.org/priorities/biodiversity-hotspots>).

Herpetofauna

5. Headwater-stream amphibians of Northwestern North America (Thurman et al., 2022).
6. Endangered amphibians of North-West Africa (Escoriza, 2022).
7. Endangered herpetofauna of Guatemala (Ariano-Sánchez and Gil-Escobedo, 2022).
8. Softshell freshwater turtles of Pakistan (Rais and Abid, 2022).
9. Sea turtles, Families *Dermochelyidae* and *Cheloniidae* (Goldstein et al., 2022).
10. Amphibians and reptiles of Mexico (Santos-Barrera et al., 2022).
11. Central American River Turtles *Dermatemys mawii* (Reyes-Grajales et al., 2022).
12. Holarctic treefrogs, especially Suweon treefrog *Dryophytes suweonensis* (Borzée, 2022).
13. Madagascar's endemic amphibians and the Harlequin Mantella frog *Mantella cowanii* (Edmonds et al., 2022).
14. Admirable Redbelly Toads *Melanophryniscus admirabilis* (Fonte et al., 2022).
15. Dunes Sagebrush Lizards *Sceloporus arenicolus* (Fitzgerald et al., 2022).
16. St Croix Ground Lizards *Pholidoscelis polops* (Angeli and Fitzgerald, 2022).
17. Australian Heath Frogs *Litoria littlejohni* (Klop-Toker et al., 2022).
18. Morelet's Crocodiles *Crocodylus moreletii* (Triminio and Tellez, 2022).
19. Komodo Dragons *Varanus komodoensis* (Yuni and Purwandana, 2022).

Mammals

20. Flying Foxes, Family *Pteropodidae* (Tsang, 2022).
21. Pacific Sheath-Tailed Bats *Emballonura semicaudata* (Reeves et al., 2022).
22. Characterizing data deficient South American rodents (Teta et al., 2022).
23. Small mammals of northern Australia (Cremona et al., 2022).
24. Clouded Leopards *Neofelis* sp. (Giordano, 2022).
25. Jaguars *Panthera onca* (Espinosa et al., 2022).
26. Wolves *Canis lupus* (Jackson et al., 2022).
27. Black Footed Ferrets *Mustela nigripes* (Livieria et al., 2022).
28. Giraffes *Giraffa* spp. (Brown et al., 2022).
29. Arabian Tahrs *Arabitragus jayakari* (Ross and Jahdhami, 2022).
30. Baird's Tapirs *Tapirus bairdii* (Meyer et al., 2022a).
31. Giant Anteaters *Myrmecophaga tridactyla* (Bertassoni and Desbiez, 2022).
32. Giant Armadillos *Priodontes maximus* (Desbiez and Attias, 2022).
33. Red Colobus monkeys *Piliocolobus* spp. (Aghomo and Cronin, 2022).
34. Primates in Northeastern India (Sharma et al., 2022).
35. Madagascar's Endemic Lemurs (Rowe and Donohue, 2022).

36. Peleng Tarsiers *Tarsius pelengensis* (Indrawan et al., 2022).
37. Parma Wallabies *Notomacropus parma* (Hayward et al., 2022).

Birds

38. African Penguins (Grigg and Sherley, 2022).
39. Congo Peafowl *Afropavo congensis* (Louette and Mulothwa, 2022).
40. Chaco Eagles *Buteogallus coronatus* (Sarasola et al., 2022).
41. Flamingos, Family *Phoenicopteridae* (Rose, 2022).
42. Forest Owlets *Athene blewitti* (Jathar, 2022).
43. Chinese Crested Terns *Thalasseus bernsteini* (Chan, 2022).
44. African White-backed Vultures *Gyps africanus* (Kendall and Bracebridge, 2022).
45. Bearded Vultures *Gypaetus barbatus* (Krüger and Amar, 2022).
46. Greater Adjutants *Leptoptilos dubious* (Mandal et al., 2022).
47. Sarus Cranes *Antigone antigone* (Mahendiran, 2022).
48. Farmland Birds of North America (Quinn, 2022).

Humans¹

49. Human climate forced displacement (Bronen, 2022).

A few highlights

Because the world's human population is at an all-time high, we tend to overlook the fact that there are imperiled human populations in certain regions. For instance, some coastal communities are in danger of being displaced due to storm surges and sea level rise. This has been described in more detail by Bronen (2022). In an interesting example, Indonesia is moving its capital from Jakarta to Kalimantan on the island of Borneo. This ambitious move intends to reduce the pressure on Jakarta. The city has been rapidly sinking, and it is predicted that up to 95% of Jakarta real estate may be underwater by 2050. While it may be advantageous for the Indonesian government to seek agricultural expansion on Borneo while strengthening supply chains and trade investments, this move may also have a devastating effect on the biodiversity and endemism of Borneo. Similarly, while the new capital will be safe from sea level rise, what about the millions of other people who inhabit this island archipelago? Indonesia is not the only country to change its capital - Brazil, Pakistan, and Nigeria have all changed theirs to newly planned and constructed cities. All four countries had advantageous reasons, including real estate and agrarian expansion, and all four countries moved their capital cities from the coast to a more secure inland location – one not subject to inundation by coastal flooding, storm surges, or sea level rise.

There are some iconic species that never fail to impress. The jaguar (Fig. 3) is currently threatened by a 50% range decrease that occurred during the last century. However, a large, dynamic, multi-scale approach to conservation, from international-level strategies to local initiatives, gives us hope for the future of the species (Espinosa et al., 2022). The primates of Northeastern India (Sharma et al., 2022) are likewise imperiled. This tea-growing region of Assam continues to see high land use conversions for agricultural expansion at the expense of the natural habitats needed for many species. The situation has reached the point where some primate species are now facing extinction debt (the future extinction of species due to past events). Lastly, there are some long-lived species, like the Laysan albatross (*Phoebastria immutabilis*), that have suffered population decreases due to several stressors, including being hooked on fishing lines, by ingestion of or entrapment by plastic debris, from sea level rise, and increased storm mortality. There's a future conservation case study unfolding with this species, seen here nesting in currently fallow agricultural land (Fig. 4). What will happen to this land: will it be available for nesting next year, returned to crop production, or sold for development? One conservation strategy for the Laysan Albatross is the preservation of safe, predator free areas on high islands that could provide the nexus for conservation through a joint effort on both private and public lands. This approach would ensure the availability of nesting habitat, combined with human control or eradication of introduced predators such as the mongoose (*Herpestes javanicus*). Multi-scaled community conservation initiatives appear to provide the best answer to how conservation and development can work together to preserve a species and its habitat requirements.

¹Humans are separated from mammals only to emphasize the complexities some human populations face, whether they are in remote coastal indigenous communities or in large coastal cities.



Fig. 3 Jaguar (*Panthera onca*) stalking prey. From Espinosa et al., 2022 (Photo Credit: Ailton Lara).



Fig. 4 Laysan Albatross *Phoebastria immutabilis* nesting on private property on the North Shore of Oahu, Hawa'ii, United States. Photo credit: Sheldon Plentovich, Pacific Islands Fish and Wildlife Office, United States Fish & Wildlife Service.

Summary

Imperiled: The Encyclopedia of Conservation provides a global synthesis of the world's imperiled species and ecosystems. It documents rarity and endangerment, the major drivers of loss, areas of conservation importance, and implementation strategies to save and restore imperiled species and ecosystems. The Imperiled Vertebrates are some of the most threatened iconic species on Earth.

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The Decline and Conservation Status of the African Penguin

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Abstract

The Endangered African penguin (*Spheniscus demersus*), endemic to the Benguela upwelling ecosystem, is the only species of penguin found in Africa. Historically, the species was abundant throughout the region, with the population estimated to be in the order of 1.5–3.0 million individuals in the early 1900s. However, the removal of guano from breeding sites, the commercial harvesting of penguins and their eggs, and reduced prey availability in the northern Benguela meant this had decreased to ~51,500 breeding pairs by 1989. Since then, the population has decreased further by >65%, and in South Africa by around 40% since it was classified by the IUCN as Endangered in 2010. This contemporary decline shows no sign of reversing and results from the cumulative impact of several threats, foremost of which are a shift in prey availability away from South Africa's west coast and the compounding influence of competition with commercial fishing. In this chapter we summarize the African penguin's biological traits and key aspects of behavior, provide an overview of the population decline and its key drivers, and finally describe both the existing and proposed conservation measures.

Characteristics and taxonomy

The African penguin (*Spheniscus demersus*) is one of four species in the genus *Spheniscus*. Other spheniscids include the Magellanic penguin (*S. magellanicus*), Humboldt penguin (*S. humboldti*) and Galapagos penguin (*S. mendiculus*). In comparison to other genera, the *Spheniscus* penguins occupy some of the most northern distributions and generally occur in warmer climates. Their breeding ranges are associated with cold, nutrient-rich currents, on which they rely for small pelagic fish as their primary prey (Davis, 2009). The four *Spheniscus* species are morphologically similar. Adult plumage is characterized by a black and white head, a black dorsal side, and a mostly white ventral side with distinctive black bands across the upper chest and/or neck (Fig. 1). The bare facial skin is pink or (rarely) black and aids the birds with heat regulation (Williams, 1995). All adult spheniscids have a clear pattern of black spots on the belly, which appear to be individually unique (Sherley et al., 2010), although the extent of the patterning varies between species and within individuals. Juvenile plumage is bluish gray on the dorsal side, which can change to brown prior to the first molt, fading into a white ventral area (Davis, 2009). African penguins are a medium sized penguin, reaching up to 70 cm in height at maturity, while adult weight typically ranges between 2.5 and 4 kg (Williams, 1995). African penguins have very few external sexually dimorphic traits. Males are often heavier than females with larger bills; however, there is a large degree of overlap, making visual determination of sex difficult.

Distribution

The African penguin is endemic to southern Africa, predominantly occurring in areas influenced by the Benguela Upwelling ecosystem (Randall, 1995), where breeding occurs at 28 localities, ranging between Hollamsbird Island (24° 38' S, 14° 32' E), off central Namibia, and Bird Island (33° 51' S, 26° 17' E), in Algoa Bay in the Eastern Cape of South Africa (Fig. 2; Kemper et al., 2007a). Historically the distribution of penguin breeding colonies has been restricted by the availability of sites protected from disturbance and land-based predators (Randall, 1995). Consequently, 24 of the 28 breeding localities are coastal islands or rocky outcrops. The remaining four are on the mainland, two near human settlements in South Africa and two in caves in Namibia that are inaccessible from the land. A fifth mainland site on the coast of De Hoop Nature Reserve, near Cape Agulhas



Fig. 1 A pair of adult African penguins *Spheniscus demersus* allopreening at a nest site on Mercury Island, Namibia. Adult plumage in *Spheniscus* penguins is characterized by a black and white head, a black dorsal side, and a mostly white ventral side, usually with a pattern of black spots, and distinctive black bands across the upper chest and/or neck. Photo credit: Richard Sherley.

(Fig. 2), was briefly occupied by about 15 breeding pairs between 2003 and 2008, but was extirpated by terrestrial, mammalian predators (Crawford et al., 2011).

South Africa holds 17 breeding colonies, which host ~75% of the breeding population (Kemper et al., 2007a; Sherley et al., 2020). Here, African penguins breed in three main regions with divergent population trends: the West Coast and South-West Coast regions, which encompass African penguin breeding localities north and to the south and east of Cape Town in the Western Cape, respectively; and Algoa Bay in the Eastern Cape (Sherley et al., 2020). The remaining colonies are found in southern and central Namibia. When breeding, African penguins will typically remain within 40 km of the colony (Pichegru et al., 2010). Fledglings on their maiden migration move as far north as southern Angola (Sherley et al., 2017), while non-breeding adults usually range between 18° south on the Namibian coast to 29° south on the coast of KwaZulu-Natal, covering approximately 3200 km of coastline (Crawford et al., 2007).

Life cycle and breeding

African penguins are monogamous and typically breed colonially. Although records exist of adults breeding at more than one locality (Whittington et al., 2005), breeding fidelity is high – i.e., individuals return to breed at the same colony for subsequent years and breeding attempts within years (Sherley et al., 2014a). However, a small proportion of individuals emigrate to non-natal colonies for their first breeding attempt (Sherley et al., 2014a), which usually occurs between three and 7 years of age (Whittington et al., 2005). Historically, penguins primarily nested in burrows dug into hard layers of accumulated guano that covered many colonies. However, the removal of guano has meant that penguins are now restricted to nesting in crevices between rocks or on the ground surface, preferentially under vegetation or in disused buildings where they can avoid direct sunlight (Cooper, 1980; Frost et al., 1976a; Randall and Randall, 1981). Eggs are laid year-round but peaks in breeding occur at different times in different localities; laying peaks generally occur between February and May in South Africa (e.g., Crawford et al., 1999) and November to December in Namibia (Kemper, 2006). Typically, clutches consist of 2 eggs laid 3 days apart, with the first egg heavier than the second (Williams and Cooper, 1984). African penguins may lay up to 2 clutches per breeding season although single breeding attempts are more common (Cooper, 1980; Randall and Randall, 1981). Incubation lasts 38–41 days and is shared equally by both sexes in alternate shifts of 1–2 days (Williams and Cooper, 1984). Hatching is asynchronous, usually within

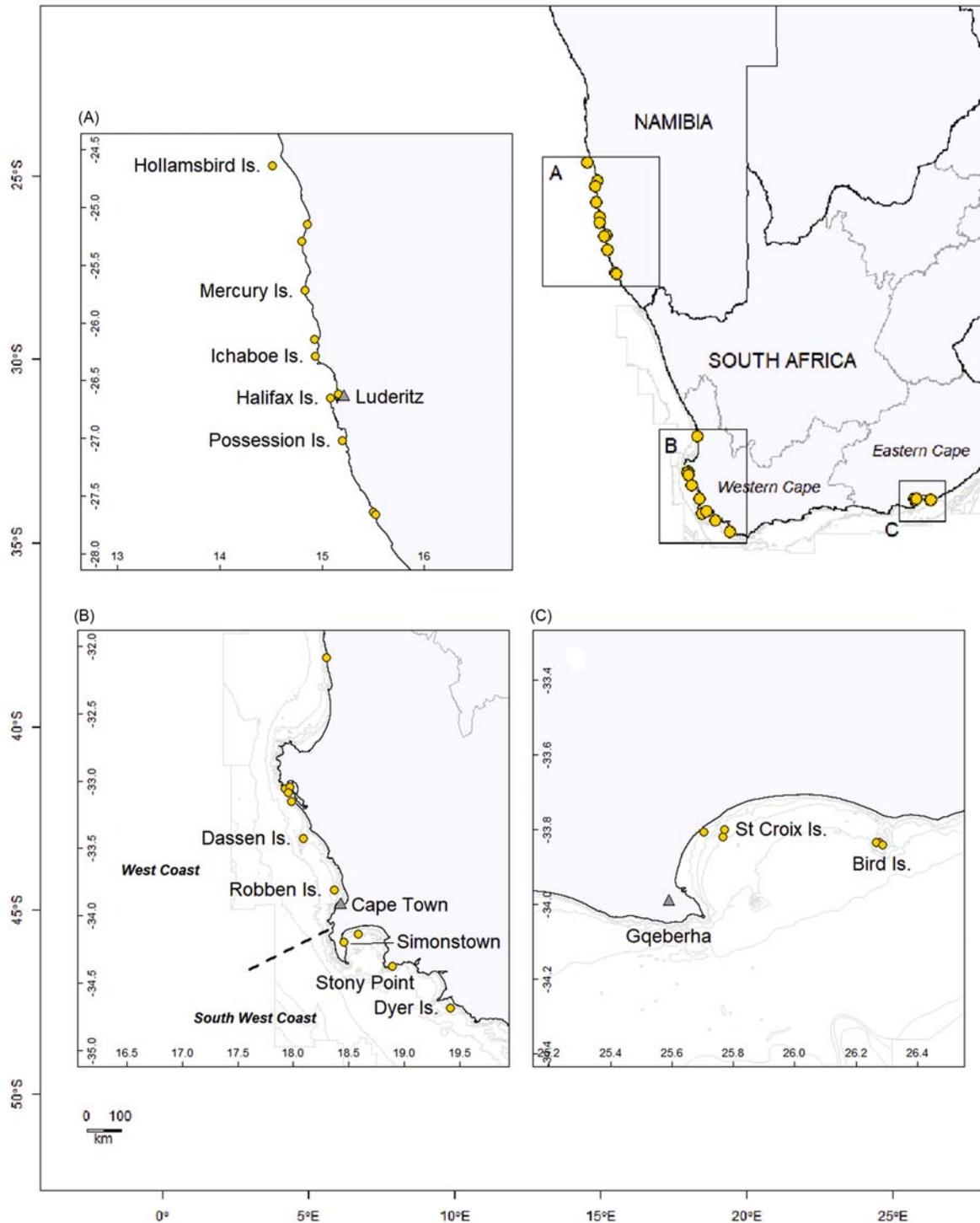


Fig. 2 The 28 extant (○) breeding colonies of the African penguin *Spheniscus demersus* in South Africa and Namibia. Multiple sub-regions are recognized within the breeding range: Namibia (A), the Western Cape (B; encompassing the West Coast and South-West Coast) and the Eastern Cape around Nelson Mandela Bay (C). Colonies mentioned in the text are named, as are the major towns and cities (△) in each region.

2 days (Seddon and van Heezik, 1991; Williams and Cooper, 1984). Chicks are provisioned by both parents (Williams, 1995) and can be guarded for up to 40 days after hatching, after which they often form crèches with chicks from nests in close proximity when left unguarded (Seddon and van Heezik, 1993). Fledging usually occurs between 55 and 130 days (Kemper, 2006; Seddon and van

Heezik, 1993). Breeding success is highly variable between colonies and years, having been recorded as low as 0.15 chicks per pair (Adams et al., 1992) and as high as 1.10 chicks per pair per year (Wolfaardt et al., 2008).

Post-fledging, first-year survival has been difficult to estimate, but appears to vary widely from year to year, ranging from ~0.05 to 0.79 per annum (Sherley et al., 2014a). After about 9 to 20 months at sea, African penguins return to the colony to undergo their first molt into their adult plumage (Kemper and Roux, 2005). Thereafter, as their plumage must be waterproof to maintain their body temperature while at sea, penguins undergo an annual catastrophic molt, whereby all their feathers are shed and replaced over a single period (Kemper, 2006). Like breeding, molt timing varies between colonies, but in South Africa usually occurs between September and January (Crawford et al., 2006). Molt takes approximately 21 days to complete (Randall and Randall, 1981), and during this time penguins do not enter the sea to feed (Cooper, 1978). As a result, they lose approximately 47% of their mass (Cooper, 1978). In preparation for molt, penguins spend about 40 days gaining weight, followed by another 40 days fattening post-molt, although there can be significant variation in the length of these foraging periods (Randall, 1995). Adults are generally long-lived, should have relatively high annual survival (above 0.80 per year), and may reach in excess of 20 years of age (Whittington et al., 2000). For example, annual adult survival averaged 0.91 from 1976/77–1981/82 at St Croix Island (33°47' S 25°46' E), in the Eastern Cape (Randall, 1983), and it was estimated at c. 0.82–0.89 at Robben Island (33°48' S 18°22' E) in 1993/94 (Crawford et al., 1999). However, if they are unable to build or recover their body condition sufficiently during the pre- and post-molt stages, African penguins may experience carry-over effects, such as reduced breeding success in the subsequent season (Sherley et al., 2013) or can be susceptible to increased mortality through starvation. For example, adult survival at Dassen Island (33°25' S 18°06' E) and Robben Island, two colonies to the north of Cape Town, declined from ~0.8 for 1994/95–2003/04 to ~0.6 for the period 2004/05–2011/12 (Sherley et al., 2014a), coincident with a decline in the abundance of sardine (*Sardinops sagax*) on the west coast of South Africa (Robinson et al., 2015).

Ecology

African penguins are specialist foragers, and primarily target pelagic schooling fish, in particular sardine and anchovy (*Engraulis capensis*) (Wilson, 1985a; Crawford et al., 2011). However, in Namibia bearded goby (*Sufflogobius bibarbatus*) is now important following the virtual extirpation of sardine in the northern Benguela (Ludynia et al., 2010). Individuals may also forage for other prey with lower energetic value, such as cape horse mackerel (*Trachurus capensis*), juvenile hake (*Merluccius* spp.), red-eye round herring (*Etrumeus whiteheadi*), beaked sandfish (*Gonorynchus gonorynchus*), and cephalopods in years where sardine and anchovy abundance is low (Connan et al., 2016; Campbell et al., 2019). However, generally these other species constitute a small percentage of the diet (Sherley et al., 2013).

The foraging behavior of African penguins rearing chicks has been well described (e.g., Campbell et al., 2019; Pichegru et al., 2010). While breeding, African penguins are central place foragers, required to commute between breeding localities and foraging grounds. Thus, they are restricted to a limited foraging range, usually within 40 km from the colony when feeding chicks (Campbell et al., 2019; Pichegru et al., 2010). African penguins primarily forage during the day, with trips lasting typically <24 h (Wilson, 1985b). Their diving behavior is characteristic of other *Spheniscus* penguins; dives in pursuit of prey have been recorded to a maximum depth of 130 m, but are typically <50 m deep and lasting up to 2.5 min (Wilson, 1985a; Ryan et al., 2007; Pichegru et al., 2013). Individuals at sea tend to aggregate in groups while preening and spend less time in groups while foraging. However, African penguins appear to benefit from foraging in groups as they are able to increase the time spent driving schools of fish up through the water column and suspending bait-balls at the surface, allowing them to catch more prey than individually (McInnes et al., 2017).

Foraging behavior during other stages of the lifecycle (i.e., prior to breeding and during the non-breeding periods) is not as well studied, as individuals spend long periods at sea without returning to land, making it more difficult to track movements (Croxall and Rothery, 1991). However, strong evidence indicates that after fledging, juvenile African penguins travel hundreds of miles northwards and westwards of their natal colony following environmental cues for primary productivity. These cues were previously associated with high quality foraging habitat; however, they are now mismatched, meaning individuals mistakenly target areas where forage fish abundance is now low (Sherley et al., 2017). This likely contributes to lower juvenile survival (Sherley et al., 2017). Outside the breeding season, adult African penguins travel and forage up to 540 km from their breeding colonies, but the direction, time spent foraging, and distance travelled can differ based on breeding colony and between the pre- and post-molt period (Roberts, 2016). At the time of writing, work was ongoing to better characterize the foraging behavior and the important at-sea habitat of non-breeding adult and immature African penguins.

IUCN status and population trends

The African penguin is classified as Endangered by the IUCN, after being up listed from Vulnerable in 2010 (BirdLife International, 2020), and is undergoing a dramatic population decline that shows no sign of reversing (Fig. 3; Sherley et al., 2020). Historically, the species was abundant throughout the Benguela upwelling ecosystem, with the population estimated in the region of 1.5–3.0 million individuals in the early 1900s (Crawford et al., 2007). However, this had decreased to ~51,500 breeding pairs by 1989

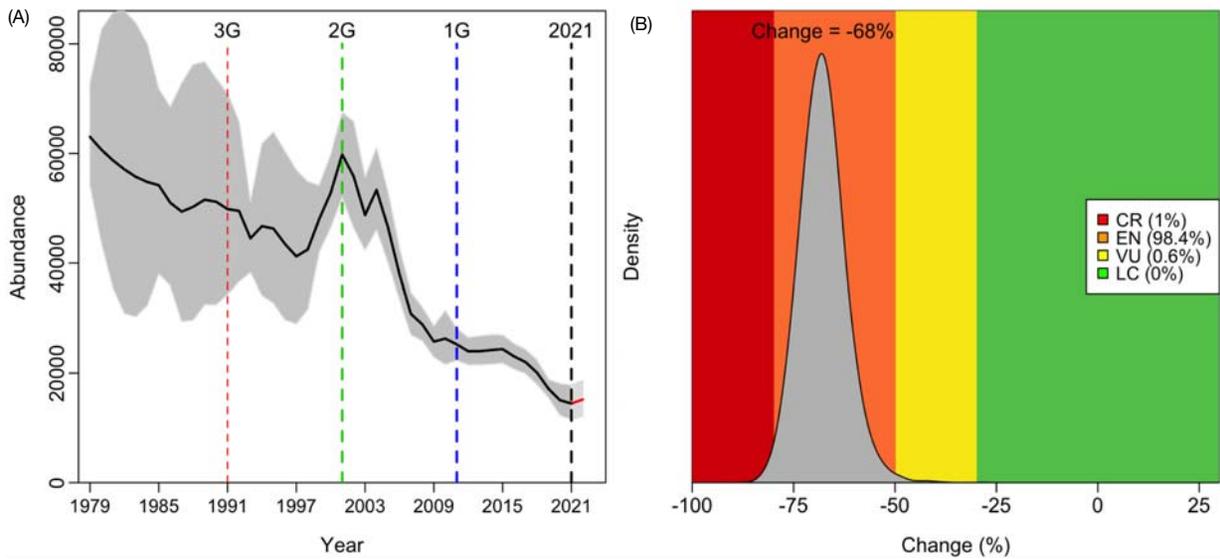


Fig. 3 The decline in the African penguin *Spheniscus demersus* breeding population since 1979. (A) the fitted median (black line) and 95% highest posterior density intervals (HPDI; gray polygon) for the population trend of African penguins based on nest counts from 22 colonies made between 1979 and 2021. The 10-year generation lengths before 2021 are denoted by a blue dashed line (1G, 2011), a green dashed line (2G, 2001) and a red dashed line (3G, 1991). (B) the median change (%) in the breeding population of African penguins over three generations (3G) or 30 years and corresponding posterior probability (gray polygon) for that change, overlaid on the IUCN thresholds for the Red List criterion A2 (LC—dark green, VU—yellow, EN—orange, CR—red). Model fit and decline probabilities are derived from a Bayesian state-space model fit using JARA (Sherley et al., 2020; Winker et al., 2020). Modified and updated from Sherley RB, Crawford RJM, de Blocq AD, Dyer BM, Geldenhuys D, Hagen C, Kemper J, Makhado AB, Pichegru L, Tom D, Upfold L, Visagie J, Waller LJ, and Winker H (2020). The conservation status and population decline of the African penguin deconstructed in space and time. *Ecology and Evolution* 8506–8516.

(Sherley et al., 2020). Since then, the global population has declined by approximately 68% (Fig. 3; Sherley et al., 2020), largely due to changes in the availability of sardine and anchovy (e.g., Crawford et al., 2011; Robinson et al., 2015), which have undergone a marked eastward shift in their distribution (e.g., Mhlongo et al., 2015).

Between 1989 and 2019, the Namibian population decreased from ~6700 pairs to ~4300 pairs (Sherley et al., 2020). Within South Africa, the African penguin decline has been most pronounced on the West Coast, previously the species' stronghold. Here, the combined effects of environmental change and localized fishing pressure have meant that prey availability is insufficient to support seabird populations (Roy et al., 2007; Coetzee et al., 2008; Crawford et al., 2019). Following a brief period of recovery between the late 1990s and early 2000s, the West Coast African penguin population crashed; the number of breeding pairs dropped from ~32,500 to ~3400 between 2004 and 2014, representing a decline of almost 90%. Since then, this population has continued to decline slowly (Sherley et al., 2020). Over the same period in the neighboring South-West Coast region where the nearest colony is separated by only ~50 km, the population has declined at a much lower rate, with growth at a number of major colonies compensating for some local declines (Sherley et al., 2020). The Eastern Cape population has continued to decline at a steady rate. However, due to the rapid decreases elsewhere, the Eastern Cape is now the region that holds the largest proportion of the total penguin population (~40%), in comparison to 40 years ago when it held just 25% (Sherley et al., 2020).

Threats

The decline of the African penguin during the early 20th century was caused by destruction of habitat, primarily the removal of guano from breeding sites, and the commercial harvesting of penguins and their eggs (Frost et al., 1976b). While these are no longer threats to the population, historical guano collection irreversibly damaged penguin breeding habitat. Adults are unable to dig burrows, thus are often restricted to nesting on the surface (Frost et al., 1976a) (Fig. 4), where they are susceptible to heat stress and chicks are at increased risk from aerial predators and nest flooding in storm events (Shannon and Crawford, 1999; Kemper et al., 2007b). However, the contemporary population decline is predominately driven by changes in the abundance and distribution of prey. In the northern Benguela, a combination of fishing pressure and environmental forcing led to the collapse of the sardine population in Namibia by the mid-1970s (Cury and Shannon, 2004). A resultant regime shift has seen sardine replaced by a higher abundance of bearded goby and jellyfish (Roux et al., 2013). African penguin (and some other seabird) populations declined as bearded goby replaced sardine in their diet (Ludynia et al., 2010) and now remains relatively stable at low levels (Sherley et al., 2020). The sardine population in Namibia has not recovered and the fishery was closed in 2018 (initially for 3 years) after the stock dropped below the crash reference point of 50,000 tons of spawning biomass (Erasmus et al., 2021).



Fig. 4 Breeding African penguins *Spheniscus demersus* at St Croix Island, South Africa. As a result of the historic removal of guano from breeding sites, adult penguins are unable to dig burrows. Thus, they are often restricted to nesting on the surface where they are susceptible to heat stress, and chicks are at increased risk from predators and storm events. Photo credit: Richard Sherley.

Off South Africa, the abundance or availability of sardine and/or anchovy have been positively correlated with African penguin breeding success (Sherley et al., 2013), and both adult (Robinson et al., 2015; Sherley et al., 2014a) and juvenile survival (Weller et al., 2016; Sherley et al., 2017). In South Africa, sardine and anchovy traditionally spawn on the Agulhas bank during the summer months (van der Lingen et al., 2001). Their eggs and larva are transported in jet currents up the west coast, then as recruits they migrate southwards back along the coast to the Agulhas spawning ground (Hutchings et al., 2002). However, since 1996, as a result of climate-driven changes in the marine environment, the primary anchovy spawning habitat has shifted eastwards, away from the western Agulhas bank (west of Cape Agulhas) to the central and eastern Agulhas bank (east of Cape Agulhas; Roy et al., 2007). Furthermore, since 2001, intense localized fishing pressure, which occurred as sardine were responding to environmental changes in their spawning habitat, may have depleted a substantial proportion of the western sardine stock (Coetzee et al., 2008; Mhlongo et al., 2015). Following this combination of changing environmental conditions and fishing pressure, sardine abruptly shifted their spawning to be predominantly east of Cape Agulhas (van der Lingen et al., 2005); now only a small portion of spawning occurs annually off the west coast (Mhlongo et al., 2015). These changes have resulted in a spatial mismatch between penguins and their prey, meaning there appears to be insufficient prey biomass to maintain current seabird populations along the west coast of South Africa (Crawford et al., 2019). Furthermore, as many of the fish processing plants are located off the west coast of South Africa, fisheries continue to target areas where forage fish abundance is now low (Crawford, 2013), meaning penguins must compete for prey with commercial purse-seine fisheries (Pichegru et al., 2012; Sherley et al., 2018, but see also Sherley et al., 2021).

Factors such as oiling, predation, and disease also present a constant threat to the population (e.g., Weller et al., 2016). Due to the proximity of many colonies to shipping ports and routes, oiling presents a significant ongoing threat to African penguins. The number of penguins oiled has increased substantially since 1990 and is likely to increase further if proposed harbor developments go ahead (BirdLife International, 2020). While single catastrophic oiling events have had devastating impacts on the population (e.g., oiling events in 1994 and 2000 resulted in over ~30,000 penguin deaths; Wolfaardt et al., 2009), smaller but more frequent incidents related to port-related activities such as ship-to-ship bunkering can also cause significant mortality (e.g., ~200 individuals killed in Algoa Bay in 2016 and 2019; Ryan et al., 2019). These events also have long-term impacts on the population through the reduced breeding success and impaired long-term survival of oiled individuals in comparison to non-oiled individuals, despite successful rehabilitation interventions (e.g., Barham et al., 2007). Although kelp gulls (*Larus dominicanus*) may prey on small chicks and unguarded eggs (Cooper, 1974), island breeding colonies face fewer threats from predation than mainland sites, where terrestrial predators such as domestic cats (*Felis catus*) and dogs (*Canis lupus familiaris*), mongooses, Cape leopards (*Panthera pardus pardus*), and caracal (*Caracal caracal*) can kill many penguins in a single event (e.g., Vanstreels et al., 2019). Competition for food and breeding space with (Crawford et al., 2001) as well as predation by (du Toit et al., 2004) a resurgent Cape fur seal (*Arctocephalus pusillus pusillus*) population previously depressed by human exploitation (Griffiths et al., 2004) likely contributed to the penguin population decline as at sea predation by Cape fur seals has resulted in significant mortality at some colonies (Weller et al., 2016). While disease is not considered one of the primary threats to the African penguin, in recent years an outbreak of highly pathogenic avian influenza (HPAI) resulted in ~100 penguin deaths in South Africa and ~600 in Namibia (Molini et al., 2020).

Conservation

Following the IUCN reassessment of the African penguin's conservation status in 2010, a biodiversity management plan (BMP) was developed to guide future research and conservation. This plan aimed to halt the species decline and achieve population growth sufficient to result in the down listing of the species in terms of its status in the IUCN Red List of Threatened Species ([Government Gazette of South Africa, 2013](#)). However, this was not successful and has since been superseded by a revised BMP that will guide conservation actions until 2024 ([Department of Environmental Affairs, 2019](#)). The BMP makes provision for conservation actions in rehabilitation, on-land habitat protection, at-sea habitat protection and fisheries management, conservation translocation, and population monitoring.

Rehabilitation

Both as an intervention following oil spills and as a continuing effort, oiled and injured African penguins are rehabilitated at the Southern African Foundation for the Conservation of Coastal Birds (SANCCOB) and released back into the population (e.g., [Barham et al., 2007](#); [Sherley et al., 2014b](#)). Since 2006, as part of the ongoing Chick Bolstering Project, penguin eggs and abandoned or emaciated chicks have been routinely removed from colonies, incubated and reared in captivity, and subsequently released ([Sherley et al., 2014b](#)). This project has been successful; the release rate is 77% ([Klusener et al., 2018](#)) and hand-reared chicks appear to survive and recruit as well as their wild-counterparts ([Sherley et al., 2014b](#)). However, this measure must be carried out in tandem with actions to mitigate the threats faced by the wild population.

On-land habitat protection

At the time of writing, the vast majority of African penguin nests are located within terrestrial protected areas under either national (e.g., in South Africa, the National Environment Management: Protected Areas Act No. 57 of 2003 and in Namibia, the Marine Resources Act 27 of 2000), provincial, or local legislation ([Kemper, 2015](#); [Department of Environmental Affairs, 2019](#)). Routine monitoring and some scientific research are undertaken at all colonies with > 500 breeding pairs. Attempts are made to limit disturbance from human activities, although research and monitoring takes place under specific license from the national government and local managing authorities, and some disturbance may occur because of tourism at some sites. However, research suggests that African penguins can and do habituate to regular, benign human approaches to nests ([Pichegru et al., 2016](#); [Scheun et al., 2021](#)). Ongoing terrestrial conservation efforts also include displacing and eradicating predators from breeding colonies, including the removal of feral cats from Dassen Island and Robben Island (e.g. [de Villiers et al., 2010](#)), and the culling of individual kelp gulls that appear to specialize on preying on penguin eggs and chicks ([Pichegru, 2013](#)). The placing of replacement nest structures, such as artificial burrows and nest boxes ([Fig. 5](#)) at breeding sites has improved breeding productivity at some sites (e.g. [Kemper et al., 2007b](#)). However, ongoing research is required to improve the design of these structures, as there is significant variation in their effectiveness based on structure and locality of installation ([Pichegru, 2013](#)).

At-sea habitat protection and fisheries management

One priority action includes identifying the critical at-sea habitats used by African penguins, to inform the spatial and temporal designation of special management areas, both around breeding colonies and at important foraging habitats for juvenile, immature and non-breeding penguins ([Department of Environmental Affairs, 2019](#)).

Since 2008, an investigation seeks to determine the effects of purse-seine fishery closures around African penguin breeding colonies on penguin demographics and foraging behavior. In the Eastern Cape and Western Cape, temporary purse-seine fishing closures (within a 20 km radius) have been alternated at two pairs of islands within close geographic proximity (Western Cape: Robben Island and Dassen Island; Eastern Cape: Bird Island and St Croix). Evidence from this experiment suggests that such fishing closures can benefit African penguins. In the Eastern Cape penguin foraging effort decreased ([Pichegru et al., 2010, 2012](#)) and at Robben and Dassen Island chick survival and condition (Robben Island only) increased when fishing closures were in place ([Sherley et al., 2018, 2021](#)). However, no decisions have yet been made as to whether permanent closures will be introduced.

Currently, marine protected areas (MPAs) exist around some penguin colonies, including the Namibian Islands Marine Protected Area (NIMPA), where purse-seine fishing is banned in a buffer zone within which the penguin colonies are located ([Ludynia et al., 2012](#)). In South Africa, 20 new MPAs were formally named in 2019 ([Government Gazette of South Africa, 2019](#)), and MPAs now surround the penguin colonies at Malgas Island, Marcus Island, Jutten Island, St Croix Island, Bird Island (Algoa Bay), Stony Point, Robben Island, and Boulders Beach. However, these MPAs were generally designated for other purposes and do not adequately protect penguin foraging habitat. Designated no-take zones where purse-seine fishing for sardine and anchovy is prohibited, are in place at Marcus Island (0.3 km²), Robben Island (229 km²), Stony Point (20 km²), St Croix Island (167 km²), Bird Island (418 km²) and in the Table Mountain MPA (17.2 km², where Boulders Beach is located). However, the majority fall far short of protecting the 20 km core foraging range used by breeding African penguins. Most key breeding colonies in South Africa still do not have adequate fishing restrictions around them.



Fig. 5 A pair of breeding African penguins *Spheniscus demersus* in a wooden nest box on Robben Island, South Africa. Replacement nest structures such as these boxes have been shown to improve breeding productivity at some sites. Photo credit: Jennifer Grigg.

The scope for competition with fisheries is apparent across the penguins' breeding range and there is increasing evidence to suggest that small-scale protected areas around breeding colonies will be insufficient to reverse the species' decline on their own (Sherley et al., 2017, 2021). Lower penguin survival during their first year of life, when the birds move over much wider areas, is a significant driver of the current population decline (Sherley et al., 2014a, 2017) as is adult mortality, which has been linked to broad-scale sardine availability (Robinson et al., 2015). Therefore, it is important to introduce effective fisheries management strategies that can protect resources at appropriate scales for penguins throughout all stages of the life cycle. Further research is required to identify the key foraging habitats of immature (1–2 year old) African penguins, as well as adults during the non-breeding season to inform the implementation of spatial and temporal fisheries management at a regional scale.

Conservation translocation

Attempts are underway to re-establish and protect the African penguin breeding colony at the De Hoop Nature Reserve in South Africa (Fig. 2), where forage fish abundance is high (Department of Environmental Affairs, 2019). This new site will also bridge the gap in the distribution between colonies in the Eastern Cape and Western Cape to buffer the population against stochastic mortality. African penguins attempted to colonize this site naturally in 2003, but it was abandoned by 2006 due to high levels of predation (see above). Following the installation of predator-proof fencing to mitigate this threat, social attraction and conservation reintroductions have been employed to populate the new colony. Decoys and call playbacks have been installed to encourage African penguins to breed, and hand-reared penguin fledglings are being released at the site, with the aim that they will return to breed upon reaching maturity (sensu Sherley et al., 2014b). Considering the management challenges related to mainland breeding sites, the feasibility of creating an artificial island breeding habitat is also being considered.

Population monitoring

As well as the outlined conservation actions, further long-term population monitoring is required to determine trends in population size, demographic parameters, foraging behavior, to monitor disease, and to assess the efficacy of any conservation actions, either in place or proposed for future implementation. Linking changes in the African penguin population to a specific management action or actions is difficult and requires carefully parameterized analytical models. Such models require the collection of data on how the components of population demography (e.g., survival, fecundity, recruitment, and natal and breeding dispersal) change over time

and in response to various biotic and abiotic drivers. Regular and consistent population monitoring is essential to this, as is following the fate of individual birds. Historically, African penguins were marked with stainless-steel flipper bands to identify individuals and monitor demographic parameters such as adult survival and dispersal (e.g. Sherley et al., 2014a). However, due to the potential detrimental effects of metal bands, this practice was halted in the early 2000s (Petersen et al., 2005). Since 2013, at several key colonies across their breeding range, adults and chicks that are about to fledge have been marked with subcutaneous passive integrated transponders (PITs) and resighted using a combination of automated and manual devices. The resulting data can be used to identify the demographic rates which have the largest influence on the population size and trajectory and evaluate the effectiveness of potential management actions. Developing novel methods to obtain data on conditions at sea, including prey abundance and availability at spatial and temporal scales relevant to foraging penguins (e.g., ocean gliders) should also be prioritized.

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Chinese Crested Tern (*Thalasseus bernsteini*)

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Abstract

The Chinese Crested Tern (*Thalasseus bernsteini*) was rediscovered in 2000. In 2010 an International Action Plan was published and its estimated global population was no more than 50 birds. In 2020 its global estimation increased to 100–150 birds and is believed to be stable or slowly increasing. Number of known breeding grounds have also increased from two to five from 2010 to 2020. A northern breeding ground in Korea was found in 2016 and this gives hope to its restoration in northern part of its former range (northern China and Korea). The turning point was 2013 when social attraction was applied to restore the breeding site of Jiushan Islands in Zhejiang, China. And since 2014 monitors were guarding the site to protect them from threats particularly egg poaching and human disturbance. It still faces threats from pollution, invasive predators, competition with other breeding birds such as Greater Crested Terns and Black-tailed Gulls, hybridization with other crested terns, adverse weather, habitat destruction and overfishing. Luckily an international network has been established since late 2010s. Good coordination and sharing of experience supported well implementation of proposed conservation actions. In the coming decades we expect good progress will be made in better understanding of its migration and wintering grounds, and restoration of more former breeding grounds in northern Asia.

Introduction: A brief history

The Chinese Crested Tern (*Thalasseus bernsteini*) is a mysterious species. The type specimen was collected only about 160 years ago (November 1861) at Kao, Halmahera, eastern Indonesia (Collar et al., 2001). It has never been recorded as a common species. La Touche (1934) described even when Short-tailed Albatrosses (*Phoebastria albatrus*) were ‘very common’ on the China coast during winter (end of 19th century), the Chinese Crested Tern was so rare that ‘only a very few examples have been obtained, and there is no information available as to the movement of this bird along the China coast’ (La Touche, 1934). The highest number recorded prior to the 21st century was 21 birds collected as specimens from Shandong from June 12 to July 31 1937 (Shaw, 1938), of which only two remained and were kept at the Chinese Academy of Sciences in Beijing today (Wang et al., 2006). Judging from the time and the number collected these 21 birds should have been collected at one or two breeding colonies. Since then there were no confirmed record of this species until it was rediscovered at Matsu (Mazu) Islands along the Fujian coast of China in 2000 (Severinghaus et al. 2012). The lack of information of this species for more than six decades is understandable as it was not correctly depicted in references: field guides published prior to 21st century had its dorsal plumage too dark and bill color too light in illustrations (Photos 1–7).

Present status: Population trend and range

Estimation of the global population and trend of the Chinese Crested Tern as of 2020: 100–150 birds and its population trend is stable to slowly increasing (but still very fragile). This is an improvement to the situation of the late 2000s, when the global population was estimated to be not more than 50 birds (Chan et al., 2010). At the time the International Action Plan was published, numbers recorded on the only two known breeding sites: Matsu and Jiushan Islands were fluctuated and patchy that the population



Photo 1 Chinese Crested Tern with chick amongst Greater Crested Terns. Tiedun Dao, Zhejiang, China. July 3, 2014. Photo taken by Simba Chan.



Photo 2 Chinese Crested Tern with fledged chick on coastal rock. Tiedun Dao, Zhejiang, China. July 23, 2014. Photo taken by Simba Chan.

trend could not be deduced (Chen et al., 2011). However, from 2015 about 20 chicks fledged annually (with the exception of 2016), and that is close to the maximum known population of Chinese Crested Terns prior to 2010 (Videos 1–3 in the online version at <https://doi.org/10.1016/B978-0-12-821139-7.00138-0>).



Photo 3 Chinese Crested Terns with newly laid egg. Tiedun Dao, Zhejiang, China. June 3, 2014. Photo taken by Simba Chan.



Photo 4 Chinese Crested Terns and Greater Crested Terns in flight. Color of the plumage is the easiest way to distinguish these two closely related species. Tiedun Dao, Zhejiang, China. May 13, 2015. Photo taken by Simba Chan.



Photo 5 Chinese Crested Tern suffered from oil pollution. Tiedun Dao, Zhejiang, China. June 11, 2015. Photo taken by Simba Chan.



Photo 6 Chinese Crested Tern defending its nesting territory. Tiedun Dao, Zhejiang, China. May 29, 2015. Photo taken by Simba Chan.



Photo 7 Chinese Crested Tern returned to nest with fish. Tiedun Dao, Zhejiang, China. July 1, 2014. Photo taken by Simba Chan.

The Chinese Crested Tern is endemic to eastern Asia. Its historic breeding grounds were probably small islands along coastal Yellow Sea: as said above the Shaw collection in 1937 was a strong indication of breeding birds in Shandong. From an old specimen reported to be collected on July 5 1917 from an island north of present-day Incheon, Korea (Kuroda, 1917) this species was also probably bred in Korea in early 20th century. It was probably very localized and quite rare even in those days.

Its present known breeding grounds are Mazu Islands (Fujian Province, under the administration of Taipei), Jiushan Islands and Wuzhishan Islands (Zhejiang Province), Penghu Islands (Taiwan. Breeding recorded from 2013 but not breeding every year), and Chilsando Islands (Korea). It was first recorded in Japan during southward migration at Miyako Island, Okinawa on October 20, 2018. At present only two regular modern wintering sites are known: one at Seram Island in eastern Indonesia (since 2010) and the other at Mindanao Island in southern Philippines (since 2018). Single birds have been reported at Leizhou Peninsula, western Guangdong, China in late 2016 and 2018 so it may also winter in areas of the South China Sea (Figs. 1 and 2).

Since its rediscovery on Matsu Islands there had been surveys along the Chinese coast searching for other breeding populations in the 2000s: at the southeastern provinces of Zhejiang and Fujian and also at Shandong (Qiao et al., 2006; Lin, 2009). No breeding colonies were found during these expeditions but in 2004 the Zhejiang Museum of Natural History discovered a breeding colony of 10–20 birds (with 5 nests) at Jiushan Islands, Zhejiang during an unintentional survey from July 28 to August 2 2004 (Chen et al., 2005). In 2008 the Jiushan colony shifted to Wuzhishan Islands about 100 km to the north because of egg poaching and human

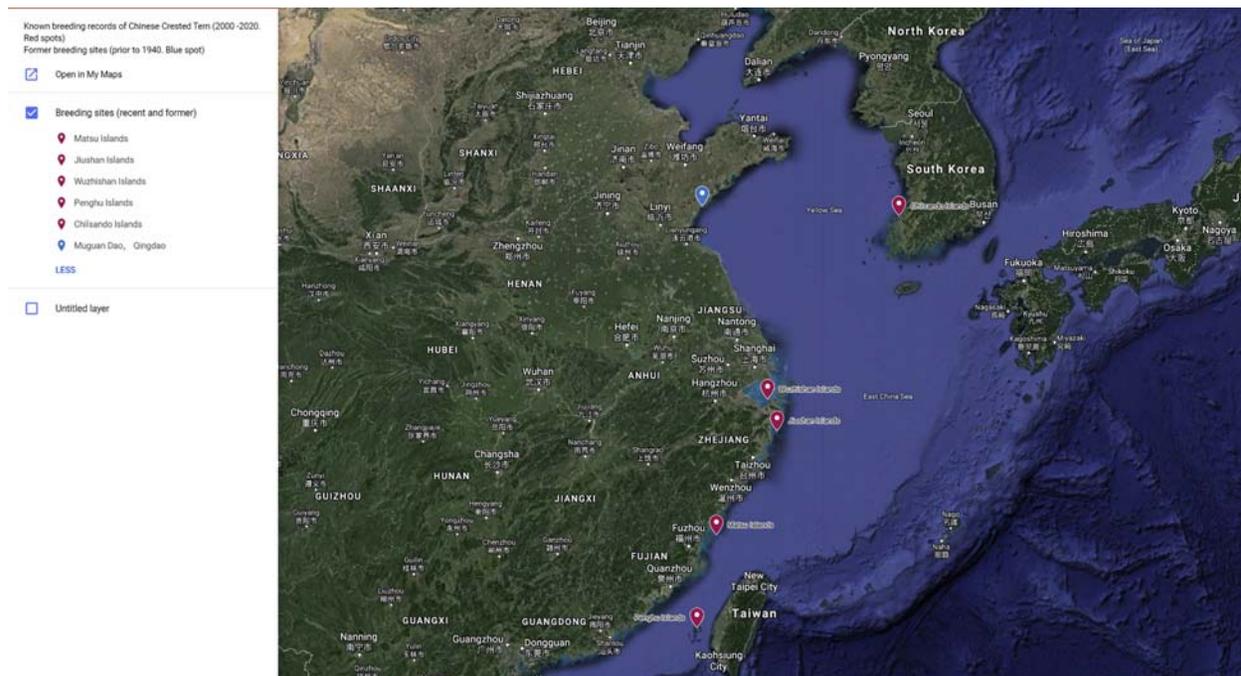


Fig. 1 Breeding sites of Chinese Crested Tern (red: 2000–20, blue: prior to 1940).

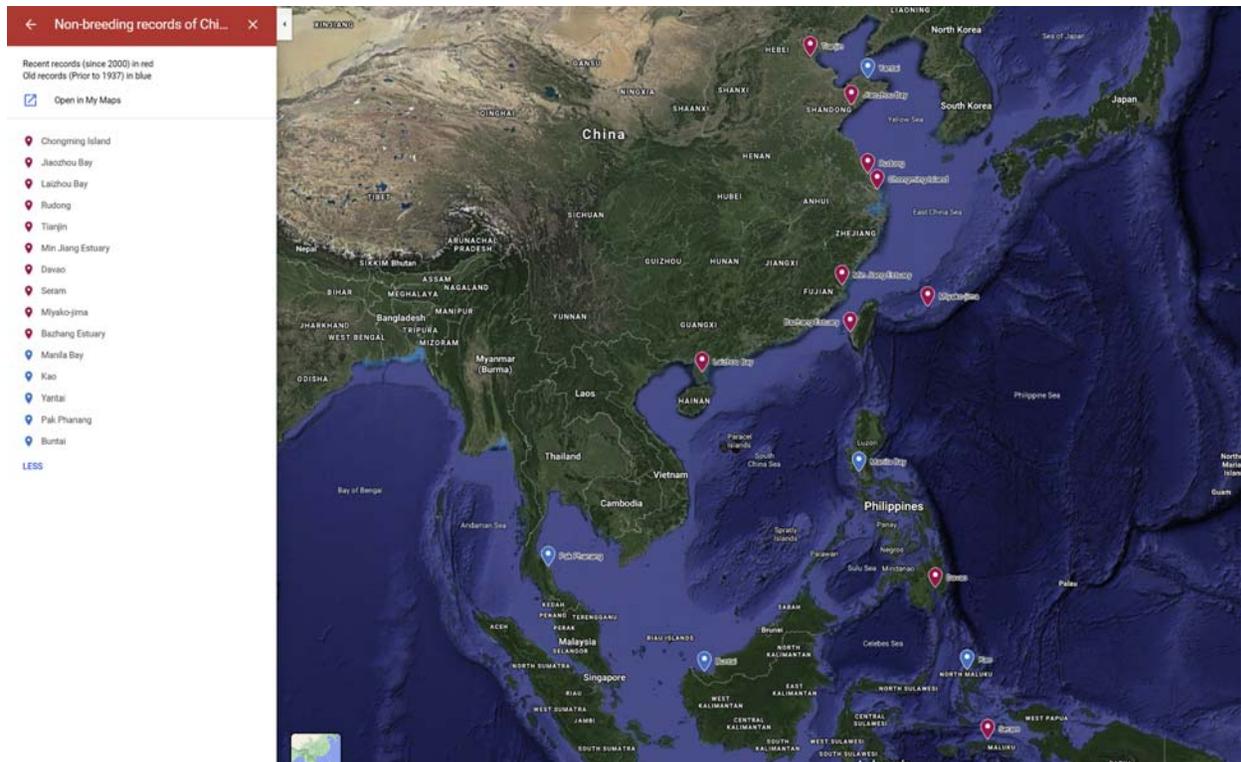


Fig. 2 Non-breeding records of Chinese Crested Terns (red: 2000–2020, blue: prior to 1940).

disturbance the year before (Chen et al., 2009). Social attraction was applied at Jiushan since 2013 and Wuzhishan since 2015. Since then the Jiushan-Wuzhishan population becomes the biggest and most stable breeding population. From observation of identifiable birds at the field, crested terns could travel between these two sites within the same day,

From La Touche's description this species was quite rare at the turn of the 19th to 20th century. As they need to reach a certain number threshold to form a breeding colony so we could safely assume there were at least several hundreds of them in early 20th century. There should be at least two colonies at the Yellow Sea: one at Shandong Peninsula and the other in western coast of Korea. They were not recorded since the late 1940s, when scientists could again visit the sites after the World War II. Apart from a handful of unverified sighting reports from China and South East Asia (Collar et al., 2001), there were no record of this species from 1937 to 2000.

Since its rediscovery in 2000–2013, the total known number of Chinese Crested Tern have not been exceeded 30 birds and the global population was estimated to be no more than 50 birds. From 2013, social attraction was firstly used on Tiedun Dao of Jiushan Islands. Nineteen Chinese Crested Terns were observed and at least one chick fledged at a very late stage (Lu et al., 2020). From 2014 Tiedun Dao was guarded 24-h by monitors during breeding season thus precise numbers could be recorded. For the first time at least 43 Chinese Crested Terns recorded and 13 young birds fledged. The success continued in 2015 when Tiedun Dao was guarded again, at least 52 Chinese Crested Terns recorded with at least 16 young birds fledged (SC unpublished data). With the exception of 2016 when the breeding failed due to snake invasion, from 2017 to 2020 number of birds in Tiedun Dao have been increased gradually, in the breeding season of 2020, at least 76 Chinese Crested Terns were recorded with 19 chicks fledged (Xie, 2020). Tiedun Dao data added up with other breeding sites has pushed the global estimation to more than 100 birds.

The sudden surge of number in 2014 was probably due to better documentation of numbers and a safe site created because of 24-h guarding on the island. This is a good example of successful social attraction to recreate seabird colonies. We recommend other breeding sites (Matsu, Wuzhishan and Chilsando) to establish similar system of guarding monitors.

At this stage we are more confident to say that the Chinese Crested Tern is slowly recovering. However, this species is still facing severe threats.

Causes of decline

Like all colonial seabirds in eastern Asia, the decline and disappearance of Chinese Crested Terns was likely to occur in middle of the 20th century, when motor boats becoming widely used by fishermen so visiting off shore islands became easier and cheaper. Egg collection and human disturbance were probably the most important causes of disappearance of seabird nesting colonies in Asian countries (Wells, 1991; De Korte, 1991). This is also the reason why the relict breeding population of Greater Crested Terns and

Chinese Crested Terns remained on Matsu Islands, which was a military closed zone from the 1950s to 1990s. It is also very likely that, with the population crashed in northern breeding grounds the Chinese Crested Tern could not form a breeding colony of a few hundred birds (this is probably the minimum number to form a colony. Detail to be explained below) they joined the Greater Crested Tern colonies in southeastern China to form breeding colonies. Greater Crested Terns are not normally found north of the Yangtze Estuary.

Threats

Egg collection and human disturbance

As stated above, the biggest threat to Chinese Crested Terns at their breeding sites is egg collection for human consumption. Chinese Crested Terns, like all colonial breeding birds, evolved to form big nesting colonies to deter and confuse predators. Big colonies can also provide a good vigilance system to nesting birds. The strategy apparently worked until the arrival of human with modern transportation and economic incentives to collect more their own consumption. [Chen et al. \(2015\)](#) noted if the first brood was collected and tern started a replacement brood, that would be later in the season and the eggs and chicks would be more vulnerable to typhoon. On Tiedun Dao, a poacher was caught on June 3, 2014 when he tried to land on the island but was reported by the monitor based on the island and arrested by police. It was clear the poacher knew when was the optimal time to collect eggs (when most birds have laid their eggs but embryos are not fully developed). That was an experienced poacher.

In addition, shellfish collectors, photographers and even ill-planned researchers would cause disturbance to the birds in the colony. From observations of the breeding birds in 2014 and 2015, both species of crested terns were very nervous during incubation and birds tried their best to nest in the center of the colony. Thus the nesting density is very high, up to 8 or 9 incubating birds per square meter at the center of the colony (SC unpublished data), when all flushed by the appearance of predators, some may not be able to get back to its original nesting sites. This accounted for the high number of abandoned eggs at the end of the season (3574 eggs counted on July 28 2014 and 1552 eggs on July 22 2015 when all birds left the colony. There were about 4000 crested terns in 2014 and 2500 crested terns in 2015. The 2015 count was done after a super typhoon hit the island in early July so many abandoned eggs might have lost), at the end of the breeding season, as more and more birds left the nesting ground and moved to the shore, reduction of number of birds in colony triggered a quicker departure of both parent birds and chicks from the nesting site. Very late hatching chicks were lured by parents to leave nesting sites as soon as they were hatched. Such behavior is also observed in Elegant Tern (*Thalasseus elegans*), a closely related species also forms dense nesting colonies (Kate Goodenough in litt). Human disturbance may have lasting effects on nesting birds. Crested Terns abandoned Jiangjunmao Island of Jiushan Islands in 2008 probably because of egg collection and human disturbance in 2007 ([Chen et al., 2011](#)). They returned to breed at Jiushan Islands from late July 2013 when social attraction devices were placed and fixed on the island of Tiedun Dao (within the vicinity of Jiangjunmao).

In wintering grounds the threat of human disturbance is not observed because so far only two wintering grounds for a handful of birds are known.

To counter illegal egg collection, strengthen law enforcement, awareness raising and education are important. After the poacher in 2014 was caught there have been no reports of egg poaching in Xiangshan (however, illegal seabird/waterbird egg collections are still reported in other places in China).

To reduce human disturbance, breeding grounds must be protected and closed to all except conservation and research staff during breeding seasons. Protocol on research conducts should be understood by all who work at the breeding ground.

In wintering grounds, threats of human disturbance seems to be much lower but regular surveillance of the regular roosting sites is needed.

Pollution

This is a neglected threat to Chinese Crested Terns, but it may be an important one if studied carefully.

In the breeding season of 2014 and 2015, a significant proportion of Chinese Crested Tern eggs on Tiedun Dao were observed failing to hatch. Normally a Chinese Crested Tern chick hatches 26 days after the egg is laid, but at least eight cases in 2014 (about 20 nesting pairs in total), and at least seven cases in 2015 (about 25 nesting pairs in total) were observed to abandon their eggs after more than 20 days of incubation. The nesting pair of Lesser Crested Tern (*Thalasseus bengalensis*) was also observed to abandon their egg in a similar manner in July 2014 (that was the first breeding record of Lesser Crested Tern in China). It seemed likely the embryos were killed by pollutants stored inside the egg. This is a point worth further investigation.

Oil spill on the sea is another potential threat to the crested terns as oil-stained birds were not rare inside the colony in 2014 and 2015, including several Chinese Crested Terns.

Plastic garbage and microplastics have proven to be a threat to seabirds worldwide. We have no details on the situation of Chinese Crested Terns. However, from July 10 to August 1 2008 one Chinese Crested Tern at Matsu was found to have a piece of plastic tube stuck at its lower beak (hence the bird nicknamed "Little Tube"). It was also recorded at Min Jiang Estuary of Fujian in late July 2008 ([Wild Bird Society of Taipei, 2008](#)). It was not observed again after August 1 2008.

At this stage there is very little we can do to counter the pollution problem. However, prevention of breeding birds concentrating at a few sites can be the best strategy to lower the risk of pollution poisoning. A detailed study on pollutants of all breeding areas is also recommended.

Predators

The main reason why crested terns nest on small islands in dense colonies is to protect themselves from predators. While avian predators like Peregrine Falcons (*Falco peregrinus*) could reach the islands, bigger terrestrial predators are usually kept away if the island is far from mainland. In Jiushan Islands, King Rat Snakes (*Elaphe carinata*) and rodents were found to be problems to breeding crested terns. In 2016 on Tiedun Dao, King Rat Snakes from unknown origin said to disrupted a breeding season. That was unexpected as the number of snake was very low in the previous breeding seasons. After a snake was found on May 10, 2014 the tern colony has been carefully monitored almost 24 h during the breeding season. The snake did not cause any problem to the breeding terns in those 2 years. Rodents were not detected in 2014 and 2015 (not even traces of scavenging from the food storage nor waste disposal) except one Lesser Ricefield Rat (*Rattus losea*) found drowned in the waste water bucket of the campsite on May 18 2015.

On small islands like Tiedun Dao (only about 2 ha in size), number of terrestrial carnivores cannot be high because very few preys available when the terns are gone (around August to April of the following year). Snakes and rodents may be carried by current or swim to the island from mainland or bigger islands nearby, or brought to the island by boats.

It is recommended a good eradication of rodents and snakes done before the terns arrive in April. Rat-baiting with poison is usually most effective during winter when food is scarce.

Avian predators like Peregrine Falcon could be a problem as birds of prey are usually more difficult to capture (and they are usually protected by law). On Tiedun Dao the first Peregrine appeared in 2014 on June 12. In 2015 the Peregrines learnt and were waiting for the terns at the beginning of May. Maintaining several alternative breeding sites may be a feasible way to reduce casualty that could jeopardize population recovery of Chinese Crested Terns to Peregrines.

Competition with other gulls/terns

Chinese Crested Terns and Greater Crested Terns need to form a colony of at least several hundred birds for breeding: the only exception known was one pair on 'islet C' of Wuzhishan Islands in 2009 (Chen et al., 2011) and another single bird observed on Tiedun Dao from June 11 till July 7 2015. The bird (a single parent) incubated the last egg till it hatched when all other birds in the colony moved to the shore. Crested tern colony can be very dense particularly when the birds felt threatened by the presence of human. Competition between nesting terns was very high. However, during the full-time observation on Tiedun Dao in 2014 and 2015, no casualty of adult birds observed and there was only one suspected killing of a Greater Crested Tern chick less than 1 week old by other terns. All nesting Chinese Crested Terns were mapped in 2014 and 2015 and they were not marginalized in the colony. Chinese Crested Terns were also observed to have a tendency to stay close to other nesting Chinese Crested Terns. On the whole the Chinese Crested Terns are not weaker as a species in competition with the Greater Crested Terns. Differences are of individuals but not of species.

On Tiedun Dao there were Black-tailed Gulls (*Larus crassirostris*) nesting in 2014 and 2015 but since they were outnumbered by the crested terns (about a hundred Black-tailed Gulls against three to four thousand crested terns) the gulls were marginalized. They were not seen wandering into the nesting territory of the crested terns so they were no threat to Chinese Crested Terns in this southern colony. However, the numbers of Black-tailed Gulls and Chinese Crested Terns reversed in the Korean breeding ground. The Chinese Crested Terns in Korea are not reported to be marginalized by the Black-tailed Gulls (Lee Yunkyoung in litt.) but interactions of these two species should be carefully studied.

Hybridization with Greater Crested Tern

Since a suspect hybrid of Greater/Chinese Crested Tern was seen at Min Jiang Estuary in July 2008, hybridization has been suggested as a potential threat to the long term survival of the Chinese Crested Tern (Chen and He, 2011). Morphologically assumed hybrids have been regularly turned up: in Tiedun Dao in 2014 two hybrids were seen and they both paired with Greater Crested Terns but breeding seemed not successful.

Courtship playing was sometimes observed between these two closely related species but generally speaking both species maintain a very strong species self-identify. The hybrids seen in 2014 on Tiedun Dao had very difficult times to find their mate as the two birds, both identified themselves as Greater Crested Terns, were constantly rejected by other Greater Crested Terns (SC unpublished data). Therefore the danger of hybridization between the two species may be exaggerated. This is another topic worth further studies.

Hybridization could be the result of wrong imprint of tern chicks because the nests were very close to the other, and the crested terns seemed only recognized their own nesting sites but not the eggs laid. When the colony is disturbed, all incubating birds flushed then returned, there would be chances that the Chinese Crested Tern sits on the wrong egg (eggs of these two species are not distinguishable). Several Chinese Crested Tern chicks on Tiedun Dao in 2014 were not in "typical" Chinese Crested Tern plumage. Those chicks could be normal (as chicks of Greater Crested Tern show variety of plumage color and pattern) or imprinted Greater Crested Tern chicks. This is a topic to be carefully studied in future.

In 2015, a very rare case of hybridization was observed on Tiedun Dao, A female Chinese Crested Tern paired with a male Lesser Crested Tern and nested for 21 days (May 31 till June 20). Incubation finally failed. Lesser Crested Terns are rare on the coastal China (2 seen in 2014 and 3 on 2015).

From the observation in 2014 and 2015, hybridization is exceptional and does not seem to be a serious threat to the Chinese Crested Tern. Avoid disturbance of incubating birds may reduce the risk. The best solution is restoration of the northern breeding population.

Adverse weather

In many literatures and reports, typhoon is stated as one of the major threats to the breeding Chinese Crested Terns. However, with the 2 years of direct observation of typhoons on the biggest colony of Tiedun Dao, including one labelled as super typhoon (Typhoon Chan-hom, around July 11 2015), most of the nesting birds and chicks were fine (it devastated the colony at Wuzhishan but that was younger than the one on Tiedun Dao). In the middle of the typhoon most birds laid low on the ground, casualties were mostly chicks less than 1 week old trapped in rock crevices and drowned in rainwater, or hit by flying objects (very few on the island but in July 2015 one wooden hide was blown down and killed some chicks), So far no Chinese Crested Tern death in typhoon recorded.

If the terns can have an early breeding success (i.e., chicks hatch by late June) the damage of typhoon to the breeding colony will be further reduced. Guarding of nesting sites to prevent human disturbance from May to June in southern breeding grounds is important in this sense. For northern breeding populations typhoon should not be a problem during normal breeding seasons.

Habitat destruction

In their breeding ground, crested terns breed on small remote off shore islands with no freshwater sources therefore almost no human settlement and economic value. Habitat destruction should not be a big threat to them. In the wintering areas, they are observed roosting on sandflats in the sea. Illegal sand dredging in Asia is a serious issue because of the surging price of sand for construction, and rampant dredging would reduce their roosting sites.

Overfishing

Depleting of fishery stock could be a potential threat to the Chinese Crested Tern, particularly during the breeding season. From observations on Tiedun Dao, Jiushan Island in 2014 and 2015 this was not a serious problem at this breeding site as parent birds have been recorded to return to their chick with fish caught in sea nearby in just 2–3 min.

Conservation recommendation: Now and then

The International Action Plan on the Chinese Crested Tern (Chan, Chen and Yuan 2010) was compiled in the late 2000s when only two to three breeding sites were known: Matsu that was relatively stable, and the Zhejiang islands of Jiushan and Wuzhishan (the Jiushan population was discovered in 2004 but shifted to Wuzhishan in 2008 because of human disturbance) The numbers of Chinese Crested Terns at all sites were dangerously low (not more than 20 birds). The following is a brief summary of what have been proposed and their implementation 10 years after the Action Plan was published. A link to the 2010 Action Plan attached at the end:

- **Legal status**

As suggested on the Action Plan, the Chinese Crested Tern is now proposed to be listed as the First (Highest) Category of Protected Species in China. Protection also covers eggs and it is illegal to sell or purchase Chinese and Greater Crested Tern eggs for consumption under the revised law effective since January 1 2017.

In Taiwan the Chinese Crested Tern has been protected since its rediscovery. From June 1 2020 it has been listed on the First Category of Protected Species (Endangered Species) under the Marine Protected Species list.

Chinese Crested Tern is also protected by law in other range countries: Japan, the Philippines and Indonesia. In the 2010 Action Plan it was suggested Viet Nam should also list the species as protected but at this stage it is not because it has not yet been recorded in Viet Nam (Manh Hung Le in litt).

In Korea it is not yet listed as an Endangered Species but is very likely to (as it is a recent discovery). At present it nests in a protected area.

- **Understanding the distribution and population**

After the Action Plan was published in 2010 there have not been serious efforts in searching of breeding colonies although some Chinese conservationists believed a northern breeding population in China existed (Qin and He, 2011). In 2016 a breeding colony was accidentally found in South Korea.

At the international workshop in Taipei (July 3 2007) researchers reached a consensus that because of the population is low and fragile, satellite tracking should only be applied to Chinese Crested Terns after intensive testing on the closely related Greater Crested

Terns. In the breeding season of 2008, five Greater Crested Terns on Matsu were attached with satellite transmitters, one was tracked to central Philippines and four were along the coast of China to Viet Nam (Wild Bird Society of Taipei, 2008). In late 2010s, Greater Crested Terns were also tracked from Zhejiang and Matsu, similar migratory routes were revealed. One first year Chinese Crested Tern was attached with a satellite transmitter from Matsu in 2017 but the signal lost when it reached Jiaozhou Bay in September of the same year.

Eight Greater Crested Terns staying with wintering Chinese Crested Tern at Seram, Indonesia from 2018 to 2020 were fitted with satellite transmitters. They did not migrate to eastern Asia but to Australia and Palau (SC unpublished and Yu Yat Tung in litt).

Greater Crested Terns (and a few Chinese Crested Terns) were also color-banded at Matsu, Zhejiang and Indonesia. One first year Chinese Crested Tern banded at Matsu in 2015 and returned to the same site in 2016, suggesting immature birds may also migrate to breeding grounds in the second year (one Chinese Crested Tern on Tiedun Dao also observed to behave like second-year bird following parents to Jiushan in May 2014).

The recommendations of survey for migration and wintering sites is not easy because there are numerous islands in western Pacific (the Philippines and Indonesia) so from 2018 we started satellite tracking of Greater Crested Terns from Seram to find out where are the locations they frequently visit during their stay in Indonesia. The tracking data may give hints on possible wintering sites of the Chinese Crested Tern. From 2018 to 2020 eight birds have been tracked and data analysis is underway. Once 'hot spots' are identified survey ships should be sent to these areas between December to February.

- The establishment and management of important sites

All existing breeding sites of Chinese Crested Terns are protected. Its known wintering ground at Seram will be included as the core site of a marine protected area. All breeding sites have regulations to prevent landing on the islands during breeding season. The most effective is probably the Jiushan Islands (the biggest breeding colony) where a monitoring team is based on the Tiedun Dao during breeding season. Contingency plan on disaster such as oil spills recommended in the action plan are not yet in place and this should be done at all known sites. Provision of alternative breeding grounds should be considered.

- Monitoring the Chinese Crested Tern and its habitat

Number of terns at all regular breeding sites are carefully monitored since 2014. Researchers from China, Taiwan and Korea are regularly sharing updated information at international conferences. However, habitat monitoring and a database and information dissemination system have not yet established and this should be considered by seabird experts and groups in the region.

- Education and outreach

Have been doing quite well since 2008. Chinese Crested Terns are now becoming a flagship species in seabird conservation, not just in China but also starting in South East Asian countries.

- Biological studies of Chinese Crested Tern

Have been going on well in both Zhejiang and Matsu with supports from universities and institutions.

- Coordination of conservation activities and information exchange

Some work has been done since the international workshops in 2009. A well-coordinated network is recommended.

Extra achievements after the action plan was published

When the 2010 Action Plan was published, a team of conservationists from Mainland China, Taiwan, Hong Kong, Japan, and United States was formed. The most important task then was to prevent illegal egg collection, and to promote public awareness on the Chinese Crested Tern and general seabird conservation in western Pacific. Because of this we organized several public events including the international workshop at Xiangshan in July 2010, 4 months after the Action Plan was published. At the workshop, local officers of Xiangshan showed interest in the case study of restoration tern sites using social attraction (example on Caspian Terns in northwestern United States). From then restoration of the deserted colony of Jiushan Islands began. And it succeeded late in the season of 2013. Only 3 years after initial discussion the Chinese Crested Terns were back and bred. Since then number of breeding birds have steadily increase. This is the biggest achievement to Chinese Crested Tern conservation of the 2010s.

What more is to be done in future?

Apart from keeping the momentum of all existing efforts, there are topics not listed in the Action Plan to be considered.

- Restoration of northern breeding population

Based on the success of restoration in Zhejiang in the 2010s, and the discovery of the breeding birds in Korea in 2016, the most important task in 2020s is probably to restore the northern breeding population: northern breeding colonies can avoid potential threats such as hybridization with Greater Crested Terns and typhoons in the breeding season. Restoration the northern breeding population may also lower the risk of local extinction. The possible sites should be along the coast of Shandong Peninsula, and the western side of the Korean Peninsula.

The natural number of Chinese Crested Terns at this stage (about 100–150 birds) may not exceed the threshold of forming a colony by themselves (and it is not advisable to attract all southern breeding birds to the northern breeding ground even if possible) so the Chinese Crested Tern will have to form breeding colony with Black-tailed Gulls at least for some years. Interaction

between the two species should be carefully studied before restoration project begins. The study should be carried out on Chilsando Islands, the existing Korean breeding site.

Since 2016, Chinese Crested Terns were found every year in coastal areas of southern Shandong (Rizhao and Qingdao) after the breeding season (early August to mid-October). With a maximum count of 37 birds (actual number probably more than 40) seen at Qingdao on October 7 2019 (Xu Keyang unpublished), this post-breeding northern movement before southward migration is probably regular to Chinese Crested Terns. Identification of suitable islands and deployed with decoys and playback system may convince some birds disperse to northern breeding sites.

- Identifying other possible breeding grounds

There are probably not many unknown breeding grounds after extensive surveys along the China coast for more than 15 years. However, the sudden surge of number of Chinese Crested Terns at Tiedun Dao in 2014 indicated unknown breeding population may exist. The most likely location is Senkaku Islands in Okinawa of southern Japan. Because of political tension human disturbance is low in that area. In addition, the area is well known as a good fishing ground. What is more convincing, is that Greater Crested Terns breed on Kita-kojima Island in Senkaku. It fits all criteria of a good potential breeding ground and should be surveyed (it is very difficult to get approval at present).

- Study of migration by satellite tracking

In the 2010s many Greater Crested Terns have been satellite tracked and we started to learn routes of their migration. We should have enough experience to track Chinese Crested Terns. Needless to say, the methodology of capture and handling the birds should be done with the greatest care not to jeopardize the bird and the breeding colony, and first year birds should never be tagged. This should also be done with careful consultation and planning with well-experienced tern researchers.

- Wintering ground survey

Surveying islands in South East Asia is not easy, but data from satellite tracking of Greater Crested Terns will guide us to the best places to look for wintering Chinese Crested Terns. From our study of the Chinese Crested Tern in Seram, the wintering bird is faithful to its wintering location (usually off shore sand bars). When wintering grounds identified these sites should be protected, particularly from sand dredging.

- Strengthen the Network on Seabird Study and Conservation in western Pacific

Chinese Crested Tern should be chosen as a flagship of seabird conservation of tropical and sub-tropical western Pacific. A network of tern experts should be maintained along the flyway.

Link to the CMS International Single Species Action Plan for the conservation of the Chinese Crested Tern <https://www.cms.int/en/publication/international-single-species-action-plan-conservation-chinese-crested-tern-sterina>.

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Threatened Flamingos: Conservation to Keep the Firebird From Being Extinguished

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Abstract

Everyone can recognize a flamingo. Yet of the six extant flamingo species, four are of conservation concern. The remote and specialized wetlands they rely on are under increasing pressures from human activities. Flamingos have evolved to inhabit specialized niches within ancient habitats that, at the landscape level, have evolved slowly but on a seasonal scale are highly variable. Consequently, the birds themselves have a long lifespan, a nomadic pattern of movements, a complex set of reproductive behaviors to organize colonial nesting, a long generation time and an irregular cycle of successful breeding. A combination of habitat specificity (and the dynamic in space and time), human encroachment, disturbance and wetland degradation has caused population decline in several flamingo species. Conservation action needs to focus on (i) ensuring the safety of their wetland ecosystems to ensure viable habitats and populations remain in the future, (ii) continued international collaboration and coordinated efforts to monitor and manage flamingo population across all of their ranges, (iii) encouraging dialog and links with industry to promote wetland-friendly practices, and (iv) integration of expertise from field biologists alongside of ex situ population managers into species-specific conservation action that involves wild birds and those housed under human care. Such an integrated approach to conservation, at the habitat and animal level, optimizes the chances of long-term success by involving as many stakeholders and interested parties as possible to identify key challenges for specific populations of flamingos and evaluate more general threats across all species.

Introducing the flamingo

Flamingos. The firebirds. So familiar to many, in terms of looks, behavior and of course, color. A staple at the local zoo. A plastic ornament for your front lawn. A symbol of tropical delights. Recognized for their abilities at balancing on one leg and their prowess on the dancefloor, the flamingo seems to be so ingrained in our conscious that it has always been known to humans and it will always be known to humans. Biologically, flamingos (Order Phoenicopteriformes) are large, wetland-inhabiting birds of a taxonomy that continues to confuse. Flamingos are found on all continents except Antarctica and Australia, although evidence of prehistoric flamingos is found in the Australian fossil record. Two species are found in the Old World and four species in the New World (Fig. 1). The word flamingo, first coined around 1560, derives from the Portuguese and Spanish “flamengo,” meaning flame-colored, and from the French Provençal dialect, “flamenc,” which has its origins in the Latin word “*flamma*” (flame). All original names reference the bright reds, oranges, and pinks of their plumage. Many flamingo populations rely on volcanic activities, hot springs, and seismic movements to form and maintain their wetland homes. The mythical firebird, the Phoenix, is acknowledged in the Genus, Family and Order names of the flamingos-again, a nod to the flame-like colors of the birds and (potentially) their fire-born habitats, see the Greek “*phoinikopteros*” meaning red-feathered. Adding to this mix of confusing derivation of names, *Phoenicopterus* may relate to the discovery of deep crimson and purple pigments by the Phoenicians, and therefore is nothing to do with volcanoes, fire, and phoenixes.

Flamingos are divided into two basic “types” (Table 1) that describe the internal structure of the upper part of their bill (the upper mandible). Shallow-keeled species have a flatter internal surface to their upper mandible, their bill contains coarse lamellae (the bristles used for filtering food out of the water), and the curve of the upper and lower mandibles is softer and less dramatic. Shallow-keeled flamingos are those species that are capable of feeding on macroscopic animal and plant materials and they collect their food either floating in the water column or from the substrate of the waterbody. Deep-keeled species have a deep ridge to the inner surface of their upper mandible and this fits into the groove made with the lower mandible. Their bills are full of fine lamellae and they have a wider and deeper lower mandible compared to their thinner upper mandible. Deep-keeled flamingos filter for

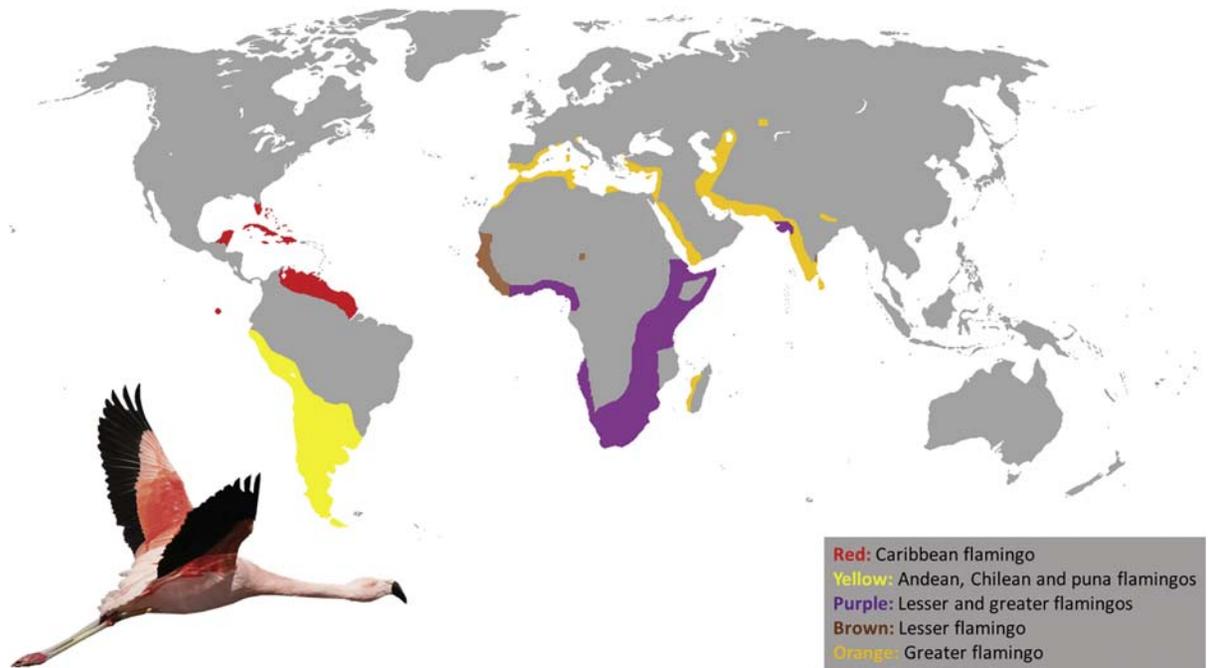


Fig. 1 The approximate distribution of flamingo populations in the Americas (red denoting Caribbean flamingos and yellow for Andean, Chilean and Puna flamingos) and for the two Old World species (greater and lesser flamingo) across Europe, Africa, and Asia.

Table 1 Flamingo taxonomy, scientific and popular names.

Bill type	Scientific name	Common name	Other names
Shallow keeled	<i>Phoenicopterus roseus</i>	Greater flamingo	European flamingo
	<i>Phoenicopterus ruber</i>	Caribbean flamingo	American, rosy or Cuban flamingo
	<i>Phoenicopterus chilensis</i>	Chilean flamingo	Flamenco austral
Deep keeled	<i>Phoenicoparrus andinus</i>	Andean flamingo	Parina grande
	<i>Phoenicoparrus jamesi</i>	Puna flamingo	James's flamingo
	<i>Phoeniconaias minor</i>	Lesser flamingo	Parina chica African flamingo

microscopic animal and plant materials; tightly packed lamellar allow the birds to sieve out the tiniest of edible particles (cyanobacteria, diatoms and algal blooms and zooplankton) from the water column.

The three-shallow keeled species are (by flamingo standards) less exacting in their habitat requirements compared to the three deep-keeled species, which connects to their more generalized feeding strategy. Greater, Caribbean, and Chilean flamingos can be found in saline and coastal wetlands, as well as at salt pans and alkaline lakes at a range of elevations. The greater flamingo has the widest geographic range of all flamingo species. The deep keeled species have a more restricted distribution that focuses around wetlands of an extreme nature (e.g., high elevation above sea level or hyperalkaline pH); this restricted distribution is not necessarily a limit to population size as, for example in the case of the lesser flamingo, if this habitat area is large and profitable enough, huge numbers of birds can gather. Flamingo species can be sympatric in their ranges (Figs. 1 and 2), but the way of feeding specific to each species and its bill shape (Fig. 3) reduces interspecific competition. Regardless of bill structure, all six flamingos are termed “extremophiles”—they are organisms that can tolerate extremes of salinity or temperature or altitude.

The genus name of the shallow-keeled flamingos, *Phoenicopterus*, means “crimson wing” and the species name relates to location (*chilensis*, “crimson wing of Chile”) or the bird’s color (*ruber*, “red crimson wing” and *roseus*, “pink crimson wing”). Translating the scientific names of the deep-keeled flamingos require a little more imagination. For the lesser flamingo, *Phoeniconaias minor* means “smaller crimson water nymph,” referring to this flamingo’s size (it is the smallest species) and dark pink color. And most strangely, *Phoenicoparrus* can be translated as “crimson bird of ill omen ...” and for each species as “...from the Andes” (for the Andean flamingo, *andinus*) and “...named for James” (as in Henry Berkley James who collected the first specimens for scientific description) for the puna (James’s) flamingo, *jamesi*.

Greater and Chilean flamingos were once thought to be subspecies of the Caribbean flamingo, but behavioral and morphological evidence shows them to be separate full species. In the past, some authorities have grouped all six flamingos into the *Phoenicopterus* genus, and some have placed the three deep-keeled species all into the *Phoenicoparrus* genus. Whilst still a subject under



Fig. 2 Smallest and largest. The diminutive lesser flamingo stands 90 cm high with a mass of around 2 kg. This species is dwarfed by the largest flamingo species, the greater flamingo that is 1.5 m tall and up to 4 kg in mass. Greater and lesser flamingos can be sympatric in some parts of their range but their specific bill structures and feeding behaviors reduce competition. Photo credit: V. Hariharan.



Fig. 3 Flamingos can be identified and classified by their head and bill shape. The three shallow-keeled flamingos are the Caribbean (far left), greater (next left) and Chilean (center left). The three deep-keeled species are the Andean (center right), puna (next right) and the lesser (far right) flamingos. The “family resemblance” of a wide upper mandible distinguishes the shallow-keeled species from the deep-keeled species, which have a thin upper mandible.

examination and review, the three genera with six species is the concept that is acceptable to most (at present). The relationship between flamingos and other birds has been hotly debated. Evolutionary alignments have been suggested with the Order Anseriformes (ducks, geese and swans), the Order Ciconiiformes (storks), and the herons (Ardeidae), ibises and spoonbills (Threskiornithidae) from the Order Pelicaniformes, but more recent evidence, including that gathered from molecular testing, suggests a link to the grebes (Podicipediformes), the pigeons and doves (Columbiformes) (Jarvis et al., 2014; Torres et al., 2014) and to the shorebirds (Charadriiformes) (Prum et al., 2015). Aging the evolution of modern flamingos is also tricky, as various authors have presented evidence suggesting that they are one of the oldest of bird families or one of the most modern (Torres et al., 2014).

The crimson Caribbean flamingo has been suggested as the most primitive species. Not only is it a shallow-keeled species with a generalized feeding strategy, it has the least organized courtship display and its overall consistent plumage color (a base of deep pink) means the flashes of black from its wings have the least impact when performing courtship rituals. The greater and Chilean flamingos, with their paler base color but more varied shades of pink, have more contrast against their black wing feathers. The message from their courtship display is clearer and more impactful. The three deep-keeled species are very closely related, and their original ancestry is hard to pinpoint. It is likely that they evolved in the western hemisphere, where the two *Phoenicoparrus* species live today, and then spread across the Atlantic Ocean.

One of the most familiar of flamingo characteristics is that they have pink feathers. This pink plumage is the result of a complex ecological and physiological relationship that has shaped the behavior and life history of the flamingos and beautifully illustrates the importance of conservation of both the animal and its environment. Without understanding how the flamingo feeds, and its adaptations to filtering for specific organisms from a particular part of the water column, wetland conservation for these species will be less successful. It is important to remember that the differences in skull anatomy (Fig. 4) and the method of collecting food



Fig. 4 (A) Skull anatomy of the flamingos showing the differences in skull size and shape between the species that feed on animal and plant materials (shallow keeled) and those that feed on microscopic plant material (deep keeled). (a) Deep keeled species on the left (lesser flamingo, front, Andean flamingo, back). Shallow keeled species on the right (Chilean flamingo, front, Caribbean flamingo, middle, greater flamingo, back). (b) Front view of bills showing the narrow upper mandible and smaller space for filtering in deep keeled (middle two skulls) compared to shallow keeled (outer skulls). (c) Differences in upper mandible keel in two South American species (Andean flamingo, deep keeled, left; Chilean flamingo, shallow keeled, right). (d) Differences in upper mandible keel in the two Old World species (lesser flamingo, deep keeled, left; greater flamingo, shallow keeled, right). Lamellae would be located on the edges and inner surfaces of the bill, and on the flamingo's tongue (that would lie in the groove of the lower mandible as shown by photos labeled b). (B) How the flamingo's bill and tongue anatomy allow for filter feeding. Water is sucked into the bill using the tongue as a piston. Suspended food particles are strained over the lamellae and swallowed. The flamingo's tongue can work at a rate of four cycles per second.

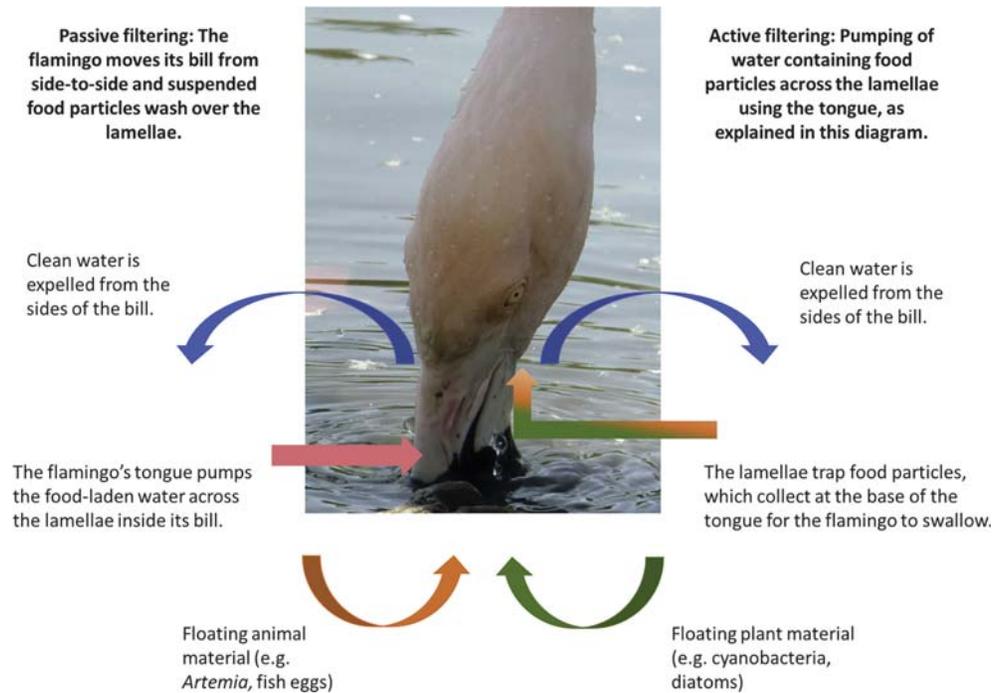


Fig. 4 (continued).

(Fig. 4B) directly influence the flamingo's plumage color and hence a whole range of social and reproductive activities and affect the types of wetland habitats that each species of flamingo can call home. All flamingos derive the color of their plumage and integument (skin) from the carotenoid pigments in the diet they consume.

Individual characteristics of the six flamingo species

For comparison, an overview of the distinguishing features of each flamingo species is provided in Fig. 5. The greater flamingo is the most widely distributed species, occurring in a range of wetland habitats across Mediterranean Europe, Africa, the Middle East, and Asia. This is a tall, pale flamingo, with its brightest pink feathers predominantly on its wings. The close relative of the greater flamingo is the Caribbean (or American) flamingo, which occurs across the Caribbean as well as in Colombia, Venezuela, Mexico, and Florida, with a small, isolated population in the Galapagos. Brazil, Guyana, and Suriname may also be important areas of South America for this species too. The Caribbean flamingo is a bright crimson red all over but in body size and shape it resembles the greater flamingo very closely. It is the only flamingo resident in Brazil and the only naturally occurring flamingo in North America. The Galapagos population of the Caribbean flamingo is considered to be a subspecies in its own right and giving these Galapagos flamingos the scientific name of *Phoenicopterus ruber glyphorhynchus* has been proposed (Frias-Soler et al., 2014). This differentiation is based on physical differences in size of adult birds and their eggs, as well as molecular and genetic differences too. The plumage color of these Galapagos flamingos is paler than their nominate counterpart too (Fig. 6).

The last of the *Phoenicopterus* flamingos is the Chilean flamingo, with its distinctive gray legs and pink joints. Chilean flamingos are found across the western side of South America and east into Brazil. Their range overlaps with that of the other two South American species. Chilean flamingos are the smallest of the three shallow-keeled species, and they have the most variable plumage, with a mixture of salmon pink, smokey pink, red and black. The bright pink joints (especially a bird's ankles) are this species' most distinguishing feature.

The Andean flamingo is the largest of the three deep-keeled species, being similar in size to the Chilean flamingo, and it is also the flamingo with the most variable colors in its plumage. In the breeding season, the Andean flamingo has vibrant purple-pink breast feathers and, uniquely among all flamingos, yellow legs. Like the closely related puna (James's) flamingo, the Andean flamingo does not have a hallux, or hind toe. The Andean flamingo is the most threatened of all flamingo species, with the smallest population.

The puna flamingo shares its range, across Argentina, Bolivia, Chile, and Peru with the Andean flamingo. These two types can also be sympatric with the Chilean flamingo in the high wetlands of the Andean plateau. "Puna" relates to the montane grasslands that are found in the altiplano of the central Andes, around 3200–4500 m above sea level, and this naming shows the strong link between the flamingos and their specific wetland homes. Puna flamingos are smaller than Andean flamingos, much closer in size to the lesser flamingo, and they have a vibrant yellow bill with a black tip. So characteristic is this yellow bill that a colloquial German name for the puna flamingo is *bananenschnabelflammingo* ("banana beak flamingo"). Puna flamingos have bright red scapular feathers

**Caribbean flamingo (*Phoenicopterus ruber*)**

Habitat: Marine and coastal wetlands.

Distribution: the Caribbean basin with important sites in Cuba, Bahamas, Dominican Republic, Mexico, Venezuela, and Bonaire. An isolated population is found on the Galapagos Islands.

Population size: Up to 330,000 birds.

Wild population trend: Increasing.

In the zoo: Common in zoological collections worldwide.

**Chilean flamingo (*Phoenicopterus chilensis*)**

Habitat: Coastal and marine wetlands, inland and upland lakes.

Distribution: Western side of South America, including Chile, Bolivia, Peru and Argentina. Has been known to fly over to the Falkland Islands.

Population size: Up to 300,000 birds.

Wild Population trend: Decreasing.

In the zoo: Common in zoological collections worldwide.

**Greater flamingo (*Phoenicopterus roseus*)**

Habitat: Coastal and marine wetlands. Salt flats, estuaries, soda lakes/alkaline wetlands.

Distribution: Throughout Africa and into Madagascar. India and the Middle East, as well as southern Europe and the Mediterranean.

Population size: Up to 680,000 birds.

Population trend: Increasing (the European population is growing fastest).

In the zoo: Common in zoological collections worldwide.

**Lesser flamingo (*Phoeniconaias minor*)**

Habitat: A highly specialised flamingo, both regarding habitat and diet. Undisturbed alkaline and saline lakes, salt pans and coastal lagoons.

Distribution: Throughout Sub-Saharan Africa and across to Madagascar, with a population in India. Can also be seen in the Middle East.

Population size: Up to 3.2 million birds.

Population trend: Decreasing.

In the zoo: Infrequently seen in zoological collections.

**Andean flamingo (*Phoenicoparrus andinus*)**

Habitat: A highly specialised flamingo, restricted to high mountain alkaline and salt-lakes at elevations of 2300-4500m.

Distribution: Specific locations within Argentina, Bolivia, Chile and Peru.

Population size: Up to 38,000 birds.

Population trend: Currently stable. Experienced a large population decline in the 1980s-90s from an estimated 100,000 birds.

In the zoo: Unlikely to be seen in zoological collections.

**Puna flamingo (*Phoenicoparrus jamesi*)**

Habitat: A highly specialised flamingo from saline lakes in remote, high Andean plateaus. Thought extinct until its rediscovery in 1956.

Distribution: Specific locations in north-west Argentina, Bolivia, Chile and Peru.

Population size: Up to 106,000 birds.

Population trend: Stable.

In the zoo: Unlikely to be seen in zoological collections.

Fig. 5 Key characteristics of each flamingo species. Key distinguishing physical features are provided, for each species, in the supplementary information (Data 3). Key characteristics of each flamingo species. Key distinguishing physical features are provided, for each species, in the supplementary information (Data 3 in the online version at <https://doi.org/10.1016/B978-0-12-821139-7.00051-9>).



Fig. 6 Examples of Caribbean flamingos from the nominate populations on mainland America and the Caribbean islands (left) compared to an individual from the Galapagos. Patterning of color across the legs, bill and plumage differs between populations. Galapagos photo credit G. Kautz.

that drape down over their wings and bright orange legs. A poorly understood species, puna flamingos were re-discovered to western science in 1957, having thought to have gone extinct some 38 years after its first scientific description in 1886.

The final flamingo species has the largest global population but is very restricted in range, this is the lesser flamingo. Lesser only in this, the smallest species of flamingo can occur in flocks of over a million individuals strong. Lesser flamingos are a bird of hyper-alkaline soda lakes (lakes of a pH between 9 and 12, with water containing high concentrations of carbonate salts) across the Rift Valley of East Africa, with smaller populations in southern and western Africa and India. The nomadic nature of this species means wandering birds have been seen in Mediterranean Europe, the Middle East and Madagascar. The movement of birds within and between continents also makes estimations of population trajectories challenging. Lesser flamingos are very susceptible to environmental change and disturbance and former breeding areas are no longer utilized due to anthropogenic influences over habitat quality.

The four flamingo species that are of conservation concern include only one shallow-keeled species (the Chilean flamingo). All three deep-keeled species are considered threatened or near threatened according to the IUCN Red List of Threatened Species. This is likely due to their more limited ranges and habitat specificity or is caused by their smaller population sizes and small number of suitable breeding areas, and the level of threat they face. Coupled with the greater impact of anthropogenic changes on suitable feeding and breeding sites, the deep keeled flamingos have less flexibility in where they can go and how they can adapt to new situations. The long generation time of flamingos (e.g., 15.5 years for the lesser flamingo), sporadic breeding events and need for exacting environmental conditions to instigate successful reproduction means that current populations may appear healthy but declines in the future will be caused by past (and present) events. Without understanding the complexity of factors, including flamingo behavior and ecology, and how they respond to local and global pressures, conservation of these species will be less successful.

The most threatened flamingos

The IUCN Red List (<https://www.iucnredlist.org/>) considers lesser, puna and Chilean flamingos to be near-threatened species, and classes the Andean flamingo as Vulnerable. The Andean flamingo is, at the time of writing, the rarest flamingo species. All flamingo species are listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (<https://cites.org/eng>). Since 2010, the Andean flamingo is also protected by the USA's Endangered Species Act 1973. Andean, puna, Chilean and lesser flamingos were all first assessed by the IUCN in 1988. Andean and puna flamingos were first categorized as "Threatened," with the Andean flamingo being upgraded to Vulnerable in 1994 and this risk status remains today. The puna flamingo was upgraded to Vulnerable in the 1990s and, after a period of uncertainty in 2000, has been consistently classified as Near Threatened. As of January 2021, both the Andean and puna flamingo populations trends are estimated as stable. Lesser and Chilean flamingos were first assessed as "Lower Risk/Least Concern," and then upgraded to "Lower Risk/Near Threatened" in 2000. The Near Threatened category has remained in place ever since and (as of January 2021) the estimated population trend for both lesser and Chilean flamingos is of a decline. Being on the brink of endangerment may be hard to comprehend for a bird whose population can number in the hundreds of thousands (e.g., Chilean flamingo) or millions (e.g., lesser flamingo), but the flamingo's reliance on specific wetland and a lack of behavioral plasticity to readily move or adapt to new areas means any sudden changes to existing preferred habitats would have disastrous consequences for overall population numbers and breeding success.

The criteria used to guide these Red List threat classifications for each of these four flamingos is outlined in **Table 2**. For each species, Criteria A (Population size reduction. Population reduction measured over the longer of 10 years or three generations based on any of A1, A2, A3 or A4 criteria) is the category used to define threat level. Explanations of the different observed population reduction but causes are reversible (A1) or not reversible (A2), or projected population reduction (A3) or including past and future population reduction (A4) are provided at iucnredlist.org/resources/summary-sheet.

Table 2 Current Red List classification (iucnredlist.org) criteria for the four threatened flamingos. Information on the criteria and description is taken from iucnredlist.org/resources/summary-sheet.

Species	Assessment (year)	Criteria	Explanation
Andean flamingo <i>Phoenicoparrus andinus</i>	VU (2020)	A2acd + 4acd	Population reduction estimated. Direct observation of population decline, decline in area of occupancy, actual or potential levels of exploitation. Decline in AOO or EOO and/or habitat quality
Puna flamingo <i>Phoenicoparrus jamesi</i>	NT (2016)	A3cd	Future population decline suggested. Decline in area of occupancy, actual or potential levels of exploitation. Decline in AOO or EOO and/or habitat quality
Lesser flamingo <i>Phoeniconaias minor</i>	NT (2018)	A2c + 3c + 4c	Population decline due to events that may not have been reversed. Past and future population decline, and estimated population decline expected to be met. Decline in AOO or EOO and/or habitat quality
Chilean flamingo <i>Phoenicopterus chilensis</i>	NT (2018)	A3cd	Future population decline suggested. Decline in area of occupancy, actual or potential levels of exploitation. Decline in AOO or EOO and/or habitat quality

For all species “a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality” is a key reason for the decline in the population and the threat level classification. The criteria used to judge conservation need for the flamingos clearly identifies the importance of the wetlands they depend upon. A reduction in the quality of the habitat or the number of such wetlands that are accessible to the birds (in terms of food availability and suitable nesting grounds) is reducing future numbers of birds or causing potential recoveries to be slow. “Actual or potential levels of exploitation” is also a reason common to all three of the South American flamingos where eggs are taken from nesting birds and adult birds are trapped and hunted in some parts of their range.

The importance of wetland stability and integrity is explained by flamingo’s requirements for specific food that provide carotenoid pigments, which are metabolized within the flamingo’s body to provide their characteristic pink plumage color. The collection of these food items has caused the evolution of their bills and tongues and associated reproductive and social behaviors have emerged because of this pink coloration (Fig. 7).

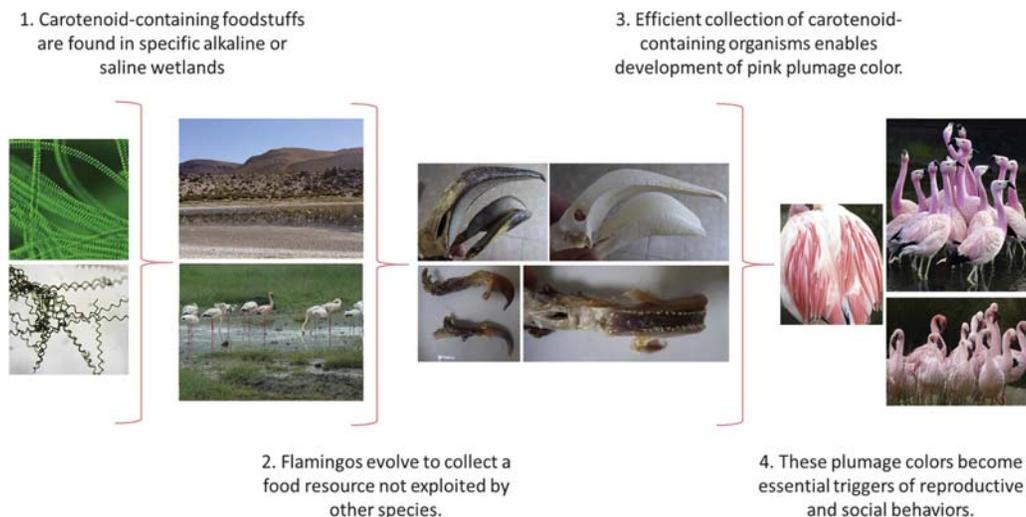


Fig. 7 The relationship between the diet of these threatened flamingo species, their habitat preferences, anatomy, and behavior. Far left, microscopic floating plant material, cyanobacteria (top) and Spirulina (bottom) that are found in abundance in (Middle left), hyperalkaline soda lakes and salt lakes frequented by Andean and puna flamingos (top) and lesser flamingos (bottom). Center: Bill structure of the Andean flamingo (colored) and lesser flamingo (bleached) showing the deep keel and narrow upper mandible that allows the bird’s tongue (Andean and lesser flamingo tongues shown in the photo) to pump suspended food over the lamellae. This microscopic algae and plant materials are rich in carotenoids which are converted in the bird’s liver to red, pink, orange, yellow and purple pigments to stain the bird’s plumage and tissues (middle right photo). These color enhancements are then used by the flamingos as signals for fitness during courtship display and social behavior (far right photo). Cyanobacteria/Spirulina photo credit: Wikimedia Commons. Andean flamingos in South America and lesser flamingos in East Africa photo credits: G. Kautz.

Large, open wetlands create conditions for huge flocks of flamingos to form. It is likely that flamingos evolved to occupy an empty niche, available thanks to the proliferation of aquatic microorganisms (both animal and plant) in saline wetlands, created by prehistoric geological activity. The flamingo's ancestor would have been able to access these food resources without competition and the harsh and inhospitable nature of these wetland environments decreased the chances of predation. Such conditions mean that flamingos can afford to not breed every year. Intermittent reproduction and several years spent without nesting are characteristics of the flamingo's reproductive strategy. Huge flocks, when they do nest successfully, can produce vast numbers of chicks. Flamingo breeding success is difficult to estimate due to the level of individual nest monitoring needed but some suggest success rates of 40–70% in good years and low as 0–30% in bad years. Flamingo nesting colonies are extremely susceptible adverse weather conditions and (in some areas) predation of eggs and chicks that can see whole colonies lost even before any eggs hatch. Once chicks do reach fledging, mortality rates drop dramatically. The long lifespan of flamingos, both in the wild (Perrot et al., 2016) and in captivity (Rose et al., 2014), means that low population recruitment should not impact long term population trends, so long as nesting events are successful and parents do raise their young to fledging when conditions are optimal and breeding does occur. This “wait and see” reproductive approach, with a complex courtship display that has evolved to bring the maximum number of reproductively viable birds into breeding condition at the right time means that flamingos can be buffered against naturally occurring environmental change without any associated negative impacts to their population number. For example, the Galapagos population of Caribbean flamingos suffered no decline in population number during an extreme El Niño event in 1982/1983 whereas surveillance of annually breeding bird populations, such as the flightless cormorant (*Phalacrocorax harrisi*) and Galapagos penguin (*Spheniscus mendiculus*) identified severe decreases in numbers (Valle and Coulter, 1987). Flamingos may have evolved to cope with disruptive events that occur infrequently, but will not be able to adapt significantly quickly enough to move ranges or change breeding habitats in response to the more dramatic, far reaching and unpredictable environmental fluctuations caused by indicators of current climate change or sustained negative human degradation of wetlands. An understanding of the flamingo's behavioral ecology is therefore an essential part of future conservation action.

Relevance of behavior to conservation needs

Flamingos are gregarious birds that perform a complex suite of social behaviors. Foraging, traveling, migration, and reproduction all take place as a flock. Many of the wetlands inhabited by flamingos shrink and grow with seasonal weather and climate variations. The Etosha Pan in Namibia, for example, is a huge ephemeral wetland that attracts lesser and greater flamingos as a feeding and breeding site. The ephemeral and/or changeable nature of such wetlands (i.e., dry and barren for many months of the year until rains causing flooding) makes them very susceptible to anthropogenic alterations that can reduce habitat quality very quickly. Like the Etosha Pan, the wetlands that flamingos inhabit need to be large enough to accommodate a gathering that can be millions of birds strong. Flamingos need room to assort in their preferential patterning of social associates that have been noted as occurring in all species. Foraging flamingos also like to maintain distances away from each other, which may reduce competition and unwanted aggression during feeding bouts (Fig. 8). Young flamingos are more likely to receive aggression from adult birds



Fig. 8 Lake Manyara in Tanzania is a shallow soda lake in the East African Rift, with an average depth of 0.8 m and a width of 40 km at its widest point. Lake Manyara can provide feeding grounds for large flocks of flamingos (left), with nearly 1.9 million lesser and 40,000 greater flamingos being estimated as present in the wet season. Flamingos show specific patterns of assortment with resting birds remaining in proximity of preferred dyads and trios as well as maintaining individual specific distances from other birds when filter feeding (right). Population estimates data from datazone.birdlife.org/site/factsheet/lake-manyara-iba-tanzania.

when mixed-age flocks are foraging together. Juvenile flamingos wear a brown/gray plumage to reduce interference from adults. Juveniles also spend longer, on average, on feeding bouts compared to adults, potentially a response to being displaced from the most profitable feeding areas. Consequently, foraging grounds need to be of expansive size and hold enough food material to provide for the various life stages of the flamingo as well as catering for their specific behavioral needs.

Ritualized courtship display

The large social groups that flamingos are found within exert an important influence over their courtship display. Birds gather to select a partner for breeding and both male and female flamingos take part in this courtship ritual (Kahl, 1975). Ritualized display is normally initiated by the tallest birds in a flock, which are most often male. And the display of male flamingos is less intense but more contracted than that performed by females. Flamingo ritualized display is broken down into various movements. Courtship normally commences with head-flagging, a behavior where the neck is held stiffly erect and the head is moved (“waved”) from side to side. This behavior is notable in all species but the puna flamingo maybe be more aberrant in its head flagging posture compared to the other flamingos (Fig. 9).

Lesser and Andean flamingos perform some of the most intricate of courtship displays, with highly synchronized marching accompanying the head flagging movements. Lesser flamingos can assume an unusual “broken neck” position during marching, where the bill is brought down in front of the neck, creating an exaggerated bend. Individual Chilean flamingos in displaying groups stand less closely together when compared to the other *Phoenicopterus* species and hence there is less squabbling and jousting within the courting flock of this bird. Head flagging is often accompanied by a range of wing and leg movements. A displaying flamingo will stretch both wings out to the side (wing salute), or lean forwards and stretch its wings (inverted wing salute), or extend one wing down the extended leg on that corresponding side of its body (wing leg stretch). The range and frequency of these wing and leg displays varies according to the individual and species; for example, puna flamingos are not known to perform an inverted wing salute, female flamingos are more likely to perform inverted wing salutes compared to male birds, Andean flamingos perform very stiff wing salutes and Chilean flamingos perform high rates of wing leg stretches. This demonstrates the complex messaging of such displays at both the species-specific and sex-specific level. Intense vocalization accompanies group courtship display and within the mass of displaying birds, signals are passed from male to female (and vice versa) and pairs are formed for that nesting season.

The precise mechanism by which birds select each other is still unknown, but it is likely a combination of size, color, range of permutations of display movement and duration, and age. Clues in the literature exist to guide our understanding of sexual selection and mate choice. For example, younger flamingos perform a wider range of variation in their display compared to older birds and, in the Chilean flamingo at least, wing leg stretches and wing salutes are orientated towards another specific individual in the flock- and this may give a clue as to who wishes to pair up with whom. Regardless of species, flamingo ritualized display is performed in a repeated sequence of movements from head flagging to wing saluting to marching, and repeat (Fig. 10).

Identifying the performance and understanding the relevance of flamingo ritualized display to viable breeding activity allows conservation managers to create and maintain suitable habitats that encourage group display by attracting sufficient birds to a site or location. Observation and data collected from flamingos under human care shows that smaller flamingo flocks are less likely to commence or complete nesting successfully. Water levels can be managed, and suitable mud islands or sand banks be exposed to assist with nesting in areas that reproductively active flamingos frequent. Human activity around such wetlands can also be managed using signage, interpretation or social media messaging asking people to avoid undue disturbance.



Fig. 9 Head flagging in the four most threatened flamingos. Similarities are evident in the performance of this behavior for Chilean (far right), lesser (right) and Andean (left) where the bill is held high and the neck is erect. Head flagging in the puna flamingo (far left) occurs with birds facing each other, with the neck held out and in front and the head waved from side to side. Wing salutes for this species are also unritualized and less developed in their movement compared to those from the other flamingo species.



Fig. 10 Stages of flamingo courtship. Low intensity display occurs at the start of courtship, with individual birds looking around and flagging (lesser flamingo, top) and/or a larger group of birds walking around each other and calling (Andean flamingos, below). If this excites enough individuals, the display becomes more energetic and medium intensity displays include group head flagging, wing stretches and twist preens (Chilean flamingos, top), wing salutes and inverted wing salutes (Andean flamingos, below). These wing and head movements ripple through the flock with more and more birds joining in. Courtship becomes more excited as birds perform high intensity displays such as marching (lesser flamingo, top and Andean and puna flamingos, below). Finally, the display may reach a climax with the highest intensity components where birds power through the water by marching and false feeding (Andean flamingos, top) or run together as a group flapping their wings (Chilean and lesser flamingos, below). The product of the display is the formation of bonded pairs. But the precise moment of choosing is still a mystery.

Nesting and rearing young

Flamingos are devoted parents. Investment in the pair bond is critical because flamingos do not always breed annually and so when they do breed a strong relationship between the parents maximizes the chances of success. A flamingo chick requires a lot of energy and parental attention to raise to fledging, as the development of the filtering apparatus and correct feeding behavior occurs over many weeks. Both the male and female bird have a role in selecting the site within the nesting colony for the construction of their nesting mound, and both parents share the duties of incubation and care of the chick. The need for a long developmental period, where the chick grows an adult size and shaped bill, and learns how to use it, is the reason why both flamingo parents must feed their chick directly (Fig. 11).

Flamingo chicks remain safe on their nest for the first week or so of life, before venturing from the mound to interact with other chicks. It takes a young flamingo around 3 months to fully develop foraging behaviors to efficiently utilize its specialized bill structures. For the first 10–12 weeks, direct feeding of the chick by its parents is therefore essential to the youngster growing normally. The rich, highly nutritious crop secretion enables rapid growth in the chick. Parent flamingos can continue to feed their chicks over a longer period however, with chicks still being fed on “crop milk” at 9 months to 1 year of age. Individual bouts of “crop milk” feeding from parent to chick can last for as long as 20 min. This chick feeding behavior constitutes a large investment of time and energy by the parent flamingos into the development and eventual fledging of their chick; if the wetland environments that are essential for nesting become degraded or negatively altered by human activities then wide-scale loss of youngsters will occur and it may be several years before the adult flamingos recommence nesting.

Direct parent-to-chick, bill-to-bill feeding has influenced the evolution of the flamingo’s visual field (Martin et al., 2005). As parent flamingos need to focus specifically on the bill of their chick immediately in front of them (and for potentially a lengthy period of time), they have evolved a frontal binocular field to aid in the transfer of crop secretions (Fig. 12). This again illustrates another evolutionary adaptation of the flamingos to live and breed in these hyperalkaline or saline wetlands. Crop milk secretion is stimulated by the chick’s begging call and chicks will chase and harass a parent, standing in front of it and pushing into the breast of the adult bird, until the parent begins to discharge this liquid lunch. Another feature of the flamingo’s reproductive strategy that has influenced this visual field is the construction of the mud nest mound itself.



Fig. 11 All species of flamingo feed their young on a secretion produced from the cells in the adult’s crop, commonly known as “crop milk” this high fat, high protein liquid is stained bright red by dietary carotenoids and fed directly from the adult to the chick. Left: drips of “crop milk” can be seen on the bill of this newly hatched greater flamingo chick and on the parent’s feathers. Right: dissected esophagus of an adult Chilean flamingo showing the enlarged expandable part of the esophagus that forms the crop. The striations highlight the lining of the crop, which contains the cells that slough off to form the crop secretions.



Fig. 12 Examples of crop feeding in (left) a newly hatched chick still on the nest, (middle) a chick of around 8 weeks old and (right) a near adult size chick of around 3 months old. Far right, the approximate binocular field of an adult flamingo in blue and the part of the front binocular field where the bird can see the tip of its bill in red. Visual field approximations taken from Martin et al. (2005).



Fig. 13 The process of flamingo nest construction requires precision in the rolling and placement of small mud pellets. The flamingo starts by making scratches in the substrate, normally wet mud or sand (far left) and, using the tip of its bill, collects together small pellets of substrate that are piled together into a nesting mound (center left). The flamingo sits in the middle of this mound of pellets and gradually its actions of piling up the mud pellets raises the height of the mound. Flamingo nests are generally built near to water to ensure that suitable mud for increasing the height of the nest is within the length of the bird's neck (center right). Flamingos are industrious builders and mounds can be very tall (far right). The height of the nest provides protection for the developing egg and growing chick from environmental fluctuations, such as flooding.

Nesting colonies of flamingos are centered around mud mounds that are produced by each pair. The female flamingo then lays her single, white chalky egg in the middle of this nesting mound. The need to create the nesting mound is the other reason why the flamingo can see precisely around the tip of its bill. The flamingo creates its nest mound out of small pellets of substrate (wet mud and sand) that it sticks together, gradually building layer upon layer of pellets to increase the height of the mound until it resembles a large upturned bucket. **Fig. 13** illustrates the process of creating the nest mound from inception to incubation. To be able to place the pellets of mud specifically in place, the flamingo again requires frontal binocular vision.

The flamingo's nest mound fulfills a range of functions. Nesting occurs after courtship display and is precisely timed around rainfall. Heavy rain and warm temperatures stimulate the flamingos to nest by providing the ideal conditions for soft, pliable substrate to be accessible but water levels still high enough to provide protection around nesting sites. Once piled up and cemented together, the pellets of mud set firm, creating a solid structure that is high enough to keep the egg and chick out of any rising water levels caused by sudden flooding events. This nest mound also soaks in water from the substrate it is built on. As this water rises to the top of the mound, it evaporates and cools the chicks in the process. Finally, the height of the mound raises the chick from the scorching temperatures at ground level, catching the prevailing breeze and cooling the newly hatched flamingo by convection.

Chicks leave the nest to form creches, where there is safety in numbers (**Fig. 14**). As the parent flamingos go to forage, bathe, and preen, this nursery group will be watched over by a small number of adults. Habitats for breeding flamingos need to provide safe, quiet areas for the chicks to creche away from deep water or mud. At the end of the nesting season, parent flamingos will have lost body condition and plumage color. Production of the crop secretion is energetically demanding and even though adult birds that are feeding young increase their time spent foraging and alter their foraging patterns to feed more overnight, there is still extensive energetic investment in "crop milk" that reduces that available for the adult's normal physiology and maintenance of homeostasis. Consequently, it is easy to spot parent flamingos in a flock of birds due to their overall paler color. Raising a chick does not drain the parent flamingo of the "pinkness" already in its feather, it reduces the amount of carotenoid available to stain newly growing feather. As mentioned previously, "crop milk" is red due to its carotenoid content. As flamingos molt at the end of breeding, so the reserves of carotenoid in the parent's body are low. These new, post-breeding feathers grow through white (the flamingo's base body color). Adult birds have to top-up their carotenoid reserves so that the next set of feathers to grow returns them to their normal pink hue (**Fig. 14**). This fluctuation in plumage coloration, from courtship pink to post-breeding white and back to pink, is thought to give flamingos time to recover from rearing their chick and it synchronizes the breeding cycle of the maximum number of



Fig. 14 All flamingo species creche their chicks to allow the adults to go and feed whilst leaving their youngster in a safe environment (left). Rearing a chick to fledging reduces the amount of carotenoid available to maintain the intensity of pink in the parent bird (middle) and so by the end of the nesting season those birds that have bred will stand out due to their overall white plumage (right).

birds in the flock—ensuring they are all recovered and in the best condition ready for the next period of good weather that is so important for successful nesting. This gives the highest chance of chick survival in the challenging environments in which flamingos live. From a conservation perspective, protection of wetlands that are rich in the correct dietary items for flamingos to produce quality, energy dense “crop milk,” and to then be able to feed and fully recover for the subsequent breeding event, are vital.

Threats to flamingos

The precarious nature of the flamingos’ survival in their wild, seemingly harsh, wetland homes is beautifully illustrated by how easy they are to lose. The type specimen of the puna flamingo, first collected in 1886, is held in the United Kingdom’s Natural History Museum (Fig. 15). Several years later, in 1924, the puna flamingo was believed to have gone extinct with no verified descriptions of wild birds being available. The rediscovery of the puna flamingo is a remarkable story fully explained by Johnson et al. (1958), the paper written by those that took up the challenge to locate this most elusive of flamingo species. Tales of deep mud and slime, of lakes with water pH of 8–9, of shredded legs and ankles from razor sharp salt crusts, and of flamingos nesting well beyond view of the shoreline evoke the same descriptions of the first trips to identify the nesting sites of the lesser flamingo in East Africa, which is explained in detail by Brown (1959). Brown’s flamingo expeditions almost ended in personal disaster, as the burns he received from walking through the hyperalkaline water required intensive treatment and hospitalization. Yet the information gleaned from such visits is essential to our understanding of 21st century flamingo conservation. Museum artifacts from these past flamingo-finding expeditions are important for studying the taxonomy, evolution and anatomy of such species, but they are no replacement for research on living individuals within the ecosystems that have molded their evolutionary pathways and formed their unique behaviors.

What is remarkable about the story of the four threatened species, three in South America and one Africa and Asia are the sharp contrasts and clear similarities. The habitats described by these authors on both sides of the globe clearly illustrate the nature of these alkaline wetlands (Fig. 16). Shallow water over viscous, unforgiving mud, glass-like salt crusts, and pH at the very high end of the scale. Exposed wetlands, supporting little life aside of diatoms, algae, crustaceans, and flamingos. And yet there are stark differences in altitude (4000 m plus for the high Andes species), in air temperature (Andes wetlands freeze down to -30°C at night, Lake Bogoria in Tanzania bakes at 30°C during the middle of the day) and in water temperature (flamingos frozen into their lakes waiting for the sun to thaw them out in the Andes, lesser flamingos drinking from water at near-to-boiling as it emerges from hot springs in the Rift Valley). And there are differences in the human disturbances too.

The South American flamingos are exploited by local people for their eggs whilst nesting. Adult birds are shot by indigenous communities in the Andes as it is thought that flamingo fat, when rubbed on the chest of a sufferer, will cure tuberculosis. Such hunting is, however, low level. Education and engagement with local communities around areas where flamingos frequent is key to long term survival. Copper mining threatens populations of the Andean flamingo and illustrates the sensitivity of these mountain flamingos to mining disturbance. Expansion of copper mines in Chile is a worrying development. The flamingo populations of the Andes Mountains are also under pressure from lithium mining. An industrial activity that has intensified in recent years with the increased demand for lithium to be used in electronic goods. Most of the world’s lithium is produced by Chile and Argentina (along with Australia). The “Lithium Triangle,” an area of high lithium sources covers parts of Bolivia, Peru, Chile, and Argentina. Lithium is an essential component for the generation of “green energy” as it is a major component of batteries, so mitigating the threats to these mountain flamingos and reducing pressure on fragile mountain habitats needs to be part of this sustainable energy agenda. The wide salt flats and shallow lakes that are vital for the survival of the three South American flamingos are drainage basins, collecting from water following down the mountains and volcanoes that surround these wetlands. Volcanic



Fig. 15 The type specimen (the specimen, or each of a set of specimens, on which the description and name of a new species is based) for the puna flamingo. Held by the Natural History Museum, this bird was collected in 1886 by Carlos Rhaner, formally described by Philip Sclater, and named after Henry Berkley James who sponsored the exhibition. Reproduced with the kind permission of the Natural History Museum’s Bird Department at Tring.



Fig. 16 The high mountain salt flats of the Andes look beautiful, but they are an extreme environment that only the toughest of species, like the Andean, Chilean and puna flamingos, can survive and thrive in. Photo credit: G. Kautz.

activity, weathering and erosion over thousands of years has deposited rich levels of lithium into this run-off water, which has settled in the lakes and salt flats. Lithium is also present in aquifers and the water table of these areas. The process of pumping water through lithium rich soils to evaporate and then extract this element changes the water table of the wetlands that impacts on the quality of the habitat for the flamingos. This harvested lithium is worth huge sums of money to the electric car, mobile phone and other industries that produce battery-powered devices. To reduce pressures on the birds, protect the lives of the indigenous communities that also share this area with the flamingos and to ensure this industry is sustainable, “Certified Lithium” (i.e., that produced in a way that causes minimal environmental damage) should be the way forward for these industries, and the process for implementing this is thoroughly outlined by [Stacey \(2019\)](#). Recycling and the correct disposal of batteries, and consideration of when battery-powered devices are updated (extending their usage rather than being disposable) can all play a role in mitigating the effects of lithium mining.

Mining is not just a threat for the high mountain flamingos. Lake Natron in Tanzania is the breeding location for 75% of the global population of lesser flamingos. Although this species numbers in its millions, its habit of quite literally putting “all of its eggs in one basket” means any change or disruption to preferred nesting locations can be devastating to productivity and severely limit future population growth. Recent proposals to mine for soda ash (used in a range of industrial products) from Lake Natron have, thankfully, been defeated but as the northern part of the lake is covered by a 1.5 m deep bed of trona (trisodium hydrogencarbonate dihydrate), the mineral that is converted into soda ash, conservation groups are vigilant should any future plans to harvest the trona be put forward. Building a soda ash factory near Lake Natron would take valuable freshwater out of the lake and away from both flamingos and local communities. The flamingos time their breeding to the period when water levels begin to lower, thus allowing soft mud to be exposed for nest building but still surrounded by enough water to deter potential predators. Soda extraction would cause long term lowering of Lake Natron’s water levels and remove these optimal breeding conditions. The pumping of waste effluent from the factory into the lake would also severely reduce the water quality and affect the blooms of algae in the lake that the flamingos feed on. Long-term impacts on ecotourism revenues, due to the loss of birds, would also result from the industrial development of these fragile ecosystems.

Breeding and foraging grounds for lesser flamingos in East Africa have been further restricted by past changes to lake hydrology, water chemistry and human activities. Lake Nakuru in Kenya was once famous for its huge flocks of lesser flamingos. The birds are still present at this lake, but in reduced numbers. Changes to Lake Nakuru’s water chemistry (due to human activity around the lake and climatic variability) have reduced its alkalinity (making it more appealing for a wider range of bird species) and the introduction of algae-eating fish species that would not have been able to survive in the Lake’s original water parameters add extra competition to the filter feeding flamingos. Records of lesser flamingos breeding at Lake Nakuru are patchy and hard to verify, so it’s likely that this lake has always been borderline in quality for sustaining a breeding flock of lesser flamingos. Large-scale die-offs of flamingos at Lake Nakuru and other Rift Valley Lakes, most noticeably throughout the 2000s, were attributed by authorities to the changed water quality of the lakes, which caused a lack of suitable food algae meaning the flamingos consumed unsuitable substitutes that contained toxins lethal to them. However, others who have sampled the algal species from the lakes and tissue samples from dead birds found no evidence of cyanobacterial toxins in the water or in the tissues of the birds. Flamingo die-offs may be a combination of reduced lake quality that causes a patchy distribution of feeding areas and an unpredictable level of food availability. This weakens the flamingos, leaving them more susceptible to other well-documented avian pathogens. For example, samples of dead flamingos taken from such mass death events have noted the presence of avian tuberculosis (*Mycobacterium avium*).

Other threats to flamingos include illegal hunting, shooting, and poaching, capture for the pet and ornamental bird trade, collisions with powerlines, pressures from unregulated tourism, development of wetlands for human usage and infrastructure, and disturbance from light aircraft or drones. Introduced species and changes to habitat quality can also reduce the suitability of wetlands for flamingos, causing them to move on. It is hard to predict the potential long-term impacts of climate change on global

flamingo populations but work from BirdLife International and available on their datazone webpages suggests a markedly changed range for the lesser flamingo based on modeling of climate change effects on rainfall and temperature from the present to 2085. More information on climate change influences on flamingo populations is available at: <http://datazone.birdlife.org/species/factsheet/lesser-flamingo-phoeniconaias-minor/climate>.

Conservation of flamingo wetlands

This review of flamingo anatomy and physiology, behavior and ecology has shown how much they depend on specific wetland habitats and are very choosy about the resources that they need. Caustic soda lakes and alkaline wetlands, undisturbed nesting sites that can hold large colonies and wide, open wetlands that bloom with microscopic aquatic plants and animals are essential to the flamingo's future survival. It has been estimated that a 2 million strong flock of lesser flamingo foraging in one of the East African soda lakes will consume 250,000 kg of algae per hectare of surface area annually. Calculation of energy budgets of wild lesser flamingos has identified that one catalyst for breeding activity may be the profitability factor (i.e., the amount of good quality food readily available) of their current foraging lake. Alongside of climatic conditions, breeding is likely to commence whenever the food concentration is sufficient to enable substantial fat reserves to form. Lesser flamingos use this fat as fuel to move between lakes, investigating which lakes are most likely to provide the optimum conditions for breeding. When a food concentration of $\geq 0.25 \text{ kg/m}^3$ is available, in a lake adjacent to a suitable breeding site, nesting is most likely to commence. Conservation of the profitability and energy content of "flamingo foraging lakes" is as important as conservation of their nesting lakes.

Direct augmentation of habitat quality to encourage the formation of breeding colonies of flamingos is possible. One high profile initiative is the Kamfers Dam artificial breeding island for lesser flamingos, constructed at Kimberley in South Africa (Fig. 17). This new breeding island was created in 2006 and has attracted more than 20,000 lesser flamingos that have nested successfully, with an estimated 9000 chicks being fledged in some years. However, challenges with maintaining water levels and water quality have impacted on the viability of this lesser flamingo colony, with an intervention required in the 2019 breeding season when falling water levels in the Dam caused parent birds to abandon eggs and chicks in huge numbers. Human rescuers from many conservation and zoo organizations in South Africa and from around the world stepped in to collect these abandoned chicks, rehabilitate them and eventually release juveniles back into the wild.

Conservation of flamingo can be achieved through ecotourism. Adding value to the birds and their environment in a sustainable manner, flamingo-centered ecotourism has been documented as a multi-million US dollar industry, with estimates by Galicia et al. (2018) of \$16,542,004 being generated by ecotourists to the biosphere reserves of Mexico's Yucatan. With approximately 80% of the tourists interviewed by Galicia et al. (2018) stating that seeing the flamingos was their main reason for visiting the biosphere reserve, the draw of flamingos as a natural spectacle is clear (Fig. 18). The lesser flamingos of East African are also a key driver of ecotourism and this industry contributes over 12% to the Gross Domestic Product of Tanzania and other Rift Valley countries. Any change to the ecosystem of the Rift Valley lakes caused by soda ash mining would decrease the number of flamingos and negatively impact on the ecotourist market.

Income generated from sustainable ecotourism can then be used to manage the nature reserves and habitats important for the flamingos and other wildlife, as well as provide income for local communities and hence added "buy in" to conservation programs. Captive flamingos can also generate high levels of visitor interest too and indirect conservation of wetlands can result from an enhanced understanding of the birds and their habitats due to such visitor engagement at the zoo where the flamingos are housed. Similar to the findings from wild flamingo encounters, flamingos are very popular with visitors to animal attractions and Rose (2018) showed that flamingos were the most popular bird to see for visitors to Wildfowl & Wetlands Trust (WWT) centers. Harnessing the popularity of the flamingos and the interest that people have in them, regardless of where they are being viewed, could provide useful and long-term means of funding conservation actions.



Fig. 17 The artificial nesting island at Kamfers Dam, Kimberley, South Africa. Created by South African flamingo experts in conjunction with a local mining company to encourage the breeding of this species of flamingo at a new location. Photo credit: M. Anderson released under license to Wikimedia Commons.



Fig. 18 Caribbean flamingos nesting at Ria Lagartos, a UNESCO Biosphere Reserve in the Yucatán, Mexico. The economic benefits of regulated and sustainable ecotourism practices centered around flamingos has the potential to generate many millions of US dollars for this region. Photo credit: E. Galicia provided with permission of D. Ramos.

The caustic soda lakes of East Africa can also bring other sustainable financial benefits. Work at Kenya's Lake Bogoria, one of the lesser flamingo's most important feeding locations, as well as at Lake Nakuru has identified that microorganisms in these hyperalkaline waters can be used to soften fabrics, help fade the color of denim and remove biological stains from cotton. Kenyan scientists are working to develop these microorganisms and the enzymes they produce into natural, sustainable compounds that can be used across a range of industries to replace some of the more environmentally damaging chemicals currently used. The United Nations Environment Programme (UNEP) has been working closely with the Kenyan scientists and with the local people, the Endorois, who are indigenous to the area and have an expert knowledge of these soda lakes. This project has a clear aim to engage all relevant stakeholders and ensure that all stakeholders, including the people who live around the lakes, benefit from any financial gains. The Endorois have been able to produce their own biocultural protocol with the help of the UNEP to provide a framework for how researchers, scientists, industry partners and other interested bodies engage with the resources of the lakes.

Many of the wetlands that flamingos inhabit have deep cultural significance to the indigenous or local people who have lived around these wetlands for millennia. It is essential that the views, beliefs, experiences and expertise of these custodians and guardians of the flamingo's wetlands are considered and included in conservation planning. Knowledge of the birds, their wider interactions with other species, and other ecological relationships is best understood by those with experience of how these habitats function. Tapping into this knowledge in an ethical and considered manner, to help develop sustainable financial practices that involve the birds and their wetlands will help secure these ecosystems for many years into the future.

Sometimes these wild flamingo populations are not in a remote, hard to reach destination, but can live right on the edge of major human habitations. For example, in the Indian state of Maharashtra, sitting on the coast of the Arabian Sea is Navi Mumbai, the largest planned city in the world. This metropolis contains some important wetlands that have become important foraging grounds for flamingos that have migrated to this part of India after breeding (Fig. 19). The arrival of the flamingos coincides



Fig. 19 Lesser and greater flamingos flock to the salt flats and algae-rich coastal wetlands around Navi Mumbai. The proximity of the human inhabitants of this city and the flamingos is clear from the high-rise backdrop to the birds as they fly between wetlands. Photo credit: V. Hariharan.



Fig. 20 The population of Navi Mumbai is watching the city's resident flamingos in increasingly large numbers. Such interest by the city's residents increases the value of the flamingos, and other wetland wildlife, and can advocate in the favor of future conservation action. Photo credit: V. Hariharan.

with winter and they reside in Thane Creek (designated as a sanctuary for the birds in 2015) until the onset of the monsoon. Thane Creek divides the island city of Mumbai and the new city of Navi Mumbai, hence the flamingos forage, rest and preen near a huge urban conurbation. Populations of lesser and greater flamingos are normally in the number of 30,000–40,000 individuals, but in some years, 120,000 birds have been recorded. During the 2020 Covid-19 pandemic, with the population of the city in lockdown and its residents remaining local, the flamingos became more widely appreciated. It is hoped, by conservation groups such as the Bombay Natural History Society, that this renewed interest in the flamingos will help secure their future as well as that of wetland areas they depend upon. Clearance of mangroves had to occur for the original development of Navi Mumbai, removing valuable wetland habitats and coastal defenses. Proposals for further development of the coastal wetlands, mudflats and estuaries around Navi Mumbai are being considered and building works that have already occurred have caused the flamingos to move on from some former foraging areas or return in lower than usual numbers.

Renewed public interest, in part caused by the “stay home, stay local” messaging during the Covid-19 pandemic, in the Navi Mumbai flamingos may be one of the best catalysts for conservation of these urban flamingos into the future (Fig. 20). “Flamingo festivals” can be an excellent way of promoting the birds to the local population, showcasing the wetlands in which they live, and the wellbeing benefits associated with visiting these wild spaces. Numerous flamingo festivals are held across India to mark the return of birds to their breeding and feeding areas. High profile government ministers and local officials are often invited to such events, a great way of advocating for the conservation of birds and habitat. Even closer to home, ex situ populations of flamingos in human care are excellent ambassadors for their wild counterparts. Zoological organizations and in situ bodies need to work closely together to share knowledge and expertise on suitable conservation measures (Rose, 2018). Research on captive flamingos can help answer questions that relate to conservation action of free-living birds; for example, behavioral studies on temporal activity patterns, favored conditions for nesting or interactions with humans at and within certain distances could inform wild management plans. Captive flamingos can also be used to trial the fitting of GPS tags or other remote sensing technology to ensure it does not impede the flamingo's movements before it is fitted to wild birds. Zoological institutions that house exceptionally large flocks (e.g., over 200 birds) could be used to test counting and monitoring methods of individuals to repeatable follow their actions and behavior patterns.

Due to the broad, international ranges of flamingos and their use of wetland complexes that cross borders, international collaborations are necessary for conservation. For Mediterranean flamingo populations, such efforts are being promoted by The African-Eurasian Migratory Waterbird Agreement (AEWA). In South America El Grupo de Conservación Flamencos Altoandinos (GCFA) has been a collaboration of coordinated monitoring and data sharing for almost 25 years. GCFA has a regional conservation strategy based on a Network of Priority Sites for Flamingo Conservation. GCFA also has worked with the Ramsar Convention and national governments to declare new and expand existing Ramsar sites. A national strategy also exists in Chile to conserve and protect high Andean wetlands.

An International Single Species Conservation Action Plan for the lesser flamingo has been written, spearheaded by the Wildfowl & Wetlands Trust (WWT) and partners, and published by AEWA. These are examples of regional/range-wide conservation actions, national strategies, and site-based conservation actions that show the collaborative approach needed for flamingo conservation to be successful and relevant. Whilst flamingos can be birds of remote habitats, they can also be found in commercial salt ponds.

Industrial work and salt extraction can be considered a threat but also an opportunity for conservation and management of these birds. The Camargue salt works in the south of France are a good example of management to favor flamingos, and similar initiatives are seen in India, Bonaire, Mexico, and Venezuela. Management of industrial practices and certification of industrial products to ensure such endeavors are “flamingo friendly” may be a clear way forward to viable conservation work for birds and habitats.

To bring all these ideas together, the following list outlines future key conservation aims for flamingos:

- Education of local communities on the benefits of wetland environments and wetland wildlife.
- Conservation advocacy of flamingos, their behavior and role in the ecosystem.
- Engagement with local communities, and specifically indigenous people who live around flamingo wetlands to integrate their knowledge and expertise in conservation action for the birds and habitat.
- Protection of wetland ecosystems that are large enough to accommodate the flock-centric behaviors of these birds.
- Protection and enhancement of suitable nesting sites to increase the number available for the most threatened species.
- Protection of key foraging areas, reduction of environmental pollution and re-establishment of natural process (e.g., seasonal flooding and drying)
- Removing or reducing the presence of invasive species where they disrupt ecological balance.
- Securing the protection of long-term breeding sites that are essential to the survival of specific populations (e.g., Lake Natron for the East African lesser flamingos).
- Promotion of conservation aims using ex situ housed flamingos.
- Enhancing the management of ex situ flamingos to ensure it is ecologically relevant and therefore populations are sustainable for future conservation needs.
- Continued census, surveillance, and monitoring of wild populations where it is already in place to assess the impact of past threats on population growth and the impact of current threats on future population viability (Fig. 21).
- Continued lobbying of government and industry to reduce non-sustainable development around fragile flamingo-important habitats (e.g., puna wetlands and East African soda lakes).
- Certification of lithium, and other mined products, to promote extraction that does the least harm to flamingos and their wetlands.
- Developing links with industries, that may use materials derived from wetlands, to implement practices that favor the persistence of flamingos or provide resources for flamingos alongside of the industrial activity (e.g., salt extraction sites that provide feeding grounds for flamingos).



Fig. 21 Lake Bogoria is an essential home for East Africa's lesser flamingos. Three quarters of the world population rely on these soda lakes for feeding and breeding. Regular surveillance and population monitoring provide valuable data to guide wetland management and conservation approaches. Photo credit: F. Juma.

Conclusions

Flamingos have a complex behavioral ecology and certain aspects of their biology and behavior are still unknown. They are charismatic and interesting birds, capturing imaginations wherever they are encountered—be that in the wild or in the zoo. Flamingos are incredibly social; all their lives are spent in a flock and the flock is essential to successful reproduction, the raising of young, the finding of a partner and the location of suitable foraging areas. The habitats that flamingos frequent need to provide sufficient space and resources to enable this social dynamic to be realized. Conservation action that monitors the birds to assess where they go and when, that allows evaluation of their responses to habitat change or the presence and influences of humans and what causes a flamingo flock to stay for the duration or leave rapidly at a wetland site is vital to the writing and updating of management plans. Alongside this needs to be measurement of water quality (e.g., stability of pH values) and of other relevant hydrological metrics (e.g., lake depth and evaporation rates) to assess the profitability of wetlands that provide the foodstuffs that flamingos rely on. Without understanding the anatomy and physiology of the flamingo, and how this governs its feeding behaviors, one cannot begin to unravel why it has pink feathers, why it lives in large groups and why it performs ritualized courtship displays. Similarly, without understanding the flamingos' behavior, it is impossible to decipher why they choose such apparently hostile wetlands as their home. To complicate matters, without knowledge of the geological processes that have formed these saline or hyperalkaline wetlands, the reason why the flamingo has evolved in the first place cannot be deduced. Protection of these wetlands, and conservation of the flamingo's food supply and its need for specific nesting sites, will ensure the birds can continue to gather in large flocks, remaining pink and carrying on dancing. A complex set of ecological and environmental interactions cause large flocks of flamingos to form and these large flocks are a key adaptive feature of viable future flamingo populations (Rose, 2017); providing information on valuable feeding patches for attainment of optimal body condition and plumage color to instigate courtship display, which in turns enables effective mate choice mechanisms that bring together the fittest and healthiest birds in the flock for reproduction (Data 1 in the online version at <https://doi.org/10.1016/B978-0-12-821139-7.00051-9>). The ecological and environmental drivers for flocking in large groups is provided in the supplementary information (Data 2 in the online version at <https://doi.org/10.1016/B978-0-12-821139-7.00051-9>).

Whether based on their color, or naming, or habitats, flamingos are clearly the epitome of the firebird. The four threatened species are found in wetlands created from fire and volcanic activity—they are not as fragile as their appearance suggests. Coping with boiling water, high pH, exposure to the direct sun, lack of shelter, baking temperatures, ice, freezing conditions and high-altitude atmospheres. Some species eat microscopic algae and plant material that can be toxic. They feed their young on a milk-like secretion and they are expert engineers when constructing their nesting mounds. They can live to be many decades old and they invest a lot of time in raising a youngster. For each of these four most threatened species, the reduction in number and population size has been caused by human activity. But these declines can be rectified by coordinated activity and common action. The current flamingo is the result of evolution of a life form adapted for extreme conditions via a unique mix of biology and behavior. A human appreciation for the tenacity and beauty of such birds implores us to keep this flame burning bright for many generations to come.



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Conserving the Forest Owlet in India: Challenges, Opportunities, and Hopes

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Abstract

The Forest Owlet *Athene (Heteroglaux blewitti)* is one of 41 globally threatened owl species. It was considered extinct for 113 years until its rediscovery in 1997, in the Toranmal Reserve Forest of Maharashtra, India and is now found in three states in India. At landscape level the Forest Owlet prefers tropical dry deciduous forests across the Central India and Northern Western Ghats. The Forest Owlet vigorously protects its territory during the breeding season and shows high nest site fidelity. Threats include habitat degradation due to encroachment, overgrazing, forest fires, illegal logging, infrastructure development, and invasive species. Habitat protection, restoration of ecosystem services, ban on pesticide and rodenticides, and alternative livelihood for communities are possible solutions for the conservation of the species. A country level Conservation Action Plan for the Forest Owlet is being developed.

Introduction

The Forest Owlet *Athene H. blewitti* is a fascinating owl species. It is one of 41 globally threatened owl species among the 234 owl species found on Earth (Birds of the World, 2021). It was considered extinct for almost 113 years until its rediscovery 1997, in Toranmal Reserve Forest of Maharashtra in India. This story has much mystery and thrill behind it, from fraudulence to forensic science and from extinction to survival. The Forest Owlet resembles the more common Spotted Owlet *Athene brama* and its distribution and niche overlap has created both past and present confusion. That could be the reason it was considered restricted to central India. However, better technology and awareness among ornithologists and bird watchers have provided a broader outlook.

Discovery

This species was first described as the Forest Owlet *H. blewitti* by Mr. Allan Octavian Hume (Hume, 1873). The specimen was collected in December 1872 from Busnah-Phooljhar highway near Basna in current state of Chhattisgarh, India. The literal meaning of *Heteroglaux* means “a different owl” (*Hetero*—different, *glaux*—an owl). He named this species “*blewitti*” after its collector Mr. Francis Robert Blewitt (or Mr. William Turnbull Blewitt). Now the interesting part of the story starts. Francis and William are brothers; Francis served in the army and William was a customs officer. Both were wildlife enthusiasts and involved in collecting birds and their eggs. Mr. Valentine Ball, another civil servant who worked for the Geological Survey of India, claimed that that it

was William who collected the specimen. He suggested that William, as a customs officer, wanted to avoid limelight and disclosing his whereabouts because his boss, Mr. Hume, was head of the customs department.

Mr. Ball collected the second specimen. In February 1877, he shot an owl near Udanti river in Khariar region of Odisha state (Ball, 1877). He then sent that specimen to Mr. Hume for further identification, subsequently Hume declared that as a Forest Owlet. This location is 100 km south of Basna. From 1880 to 1883, another civil servant, Mr. James Davidson, collected five specimens from the Satpuda Mountains of Maharashtra in the Khandesh region (Davidson, 1881). Interestingly, no other record of the species exists until 1914, where a single specimen was shot near Mandvi, Gujarat, a village on the banks of Tapti River. By Col. Richard Meinertzhagen. No trace of the species was then seen for over 83 years. Several attempts were made to rediscover this species by Ali and Ripley (1981), although none succeeded. An expedition carried out on its last known location at Mandvi also failed. However, the story continued with another facet of scientific enquiry and pursuit.

The pursuit of Dr. S Dillon Ripley was continued by his student Dr. Pamela Rasmussen, an American Ornithologist from the Smithsonian Institution. She was particularly interested in the Forest Owlet because she believed that the owl could still be rediscovered. With Dr. Nigel Collar of Cambridge University, United Kingdom, she revisited the literature and scrutinized the museum specimen. While doing so they found several anomalies with Col. Meinertzhagen's specimen from Mandvi, Gujarat. A forensic investigation of the museum specimen revealed that the specimen was stolen from British Museum of Natural History by Col. Meinertzhagen and labeled as his own (Rasmussen and Collar, 1999). It was a shocking discovery, and the world of ornithology was shaken. This finding paved its way to the rediscovery of the species in India.

Rediscovery

After uncovering the fraud, Dr. Rasmussen searched for the species in India with eminent ornithologists Mr. Ben King and Mr. David Abbot. They searched across Central India (Chhattisgarh, Odisha, and Maharashtra) in November 1997. They visited Gomarda Wildlife Sanctuary, which is 60 km from the location of the first specimen in Phuljhar, Chhattisgarh. They also visited Paikmal, 100 km from Khariar, where the second specimen was collected. However, the forested habitat described a century ago was gone. They stopped the search and headed for Mr. Davidson's location in the western part of India. This was a promising site as most of the specimens were collected from this area. However, when they reached the site, they were disappointed it was not as described in the literature. The landscape was no better that what it was in Chhattisgarh and Odisha. The same story of habitat degradation was visible here as well. The only hope for the team was the Toranmal Reserve Forest, which had some vegetation left. On 25th November 1977, around 8:30 am, Mr. King located a Forest Owlet perched on a leafless tree, rediscovering the species after 113 years (King and Rasmussen, 1998). The team observed the bird for next 3 days and took photographs and videos for the evidence. Most importantly, they recorded the species call, which was not known previously to science. This discovery brought the Forest Owlet back from presumed extinction and set the foundation for further research on the species (Fig. 1).



Fig. 1 A female Forest Owlet.

Ecology

Identification

This is a small owl, 20–23 cm in height and weighing around 240 g. It is stocky in appearance with strong legs and feet. From above, the body is gray-brown overall with some white spots on the body; the crown and head are generally not spotted. The neck has a uniform brown collar with faint white spots. Below the belly is cotton white with gray-brown spots and blotches, sometimes appearing like bars, especially on the flanks. The head is squarish, rather than round, with a distinct white facial disc. Flight feathers have broad bars of dark brown and white with predominantly black or blackish brown tips. The tail is banded with alternate white and gray-brown bands, more prominent on the dorsal side. The legs and feet are heavily feathered and mostly cotton white; tarsi and claws are heavy. Male and female look similar however in some cases show distinct color dichromatism (Figs. 2 and 3). They are sexually dimorphic, with females larger than males.

Taxonomy and systematics

Hume (1873) described the new species as its own genus, *Heteroglaux*, based on morphology. Ali and Ripley (1981) further nested it in the genus *Athene*, which was later restated to the genus *Heteroglaux* based on the comparative osteology, vocalization, and



Fig. 2 A male Forest Owlet.

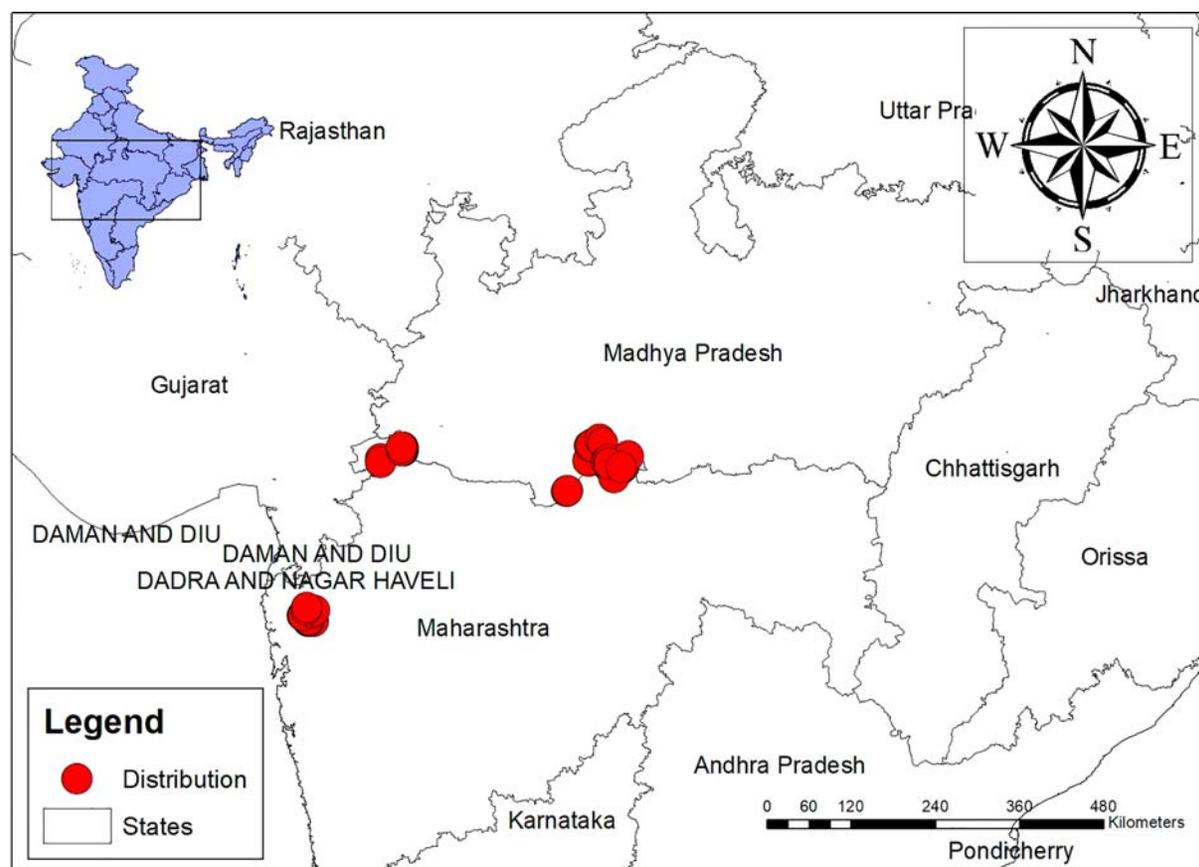


Fig. 3 Habitat of the Forest Owlet.

morphology (Rasmussen and Collar, 2013). A recent phylogenetic study assumes that this should be treated in *Athene* (Koparde et al., 2018), however, this needs further genetic substantiation.

Distribution

Historically the Forest Owlet was considered confined to Central India from Eastern Madhya Pradesh up to in Western Maharashtra (Ali and Ripley, 1981; BirdLife International, 2001; Ripley, 1976). The extent of species occurrence was thought to be 500 km². However, post rediscovery revealed its presence at four locations in states of Maharashtra and Madhya Pradesh (Ishtiaq and Rahmani, 2000a). This has led to discovery of new locations and populations. Jathar and Rahmani (2004) noted that the largest population was in Melghat Tiger Reserve. Jathar et al. (2015) later proposed that the potential distribution of the species based on ecological niche model between 4300 and 70,700 km². The model identified narrow and restricted areas in the Satpuda Mountains, northern Western Ghats, along the east coast, and some patches in the Vindhya Mountains (Fig. 1). The second largest population was found in the Northern Western Ghats (Laad et al., 2016). A new location (87 km south of Mandvi) in Ankalakh village in Navsari District of Gujarat was discovered by Patel et al. (2017).



Habitat

Davidson (1881), King and Rasmussen (1998), and Ishtiaq and Rahmani (2000a), Ishtiaq et al. (2004a,b) described Forest Owlet habitat as predominantly dry deciduous forest. Altitude of dry deciduous forests range between 50 m (Mehta et al., 2017) and 920 m (Chavan et al., 2013). Jathar and Rahmani (2004, 2012) said the Forest Owlet selectively preferred teak-dominated, open type forests interspersed with patches of grasses and herbs, and close to streams (Fig. 3). The Central India and Northern Western Ghats have several sub-types of dry deciduous forest habitats and the Forest Owlet has adapted well to those local conditions. However, in most areas, its original habitat has disappeared. Although small patches of original forests exist in protected areas, most areas have monoculture teak plantations to which the Forest Owlet has adopted. Similarly, the species can tolerate a degree of human disturbance (see Jathar and Rahmani, 2004, 2011; Patel et al., 2017). The Forest Owlet also needs suitable cavities for nesting, originally found in mature old growth forests. Conversion to monoculture plantations has resulted in the loss of nesting cavities. Such suboptimal habitats are not suitable for long term survival of the species.

Diet and foraging

The Forest Owllet is an efficient diurnal and crepuscular predator. Of 186 foraging observations, 63% feeding attempts were observed during morning, 15% in the afternoon, and 22% in the evening; peak hunting activity was observed between 0700 and 1300 h (Jathar and Rahmani, 2004). Forest Owllet prey species include 12 species of small mammals (rodents and shrews), five species of reptiles and a variety of insects, and occasionally amphibians and birds (Jathar and Rahmani, 2004). A pellet diet analysis showed that grasshoppers and rodents comprise the bulk of its prey followed by lizards, beetles, shrews, and birds (Fig. 4 and Table 1). Rodents and reptiles comprise > 80% of prey biomass (Table 2).

Breeding

The Forest Owllet breeding season lasts from October until May. They show strong site and nest fidelity, in one case for at least 15 years, from 1999 to 2015 (*pers observation* Fig. 5). They prefer to nest in softwood trees either in natural cavities or those excavated by woodpeckers. Although they prefer old tall trees with larger circumference and cavities (Ishtiaq et al., 2004a,b; Jathar and



Fig. 4 Different prey species of the Forest Owllet retrieved from pellet analysis.

Table 1 Proportion of prey species, by number, in the Forest Owllet diet, as identified by pellet analysis (Jathar and Rahmani, 2004).

Prey species	Proportion (%)
Grasshoppers	25.34
Rodents	22.04
Skinks and Lizards	15.70
Beetles	10.19
Shrews	7.99
Birds	6.89
Other insects	5.51
Arachnids	0.55
Amphibians	0.28
Bird eggs	0.28
Unidentified prey species	5.23

Table 2 Forest Owlet prey species percentage by biomass, as identified through pellet analysis (Jathar and Rahmani, 2004).

<i>Prey species</i>	<i>Biomass (%)</i>
Rodents	51.05
Reptiles	30.22
Insects	13.74
Shrews	4.97

**Fig. 5** Nesting tree of the Forest Owlet.

Rahmani 2004), other hardwood trees are also opted by the species. Forest Owlets compete for nest cavities with the Indian Roller (*Coracias benghalensis*), Indian Scops Owl (*Otus bakkamoena*), Common Myna (*Acridotheres tristis*), and Brahminy Starling (*Sturnus pagodarum*).

Egg laying begins in late October and early November; sometimes, second clutches are laid if the first breeding attempt fails. Clutch size varies from 1 to 3 eggs. The eggs are opaque marble-white in color, oval shaped, and with a slightly coarse surface. Average egg length is 3.19 cm, width is 2.59 cm, and weight is 10 g. Forest Owlets lay their eggs asynchronously and start incubating with the first egg. Mean incubation period is 29 day (range 28–31 day). Hatching success is 59%, due to egg predation, oviduct, and egg by humans (Jathar and Rahmani, 2004).

Forest Owlet nestlings hatch altricially and fledge around 30 day (range 26–33 day) (Figs. 6 and 7). Fledgling success is 41%; fledglings are prone to predation, infanticide (Ishtiaq and Rahmani, 2000b), and killing by humans (Jathar and Rahmani, 2004). It appears that during a dearth of food, only one fledgling survives, and the weaker siblings die. Males and females share parental duties; like other owl species, and males provide food to the female and young. Prolonged parental care of 150 days has been observed (Jathar and Rahmani, 2004).



Fig. 6 30 days old fledgling of the Forest Owlet.



Fig. 7 120 days old fledgling of the Forest Owlet.

Behavior

The Forest Owlet vigorously protects its territory, especially during the breeding season. Territorial fights between males are common during October and November, although physical fighting has not been observed. Territories are coarsely defined and shrink or expand depending on food availability and environmental conditions.

Further study is needed to determine whether Forest Owlets live-in pairs and are monogamous, although clear sex-linked resource partitioning exists. Males protect territories and bring food for the young. Females incubate eggs and protect them from predators. After hatching, females also feed the young.

Six vocalizations have been documented as signal, territorial, alarm, threat, begging, and hissing calls ([Rasmussen and Ishtiaq, 1999](#); [Ishtiaq et al., 2004a,b](#); [Jathar and Rahmani, 2004](#)).

The Forest Owlet shares its habitat five sympatric and resident owl species which are similar in size, namely Spotted Owlet (*A. brama*), Indian Scops Owl (*O. bakkamoena*), Jungle Owlet (*Glaucidium radiatum*), Oriental Scops Owl (*Otus sumia*), and Brown Boobook (*Ninox scutulata*). Diet overlap exists between these species ([Jathar and Rahmani, 2004](#); [Mehta et al., 2018](#)), which could have led to diurnal foraging to avoid this competition. Diurnal foraging competition exists with Shikra (*Accipiter badius*) and White-eyed Buzzards (*Butastur teesa*).

Conservation status

The Forest Owlet is considered Endangered by IUCN ([BirdLife International, 2001](#)) owing to its small and severely fragmented population and threats to its long-term survival across the landscape. The population estimate is 500–1000 mature individuals. The Forest Owlet is also protected under Indian Wildlife Protection Act 1972. It is in the Schedule I category and receives as much protection as the Tiger. However, it is much neglected species in terms of active protection.

Prior to year 2000, the species was listed as Critically Endangered. Subsequent rediscovery showed the species at 14 locations in Central India and Northern Western Ghats ([Ishtiaq and Rahmani, 2000a](#); [Jathar and Rahmani, 2004](#); [Jathar and Rahmani, 2011](#); [Jathar and Patil 2011](#); [Mehta et al. 2008](#); [Laad and Dagale, 2014](#); [Jathar et al. 2015](#); [Patel et al., 2015, 2017](#)). A niche modeling

exercise (Jathar et al., 2015) indicated it could occur in other areas with suitable habitat characteristics, with an extent estimated between 4300 and 74,000 km² (Jathar et al., 2015). This led to down listing the species from Critically Endangered to Endangered.

Challenges

The Forest Owlet has several threats to survival, namely, degradation of the habitat owing to encroachment, overgrazing, forest fires, illegal logging, infrastructure development, and invasive species. Other threats include direct persecution, hunting and egg collection by humans, and pesticide poisoning. Following is the detailed assessment of these challenges.

Encroachments

From 2001 to 2006, 30% of the forest in Toranmal Reserve Forest, Maharashtra and 7% forest in Burhanpur and Khandwa in Madhya Pradesh was degraded (Jathar and Patil, 2011). Since the inception of Forest Rights Act (2006) huge swaths of forests in Central India and Northern Western Ghats have been encroached by people (Fig. 8), which has both reduced and fragmented habitat.

Overgrazing

Except for protected areas, most of the Forest Owlet sites have some degree of human presence and disturbance. The communities living close to such sites are mostly agrarian. Such communities hold on average at least 500–800 cattle (Fig. 9) and are entirely dependent on the forest for survival. Daily cattle grazing in the forest destroys prey species habitat. The Owlet generally abandons areas when cattle extensively graze its habitat (Jathar and Rahmani, 2004).

Firewood collection

The average forest-dwelling family requires 3.4 tons of firewood per year, which is collected from the Forest Owlet's prey species habitat (Jathar and Rahmani, 2004; Jathar and Patil, 2011). Human population pressure on this habitat causes concern.

Forest fires and illegal logging

Accidental and intentional forest fires are annual events in Central India and Northern Western Ghats from March to May. Forest fires allow people to acquire land for cultivation. From 2017 to 2021, forest fires increased 87.6% in Madhya Pradesh and 13.4%



Fig. 8 Encroachments on the habitat of the Forest Owlet.



Fig. 9 Cattle grazing in Forest Owlet habitat.



Fig. 10 Forest fire a threat to the habitat of the Forest Owlet.

rise in Maharashtra (Palicha, 2021). Forest fires destroy native flora and fauna and create opportunities for invasive species such as *Lantana camara* to occupy vacant microhabitat (Fig. 10). Such habitats become unsuitable for the other vegetation and associated Forest Owlet prey.

Illegal teak logging is rampant in unprotected forests (Jathar et al., 2015). Bamboo forest harvest at lower elevations altered bird communities in Forest Owlet habitat upslope (Jathar and Rahmani, 2004). Forest Owlet habitat is vulnerable to illegal logging (Fig. 11) and deserves more attention.

Pesticide use

Almost 70% of forest dwelling people in Maharashtra (Jathar and Rahmani, 2004) and Madhya Pradesh (Jathar and Patil, 2011) use contraband pesticides to protect their crop from pests, such as dichlorodiphenyltrichloroethane (DDT), benzene hexachloride (BHC), endosulfon, and endrin (Fig. 12). Hickey and Anderson (1968) showed strong links between chlorinated hydrocarbon pesticides and raptor eggshell thinning, resulting in long-term population declines.



Fig. 11 Illicit wood cutting in the in the Forest Owlet habitat.



Fig. 12 Pesticides and insecticides used in agricultural fields near the Forest Owlet habitats.

Myths and misconceptions

The forest dwellers in Central India and Northern Western Ghats have numerous misconceptions about owls. They use owl body parts for witchcraft and for luck in gambling (Jathar and Rahmani, 2004). Generally, owl eggs are collected from active nests, taken to a witch doctor, who performs a ritual and applies black soot on the egg (Fig. 13). Later, this egg is kept under an earthen pot for an entire night. The next day the number formed on the egg under the earthen pot is checked; this is considered as the lucky number that is to be played for that day. This misconception has taken a heavy toll on owls in this area. In 2004, Forest Owlet eggs were stolen twice in Toranmal Reserve Forest (Jathar and Rahmani, 2004). Such myths and misconceptions are widespread and are a real threat to all owl species in protected and unprotected landscapes.

Opportunities

The ecosystem within which the Forest Owlet lives provides several ecosystem services that are crucial for communities living in the landscape and beyond. This is a good enough reason to conserve of the Forest Owlet and its habitat. Sustainable habitat management such as controlled livestock grazing, provision of alternate energy solutions to communities through Government Scheme, and least invasive forest management activities can better protect the habitat. Strengthening the livelihood of the local communities is necessary to reduce their dependency on the habitat. Thus, incentivizing local communities to protect nest sites coupled with ecotourism initiatives can directly benefit the communities and motivate them. Programs such as Watershed Development to restore the habitat will bring the community together, to work together. This leverage point along with activities like ecotourism, boosting arts and crafts, promotion of organic agricultural produce, and empowering women, will bring awareness and create conservation opportunities. Long term conservation education and awareness programs for forest dwellers will help in changing environmental economics paradigms and ensure the future survival of the species.



Fig. 13 Tribal performing black magic rituals using owl body parts.

Hopes

Since its rediscovery in 1997, momentum for conservation action for the Forest Owllet has been slowly taking shape:

- The Toranmal Reserve Forest is a rediscovery site of the Forest Owllet. It is home to 260 bird species (Jathar and Rahmani, 2004), 450 plant species (Jagtap et al., 2008), and nine forest dwelling tribes. It was declared as Conservation Reserve on 11th July 2016 (http://forestclearance.nic.in/writereaddata/wildlife/Add_info/0_0_71122122412181part1.pdf). The proposal to declare Toranmal as wildlife sanctuary is currently under consideration.
- In 2017, the Owl Conservation Foundation, a small Non-Profit Organization declared, 24th October as the “Forest Owllet Conservation Day” for awareness and conservation of the Forest Owllet in Tansa Wildlife Sanctuary in Northern Western Ghats. This day was then adopted by the Ministry of Environment, Forest and Climate Change, Govt of India [GENERAL/LATEST NEWS: ENVIS Centre, Ministry of Environment & Forest, Govt. of India (bnhsenvis.nic.in)]. Its outreach has become nationwide, and it is strengthening the conservation movement.
- In 2020, under the leadership of Salim Ali Centre for Ornithology and Natural History, 18 other organizations working on the Forest Owllet came together. The scientists, researchers, and other stakeholders shared their knowledge on the species and developed a draft conservation action plan for the species. This plan will be presented to the Government of India, to be implemented for next 10 years.

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The Population Abundance of the Vulnerable Sarus Crane (*Antigone antigone*) Species in Uttar Pradesh, India

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Abstract

The Sarus Crane *Antigone antigone*, the only resident crane in India, is listed as Vulnerable on the IUCN Redlist. As land-use and land-cover patterns have changed in recent years, assessing the population abundance of the Sarus Crane in these landscapes assumes significance. Therefore, this work reviews previous studies on Sarus Crane and assessed their food & feeding habits, the current population abundance in Uttar Pradesh. Here, we conducted our fieldwork from February 2018 to October 2019, and estimated the density and abundance of the Sarus Crane using the Distance Sampling method. The highest numbers of Sarus Crane observations were in the districts of Etawah (27.6%), Mainpuri (19.5%), Shahjahanpur (8.2%), Maharajganj (6.9%), and Auraiya (6.3%). We estimated the population of Sarus Crane by detection probability using the hazard-rate key function model ($\hat{P}_a = 0.415 \pm 0.0105$). Therefore, the estimated population of Sarus Crane population in Uttar Pradesh was $15,193 \pm 2905$ (mean \pm SE) individuals. The Sarus Crane density was 0.0608 ± 0.0116 (mean \pm SE) birds per sq. km. We also recorded the observations on the food & feeding habits of the Sarus Crane. We identified 64 plant species belonging to 23 families as food plants of the Sarus Crane.

Background

Distribution

The tallest flying crane, the Sarus Crane *Antigone antigone*, is spread across two continents, including the Indian subcontinent, South-east Asia, and Australia (Meine and Archibald, 1996; Archibald et al., 2003). At present, in the Sarus Crane, four subspecies are recognized, namely the Indian Sarus Crane (*Antigone antigone antigone*), the South-eastern Sarus Crane (*Antigone antigone sharpii*), the Australian Sarus Crane (*Antigone antigone gillae*), and the extinct Philippine Sarus Crane (*Antigone antigone luzonica*). They were classified based on their morphological, plumage, and geographical differences, but molecular taxonomists placed four subspecies in *Antigone* earlier in the genus *Grus* according to the new nomenclature. The distribution of all subspecies is shown the Fig. 1.

The Indian Sarus Crane (*Antigone antigone antigone*) is the largest bird, almost six feet tall with a wingspan of eight feet that differentiated from the south-eastern population (*Antigone antigone sharpii*) by the white-collar below their bare head and upper neck, and white tertiary remiges (BirdLife International, 2001). The South-eastern population is smaller, weighing (5400–8400 g), than Indian Sarus Crane weighing (6800–12,240 g), but larger than the Australian Sarus Crane (*Antigone antigone gillae*) weighing (5200–8400 g). The Sarus Crane of the Australian population looks similar to the South-eastern population having no white collar on the neck and tertiary remiges, but with a distinguishing larger gray patch of ear-coverts. There is no sexual dimorphism between

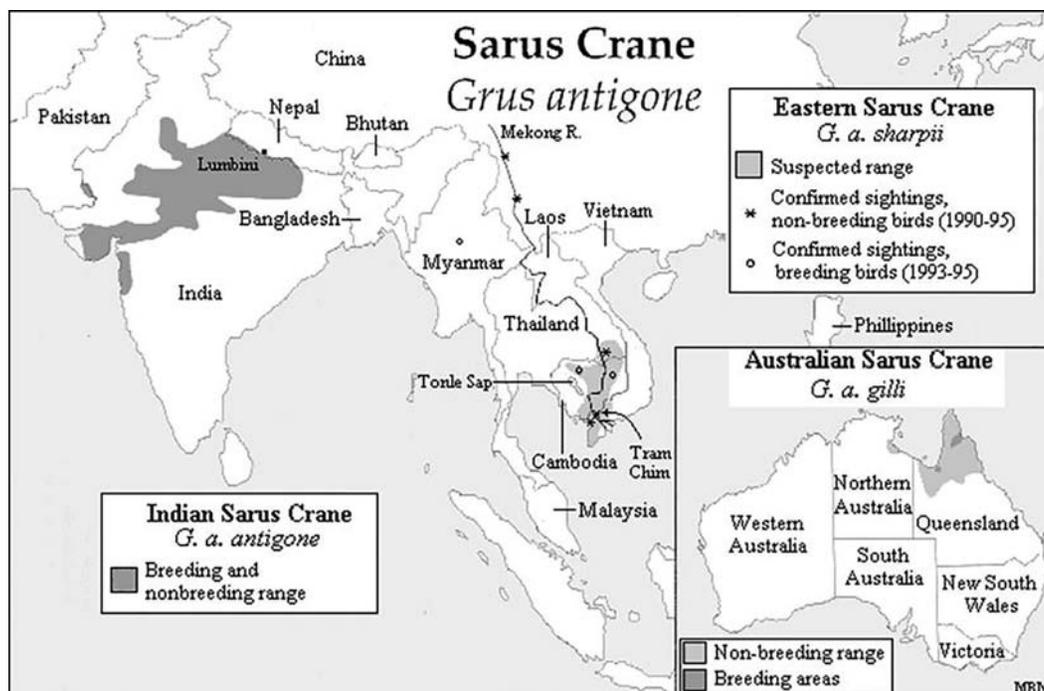


Fig. 1 The breeding and non-breeding distribution of Indian Sarus Crane, Eastern Sarus Crane, and Australian Sarus Crane are shown. Data source: BirdLife International (2001) *Threatened Birds of Asia: The BirdLife International Red Data Book*. Cambridge, UK: BirdLife International.

sexes and hence no differences in their plumages. However, the races differ notably in size; generally, males are larger than females in all the subspecies. All the subspecies make a high-pitched penetrating loudest call of any other crane species (Archibald et al., 2003).

Indian Sarus Crane

The Indian Sarus Crane is the only resident crane in India. It is distributed from Sind (Pakistan) in the west to Assam in the east, and from the Himalayas (Kashmir valley and Nepal) in the north to the Godavari delta (Andhra Pradesh) in the south. Its subspecies are distributed from Assam to northern Malaysia and Cambodia in Southeast Asia (Ali and Ripley, 1983).

Gole (1989a,b) conducted the first country-wide survey of Indian Sarus Crane, who estimated the species' population to be 12,000–15,000. Almost a decade later, Meine and Archibald (1996) estimated the Sarus Crane population to be 8000–10,000 and reported that the Sarus Crane population was declining due to the degradation and permanent loss of wetlands across its distributional range. Over the years, the population of this species has declined in Southeast Asia and was designated in the IUCN Redlist as Vulnerable (BirdLife International, 2001; IUCN, 2016). The Annual Waterfowl Census (AWC) also indicated a declining population of the Sarus Crane across Asia. A recent study has recorded the species and their wetland habitats in northern parts of the Uttar Pradesh (Rahmani et al., 2019).

Habitats

The Sarus Crane uses various habitats, such as marshes and cropping lands, depending on food availability (Figs. 2 and 3). Often they are found foraging in cultivated fields, open plains, and human-made and natural wetlands (Ali and Ripley, 1983). While foraging in marshes, they venture into the water up to their wading limit, approximately 45 cm deep. Their food items mainly include grains gleaned from stubble-covered fields, tubers of aquatic and marsh plants, green shoots of grasses and cereal crops, pods of groundnut, and tubers of native wetland plants such as *Eleocharis* spp. (Ali and Ripley, 1983). Other items in their food include grasshoppers, snails, fishes, frogs, and snakes (Walkinshaw, 1973). Compared to other crane species, the Sarus Crane utilizes open forests, wetlands, and grasslands.

Sarus Cranes nest from August–October (coinciding with the end of the South-West Monsoon season) in water-logged areas and marshes, where they may forage in nearby agro-ecosystems (Figs. 2 and 3). During summer (April–June), they congregate in dried marshes with puddles of water (Vijayan, 1991). Breeding pairs place their nests in various habitats associated with water (e.g., natural wetlands, along canals and irrigation ditches, village ponds, and rice paddies).

Sarus Cranes build nests on raised areas in shallow water where short emergent vegetation is abundant (Vijayan, 1991). While most crane species are migratory, Sarus Crane is primarily resident, showing some local movements, shuttling between nesting and foraging grounds, and summer congregation sites. Walkinshaw (1973) described the diurnal movement of the Sarus Crane between



Fig. 2 Male and female Sarus Cranes are standing in a wheat field at Etawah, District, Uttar Pradesh. Photo credit—Astha Chaudhary.

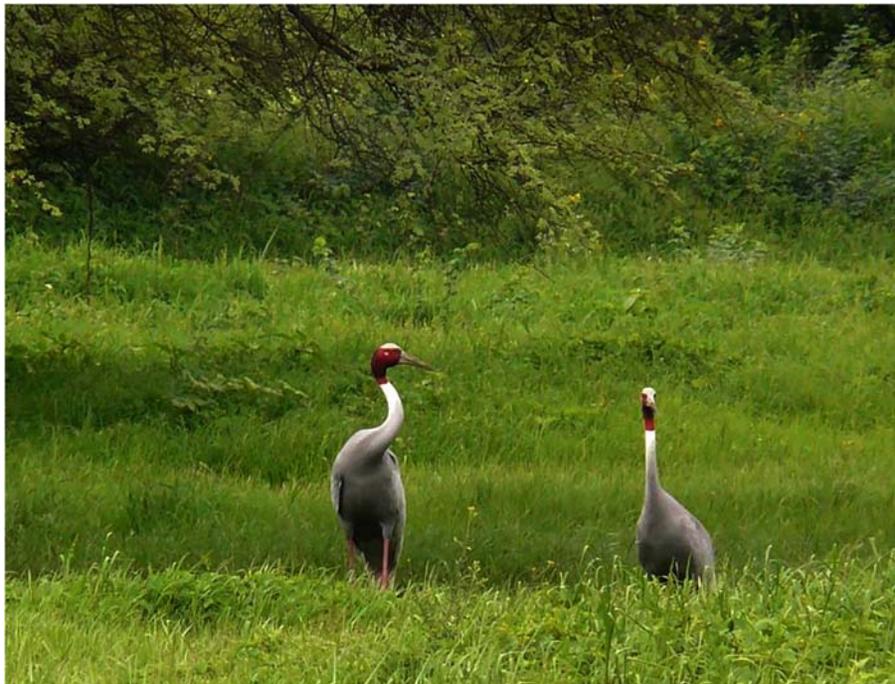


Fig. 3 Sarus Cranes in a marshy vegetation. Photo credit—Rajneesh Dwevedi.

the roosting to the foraging grounds in Keoladeo National Park, Rajasthan. The pre and post-breeding social group structure in the Sarus Crane play an essential role in the biology of the birds.

Food and feeding habits

Walkinshaw (1973) was the first to gather information on the food habits of the Sarus Crane in India. Ali and Ripley (1983) provide general information about its diet and feeding habits. In recent years, the food habits have been studied by many authors in different states of India: Verma and Prakash (2016) and Parasharya et al. (1986, 1996) in Uttar Pradesh; Ramachandran and Vijayan (1994) in Bharatpur, Rajasthan; Vyas (2002) in Rajasthan; Parasharya et al. (2000), Triet (1999) and Mukherjee (2000) in Gujarat. Sarus Cranes utilize a wide variety of landscapes, depending on the food availability, cropping pattern, and other seasonal factors (Mukherjee et al., 2001). Sarus Cranes were observed pecking the shoots and tubers of the aquatic plant species growing in wetlands, streams, and canals. In winter, most wetlands are used to cultivate aquatic species such as *Nelumbo nucifera*, *Nymphaea nouchali*, *Nymphaea pubescens*, *Trapa bispinosa* and *Trapa natans*. The Sarus Crane forages on tubers of the species. Other herbaceous species bearing tubers, namely *Cyperus* spp., *Eleocharis* spp., *Kyllinga* sp., and *Scirpus* spp., found in aquatic habitats, are consumed by Sarus Crane.

Ramachandran and Vijayan (1994) and Mukherjee (2000) also reported that the Sarus Crane consume tubers and roots of aquatic plants found in the wetland landscape.

Sarus Cranes also visit barren land and open areas for foraging during summer. They foraged on seeds of species of the family Poaceae such as *Brachiaria ramosa*, *Coix lacryma-jobi*, *Cynodon dactylon*, *Echinochloa colonum*, *Echinochloa crus-galli*, *Eleusine indica*, *Paspalum distichum* and *Sporobolus diandrus*. Mukherjee (2000) observed Sarus Cranes pecking grains from the cattle dung in central Gujarat. We also recorded that roots and tubers of herbaceous species found in and around wetlands and agricultural fields were consumed by probing or scraping loose soil. The herbaceous food plant species are *Ammania baccifera*, *Aponogeton* spp., *Eclipta prostrata*, *Polygonum* spp., *Typha* spp. and *Solanum tuberosum*. Sarus Cranes also foraged on small floating herbs of *Lemna perpusilla*, *Azolla pinnata* and *Vallisneria spiralis*.

The bulbs of a cultivated species, *Allium sativum* were also consumed by Sarus Cranes (Mukherjee, 2000). Vyas (2002) reported crop damage by Sarus Cranes in agricultural fields and observed that Sarus Cranes ate *Glycine max*, *Brassica* sp. and *Zea mays*. Mukherjee (2000) said that the Sarus Crane consumed the berries of *Lantana camara*, *Ziziphus nummularia* and *Physalis minima* in central Gujarat. Walkinshaw (1973) and Latt (2001) observed that the food plants of Sarus Crane in agricultural areas included *Cicer arietinum* and *Pisum sativum* pods. Although Rice and Wheat grains were the food most preferred by Sarus Cranes, other seasonal crops such as maize, millets, peas, beans, and mustard were also eaten. Insects, small fishes, and aquatic vegetation were regular food items of Sarus Cranes in Uttar Pradesh (Gole, 1991; Singh and Tatu, 2000).

Sarus Cranes are considered to be omnivorous since they have been recorded eating amphibians (mainly frogs), reptiles (especially lizards, but also water snakes), insects (particularly grasshoppers), molluscs, freshwater fishes, and terrestrial and aquatic snails (Hume and Marshal, 1879; Baker, 1928; Dharmakumarsinhji, 1955; Ali and Ripley, 1983; Walkinshaw, 1973; Johnsgard, 1983; Law, 1930; Mukherjee, 2000). According to Sundar and Choudhury (2008), Sarus Cranes are omnivorous, opportunistic feeders, and their diets include aquatic plants, invertebrates, and grains, and these remarks have been corroborated by Johnsgard (1983); Meine and Archibald (1996).

Occasionally Sarus Cranes consumed the eggs of other birds (Sundar, 2000). According to Aryal et al. (2009), Sarus Crane helps maintain the food chain and food web, thus strengthening the wetland ecosystem. The Sarus Crane also have been reported to consume the eggs of certain birds, e.g., the Spot-billed Duck (*Anas poecilorhyncha*) (Gole, 1987), Laughing Dove (*Streptopelia senegalensis*) (Gole, 1989a), and Spotted Dove (*Streptopelia chinensis*) (Sundar, 2000). There is also a report of cannibalism, an adult feeding on the remains of its chick in Uttar Pradesh (Xavier, 1995).

We summarized the dietary information obtained from published sources in Tables 1 and 2. The animal items were observed in the diet of the Sarus Crane, including grasshopper, the Apple Snail (*Pila globosa*), Common Indian Bull Frog (*Rana tigrina*), Indian Skipper Frog (*Euphyctis cyanophlyctis*), crustaceans, eggs of the Red-wattled Lapwing (*Vanellus indicus*) and Spotted Dove (*Spilopelia chinensis*). In conclusion, the Sarus Crane is a significant consumer of vegetable matter, particularly grains, though it consumes various animal food items. As agricultural landscapes are the primary habitats of the Sarus Crane, a good farming practice is essential for the conservation of this species.

Usage of pesticides in agriculture commenced in India around 1948–1949, and increased manifold with the Green Revolution. However, India has legally phased out most of the persistent organochlorine group of pesticides; however, a few are still used for agriculture or civic health. India banned the agricultural use of DDT in 1989, with a ceiling of a maximum of 10,000 MT per annum for control of malaria and kala-azar. During India's Ninth Five Year Plan (1997–1998 to 2001–2002), the National Anti-Malaria Program sprayed 42,200 MT of DDT, including 11,600 MT for kala-azar disease control. Hence, due to their long half-life, DDT and other organochlorine compounds remain in the environment for many years, and continue causing chronic deleterious effects on birds and other biotas. Most of the wetlands that are prime habitats for the Sarus Crane face heavy anthropogenic pressures, mainly with draining and inflow of industrial and domestic wastes, agricultural runoff, and pesticides (Muralidharan, 1993). These pressures have increased recently (Gole, 1989a,b; Meine and Archibald, 1996). This work reviews previous studies on Sarus Crane in India and assesses food and foraging habits, the current population abundance, correcting population estimation with detection probabilities, and maps the distribution of Sarus Crane in India.

Study area and methods

Food and feeding habits of the Sarus Crane

Observations on the food, feeding habits, and habitats of the Sarus Crane were made from February 2018 to October 2018 in Uttar Pradesh. We recorded the food items consumed by the Sarus Crane during surveys. Consumption of various food items was observed using a pair of binoculars. Food items were collected and identified in the field. We watched and noted the feeding techniques adopted to capture animal prey and obtain different edible parts of plants.

Population abundance

Depending on varied edaphic-climatic factors and cropping patterns, the state of Uttar Pradesh is divided into nine different agro-climatic zones, namely the Bundelkhand, Central Plain, Central Western Plain, Eastern Plain, North-Eastern Plain, Tarai Bhabar, Western Plain, South-Western Semi-Arid Plain, and Vindhyan zones (Jha and McKinley, 2014). The area of Uttar Pradesh is 2,43,290 km², equal to 7.33% of the total extent of India. The entire Uttar Pradesh was gridded using GIS (10 × 10 km). We ensured

Table 1 List of plant food items consumed by Sarus Cranes.

S. No	Species	Parts used	References
1	<i>Eleocharis ochrostachys</i>	Tubers	Triet (1999) and Mukherjee (2000)
2	<i>Eleocharis dulcis</i>	Tubers	Triet (1999)
3	<i>Nymphaea pubescens</i>	Roots	Ramachandran and Vijayan (1994) and Mukherjee (2000)
4	<i>Scirpus tuberosus</i>	Tubers	Ramachandran and Vijayan (1994)
5	<i>Eleocharis plantaginea</i>	Tubers	Ramachandran and Vijayan (1994)
6	<i>Cicer arietinum</i>	Pods	Ramachandran and Vijayan (1994), Walkinshaw (1973), and Mukherjee (2000)
7	<i>Oryza sativa</i>	Grains	Parasharya et al. (1986, 1996) and Mukherjee (2000)
8	<i>Eleocharis</i> sp.	Tubers	Nandi (2006)
9	<i>Triticum aestivum</i>	Grains	Mukherjee (2000) and Nandi (2006)
10	<i>Zea mays</i>	Seeds and Cobs	Vyas (2002)
11	<i>Pennisetum typhoides</i>	Cobs	Mukherjee (2000) and Vyas (2002)
12	<i>Sorghum bicolor</i>	Cobs	Mukherjee (2000)
13	<i>Phaseolus aureus</i>	Pods	Mukherjee (2000)
14	<i>Cajanus cajan</i>	Pods	Mukherjee (2000)
15	<i>Arachis hypogaea</i>	Pods and Nuts	Mukherjee (2000)
16	<i>Solanum tuberosum</i>	Tubers	Mukherjee (2000)
17	<i>Allium sativum</i>	Bulbs	Mukherjee (2000)
18	<i>Echinochloa colonum</i>	Panicles & roots	Ali and Ripley (1983) and Mukherjee (2000)
19	<i>Cyperus</i> spp.	Tubers	Mukherjee (2000)
20	<i>Scirpus littoralis</i>	Tubers	Mukherjee (2000)
21	<i>Oryza rufipogon</i>	Grains	Mukherjee (2000)
22	<i>Brassica</i> sp.	Roots	Vyas (2002)
23	<i>Glycine max</i>	Pods	Vyas (2002)
24	<i>Nelumbo nucifera</i>	Flower buds and roots	Mukherjee (2000)
25	<i>Ipomoea aquatica</i>	Roots	Mukherjee (2000)
26	<i>Corchorus capsularis</i>	Pods	Mukherjee (2000)
27	<i>Colocasia antiquorum</i>	Roots	Mukherjee (2000)
28	<i>Trapa natans</i>	Tubers	Mukherjee (2000)
29	<i>Convolvulus batatas</i>	Roots	Mukherjee (2000)
30	<i>Physalis minima</i>	Fruits	Mukherjee (2000)
31	<i>Lantana camara</i>	Fruits	Mukherjee (2000)
32	<i>Ziziphus nummularia</i>	Fruits	Mukherjee (2000)
33	<i>Lens culinaris</i>	Fruits and seeds	Latt (2001)
34	<i>Pisum sativum</i>	Leaves and fruits	Latt (2001)

Secondary data and their sources are cited in the text and in the reference section as well; Mahendiran M, Muralidharan S, Balasubramanian P and Karunakaran PV (2020). Assessment of status, distribution and threats to the population of threatened Sarus Crane *Antigone antigone* in Uttar Pradesh. Final report, Submitted to the Ministry of Environment, Forest and Climate Change, Government of India. SACON TR 209, pp. 244.

that the grids covered all the agro-climatic zones in the state. Uttar Pradesh has a subtropical climate with three distinct seasons, namely monsoon (Jul to Oct), winter (Nov to Feb), and summer (Mar to Jun). It receives an average annual rainfall between 600 and 2500 mm, most of which comes during the monsoon. Winter temperatures may reach as low as two degrees Celsius, and summer temperatures may go as high as 48 °C.

We collected secondary information on the distribution of the Sarus Crane in Uttar Pradesh from online databases such as e-Bird, and BirdLife International. The primary survey effort was made using the adaptive cluster sampling method in those grids falling in the known Sarus Crane locations. We selected an initial set of field units (known locations through historical records) to sample using a probability-based design (e.g., simple random sampling). Then, we selected additional neighboring samples for observation when we found a characteristic of interest (Sarus Crane) in an initial unit or location following the adaptive cluster sampling (Fig. 4).

We used existing transects, roads, bunds, and dikes as transects. Before starting the survey, transects were selected randomly from the GIS platform, saved as shape files, and later transferred to GPS (Garmin etrex 10). We noted the Sarus Crane sightings along these transects during the survey. We also recorded the starting and ending (Latitudes and Longitudes) of each survey route. We observed Sarus Cranes using binoculars (Olympus 10 × 50 DPS) and noted the GPS locations of the birds, the group size, and associated other variables such as the land cover, land use, habitat, time, date, and weather conditions as covariate information.

We conducted field surveys during the breeding and non-breeding seasons (pre-and post-monsoon months) in the early morning and evening hours when the birds were active. We drove the wheels at <20 km per hour while surveying. We detected birds on either side of the route up to the maximum visibility (approximately 500 m). Where transects were away from roads,

Table 2 List of animal food items consumed by Sarus Cranes.

S. no.	Species	Scientific name & other information	Source
<i>Birds</i>			
1	Red-wattled Lapwing	<i>Vanellus indicus</i> (Its eggs consumed by SarusCrane)	Mukherjee (2000)
2	Sarus Crane	<i>Antigone antigone</i> (consumed its own dead chicks—Cannibalism)	Xavier (1995)
3	Spot-billed Duck	<i>Anas zonorhyncha</i> (Its eggs consumed by Sarus Crane)	Gole (1987)
4	Laughing Dove	<i>Spilopelia senegalensis</i> (Its eggs consumed by Sarus Crane)	Gole (1989a)
5	Spotted Dove	<i>Spilopelia chinensis</i> (Its eggs consumed by Sarus Crane)	Sundar (2000)
<i>Reptiles</i>			
6	White-spotted Supple Skink	<i>Lygosoma albopunctata</i>	Hume and Marshal (1879), Baker (1928), Dharmakumarsinhji (1955), Ali and Ripley (1983), Walkinshaw (1973), and Johnsgard (1983) Mukherjee (2000)
7	Keeled Indian Mabuya	<i>Mabuya carinata</i>	Mukherjee (2000)
8	Bronze Grass Knick	<i>Mabuya macularia</i>	Mukherjee (2000)
9	Fan-throated Lizard	<i>Sitana ponticeriana</i>	Mukherjee (2000)
10	Checkered Keelback	<i>Xenochrophis piscator</i>	Mukherjee (2000)
<i>Fishes-Fresh water</i>			
<i>Amphibians</i>			
11	Indus Valley Toad	<i>Bufo stomaticus</i>	Hume and Marshal (1879), Law (1930), Singh and Tatu (2000), and Mukherjee (2000) Mukherjee (2000)
12	Asian Common Toad	<i>Bufo melanostictus</i>	Mukherjee (2000)
13	Dicroglossid Frog	<i>Euphyctis cyanophlyctis</i>	Mukherjee (2000)
14	Indian Bullfrog	<i>Rana tigrina</i>	Mukherjee (2000)
15		<i>Hoplobatrachus</i> sp.	Mukherjee (2000)
16		<i>Uperodon</i> sp.	Mukherjee (2000)
17	Indian Skipper Frog	<i>Euphyctis cyanophlyctis</i>	Mukherjee (2000)
18	Water Snake	–	Ramachandran and Vijayan (1994)
<i>Annelids</i>			
19	Earthworm	–	Mukherjee (2000)
20	Leech	–	Mukherjee (2000)
<i>Molluscs and crustaceans</i>			
21	Apple Snail	<i>Pila globose</i>	Ansari (2015), Hume and Marshal (1879), Baker (1928), Dharmakumarsinhji (1955), Ali and Ripley (1983), Walkinshaw (1973), and Johnsgard (1983) Mukherjee (2000)
22	Planorbid	<i>Gyraulus rotula</i>	Mukherjee (2000)
23	Lymnaea	<i>Lymnaea</i> sp.	Mukherjee (2000)
24	Pond Snail	<i>Bellamya bengalensis</i>	Mukherjee (2000)
25	Bivalve	<i>Lamellidens corrians</i>	Mukherjee (2000)
<i>Arachnids</i>			
26	Spiders	–	Mukherjee (2000)
<i>Insects</i>			
27	Dragonflies	<i>Erythromma</i> sp.	Jha and McKinley (2014), Hume and Marshal (1879), Baker (1928), Dharmakumarsinhji (1955), Ali and Ripley (1983), Walkinshaw (1973), and Johnsgard (1983) Mukherjee (2000)
28	Grasshopper	<i>Hieroglyphus banian</i>	Mukherjee (2000)
29	Field Cricket	<i>Acheta domesticus</i>	Mukherjee (2000)
30	Mole Cricket	<i>Gryllotalpa gryllotalpa</i>	Mukherjee (2000)
31	Giant Water Bug	<i>Belostoma indica</i>	Mukherjee (2000)
32	Termites	<i>Odontotermes obesus</i>	Mukherjee (2000)
33	Butterflies	<i>Lepidopteran</i> larvae	Mukherjee (2000)

Secondary data and their sources are cited in the text and in the reference section as well; Mahendiran M, Muralidharan S, Balasubramanian P and Karunakaran PV (2020). Assessment of status, distribution and threats to the population of threatened Sarus Crane *Antigone antigone* in Uttar Pradesh. Final report, Submitted to the Ministry of Environment, Forest and Climate Change, Government of India. SACON TR 209, pp. 244.

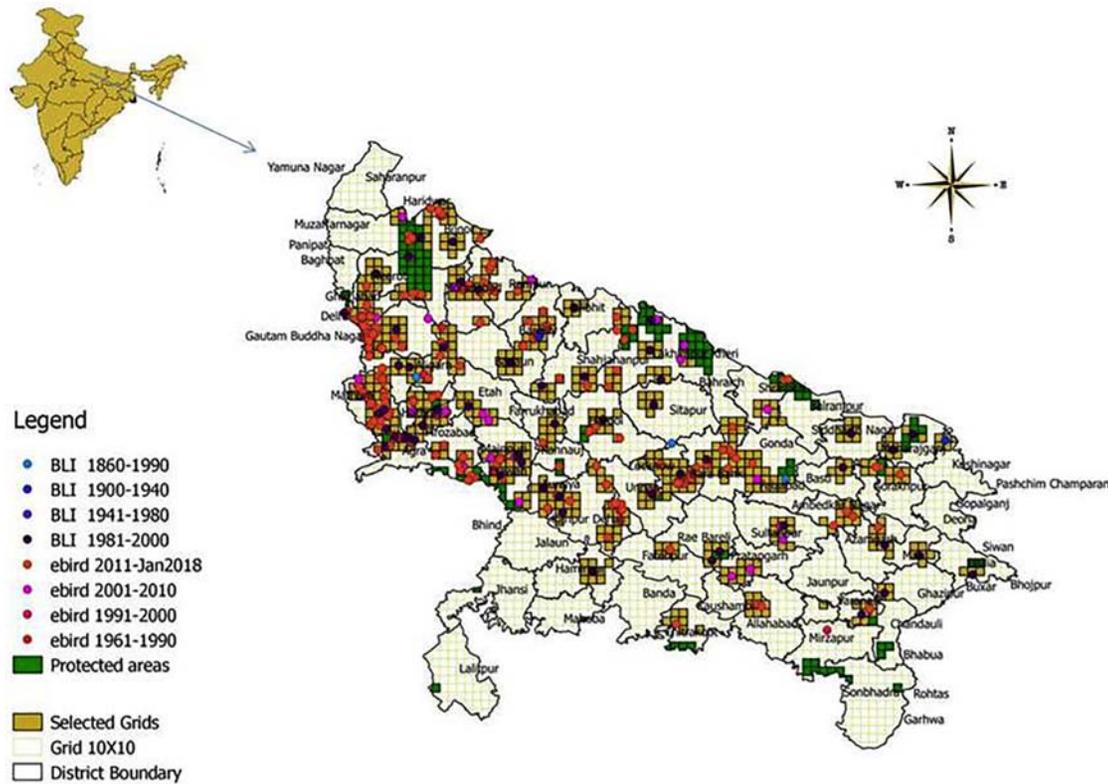


Fig. 4 The Sarus Crane (*Antigone antigone*) distribution in Uttar Pradesh (based on secondary data). The selected grids for this study are shown in brown.

we covered them on foot, and we used existing transects/bunds/dikes in such places. In each grid, five transects of length 2 km or 10 transects of length 1 km, a continuous 10 km transect, or multiple transects were covered, depending upon the availability of routes.

With a minimum $N = 10$ (repeated sampling), spatial replication was done in select transects in each grid. For each detection, we recorded the following parameters: (a) number of birds (Group size), (b) distance of the bird from the observer (using laser range finder (Prostaff 3i)), (c) angle at which the bird was sighted (from the bearing, estimated using a compass (Sunto KNB20/360R)).

The distribution of distances is a probability density function. The key to distance sampling is to use the distribution of the observed distances to estimate the "detection function," $g(y)$ or $\text{hat}(P_a)$, the probability of detecting a bird at distance y (Buckland et al., 2004). In the line transects, " y " is the perpendicular distance from the line. In addition to the bird's distance from the line, the probability of detection depends on many factors, including the habitat, weather conditions, observer, time, and bird behavior. Thus, changes in the number of birds observed with increasing distance from the transect are interpreted as changes in $\text{hat}(P_a)$.

We estimated the density, abundance, and distribution of Sarus Crane populations by this Distance Sampling (DS) (Buckland et al., 2004; Thomas et al., 2010; Miller, 2015). In the present study, the detection function was modeled as a function of the distance " y " with one or more additional sampling covariates. We applied the multiple-covariate distance sampling (MCDS) methods (Buckland et al., 2004) as implemented in the package "Distance" (Miller, 2015) in the R environment (R Core Team, 2018). We accounted for the effects of covariates on the detection probability of the species as it could influence estimation. We used parametric key functions (Uniform, Half-normal, and Hazard-rate), and $s(y)$ is a series expansion (Cosine, Simple polynomial, and Hermite) to improve the fit of the models. The final models were selected based on model selection criteria such as the Akaike Information Criterion (AIC) ranking (Buckland et al., 2004). A lower value of AIC means a better fit of the detection function to the observed data. Both the Half-normal and the hazard-rate key functions have a scale parameter (σ), and so we modeled this parameter as a function of the covariates. The Uniform key function does not have a scale parameter, so only adjustments were (Cosine, Simple polynomial, and Hermite) included and not the covariates. We assessed the model fit using chi-square, a non-significant Kolmogorov-Smirnov test, and the Cramér-von Mises goodness-of-fit statistic (Buckland et al., 2004). The estimated density was extrapolated to the entire area (Uttar Pradesh) within a given land cover type.

Further, we generated species distribution models using the Maxent algorithm and the Wallace package (v1.0.0) in the R environment. All the presence data collected from the field were analyzed using an appropriate spatial-thinning algorithm. We used the WorldClim bioclimatic raster so that the gridded predictor variables characterized the species' response to the environment (Hijmans et al., 2005). We used the following WorldClim as predictor variables, such as BIO1 (annual mean temperature), BIO2 (mean diurnal range (mean of monthly (max temp—min temp))), BIO4 (temperature seasonality (standard deviation \times 100)), BIO8 (mean temperature of the wettest quarter), BIO9 (mean temperature of the driest quarter), BIO12 (annual precipitation),

BIO14 (precipitation of the driest month), BIO15 (precipitation seasonality), and Alt (altitude). To evaluate the models, we selected spatial methods to partition occurrence localities into groups for k-fold cross-validation. To assess the suitability of predictions, we examined the response curves of the predictor variables (WorldClim). A species distribution map was produced using Maxent evaluation plots for the extent of the study area.

Results

Survey effort

We surveyed 521 grids (10 × 10 km each), spread across the 75 districts of Uttar Pradesh. In each grid, we covered a minimum transect of 10 km and divided each transects into different sub-sets of transects/segments, each with a minimum length of 1 km. We covered a uniform strip width of 500 m on either side of the transect during the survey. We obtained 1642 observations of Sarus Cranes (1485 adults and 157 juveniles) and recorded the distances between the Sarus Crane and the observer in all the selected transects laid across the districts of Uttar Pradesh. We recorded a maximum number of observations of Sarus Cranes in the districts of Etawah (27.6%), Mainpuri (19.5%), Shahjahanpur (8.2%), Maharajganj (6.9%), and Auraiya (6.3%).

We covered a total length of 3289 km of transects, and the length of each transect was multiples of 1 km. Our sample covered 11 km in Siddharth Nagar, the minimum distance, and the maximum (220 km) in Mathura District. We observed large congregations of Sarus Cranes in different wetlands during the peak summer and in winter. When groups (> 25) were observed on a selected transect, the count was omitted as their distribution was not independent of each other due to the nature of social behavior.

Food and feeding habits

We noticed the Sarus Crane in the following habitats: agricultural lands, barren/open land, marshy wetlands, rivers, and irrigation canals. We observed ($N = 275$) maximum sightings of Sarus Cranes in agricultural lands (84%), followed by marshy wetlands (7.6%), barren/open lands (5%), and irrigation canals (1.8%). As wheat is the staple food and grown widely in the region, we observed maximum sightings of the Sarus Crane in the wheat fields (82%) followed by sugarcane fields (7.2%), rice fields (3%), grass fields (1.5%), potato fields (1.5%), mustard fields (1.5%), and maize fields (0.5%).

Although the Sarus Crane is an omnivore, it mainly subsists upon plant matter. Sarus Crane consumed various food items according to seasonal availability in the locality. The Sarus Crane consumed both animal and vegetable matter. The vegetable matter included tubers, grains, and shoots, and the animal matter comprised insects, avian eggs, crustaceans, molluscs, fishes, and frogs. A total of 64 food plant species belonging to 23 families were recorded during our study (Table 3).

We also sighted small and large wading birds along with the Sarus Crane, which includes Painted Stork (*Mycteria leucocephala*), Asian Openbill Stork (*Anastomus oscitans*), Woolly-necked Stork (*Ciconia episcopus*), Grey Heron (*Ardea cinerea*), Purple Heron (*Ardea purpurea*), Black-headed Ibis (*Threskiornis melanocephalus*), Median Egret (*Ardea intermedia*), Cattle Egret (*Bubulcus ibis*), Red-wattled Lapwings (*Vanellus indicus*), Bronze-winged Jacana (*Metopidius indicus*), Sandpipers, and Cormorants.

Detection probability

We observed Sarus Cranes at distances ranging from 50 to 500 m from the observer (Fig. 5) with a mean distance of 0.12 km ($n = 825$). However, there were variations among the observers for detecting the birds at different distances (Fig. 6). Similarly, detections of Sarus Cranes varied over months, indicating seasonality.

Exploratory analyzes revealed no evidence of data collection errors. It is clear that the birds seen along the transect have a probability of 1, and the number of birds sighted away from the line decreases in a tapering fashion. The fitted detection functions were heavy-tailed when distances < 500 m were included ($n = 825$) in the analysis.

We fitted different detection models for the dataset, and details of the models are in Table 4. In the dataset, sampling covariates such as researchers, experience, and months showed significant variations. The Hazard rate key functions along with sampling covariates occupied the top position. We estimated the probability of detection function from the top model with the Hazard-rate key function, $\text{hat}(P_a) = 0.415 \pm 0.0105$ (Table 4). The $\text{hat}(P_a)$ values of the models ranged from 0.35 to 0.69. These values are essential for accounting for undetected animals during a survey, and the value depends upon the properties of the fitted detection functions.

Density and abundance

Using the same dataset, we estimated encounter rates that ranged between 0.252 and 0.243 Sarus Cranes, which means that the surveyor sights one Sarus Crane every 20 km (Table 5).

We estimated the abundance of Sarus Cranes using the *herm.mod.covsER5*, one of the top models with the Hazard-rate key function (Fig. 7). As per the top model, the mean of the estimated population was $15,193.25 \pm 2905.1$ (mean \pm SE) individuals across Uttar Pradesh with coefficient of variation (CV) = 0.191, lower confidence interval (LCI) = 10,465.87, upper confidence interval (UCI) = 22,055.96, with $df = 340.23$ (Tables 4 and 5). The detection function of the other top model is in Fig. 8.

Table 3 Food plants of the Sarus Crane observed during the present study in Uttar Pradesh.

S. no.	Species	Family	Habit	Parts consumed
1	<i>Aeschynomene aspera</i>	Fabaceae	Herb	Pods
2	<i>Aeschynomene indica</i>	Fabaceae	Herb	Pods
3	<i>Ammannia baccifera</i>	Lythraceae	Herb	Roots
4	<i>Ammannia multiflora</i>	Lythraceae	Herb	Roots
5	<i>Aponogeton crispus</i>	Aponogetonaceae	Herb	Tubers
6	<i>Aponogeton natans</i>	Aponogetonaceae	Herb	Tubers
7	<i>Arachis hypogea</i>	Caesalpinaceae	Herb	Pods and nuts
8	<i>Azolla pinnata</i>	Azollaceae	Herb	Whole plant
9	<i>Brachiaria ramosa</i>	Poaceae	Grass	Young shoots
10	<i>Dysphania ambrosioides</i>	Chenopodiaceae	Herb	Flowers and fruits
11	<i>Cicer arietinum</i>	Fabaceae	Herb	Pods
12	<i>Coix lacryma-jobi</i>	Poaceae	Grass	Seeds
13	<i>Cynodon dactylon</i>	Poaceae	Grass	Young shoots, stems, and roots
14	<i>Cyperus cyperoides</i>	Cyperaceae	Sedge	Roots
15	<i>Cyperus difformis</i>	Cyperaceae	Sedge	Tubers
16	<i>Cyperus exaltatus</i>	Cyperaceae	Sedge	Roots
17	<i>Cyperus iria</i>	Cyperaceae	Sedge	Tubers
18	<i>Cyperus rotundus</i>	Cyperaceae	Sedge	Tubers
19	<i>Cyperus triceps</i>	Cyperaceae	Sedge	Tubers
20	<i>Echinochloa colona</i>	Poaceae	Grass	Roots, young shoots, and panicles
21	<i>Echinochloa crus-galli</i>	Poaceae	Grass	Roots, young shoots, and panicles
22	<i>Eclipta prostrata</i>	Asteraceae	Herb	Roots
23	<i>Eichornia crassipes</i>	Pontederiaceae	Herb	Young shoots and phyllodes
24	<i>Eleocharis acutangula</i>	Cyperaceae	Sedge	Tubers
25	<i>Eleocharis dulcis</i>	Cyperaceae	Sedge	Tubers
26	<i>Eleocharis ovata</i>	Cyperaceae	Sedge	Tubers
27	<i>Eleocharis palustris</i>	Cyperaceae	Sedge	Tubers
28	<i>Eleocharis plantaginea</i>	Cyperaceae	Sedge	Tubers
29	<i>Eleusine indica</i>	Poaceae	Grass	Panicles, and roots
30	<i>Hydrilla verticillata</i>	Hydrocharitaceae	Herb	Roots
31	<i>Kyllinga brevifolia</i>	Cyperaceae	Sedge	Tubers
32	<i>Lemna perpusilla</i>	Lemnaceae	Herb	Whole plant
33	<i>Limnophila indica</i>	Scrophulariaceae	Herb	Leaves, fruits, and flowers
34	<i>Melochia corchorifolia</i>	Sterculiaceae	Herb	Leaves, fruits, and flowers
35	<i>Monochoria vaginalis</i>	Pontederiaceae	Herb	Seeds, and young shoots
36	<i>Najas minor</i>	Najadaceae	Herb	Stems and young shoots
37	<i>Neptunia prostrata</i>	Mimosaceae	Herb	Pods
38	<i>Nymphaea nouchali</i>	Nymphaeaceae	Herb	Stem and flower buds
39	<i>Nymphaea pubescens</i>	Nymphaeaceae	Herb	Stem and flower buds
40	<i>Oryza sativa</i>	Poaceae	Grass	Grains, husk, and straw
41	<i>Oryza rufipogon</i>	Poaceae	Grass	Grains, husk, and straw
42	<i>Oxalis corniculata</i>	Oxalidaceae	Herb	Roots
43	<i>Paspalum distichum</i>	Poaceae	Grass	Inflorescences, young shoots, and roots
44	<i>Pisum sativum</i>	Fabaceae	Herb	Pods
45	<i>Polygonum barbatum</i>	Polygonaceae	Herb	Roots
46	<i>Polygonum glabrum</i>	Polygonaceae	Herb	Roots
47	<i>Potamogeton pectinatus</i>	Potamogetonaceae	Herb	Shoots
48	<i>Saccharum spontaneum</i>	Poaceae	Grass	Roots
49	<i>Scirpus articulatus</i>	Cyperaceae	Sedge	Tubers
50	<i>Scirpus maritimus</i>	Cyperaceae	Sedge	Tubers
51	<i>Scirpus mucronatus</i>	Cyperaceae	Sedge	Tubers
52	<i>Scirpus squarrosus</i>	Cyperaceae	Sedge	Tubers
53	<i>Solanum tuberosum</i>	Solanaceae	Herb	Tubers, and young shoots
54	<i>Spirodela polyrhiza</i>	Lemnaceae	Herb	Whole plant
55	<i>Sporobolus diandrus</i>	Poaceae	Grass	Panicles
56	<i>Syzygium cumini</i>	Myrtaceae	Tree	Fruits and seeds
57	<i>Trapa bispinosa</i>	Trapaceae	Herb	Fruits, roots and phyllodes
58	<i>Trapa natans</i>	Trapaceae	Herb	Fruits, roots and phyllodes
59	<i>Triticum aestivum</i>	Poaceae	Grass	Grains, husk, and straw

Table 3 Food plants of the Sarus Crane observed during the present study in Uttar Pradesh.—cont'd

S. no.	Species	Family	Habit	Parts consumed
60	<i>Typha angustifolia</i>	Typhaceae	Herb	Roots
61	<i>Typha domingensis</i>	Typhaceae	Herb	Roots
62	<i>Vallisneria spiralis</i>	Hydrocharitaceae	Herb	Whole plant
63	<i>Vetiveria zizanioides</i>	Poaceae	Grass	Roots and young shoots
64	<i>Zea mays</i>	Poaceae	Grass	Grains

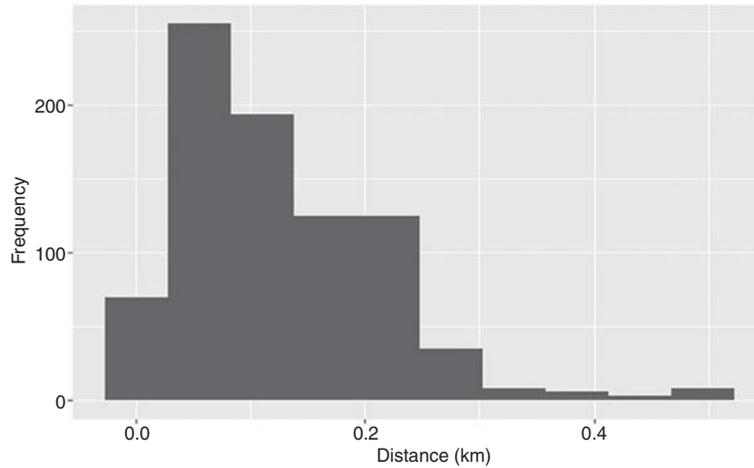


Fig. 5 Frequency of Sarus Crane (*Antigone antigone*) sighting distances from the observer on transects surveyed in Uttar Pradesh.

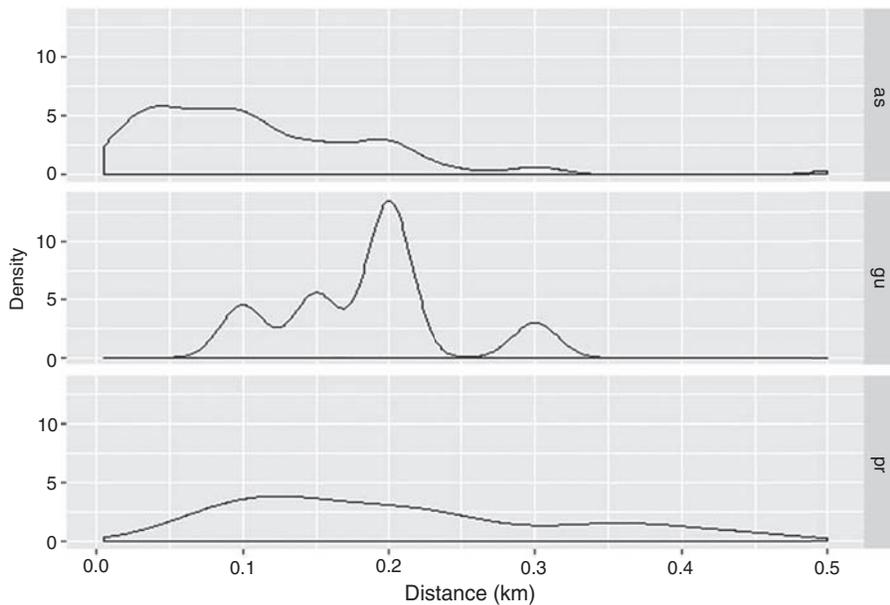


Fig. 6 Comparative charts indicating variations among different observers in estimating the density of Sarus Crane (Research fellows who noted the distance of Sarus Cranes from the transect: as = Astha, pr = Prakash, gu = Gautam).

We estimated the density of Sarus Crane with a mean and SE of 0.0608 ± 0.0116 birds per sq. km ($CV = 0.1912$, $LCI = 0.0419$, $UCI = 0.0882$, $df = 340.23$). The other top models also indicated similar density values ranging from 0.061 to 0.073. The coordinates (Latitude and Longitude) of the sampling grids used to estimate the density of Sarus Crane in Uttar Pradesh are available in Mahendiran et al. (2020).

Table 4 Detection function models fitted with different key functions and adjustments on data of the sighting distance of Sarus Crane (within 500 m from the observer).

Model	Key function	Formula	C-vM P-value	\hat{p}_a	$se(\hat{p}_a)$	Delta AIC
herm.model.covsER5	Hazard-rate	~ Researcher + experience	0.02487	0.414744	0.010538	0
hn.model.covsss5	Half-normal	~ Researcher + Month + experience	3.13E-05	0.345236	0.010354	9.218901
hn.model.covs5	Half-normal	~ Researcher + Month	0.000203	0.349506	0.010136	16.11206
herm.model.covs5	Hazard-rate	~ Researcher + Month	2.02E-05	0.425347	0.010872	47.58214
herm.model.cov5	Hazard-rate	~ Researcher	0.012778	0.414449	0.011075	59.39733
hn.model.cov5	Half-normal	~ Researcher	0.000376	0.369564	0.008834	95.25839
herm.model.C.5	Hazard-rate with cosine adjustment terms of order 2, 3	~ 1	0.013862	0.426485	0.021746	108.4729
herm.model.5	Hazard-rate	~ 1	0.011842	0.441047	0.011376	119.4789
herm.model.P.5	Hazard-rate	~ 1	0.011842	0.441047	0.011376	119.4789
herm.model.H.5	Hazard-rate	~ 1	0.011842	0.441047	0.011376	119.4789
uni.model.P.5	Uniform with simple polynomial adjustment terms of order 2, 4, 6, 8, 10	NA	0.002669	0.38731	0.020541	120.1808
uni.model.C.5	Uniform with cosine adjustment terms of order 1, 2	NA	0.00228	0.387086	0.00943	120.4978
hn.model.5	Half-normal	~ 1	0.001525	0.382951	0.00866	144.9375
hn.model.C.5	Half-normal	~ 1	0.001525	0.382951	0.00866	144.9375
hn.model.P.5	Half-normal	~ 1	0.001525	0.382951	0.00866	144.9375
hn.model.H.5	Half-normal	~ 1	0.001525	0.382951	0.00866	144.9375
uni.model.H.5	Uniform with Hermite polynomial adjustment term of order 4	NA	0.021483	0.608275	0.002935	382.9512

Table 5 Summary of top models with the estimation of encounter rate, abundance, and density of Sarus Crane in Uttar Pradesh.

Model	Average $p \pm SE$; CV SE; CV	Encounter rate $\pm SE$	Abundance $\pm SE$	Density $\pm SE$
herm.mod.covsER5 (Hazard-rate key function)	0.415 \pm 0.0105; 0.0254	0.252 \pm 0.04; 0.161	15,193.25 \pm 2905.1, CV = 0.191, LCI = 10,465.87, UCI = 22,055.96, df = 340.23	0.0608 \pm 0.0116, CV = 0.1912, LCI = 0.0419, UCI = 0.0882, df = 340.23
hn.model.covsss5, (Half-normal key function)	0.345 \pm 0.01; 0.03	0.252 \pm 0.0406; 0.161	18,252.19 \pm 3454.445, CV = 0.189, LCI = 12,620.27, UCI = 26,397.42, df = 345.28	0.073 \pm 0.0138, CV = 0.189, LCI = 0.0505, UCI = 0.105, df = 345.28

The model (herm.model.covsER5), highlighted in bold letters, was selected.

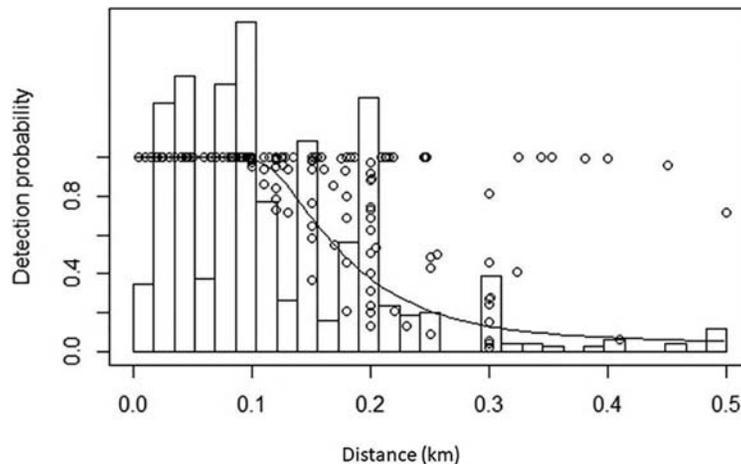


Fig. 7 The probability of detection functions observed in the dataset (truncation < 500 m), fitted with Hazard-rate key functions and covariates.

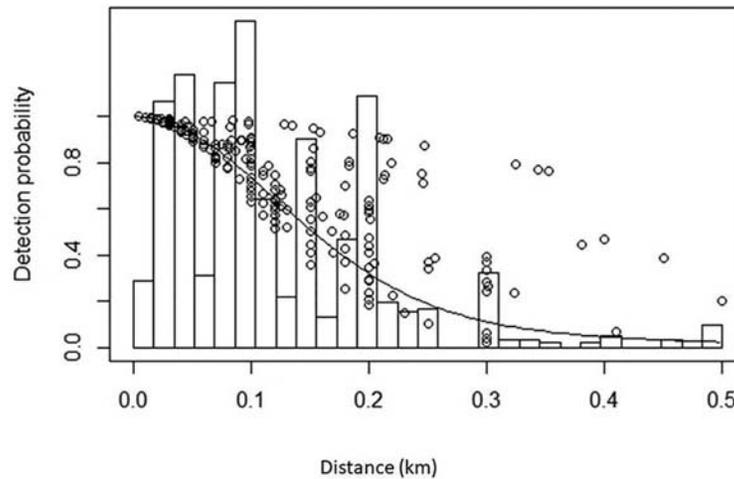


Fig. 8 The probability of detection functions observed in the dataset (truncation < 500 m) was fitted with Half-normal key functions and covariates.

Species distribution models

The species distribution map clearly showed that the probability of occurrence of Sarus Cranes was highest ($P = 1-0.8$) in the districts of Etawah, Mainpuri, Shahjahanpur, Auraiya, Aligarh, and Hathras. At the same time, the values of the entire Tarai belt and eastern Uttar Pradesh ranged from $P = 0.7-0.6$ (Fig. 9). Among the different environment variables used as predictors on the occurrence of the Sarus Crane, the BIO15 (precipitation seasonality) variable got the highest gain in terms of percentage contribution (38.1) compared to the percentage contribution of other variables such as BIO2 (mean diurnal range) as 16.6, Alt (altitude) as 15.2. When we omitted BIO2, the gain of the environmental variables drastically decreased, and BIO15 appeared to have the most useful information by itself. Maximization of Area Under Curve (AUC) test values generally favor models discriminating between presence and absence. Given the above, the average test AUC for the replicate runs is 0.920 (SD = ± 0.006).

Discussion

Earlier surveys of Sarus Crane

Uttar Pradesh is one of the stronghold states of the Sarus Crane population in India. This state once supported the largest population of this species, as indicated by the 1980s AWC data (Lopez and Mundkur, 1997). The Sarus Crane has enjoyed the respect and affection of the local people, and there are particular references in their folk songs and literature (Ali and Ripley, 1983). The first Sarus Crane census (estimated at 19,659 individuals) was conducted in January 1984 by the Gujarat Forest Department. Although the population of the Sarus Crane was high, some experts commented that it had possibly been overestimated (Singh and Tatu, 2000). Gole (1989a,b) carried out a nationwide survey of the Sarus Crane (apart from Haryana, Uttar Pradesh, Rajasthan, Madhya Pradesh, Odisha, and Bihar). The Wildlife Institute of India, Dehradun, conducted the second survey in 1998 and 1999. A total of 112 districts and 143 points (transects and wetlands) were covered, and 510 Sarus Cranes were counted in Gujarat (Sundar et al., 1999). In a few areas of India, Sarus Cranes are abundant when agricultural practices are maintained (Parasharya et al., 2000). The information on the abundance of Indian Sarus Crane across different districts of Uttar Pradesh is available from a rapid survey (Maheswaran et al., 2010). Less than 5% of the Indian Sarus Crane, almost 3000 birds or 30% of the nation's crane population, resides in the wetlands and agricultural lands of Etawah and Mainpuri in Uttar Pradesh (Sundar et al., 1999).

Jha and McKinley (2014) estimated the total Sarus Crane population in Uttar Pradesh at 11,905 individuals, with a recruitment rate of 13%. A recent survey showed a continuous distribution of the Sarus Cranes in eastern Uttar Pradesh in addition to the known western population (Rahmani et al., 2019). Crane numbers were low in Vindhyan Zone, probably due to landscape changes, pollution, and agricultural developments.

Detection probabilities

Estimation of the population density (D) is a key objective of many ecological studies. Estimating the abundance and spatial distributions of species is essential for conservation and management. Distance sampling has been found effective and robust in estimating population abundance across the globe (Buckland et al., 2004).

For the first time in India, we have used a grid-based sampling of Sarus Cranes and applied the distance sampling approach across Uttar Pradesh. Earlier studies had restricted sampling to certain pockets or regions or, an issue highlighted in a review of

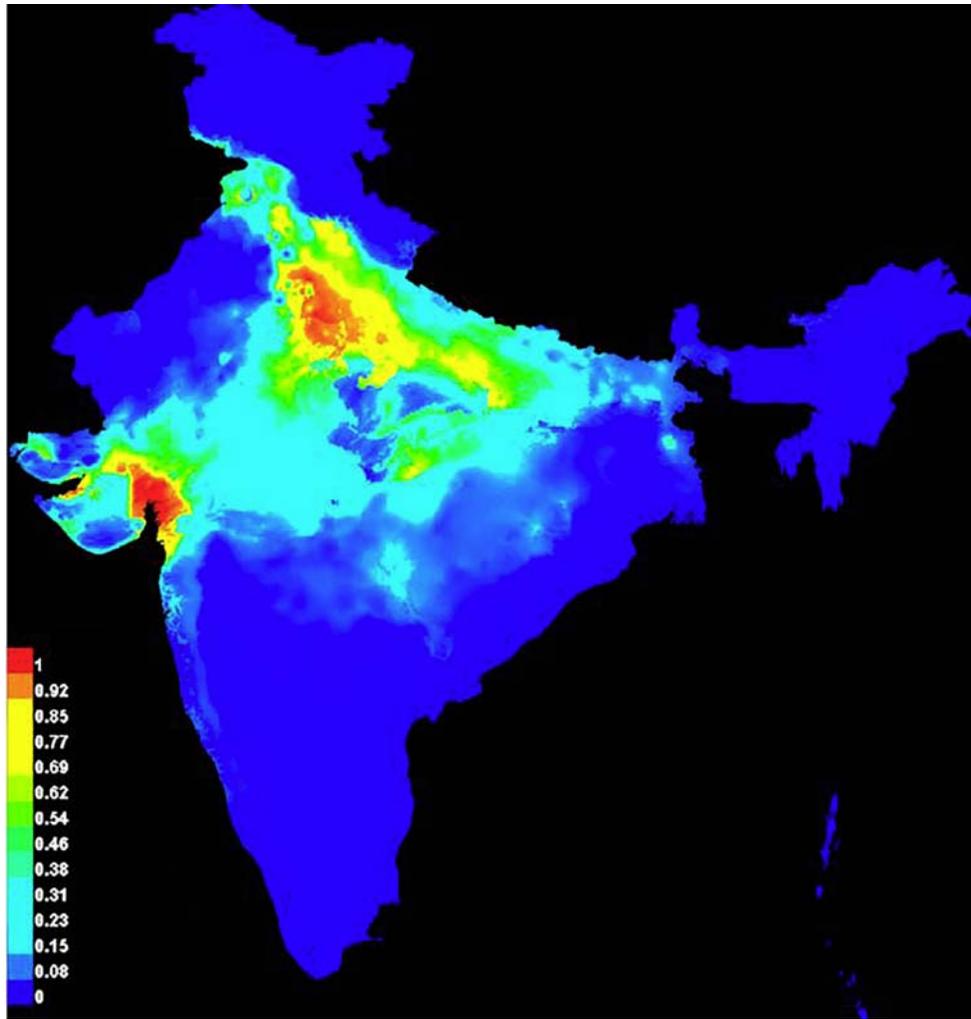


Fig. 9 The distribution model of Sarus Crane (*Antigone antigone*), predicted using Maxent algorithms, where the red region indicates high probability of the Sarus Crane occurrence and the blue with low probability of occurrence.

the methodologies of counting birds in India (Urfi et al., 2005). Earlier surveys somehow also did not take into account the probability of detection for total population estimation. The probability of detection helps correct the count of animals, which is the false-negative part of population estimations. In other words, the probability of animals during the survey failed to detect or non-detected or remain hidden during the whole exercise (Figs. 7 and 8). This component is essential to quantify the total population (Total population = False negative (undetected) + True Positive (detected individuals) – False positive (misidentified individuals)).

Recommendations

We recommend consistent long-term monitoring (1 in 4 years) of the Sarus Crane population across Uttar Pradesh using the “grid-based sampling approach” with the “Distance Sampling” technique to estimate the population’s density and overall population in the state.

We also recommend estimating the population of Sarus Cranes across its entire range using the “total count” method, twice a year, one each in summer and winter. It may be coordinated by the Forest Department, involving local/national NGOs and volunteers. Based on the results obtained, site-specific management interventions, as required, may be executed by the Forest Department for the conservation of the Sarus Crane.

It is understood that the current format of intensive farming is bound to continue in Uttar Pradesh, more specifically Etawah, Mainpuri, and Maharajganj districts, where we did intensive study during the last 2 years. Hence, it is evident that the use of agrochemicals will continue to increase, so also the impact on birds, specifically on the Sarus Crane. Sarus being a flagship species, saving it will also save many species of birds dependent on the agricultural landscape.

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The Struggle of Existence for Scavenging Greater Adjutants *Leptoptilos dubius*

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Abstract

Greater Adjutant *Leptoptilos dubius* are large birds measuring approximately 1.5 m in height with long thick beaks. The species is currently distributed in Brahmaputra floodplains (Assam, India), Gangetic plains (Bhagalpur, Bihar, India), and in Cambodia. The global population of the species is estimated to be around 1200–1800 individuals, two-thirds of which are found in the Brahmaputra valley. *L. dubius* prefers tall canopy trees for nesting. They are efficient scavengers and occasional feeders, especially during the breeding season. Multiple anthropogenic threats exist, the largest of which are associated with toxic compounds at garbage dumps. Here we describe an example of the impacts at the Guwahati garbage dump in Brahmaputra valley, and how a solid-waste management system within the urban city of Guwahati can itself reduce the risk of health hazards.

Introduction

India has six resident stork species: Asian Openbill *Anastomus oscitans*, Asian Woollyneck *Ciconia episcopus*, Black-necked Stork *Ephippiorhynchus asiaticus*, Painted Stork *Mycteria leucocephala*, Lesser Adjutant *Leptoptilos javanicus*, and Greater Adjutant *Leptoptilos dubius*; and two winter visitors: Black Stork *Ciconia nigra* and White Stork *Ciconia ciconia* (Ali and Ripley, 1983). *A. oscitans* and *C. episcopus* are well spread throughout the country, except at higher altitudes of the Himalayas. *M. leucocephala*, more common in western, central, and southern parts though spreads to eastern region during winter. *E. asiaticus* though confined to parts of central and north-eastern regions, they occur to western region (Gujarat). *L. javanicus* are found in parts of the northern and southern regions although they are mostly confined to northeastern states. On the other hand, Greater Adjutant are known to occur primarily in the Brahmaputra floodplains (Assam) and Gangetic (Bhagalpur, Bihar) plains of India (Fig. 1). The global population of the Greater Adjutant is estimated at 1200–1800 individuals, of which the Brahmaputra valley has 650–800 individuals (Birdlife International, 2021).

Despite the similarity in the preferences of feeding and nesting habitats of Storks, there are several ecological and behavioral differences among all of them. For instance, *M. leucocephala* breeds in heronries with other waterbirds (Urfi, 2010), while *A. oscitans* breeds in large mono-specific colonies (Kahl, 1970, 1972a; Urfi et al., 2005). Some form lifelong pairs and are monogamous, while others may be polygamous (Verner, 1964; Beehler, 1983; Korpimäki, 1988; Black, 1996; Reichard and Boesch, 2003). Some breed solitary while others breed in colonies (van Vessem and Draulans, 1986; Arroyo et al., 2001; Schreiber and Burger, 2002; Ebensperger et al., 2007). Some form social groups, the 'cooperative breeder' in which one or more members provide care to young (Stacey and Koenig, 1990).

The breeding behavior of *L. dubius* is reported to be similar with its congener the Marabou Stork *L. crumenifer* of South Africa, and differs only in certain aspects of plumage structure, and in the sequence of 'Up-Down' display (Kahl, 1972b; Saikia and Bhattacharjee, 1996; Singha, 1998; Singha et al., 2003; Mandal, 2018). Post-breeding, *L. dubius* move to various garbage dumps in cities and towns for feeding on rubbish, juveniles after fledging also move directly to these areas (Saikia, 1995; Mandal, 2018). The non-breeding individuals mostly remain throughout the year in areas with small wetlands adjacent to waste disposal sites (Saikia, 1995; Mandal, 2018). The breeding season starts after monsoon, with the onset of dry season when there is an increase in prey density in drying out agricultural lands, pools, and wetlands in the Brahmaputra valley (Saikia, 1995; Saikia and Bhattacharjee, 1996; Singha, 1998; Singha et al., 2003; Mandal, 2018). The nests are constructed using twigs and sticks on horizontal branches of tall trees on rocky cliffs along the bank of Attaran river (Jerdon, 1864; Bingham, 1878; Oates, 1878). Later Saikia (1995) and Singha (1998) individually studied breeding biology and behavior of the species in the Brahmaputra valley suggesting resemblance of most of the behavior with Marabou as described by Kahl (1972b). The distribution pattern of *L. dubius* in Brahmaputra valley, showed seasonal variation following the breeding cycle of the species and climatic conditions in accordance with food availability

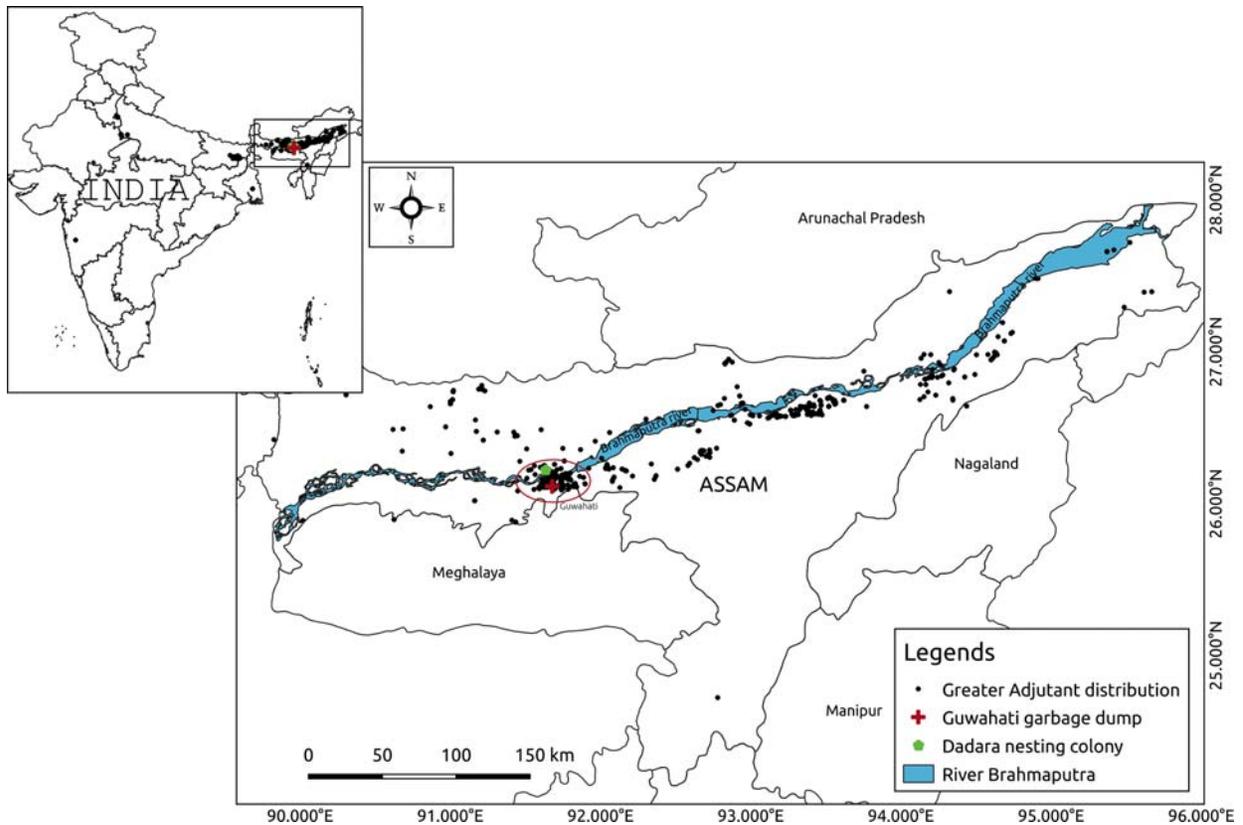


Fig. 1 Map showing distribution of Greater Adjutant in India, with its highest density in Brahmaputra valley, Assam.

(Mandal, 2018). This distribution pattern significantly correlates with the suitable habitats and availability of food resources across different seasons. Though there are some differences in aggressiveness while flocking at the nesting site (Saikia, 1995; Singha, 1998). Other differences observed were in the acquisition and patterns of various display behaviors such as the 'swaying twig-grasping' display.

More recently, Saikia in (1995), Saikia and Bhattacharjee (1996), Singha (1998), and Singha et al. (2003) studied the breeding biology of the species and came up with similar conclusion as Kahl. All of these studies were carried out on small colonies and the described behaviors were based on few individuals. Further there were no studies on the influence of city garbage dump on the breeding behavior of the population. Since, they are well known scavenging birds, and human discarded food serve as one of the major components of their diet including for the nestling. On the other hand, during past two decades the natural habitats (foraging and nesting) of the species have greatly altered following the continuous urbanization and human demand. But somehow, they were able to flourish close to the largest city Guwahati in Assam, scavenging on the garbage dump and utilizing the remnants of the natural habitats for breeding (Fig. 1). In this chapter, we will discuss the distribution of the Greater Adjutant with a focus on its presence in Brahmaputra valley (Kamrup and Kamrup Metro districts, Assam, India).

Morphological characteristics

Greater Adjutant are large waterbirds measuring 1.52 m in height (Adam, 1825), with males usually larger than females. The wingspan is 2.12 m (Adam, 1825) in length (Fig. 2). The color of the plumage changes during breeding and non-breeding seasons. The head, neck, nape, and gular pouch devoid of feathers, and have scattered short hairs (Fig. 3). It is more prominent in juveniles and sub-adults. A ruff of white feathers on the back of shoulders borders the body with head and neck. Plumage color on the upper side of lesser and median wing-coverts vary from ashy or slaty to slaty black in fresh molt, with a tinge of glossy green (Adam, 1825; Jerdon, 1864; Oates, 1883; Baker, 1929). The neck feathers, breast, abdomen, flanks, vent, and underwing coverts are white (Adam, 1825; Jerdon, 1864; Baker, 1929).

Greater Adjutants are easily distinguished from other species by the presence of a pendulous gular pouch on the neck descending from the throat attaining up to 40 cm in length (Adam, 1825; Baker, 1929; Ali and Ripley, 1983). The head and neck are devoid of feathers, though there are some hairs on nape, neck, and head, most prominent in juveniles and sub-adult individuals (Fig. 4). In non-breeding plumage, the silvery grey wing band becomes duller, and the head and neck turn pinkish red (Adam, 1825; Baker, 1929). Ali and Ripley (1983) described them as one of the ugliest of the Asian storks. They have an average lifespan up to 45 years



Fig. 2 Greater Adjutant on its nesting tree displaying wings.



Fig. 3 Morphological features of Greater Adjutant.



Fig. 4 Adult Greater Adjutant with juvenile on nest.

(Brouwer et al., 1992). The clutch size was reported to vary, usually two to three eggs, sometimes four (Bingham, 1878). Eggs are large, 77.3 mm in length and 57.5 mm wide. They are oval shaped, chalky or pure white initially and turning earth brown with successive incubation days becomes much dark prior to hatching (Bingham, 1878; Oates, 1878; Hume, 1890; Baker, 1929). The interior lining of eggs was reported to be a dark green (Oates, 1878).

Historical distribution

First breeding records of *L. dubius* were reported by Tickell and Sparks on the trees along the cliffs of rocky limestone and occasionally on tall trees in plains from Myanmar (Jerdon, 1864). In India *L. dubius* nesting colonies were reported from Sundarbans in West Bengal, parts of Odisha, Gorakhpur in Uttarakhand, and from Brahmaputra valley in Assam (Jerdon, 1864; Blanford, 1898; Baker, 1929). *Leptoptilos dubius* were once distributed across India, Nepal, Bangladesh (Adam, 1825; Tytler, 1854), Indonesia, Burmah (Myanmar) (Jerdon, 1864; Bingham, 1878), and the Malayan peninsula. However, most of the records in India were from Brahmaputra river basin and Gangetic plains in the North, Central, and North-Eastern region. Large colonies found in Myanmar were also considered as migrants from India during winter seasons. Since they are tall birds with 7 ft of wingspan they can easily migrate from one place to another in search of food and shelter (Adam, 1825).

The species has been rarely observed in the South of India, with reports from Hyderabad and only occasional records from Mysore (Jerdon, 1864). *L. dubius* have been reported breeding in the north-eastern state of Assam (Table 1) where the Brahmaputra River and its tributaries form an immense flood plain, the Brahmaputra valley (Fig. 1). Two other disjunct colonies are present in the Kosi River floodplain (Mishra and Mandal, 2009; Choudhary et al., 2011) in Bhagalpur District in Bihar, India, while the third breeding colony is along the Tonle Sap Lake, Cambodia (Mundkur et al., 1995; Campbell et al., 2006; Clements et al., 2013). They were also reported during the non-breeding season from Bihar, Odisha, parts in Rajasthan, but later observed a drastic decline in the range and population (Dover and Basil-Edwards, 1921). Following this continued decline in the range and population *L. dubius* was listed in the IUCN Redlist as 'Endangered' since 1994 (Birdlife International, 2021). Kahl in (1970, 1972a,b) reported a nesting colony from Kaziranga National Park (KNP), Nagaon District a protected area in Assam. During 1994–95 surveys, Singha et al. (2002) found two new nesting colonies, one in Manaha, Morigaon and second in Daulasal, Nalbari Districts. During 1994–97 surveys, Singha et al. (2003) again reported two new colonies, one in Mandarkata (Satgaon, Kamrup), and the other in Bikrampur (Maganapara, Sibsagar). In the years 2012–15, another colony was found in Maloibari (Kamrup District). Thus, 12 nesting colonies (11 in human settlements and one in the protected area) were reported from the Brahmaputra valley (Kahl, 1970; Saikia and Bhat-tacharjee, 1990; Singha et al., 2003, 2002) from 1970 to 2015.

Current distribution in Brahmaputra valley

The Brahmaputra valley provides immense natural habitats for *L. dubius* in the form of wetlands, swamps, and marshes. On the other hand, human made agricultural landscapes and home gardens also allow the species to forage and breed. The species had congregated to few major cities, for foraging on human discarded waste, and nesting in human home gardens. These colonies were spread across seven Districts, namely Barpeta, Nalbari, Kamrup, Morigaon, Nagaon, Sibsagar, and Golaghat. The Kamrup District had the highest number (4) of colonies, one in Dadara and Singimari, second in Rojahat (Rangmahal), third in Mandakata (Satgaon), and the fourth in Maloibari. According to the study done by the authors, it was found that two sites (a) Nesting colony in Dadara (Dadora), Pacharia and Singimari villages and (b) Guwahati garbage dump, are potential locations to observe Greater Adjutants.

(a) Nesting colony in Dadara (Dadora), Pacharia and Singimari villages

The nesting colony is located on the north bank of Brahmaputra River in Kamrup (Rural) District of Assam, India. This study area spreads over 1.6 km² in six villages, Pub-Dadara, Pachim Dadora, No. 1 Singimari, Na-para Pacharia, Pacharia Dalar Pahar, and Pacharia 26.21°–26.23° N to 91.62°–91.64° E, 50 m above mean sea level (Fig. 1). The total population of the area is 12,278 according to 2011 census (Government of India, 2011). Like other agricultural landscapes and home gardens in the valley, this study site is predominantly paddy *Oryza sativa* and home gardens of fruit trees such as Mango *Mangifera indica*, Jackfruit *Artocarpus heterophyllus*, and agro-forestry containing trees like Kadam *Neolamarckia cadamba*, Coconut *Cocos nucifera*, Areca Palm *Areca catechu*, Bamboos *Bambusa balcooa* (Galluzzi et al., 2010; Saikia et al., 2012). There are number of wetlands, such as Digholi beel, swamps, and marshes such as Mara-suti, Duramari, small water bodies, and ponds in the village.

(b) Guwahati garbage dump

This site is located in west Baragaon, Guwahati, Kamrup (Metro) district, Assam, India (26°06' N 90°40' E) area, along the northeast corner of Deepor beel wildlife sanctuary, a Ramsar site (Fig. 1). It was established during 1990s over a spread of 0.33 km² on the fallow lands. The surrounding area is also dominated by agricultural lands, and crop fields of paddy cultivation. Within the immediate vicinity there are roughly 80 families belonging to marginalized households. For the past several years *L. dubius* had congregated in high numbers (100–500 individuals) in this site, which now serves as year-round scavenging site for the species (Saikia, 1995; Choudhury, 2009; Mandal and Saikia, 2013; Mandal, 2018).

Table 1 Historical distribution records of *L. dubius* nesting colonies and foraging habitats in Brahmaputra valley, Assam.

District/state	Lat/long	Year	Area/Colony name	Nesting (pop.)	Foraging (pop.)	Source ^a
Nagaon/Golaghat	–	1967	Kaziranga National Park	2	–	1
Nagaon	–	1986	Nagaon Town	2	–	2
Assam	–	1987–90	Brahmaputra valley	150	–	3
Nagaon	–	1987–90	Nagaon Town	12	–	2
Kamrup	–	1988	Guwahati	–	165	4
Kamrup	26°08'N 91°50'E	1988–89	Hengrabari, Dispur (wetland)	–	10	5
Sonitpur	–	1989	Orang National Park	–	9	6
Nagaon/Golaghat	–	1989	Kaziranga National Park	–	2	6
Sonitpur	–	1989	Tezpur	–	56	6
Kamrup	–	1989	Guwahati	–	83	6
Assam	–	1989	Brahmaputra valley	–	300	6
Kamrup	26°20'N 91°45'E	1989	Baihata Chariali (paddy fields)	–	1	5
Nagaon	–	1991	Khutikotia	12	–	2
Sibsagar	–	1991	Dichialgaon	16	–	2
Kamrup	–	1994	Brahmaputra riverbank	–	87	7
Kamrup	26°13'N 91°38'E	1994–95	Singimari, Dadara	23	351	8
Kamrup	–	1996	Garbage dump	–	200	8
Kamrup	–	1996	Rangia army butchery and fish market	–	9	8
Kamrup	–	1999	Guwahati Commerce College backside	–	54 ^b	9
Kamrup	–	1999	Ulubari Bazar	–	39 ^b	9
Kamrup	–	1999	Paltan Bazar, Behind Meghdoot cinema hall	–	28 ^b	9
Kamrup	–	2000	Commerce college backyard	–	133 ^b	10
Kamrup	–	2000	Ulubari Bazar	–	125 ^b	10
Kamrup	–	2000	Paltan Bazar Area	–	117 ^b	10
Kamrup	–	2002	Backside of RG Baruah College	–	254	7
Kamrup	26°10'N 91°45'E	2002–2007	Islampur Graveyard	–	80	7
Kamrup	–	2005	Borbari dumping ground	–	233	7
Kamrup	26°06'N 91°40'E	2008	Guwahati city garbage dumpyard	–	761 ^b	7
Kamrup	26°13'N 91°38'E	2011	Dadara and Singimari	200 ^b	–	11
Kamrup	26°06'N 91°40'E	2011	Guwahati city garbage dumpyard	–	400 ^b	11
Nagaon	26°30'N 92°40'E	1988	Laokhowa wildlife sanctuary (wetland)	–	1	5
Nagaon	26°07'N 92°10'E	1989	Jagiroad (dog carcass)	–	1	5
Nagaon	–	1994–95	Haibargaon, Khutikatia, Barpujia	31	65	8
Nagaon	–	1996	Missamari army butchery	–	17	8
Nagaon	–	1996	Garbage dump	–	92	8
Sonitpur	26°39'N 92°47'E	1989	Tezpur graveyard	–	57	5
Sonitpur	–	1996	Tezpur garbage dump, burial ground, fish- and meat market	–	53	8
Darrang	26°27'N 92°02'E	1989	Mangaldoi (cow carcass)	–	9	5
Darrang	26°35'N 92°25'E	1988–89	Orang National Park	–	6	5
Golaghat and Nagaon	26°40'N 93°28'E	1988	Kaziranga National Park (wetland)	–	5	5
Nalbari and Barpeta	26°30'N 91°20'E	1989	Beside National Highway—31	–	4	5
Nalbari	26°28'N 91°25'E	1988–89	Nalbari, fellow field and cow carcass	–	3	5
Nalbari	–	1994–95	Daulasal	4	14	8
Nalbari	–	1996	Near fish market	–	16	8
Nalbari	–	2003–2004	Daulasal	8	–	12
Dibrugarh	27°25'N 94°50'E	1989	Laluka village (paddy fields)	–	13	5
Dibrugarh	–	1996	Near slaughterhouse	–	10	8
Jorhat	–	1994–95	–	–	5	8
Jorhat	–	1996	Garbage dump	–	3	8
Sibsagar	27°N 94°40'E	1989	Waste dump	–	16	5
Sibsagar	–	1994–95	Dichial, Bhangarchuk, Maganapara	24	32	8
Sibsagar	–	1996	Near slaughterhouse	–	40	8
Morigaon	–	1994–95	Manaha	21	–	8
Barpeta	–	2003–2004	Kapla beel complex	–	4	12
Barpeta	–	2003–2004	Bhawanipur (Dangarpar)	5	–	12
Barpeta	–	2003–2004	Nagaon (village in Barpeta district)	–	3	12
North Lakhimpur	–	1994–95	–	–	3	8

^aAuthor and contributors (1 = Kahl, 1970; 2 = Choudhury, 1993; 3 = Saikia and Bhattacharjee, 1990; 4 = Saikia, 2000; 5 = Rahmani et al., 1990; 6 = Saikia and Bhattacharjee, 1989; 7 = Choudhury, 2009; 8 = Singha et al., 2003; 9 = Basu, 1999; 10 = Saikia and Saikia, 2011; 11 = Mandal and Saikia, 2013; 12 = Dewan and Saikia, 2011).

^bAverage count of individuals.

Table 2 Breeding and non-breeding distribution of Greater Adjutant *L. dubius* in Kamrup and Kamrup (metro) Districts.

Name of location	No. of individuals		ET	FO	RO	NE	SF
	Breeding season	Non-breeding season					
Amingaon	10.25 ± 1.45	0	4	N	N	N	Y
Uzanbazar	4	0	1	N	N	N	Y
Dadara-Pacharia colony	45.47 ± 0.19	64.70 ± 0.79	460	Y	Y	Y	Y
Deepor beel WLS	30.16 ± 1.19	103.00 ± 2.53	38	Y	Y	N	Y
Digholi beel	14 ± 0.49	2	8	Y	N	N	Y
Duramari beel	1.33 ± 0.29	0	3	Y	N	N	Y
Guwahati city garbage dump	178.16 ± 0.71	314.38 ± 1.08	112	Y	Y	N	Y
Gauhati University campus	6.67 ± 0.21	5.81 ± 1.19	167	Y	N	N	Y
Gotanagar	1	0	1	N	N	N	Y
Paltanbazar	3	0	1	N	N	N	Y
Pandu	1	0	1	N	N	N	Y
Ahom gaon	5	0	1	N	N	N	Y
Jalukbari	10 ± 2.85	0	2	N	N	N	Y
Jengdia beel	4	0	1	Y	N	N	Y
Kamakhya colony	1	1.50 ± 0.41	3	N	N	N	Y
Lachitpura beel	7.8 ± 1.22	0	5	Y	N	N	Y
Maligaon fish market	1.8 ± 0.6	0	5	Y	N	N	N
Maloibari colony	2 ± 0.71	0	2	N	Y	Y	Y
Maloibari (wetlands)	1	0	1	Y	N	N	N
Morasuti beel	1	0	4	Y	N	N	Y
Rangmahal colony	7 ± 0.27	0	4	N	Y	Y	Y
Rani Garbhanga RF	4	0	1	N	N	N	Y
Sualkuchi	5	0	1	Y	N	N	Y

ET = No. of encountered times, FO = Foraging, RO = Roosting, NE = Nesting, SF = Seen in flight; N = No, Y = Yes.

A study by the authors recorded the presence of breeding and non-breeding populations of *L. dubius* from Kamrup and Kamrup (Metro) districts of Assam, India from 2015 to 2017. The breeding and non-breeding distribution of *L. dubius* in Kamrup and Kamrup (metro) Districts are provided in [Table 2](#).

Garbage dump and Greater Adjutant

The city of Guwahati produces approximately 570 ton of garbage per day, of which approximately 90% of the waste is directly dumped to waste disposal site in Boragaon, Assam. The major source comes from domestic kitchens, though a considerable amount also comes from various hotels and restaurants, marriage, and other ceremonial occasions. However, Guwahati city garbage dump serves as a continuous source of food supply for the *L. dubius* and other animal groups foraging on it throughout the year ([Fig. 5](#)). Most of the foraging habitats (Guwahati garbage dump and city fish markets) from this nesting colony are within the 30 km radius from the dump, providing short distance travel during breeding seasons for food. As found by [Bryan and Coulter \(1987\)](#), and [Bryan et al. \(1995\)](#) in *M. americana*, nest colonies tend to shift to places with short foraging distance in order to cut energy costs.

Further, Greater Adjutants show habituation to humans (both people and vehicles) and other animal groups at the dump ([Fig. 6](#)). To some extent, *L. dubius* has learned to associate their food with working rug pickers and waste disposal vehicles. The foraging flock often gathers around rug pickers for easy access to consumable food. The Guwahati garbage dump was most crowded by people during early morning to mid-day, either so their cattle can graze in the nearby field or to scavenge for collectable items. A constant array of vehicles brought items to the dump. Rug pickers followed to gather recyclable materials, and while collecting, accidentally expose consumable food. Thus, *L. dubius* followed rug pickers and dumping vehicles in search of food. This habitual behavior has been seen in many species. For instance, sea birds follow fishing vessels and tankers for food ([Skov and Durinck, 2011](#); [Wahl and Heine-mann, 1979](#)). This shows why foraging duration and feeding success were higher in the presence of humans (rug pickers).

Greater Adjutants devoted the highest foraging time budgets at the garbage dump during the monsoon season because all of their natural habitats were inundated by water. While foraging, inter and intra-specific agonistic interactions were very common to secure food and territory. During the breeding season, *L. dubius* tend to disperse over a large and wide range of foraging habitats and can be seen solitary or in small flocks across different nesting colonies. Whereas during the non-breeding season they remain over a continuous source of food supply on garbage dumps close to large cities and towns. This is because the Guwahati city and adjacent areas provide a continuous and never-ending food supply and suitable nesting habitats. *L. dubius* often consumes plastic and polythene bags while eating. This has resulted in motility from time to time. Nestling loss also occurred following the consumption of such non-degradable items.



Fig. 5 Large gathering of Greater Adjutant on Guwahati garbage dump yard.



Fig. 6 Greater Adjutant foraging on garbage dump alongside other animals.

Foraging ecology

Leptoptilos dubius is well adapted to urban and human modified landscapes. They are efficient scavengers and opportunistic feeders on carcasses and discarded wastes. In many parts of the country, especially in large towns and cities they have been recorded feeding in waste dumping areas along with the Black Kite *Milvus migrans*, House Crow *Corvus splendens*, domestic cattle, and stray dogs (Adam, 1825; Jerdon, 1864; Saikia, 1995; Choudhury, 2009). Jerdon (1864) has also mentioned feeding on half-burnt human bodies. They have often been reported around slaughterhouses and fish markets (Jerdon, 1864; Baker, 1929; Ali and Ripley, 1983; Saikia, 1995; Singha, 1998; Singha et al., 2003). Apart from their scavenging habits, they also feed on fishes, amphibians, and reptiles, and occasionally prey on small birds and mammals. They frequent ditches, pools of water, and tanks (Jerdon, 1864), paddy fields and grass plains (Oates, 1878), shallow or deep lakes, swamps and marshes, river and canal beds, and stagnant pools (Oates, 1878; Ali and Ripley, 1983; Saikia, 1995). They use natural foraging habitats more frequently during the breeding season when the water level drops and prey concentrate in shallow water bodies (Kahl, 1970; Saikia, 1995; Singha, 1998; Choudhary, 2007; Mandal and Saikia, 2013).

Foraging interactions of focal individuals (adult and sub-adult) in the study site were observed for 58 h 28 min and 18 s over a period of 24 months from February 2015 to March 2017 during early morning hours when the activity of the birds were higher. In their urban feeding habitat, at Guwahati garbage dump, focal individuals of *L. dubius* devoted 32 h 14 min and 15 s (55.1%) of time in foraging activity (Fig. 7). Searching of food components found to be 92.6%, whereas feeding took only 7.4% of the time. The

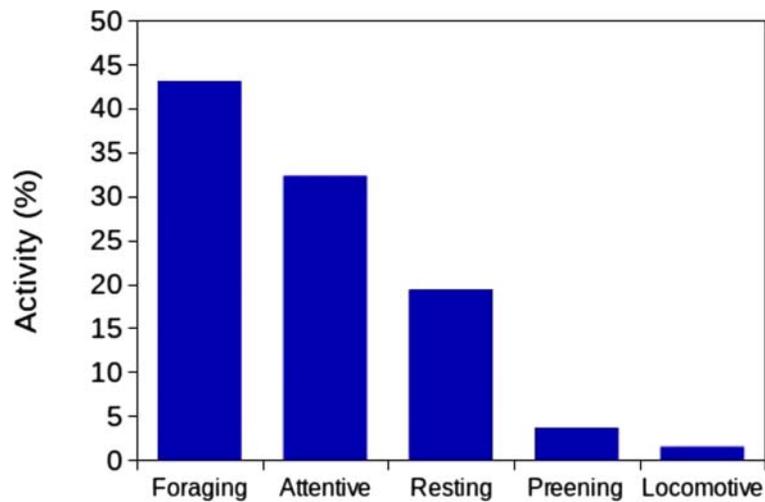


Fig. 7 Percentage mean of scan observation of state activities of *L. dubius* flock at Guwahati garbage dump ($n = 16,800$).

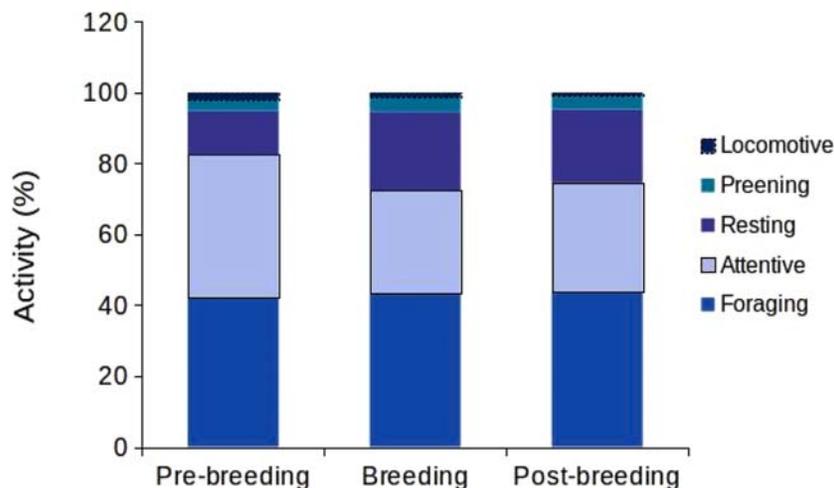


Fig. 8 Seasonal variation of state activities in *L. dubius* in Guwahati garbage dump.

consumed food items by *L. dubius* were mostly unidentified discards of animal parts (79.81%), followed by bones, and fish and meat market leftovers 11.76% and 8.06%, respectively. There were differences in the mean duration of various behaviors during successive biological cycle of the species. The observed foraging duration of focal *L. dubius* fluctuated across year, peaking in July to August and December to February in two successive years (Fig. 8). The scan results also show similar pattern with highest proportion of time (43.09%) were allotted to foraging activities (Fig. 7). Searching of food components found to be 92.6%, where as feeding took only 7.4% of the time. The consumed food items by *L. dubius* were mostly unidentified discards of animal parts (79.81%), followed by bones, and fish and meat market leftovers 11.76% and 8.06% respectively (Table 3). On the other hand, overall flock shows highest foraging effort given during the month of September (54.09%) and October (50.14%) in 2015, and in June and July in the 2016 averaging 55.96% and 52.1%, respectively. There were no significant differences on the foraging effort pre-breeding 42.21%, breeding 43.23%, and post-breeding 43.68% seasons (Table 4).

The mean foraging duration of the flock was found highest during peak monsoon season, July to September, when all natural habitats were inundated by water. As found by Saikia (1995), and Singha (1998) *L. dubius* forage on shallow wetlands, where prey were concentrated. The higher foraging effort in September correlates with the breeding cycle of the species. Since their breeding season starts from October, adults usually consume more food just prior to breeding. Increased foraging efforts during December to February correlated to the higher demand for food for growing nestlings.

Table 3 Percentage composition of preferred diet consumed by *L. dubius* in Guwahati garbage dump.

Category of food items	Observed feeding (%)
Bones	11.76
Discarded meat and fish products	8.06
Dead animals	0.37
Unidentified	79.81

Table 4 Seasonal variation in different activities performed by *L. dubius* in Guwahati garbage dump.

Season	Attentive (%)	Foraging (%)	Locomotion (%)	Preening (%)	Resting (%)
Breeding	29.12	43.23	1.44	3.97	22.24
Post-breeding	30.89	43.68	0.98	3.78	20.67
Pre-breeding	40.17	42.21	2.18	3.04	12.41

Causes and factors of decline of Greater Adjutant

Most stork species have managed to adapt to human-modified environments and altered natural habitats. However, many species have been negatively affected by human-caused landscape habitat alterations and land-use change leading to decreasing ranges or population declines (Hoyo et al., 1992; Turner et al., 2000; Hancock et al., 2011). Excessive use of pesticides for agriculture is known to have affected many species (Sakellarides et al., 2006; Pique et al., 2006) of storks such as *C. ciconia* in Turkey (Yavuz et al., 2012), *L. javanicus* in Sri Lanka (De Silva et al., 2015). Species like *C. nigra*, once abundant in woodlands of Poland, have declined due to massive deforestation (Hampl et al., 2005; Löhmus et al., 2005).

Food and feeding habits of storks may vary with geographic area, season of the year, and corresponding variation in availability of food resources (Hoyo et al., 1992; Hancock et al., 2011). Being carnivorous, the food of storks mostly includes fish, frogs, crustaceans, small rodents, salamanders, snakes, as well as carcasses and human discards for scavengers (Hoyo et al., 1992; Hancock et al., 2011). Such specialized food habits may pose threats to the long-term survival of stork species, as they may suffer population declines if this food abundance decreases.

As scavengers, Greater Adjutants forage around garbage disposal sites where they can find their food. However, due to improper solid-waste management systems organic and inorganic materials are mixed. Unsegregated household waste may contain plastic, ceramic, glass, and other non-biodegradable substances. Polythene bags, usually in which food is discarded, if swallowed by *L. dubius* can impose serious health threats and may be even fatal. Authors have also observed traces of plastic and other non-biodegradable compounds in the intestine of *L. dubius* dead carcasses. Serious toxic chemicals in the form of lead from disposed battery wastes also threaten the survival of the species. Disposed medical waste, including expired chemicals and medicines also end up in the garbage, when not segregated. In several instances, it has been observed by the authors that the rag pickers around Guwahati garbage dump who depend on the garbage for their livelihood, empty the bottles of chemicals and medicines by pouring the inside content at the same place. It is because the expired chemicals and medicine do not have a market value, unlike the glass or plastic bottles which can be recycled. Additionally, insecticide and pesticide bottles also end up in the same place which can prove to be neurotoxic or nephrotoxic, if consumed. The behavior of *L. dubius* shows that they have a tendency to drink water and wash their food before eating. If in case the water gets contaminated due to improper waste disposal or due to heap leaching, there is a chance that the species will consume the toxic compounds while washing its food. In one instance, a count of 28 individual *L. dubius* were found dead along the Deepor Beel wetland, adjacent to Guwahati garbage disposal site. Although the exact reason remains unknown, incidental poisoning is the most suitable reason.

Another cause of decline of Greater Adjutants is the lack of proper nesting sites. Greater Adjutants are usually observed nesting on Kadamba *Neolamarckia cadamba*, Blackboard tree *Alstonia scholaris*, and Silk Cotton *Bombax ceiba* trees. Due to development, unregulated agricultural practices, and promotion of cash crops, much of this vegetation has been cleared. Without the tall canopy trees, Greater Adjutants will not be able to nest and breed successfully. It will also be difficult for them to breed successfully if suitable foraging and nesting grounds are too far apart. Many wetlands, another important resource on which the Greater Adjutants depend for foraging are cleared due to developmental activities. All these reasons effect the life cycle of the bird species, putting them in a constant threat. The changing climate may impact the breeding mechanisms of Greater Adjutants, however no studies have yet been published on this species.

Future of Greater Adjutant

A few decades ago, the presence of Greater Adjutants near homes were considered a bad omen to a family. The bird, which was not considered beautiful unlike other birds due to its large bill, huge size and cluttery call, used to be a subject of revulsion. This

scavenger usually left dead or decayed animal materials in its nest, which people disliked and led to the destruction of the nests and poisoning of the birds. However, today in Assam, where almost two-thirds of the population of Greater Adjutants are found, the bird species has been widely accepted socially. This was possible through years of scientific study done by researchers on the bird which helped in breaking the taboo and find its acceptance. With enhanced scientific communication on the Brahmaputra floodplains during the present decade, Greater Adjutant issues were highlighted. Mass campaigns by a female led group 'Hargila Army' also played a significant role in generating awareness on Greater Adjutants (vernacularly called as Hargila in Assamese). Women involved here promote conservation of nests, in addition to finding socio-economic value by commercially promoting traditional handlooms with motifs of the bird as an aesthetic design. Further conservation methods need to be implemented to conserve the habitat of Greater Adjutants, not only in Assam but also abroad.

The colony in *Dadara* and *Pacharia*, is an ideal stronghold for nesting of the species, because of the availability of number of nearby wetlands and agricultural lands as well as the Guwahati city garbage dump. The species is mainly found feeding within 10 km radius of the nesting colonies; hence it is crucial that the area remains devoid of any anthropogenic disturbances. As it has been observed that *L. dubius* mostly use *N. cadamba* trees for nesting in the intensive study site, it will be ideal to plant this species in available places. *L. dubius* selects tall trees and broad canopy averaging 20 m, and 13 m, respectively. The selectivity of *N. cadamba* over other tall trees with horizontal branches could be because of the presence of dense foliage during the construction of nests. Thus, we would recommend to plant *N. cadamba* tree in areas where *L. dubius* nesting colonies were reported historically. Bamboo sticks and other shrubs used for fencing in agricultural lands of the study area are also used by *L. dubius* as nesting materials. Keeping such materials in the agricultural lands close to nesting colonies will make nest building more accessible for the Greater Adjutants.

The breeding season starts after monsoon, with the onset of dry season when there is an increase in prey density in drying out agricultural lands, pools, and wetlands in the Brahmaputra valley. Thus, it is important that Greater Adjutants forage without any anthropogenic impacts for a successful breeding season. In the post-breeding season, they move to various garbage dumps in cities and towns for feeding on rubbish, followed by fledglings. The non-breeding individuals mostly remain throughout the year in areas with small wetlands adjacent to waste disposal sites. Further, in Guwahati garbage disposal areas, where the highest density of the population has been recorded, utmost care must be taken by the authorities (Guwahati Municipal Corporation) to prevent hazardous wastes from mixing with discarded food items. A waste management process must be enforced in Guwahati city to reduce the health risk to Greater Adjutants and other avian scavengers. A regulated solid-waste management system following national and local level rules (e.g., Municipal Solid Wastes (Managing and Handling) Rules, 2000) will also prevent leaching of toxic compounds to the adjacent Ramsar site, the Deepor Beel, on which numerous lives thrive.

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Ecology and Conservation of African White-backed Vultures (*Gyps africanus*)

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Abstract

African white-backed vultures are a medium-sized vulture with characteristic long-neck and white patch of feathers along their lower back, which is revealed when they are in flight. White-backed vultures are obligate scavengers feeding in social groups across sub-Saharan Africa. Through their soaring flight and communal feeding, this species plays an important role in waste removal and disease control as well as facilitation of mammalian scavengers. As a slow reproducing, long-lived bird, they are particularly susceptible to decline. Anthropogenic threats, particularly poisoning of carrion, are leading to rapid loss of this important species across their range. Only through concerted efforts to prevent poisoning as well as long-term focus on bird-friendly approaches to new electrical infrastructure will this Critically Endangered species persist in the wild.

Physical description and identification

African white-backed vulture, *G. africanus* Salvadori, 1865, is an iconic species that we typically associate with African savanna plains, seen circling above on large broad wings or feeding and squabbling in large numbers at a carcass. It is a medium-sized vulture, smaller than the other *Gyps* species, Ruppell's, that it is sympatric with, averaging a height of 94 cm, wingspan of 2.2 m and weighing around 5.5 kg (Mundy et al., 1992) (Fig. 1). In adult birds, color is variable from brown to cream/off-white, becoming lighter over time as the bird ages. In contrast the wing and tail feathers are black, with a white back and rump, and a prominent white ruff at the base of the neck. Its long neck is covered in thin downy feathers, which darken over time, stained from their tendency to feed inside large carcasses. No clear sexual dimorphism exists in adults. Juvenile birds are brown with a streaked appearance on the belly, some white downy feathers on the chest, a very pale head, and a prominent buff ruff on the neck (Mundy et al., 1992). In air, adult birds are identifiable by their white underwing coverts (non-flight feathers), which contrast with black flight feathers, and the juveniles by a thin white crescent line along the leading edge of the coverts. By the time the bird reaches adulthood at 6 years, it has the diagnostic white back and white underwing coverts, hence its name (Mundy et al., 1992).



Fig. 1 Adult African white-backed vultures (*Gyps africanus*) wait patiently near a carcass in Masai Mara National Reserve, Kenya (photo credit: Corinne Kendall).

Biogeography

White-backed vultures are the most widespread and common vulture in Africa, distributed throughout sub-Saharan Africa. They occur from Senegal, Gambia and Mali in the west throughout the Sahel region to Ethiopia and Somalia in the east, through East Africa into Mozambique, Zimbabwe, Botswana, Namibia and South Africa in the south (2018). This species is found primarily in open wooded savanna to grassland plains from 0 to 3500 m a.s.l., particularly in drier *Acacia* habitats, where there are large aggregations of ungulates and greater wildlife densities than associated with the moister *miombo* (*Brachystegia* spp.) woodland/savannas. With a global population estimated at 270,000 individuals, both their overall numbers and range have contracted to varying degrees in different geographic regions, leading to their current listing on the IUCN Red List as Critically Endangered (2018).

Breeding behavior

White-backed vultures usually start breeding on reaching maturity at 6 years old and tend to breed for life, with both parents playing a significant role in the successful rearing and fledging of a chick (Mundy et al., 1992). A chick is raised every 1–2 years, and often the same nest is used across many years. White-backed vultures prefer to use tall trees, such as *Acacia* and *Ficus* species or palms such as *Hyphaene*, particularly along riparian habitats (Houston, 1976). They often form loose colonies of around 10 pairs, usually with one nest per tree, often with synchronous breeding (Mundy et al., 1992). Whilst non-territorial, the adults will defend the nest itself (Houston, 1976), a somewhat flimsy-looking stick nest of 65 cm diameter × 27 cm thick at the top of the canopy or in a fork just below it. Nests are generally located within protected areas, most likely due to the impact of human disturbance in non-protected areas, rather than direct habitat differences (Monadjem and Garcelon, 2005, Bamford et al., 2009).

One egg is laid and incubated approximately for 50 days by both parents. The start of the breeding season varies geographically with egg laying between March to May in East Africa, April to June in South Africa, November to January in West Africa and October to December in Ethiopia (Mundy et al., 1992) with hatching timed to coincide with the end of the rains when food availability is greater. Both adults brood and feed the chick until it is nearly adult size (4.7 kg) and close to fledging at 4–4.5 months. Breeding success i.e., a fledged chick per adult pair, is 55–60% (Mundy et al., 1992; Virani et al., 2010), although around 20% of the adult population may not breed in any given year. Post fledging dependency on parents for food provisioning may continue for up to another 5.5 months, and first yearlings have a 50% mortality rate as they struggle to compete with more experienced birds at a carcass (Mundy et al., 1992). This also coincides with entering the rainy season again where there is less food available, further increasing competition levels. If the bird survives its first year and reaches maturity, natural adult mortality is low at 5% and birds can live for at least 20 years, and often much longer (Mundy et al., 1992).

Foraging ecology and diet

White-backed vultures are adapted for soaring flight that allows them to forage across large landscapes searching for ephemeral and disparate food resources with minimal energetic cost (Pennycuik, 1972; Ruxton and Houston, 2004). They use rising air currents (thermals) to provide lift and thus minimize flapping flight. Thermals are caused by the sun heating the ground and the creation of a vortex of hot air rising. A vulture will circle upwards in the middle of a thermal gaining on average about 3 m in height per second, often reaching as much as 3000 m above ground (Mundy et al., 1992). A group of vultures circling upwards together is called a “kettle,” and they may often be seen flying in “stacks” (three or more birds flying in a column). Open, semi-arid country produces good thermals, whilst water absorbs much of the heat, explaining why vultures cannot cross large bodies of water. Flapping flight can only be sustained for a few minutes before the bird suffers extreme heat exhaustion. Being reliant on thermals to get off the ground has its disadvantages, and without optimal weather conditions, vultures can be grounded for hours to several days in the rainy season.

To further optimize use of even weak thermals, White-backed vultures’ wing shape is designed for high lift with large, broad wings compared to length (low aspect ratio and low wing loading capability) and the downward curved primary feathers are opened out like fingers (slotted tips), each functioning as an aerofoil, allowing smooth airflow over the wing, reducing drag, and increasing lift. The 10 primary feathers are black due to the presence of the pigment melanin, which serves to harden and increase durability of these flight feathers (Mundy et al., 1992). Vultures often glide between thermals at speeds of up to 100 kph and have been recorded at foraging speeds of around 63 kph in the Serengeti (Pennycuik, 1972). To increase speed, such as to land at a carcass, the birds will tuck their wings in reaching up to 120 kph, likened to “feathered bullets” (Mundy et al., 1992).

White-backed vultures are obligate scavengers, relying on large carrion, and are the most numerous vulture species at such a carcass. As gregarious feeders, several hundred birds could be observed at an elephant carcass (6 tons) or 150 at an impala carcass (around 60 kg). Specially adapted to feed on the soft internal organs, White-backed vultures’ long neck allows them maximal reach inside the carcass, the razor-sharp hooked bill facilitates rapid tearing, and their long serrated/grooved tongue enables efficient slurping up of the soft tissue. An individual can fill its crop with 1 kg of meat within 5 min, increasing their body weight by a remarkable 20% (Fig. 2). A group of White-backed vultures can finish an impala within 30 min or less if it is already opened up. A bird needs approximately 400 g per day, therefore if it successfully competes at a carcass, it does not need to feed daily. This is important



Fig. 2 African white-backed vultures (*Gyps africanus*) roosting in a tree after feeding. Note the engorged crop on the individual on the left which has recently fed (photo credit: Corinne Kendall).

with ephemeral and seasonally variable food sources, like the carrion on which they rely, as well as the reliance on good weather conditions to soar.

Whilst White-backed vultures are often cautious to land at a carcass without other conspecifics around, early arrivals to a carcass, such as Bateleur and Tawny eagles, can signal that there is no threat, such as the presence of a lion or hyena (Kendall, 2013; Kane et al., 2014). Birds will potentially spend hours perched in a tree nearby, until one individual initiates a frenzy of feeding. Intraspecific competition is very high at a carcass, with individuals jostling, pecking, kicking, hissing, and displaying with wings outstretched. Quite often, it is just a few individuals who leave with a full crop, and adults usually outcompete immature birds. Interspecific competition is lower at a carcass, as different species specialize on different parts of a carcass and prefer different sizes of carcasses (Kruuk, 1967). White-backed vultures specialize on soft tissues, particularly the organs, whereas Lappet-faced vultures and White-headed vultures feed on tendons, ligaments, and muscle and Hooded vultures (*Necrosyrtes monachus*) feed on small pieces of meat along the bones. White-backed vultures preferentially utilize large carcasses, like an elephant, whereas Lappet-faced vultures specialize on smaller carcasses which are easier to dominate. This resource partitioning helps to limit interspecific competition, but where it does occur, dominance is generally dictated by size (not weight). However, social foraging of White-backed vultures can help them to dominate when feeding in large groups (Kendall, 2013).

After feeding, birds will likely rest, potentially gathering at favored bathing locations along sandbanks of wide rivers, to spend time preening and maintaining their flight and tail feathers, using a combing action to “zip” up the barbules of each feather.

Threats to African white-backed vultures

African vultures are one of the fastest declining groups of birds and White-backed vultures are projected to decline by 90% over the next three generations (approximately 55 years), which has led to their current IUCN status as Critically Endangered (Ogada et al., 2016). The most significant threat to White-backed vultures is poisoning which has several different drivers. Unintentional poisoning of vultures, primarily with agricultural pesticides, is often motivated by human-wildlife conflict or pest removal. Pastoralists attempting to kill carnivores, particularly lions and hyenas, or those wishing to control feral dog populations may lace carcasses with toxic pesticides. While this behavior has had a substantial impact on carnivore populations, it has been devastating for vultures which can die in the hundreds at a single poisoning event. In addition, ivory poachers have begun poisoning vultures to avoid detection by rangers, who may be attracted to carcasses by circling and landing birds (Ogada et al., 2015). Poachers may also be motivated to kill vultures for trade in vulture body parts with significant markets known in west and southern Africa (Ogada and Buij, 2011).

White-backed vultures are particularly vulnerable to poisoning because of their wide ranges and social foraging behavior. Because White-backed vultures are obligate scavengers, relying on energetically efficient soaring flight to travel long distances (Penycuik, 1972; Ruxton and Houston, 2004), they extensively utilize both protected and unprotected areas bringing them into greater contact with potential poisoning events (Phipps et al., 2013). In addition to covering large areas, this species also aggregates

when feeding. White-backed vultures rely on aerial social networks to find carrion and preferentially feed in large groups (Houston, 1974a, 1974b; Kendall, 2013; Cortes-Avizanda et al., 2014). These activities make them susceptible to potential Allee effects such that they can't forage successfully if their populations are reduced to sufficiently low levels (Jackson et al., 2008). In addition, by foraging in large groups, poisoning events take a larger toll on this species than on other more solitary scavengers.

In addition to poisoning, White-backed vultures are threatened by habitat loss, declines in prey species, as well as collision with powerlines and windfarms, and electrocution at powerlines (Virani et al., 2011; Ogada et al., 2016). *Gyps* vultures are particularly susceptible to wind farms due to their visual acuity which is focused on peripheral vision rather than looking directly ahead of themselves (Martin et al., 2012). Combined with their soaring flight, these adaptations have made wind farms devastating for vultures in Europe. As wind farms and electrical power infrastructure expands across the African continent, this threat to White-backed vultures will continue to grow. The potential threat of lead poisoning from spent ammunition has also been recognized, particularly in southern Africa (Kenny et al., 2015; Naidoo et al., 2017). Lead toxicity is the primary threat to the California Condor but its effects on African vultures are not as well understood (Plaza and Lambertucci, 2019). Nonetheless evidence suggests that lead exposure is occurring and may be exacerbating declines.

Why we need vultures

As scavengers, vultures provide critical ecosystem services. Vultures play crucial roles in the environment by recycling nutrients, removing waste, facilitating other scavengers, and controlling diseases (Sekercioglu et al., 2004). African vultures are better at locating carcasses than mammalian scavengers and can consume 84% of available meat (Houston, 1979). While vultures may be common at predator kills, the majority of their diet comes from feeding on non-predator kills, particularly animals that have died of starvation, old age, or illness, where scavengers are able to consume the entire carcass. In the absence of vultures, carcass decomposition rates are nearly triple (Ogada et al., 2012). Vultures have highly acidic stomachs which allows them to consume rotting flesh and destroy microbial organisms (Houston and Cooper, 1975). While the epidemiological implications of vulture scavenging have rarely been studied in-depth, they are believed to play a role in eliminating disease agents and thus reducing disease spread.

White-backed vultures facilitate carcass discovery by mammalian scavengers. Vultures tend to arrive earlier at carcasses than mammals and serve as an important cue for jackals and hyenas. In particular, hyenas appear to preferentially follow White-backed vultures over other avian scavengers, possibly because they are more likely to feed on large carcasses (Kane and Kendall, 2017). However, mammalian scavenger numbers and time at the carcass is nearly three times greater in the absence of vultures, when competition is reduced (Ogada et al., 2012). As a result, local extirpation of vultures has the potential to lead to increased interaction amongst facultative mammalian scavengers with accompanying possibility of higher spread in diseases such as rabies and canine distemper. In India, dramatic declines in *Gyps* vultures, caused by veterinary use of diclofenac, led to a parallel increase in feral dog populations, with accompanying rabies outbreaks in dogs and human populations (Markandya et al., 2008). Overall, the loss of vultures in India was estimated to have cost nearly \$34 billion and possibly have led to an additional 50,000 human deaths due to rabies over a 14-year period.

The ecological significance of vultures in general, but particularly of highly social and abundant *Gyps* species, particularly African white-backed vultures, is evident and thus conservation of these species is imperative.

Conservation of white-backed vultures

Vulture conservation is closely linked to the protection of many other species. For instance, poisoning affects multiple species, including all African vultures, other avian scavengers such as Tawny Eagles and Bateleurs, and mammalian carnivores and scavengers like lions, hyenas, and jackals. Ivory poachers are decimating elephant populations but also poison vultures. Finally, vultures wide-ranging movements can be indicative of habitat connectivity, not only for vultures, but for other species, and the study of their movements can thus be informative for conservation efforts of other species. Efforts to conserve vultures thus have broad implications for wildlife conservation.

Successful conservation of White-backed vultures will rely on addressing the key threats to their survival, particularly poisoning. Several different approaches have been suggested to address poisoning, including more stringent regulations and bans on pesticides, raising awareness about the dangers of illegal poisoning to human health as well as wildlife, and addressing the threats that motivate and encourage poisoning such as elephant poaching, livestock loss to carnivores, and illegal wildlife trade (Botha et al., 2017). Efforts to address human-wildlife conflict such as improving bomas (i.e., corrals where livestock are kept overnight), novel predator deterrent techniques, and Lion Guardians (<http://lionguardians.org/>) schemes that empower community members to protect livestock, sometimes through greater knowledge about lion movement based on collared individuals, have proved effective in certain locations and should help to protect carnivores as well as scavengers. In addition, GSM-GPS or satellite tagged vultures can provide information about where poisoning is occurring, which can help enable rapid response to poisoning events. Faster response times along with appropriate training in what to do at a poisoning event (decontamination and disposal of poisoned meat, rehabilitation for poisoned wildlife, proper evidence collection) can help to reduce the number of individuals affected while also increasing chances of arresting perpetrators (Murn and Botha, 2017).

Illegal wildlife trade and habitat loss are substantial threats for biodiversity conservation as a whole and have significant impacts on vultures. Efforts to improve protected area management and reduce snaring and ivory poaching will be critical for African wildlife. In addition, addressing the trade in vulture body parts by understanding existing markets and perceptions while looking for appropriate alternatives will be crucial, particularly for heavily traded vulture species, such as Hooded vultures.

Powerline collision and electrocution and wind farm collisions are widespread problems for a variety of bird species, particularly raptors. As a result, significant efforts already exist to design raptor-friendly powerlines that reduce electrocutions and implement flapping or flashing bird deterrents to lessen collisions (Jenkins et al., 2010). These measures have not been widely adapted in the African context. However, a significant opportunity exists to utilize these techniques as new infrastructure is implemented. In general, methods to reduce collision and electrocution are more cost-effective when integrated with initial design as well as with careful environmental impact assessment to consider appropriate placement of new construction. As the power grid expands across the African continent, implementation of bird friendly infrastructure could reduce this threat but only with concerted effort at the national and international level. Similarly, the impact of wind farms on raptors can be reduced, principally by turning wind farms off when observers detect imperiled species, though other deterrent methods and design solutions are also being tested (Watson et al., 2018). However, the potential devastating effects of wind turbines remains and careful siting decisions and thoughtful protocols to reduce impact on wildlife will need to be taken as their construction grows in coming years.

White-backed vultures are a unique, fascinating scavenger species, which contribute important ecosystem services through their waste removal and disease control. Their conservation is challenged by widespread poisoning accompanied by their wide-ranging, social behaviors, which make them especially susceptible to this threat. Only through focused conservation efforts across their distribution will the species be protected for future generations.

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The Congo Peafowl *Afropavo congensis*, Endemic and Elusive Bird of the Democratic Republic of the Congo

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Glossary

Endemic Native to a particular country.

Galliformes Order of large ground-feeding birds that includes the chicken.

Iridescent Glittering with the colors of the rainbow.

Monogamous Having only one mate.

Ocellated With eye-shaped spot on its feathers.

Phasianidae Family of pheasant-like birds within the Galliformes.

Phylogeny The history of the evolution of a species or group.

Abstract

Among the endemic birds in the Democratic Republic Congo, the Congo Peafowl occupies an outstanding position, being the only phasianid in Africa. This large bird was described as late as 1936 from specimens that were originally thought to be Common Peafowl, a relative from Asia. Molecular research has indicated that the two species are each other closest relatives, but they differ quite a bit in functional morphology (colorful feathering in both sexes of the Congo Peafowl) and aspects of ecology (monogamy in Congo Peafowl). Congo Peafowl has a rather puzzling range, encompassing parts of the Congo equatorial forest; it is thought that it is limited by (or excluded from) the general area of flooded forest in the west, close to the Congo river and Ubangi river confluence, and by the mountains of the Albertine Rift in the east, but even then it seems to be absent from seemingly convenient intermediate forest areas. This may be due to local extirpation from human activity or from historical dispersion differences. Field work in Salonga National Park revealed that it lives in both secondary and primary forest habitat, perhaps using the secondary strips to connect with primary forest patches. Areas with good canopy cover, sufficient litter coverage of the soil and not too far from water (but not flooded) are preferred. Its food is rather unspecialized. Continuing survival of this emblematic bird will, to a limited extent, depend on successful breeding in captivity (which at present does not work well), but much more so on sufficient protection in the wild, where it is vulnerable because of hunting and habitat degradation.

Introduction

The DRC has the highest bird count for any African country: 1139 species (African Bird Club; <https://www.africanbirdclub.org/countries/Congo-%28Dem.-Republ.%29/introduction>; accessed 27 February 2021). Demey and Louette (2001) listed at the time already 1117 species, including 96 Palearctic migrants and 88 intra-African migrants. The remainder are considered resident. The central position of this large country in tropical Africa, where several vegetation belts meet—see Fig. 1—and the great altitudinal range are two reasons for this high number. Although some parts of the DRC have been relatively well-studied, many other parts

[†]Deceased.

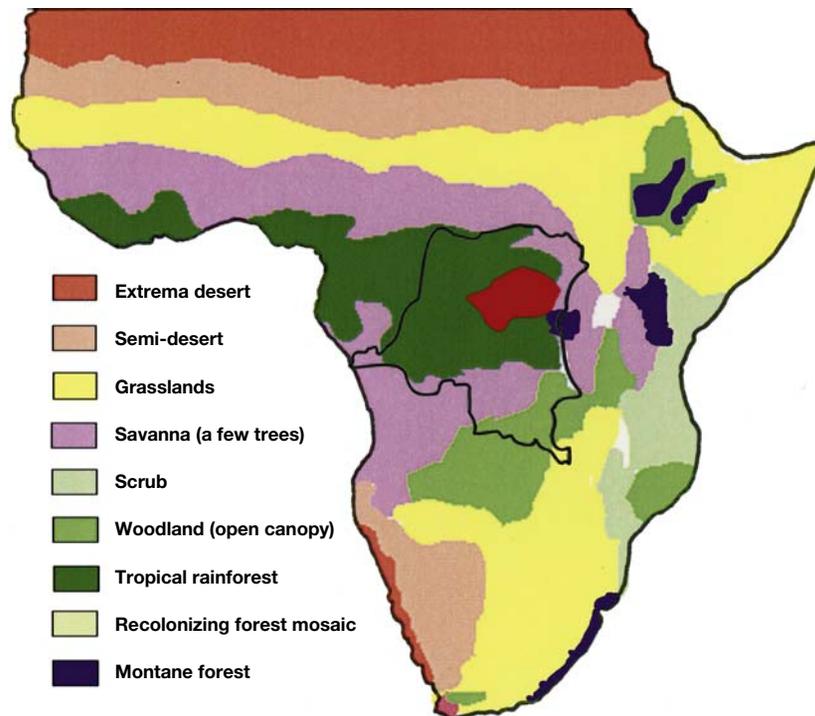


Fig. 1 World distribution of Congo Peafowl (in bright red) on map of potential vegetation belts in tropical Africa; black line delimits border of the DR Congo. Original map from: Adams JM (1997) *Global Land Environments Since the Last Interglacial*. Oak Ridge National Laboratory: Oak Ridge, TN. <http://www.esd.ornl.gov/ern/qen/nerc.html>. Redrawn by Alain Reygel.

have yet to be properly explored. The population size and the exact distribution of a good number of bird species are thus still imperfectly known. It is significant that some are known to science only from one or a few specimens, collected for museums long time ago and never (or only a few times) observed in life later. Famous examples are the Congo Bay Owl *Phodilus prigoginei* and Prigogine's Nightjar *Caprimulgus prigoginei*, both only represented by singletons collected in the east of the country, and three species from the southern part: Lippens's Ground Thrush *Zoothera lippensi*, Black-lored Waxbill *Estrilda nigriloris* and Upemba Weaver *Ploceus upembae*. The latter's relative, the Lufira Weaver *Ploceus ruweti* (a single specimen obtained in 1960) was rediscovered many years later, in 2009–10. In fact, 47 bird species of global conservation concern occur among which 15 are endemic to the DRC, and eight occur in only one other country. The fringes of the Congo River contain, apart from the migratory aberrant "swallow" African River Martin *Pseudochelidon eurystomina*, a few resident endemic birds like Congo Sunbird *Cinnyris congensis* and Bob-tailed Weaver *Brachycope anomala* (the latter occurs within the city limits of Kisangani. Okapi Forest Reserve has the near-only localities for Golden-naped Weaver *Ploceus aureonucha*. These species ranges are entirely within one of the two massive Endemic Bird Areas (EBAs, according to BirdLife, the International Union for the Conservation of Nature's body for birds, abbreviated IUCN): the "Eastern DRC lowlands." The second EBA, the "Albertine Rift Mountains" include famous specialties, such as the near-passerine African Green Broadbill *Pseudocalyptomena graueri* and the beautiful black-and-yellow Yellow-crested Helmet-Shrike *Prionops alberti*. One of the massifs of the chain, Itombwe, supports the highest number of endemic bird species, but it is unprotected; conservation initiatives are needed urgently, taking into account the altitudinal distribution of the endemic birds. These two EBAs constitute the Central Refugium which is one of Africa's major centers of endemism. A famous endemic for the DRC, the Congo Peafowl, occurs in a large area of undisturbed tropical forest in the middle of the Congo River basin (and thus in- and outside the EBA "Eastern DRC lowlands"); it is nowadays rare, because of poaching and habitat deterioration. It is assumed that the Congo Peafowl has a relatively small global population of between 2500 and 9999 mature individuals, with a decreasing trend over an estimated area of 700,000 km² (BirdLife).

Discovery

Congo Peafowl discovery was one of the most sensational ornithological events of the 20th century, partly because such a large bird had eluded discovery and partly because of its potential affinity with Asiatic species. In 1913, James Chapin attended a party in Avakubi, a village in the Ituri forest at 1° 20' N, 27° 34' E. The headgear made of feathers worn by one of the dancers attracted his attention and he was able to acquire one feather of a bird which he could not identify with any recorded species. On his return to the American Museum of Natural History, New York, Chapin compared this feather to likely candidates. It was red-brown in

color, marked with regular dark stripes and therefore presented a certain resemblance to secondary flight feathers of coucals (*Centropus*; non-parasitic cuckoos); but, on the other hand, by its robustness and by the curvature of its shaft, it rather resembled the feathers of Galliformes, although it was too big to come from the two existing equatorial forest representatives (guinea fowl and francolins) and its color was different. Chapin dismissed the possibility of a hybrid between a guinea fowl and a domestic hen. In the first volume of his book “The birds of the Belgian Congo” Chapin (1932-1954) did not allude to this feather. It was later that the mystery was resolved. In 1936, he went to the Museum of the Belgian Congo—now renamed AfricaMuseum—in Tervuren near Brussels, to study the ornithological collections for the preparation of the other volumes of his book.

In 1914 the Museum of the Belgian Congo had received a donation from the colony. This included stuffed birds, representing species native to Congo, but also domestic chickens, ducks, and two others defined by their label as “*Pavo cristatus*, young, imported” (= Common—Asiatic—Peafowl; a species domesticated since times immemorial). So, in 1936 Chapin noticed these two stuffed birds, perched on top of a cabinet in the basement of the building. Both had a crest of feathers. The first had a blackish color with purple and green reflections, while the second was of a brownish color and its wing feathers were streaked with greenish black, immediately recalling to Chapin his unidentified secondary feather from 1913! It was clear that the mention on the label “*Pavo cristatus*, young, imported” was wrong, since the first bird had powerful spurs and therefore had to be an adult male. When donated to the museum their resemblance with the Common Peafowl certainly had led to suppose that they were imported and because of their apparent lack of scientific value they ended up in the basement. Chapin took one of the flight feathers from the female specimen to the American Museum of Natural History. The comparison left no doubt, the two feathers were identical: it was the same species, which he described as new to science soon afterwards (Chapin, 1936).

Over the years, although many residents of the then Belgian Congo came forward to announce their acquaintance with this bird (Chapin, 1932-1954), not much more was learned about its life in nature. Captive birds were taken to the New York Zoological Society as early as 1949 and it became also well known to zoo visitors in Belgium, because, having acquired live birds in 1959, Antwerp Zoo showed and bred the species; this zoo still houses the European Endangered Species Program (affiliated to the European Association of Zoos and Aquariums), which oversees a breeding program for this endangered species. But captive breeding in European zoos proved difficult after some initial successes (Van Bemmelen, 1961). Many photos of the bird in captivity were taken (Fig. 2 shows captive birds).

Notwithstanding the fact that locals know the bird, it has remained an elusive and rarely seen species in nature by ornithologists. It was filmed in the wild for the first time as late as 1993 by wildlife film-maker Alan Root. The Macaulay Library, Cornell University, which houses an important bird photo and video collection, presents only one photo (taken by a camera trap) (September 2020)—Fig. 3.

Description

On Figs. 2 and 3 the bird’s characteristics are seen.

Adult male: head covered with short black downy feathers; crown surmounted by a tuft of spiky white feathers about 90 mm long. Throat sparingly feathered black; base of the neck and chest black with iridescent green and purple. Rest of dorsal side dark metallic green. Black tail, shining purple-blue and green. Ventral side black with greenish flashes. Wings brown-black, most of the inner part of the secondaries green, some shiny purple present on wing coverts. Soft parts: blue-gray beak; brown eye; bare skin between ear and eye blue; throat skin red; blue-gray legs; whitish claws.



Fig. 2 Male and female Congo Peafowl. Photo: Emile Mulotwa.



Fig. 3 Two males and one female Congo Peafowl. Permission to obtain from: <https://search.macaulaylibrary.org/catalog?taxonCode=conpea1andq=Congo%20Peacock%20-%20Afropavo%20congensis>, Photo taken by camera-trap.

Adult female: shorter tuft and brown crown. Dense red-brown head, chin brown-white. Dorsal side iridescent metallic green. Chestnut tail, barred and dotted with black with broad green tips. Neck, chest and flanks russet, spotted and barred with brown; rest of the ventral side blackish. Wings reddish, barred and dotted with black, more distinctly on secondaries than on primaries.

Immatures have the upper part of body without luster, back brown, rest of feathers with narrow blue-violet borders. Black front without luster; white plumes on crown. Sexual feather dimorphism is apparent at 2 months. Adult plumage is presumably acquired in second year.

The following measurements were taken at Antwerp Zoo.

Total length: Male 64–70 cm; Female 60–63 cm.

Weight: Male 1300–1500 g; Female 1100–1200 g.

Length of tail: Male 23–26 cm; Female 19,5–22,5 cm.

Phylogeny

Although some early authors suggested a possible phylogenetic relationship with guinea fowls (a group restricted in distribution to Africa), [Kimball et al. \(1997\)](#) proved the proximity between the Common Peafowl and the Congo Peafowl. Still, this study stresses rather important differences concerning the morphological characteristics, lack of elaborate ornamentation, and monogamous mating system in *Afropavo* which differentiates it from *Pavo*. Also remarkable is the restricted distribution of *Afropavo*, far removed from the Asian distribution of all other pheasant (family Phasianidae in the Galliformes) species. In fact, the sexual dimorphism, combined with an elaborate female plumage is unique. The dorsal feathers of both sexes are equally iridescent. The upperparts and tail lack the ocellated feathers (present in the Common Peafowl). They obtained complete cytochrome band partial D-loop sequences from Congo Peafowl and compared with Common Peafowl, guinea fowl species, francolin species, and other galliform taxa. Results strongly demonstrate a close relationship between *Afropavo* and *Pavo* and reject alternative phylogenetic hypotheses. Molecular studies, the most recent one available is [Wang et al. \(2013\)](#), strongly support the relationship *Afropavo/Pavo* and this study places the “peafowl clade” as “sister” to all other Phasianidae.

Distribution

The Congo Peafowl is present on both banks of the Congo River ([Fig. 4](#)). [Verheyen \(1962\)](#) suggested it is limited by the very humid soils in the west of the Congo forest block near the Congo and Ubangi rivers confluence, where there is much flooded (swamp) forest, and by high altitude in the east. But why is it seemingly absent from parts of the right bank of the Congo River where the forest is “dry,” as in the bird’s actual range? Possibly this species became trapped in pockets of forest on both banks of the Congo and Aruwimi rivers during a dry climatological period, before spreading out and living now on different banks [Louette \(1992\)](#). There is much reason to believe that in relatively recent times continuous forest was lacking in what is now the western part of the DRC (see especially [Maley et al. \(2018\)](#) on forest contractions in the past in this general area). We can postulate that forest cover fluctuated throughout the history of the Congo Basin due to climatic variability, reducing speciation and increasing extinction, while immigration was limited due to the barrier effect of the Congo River.

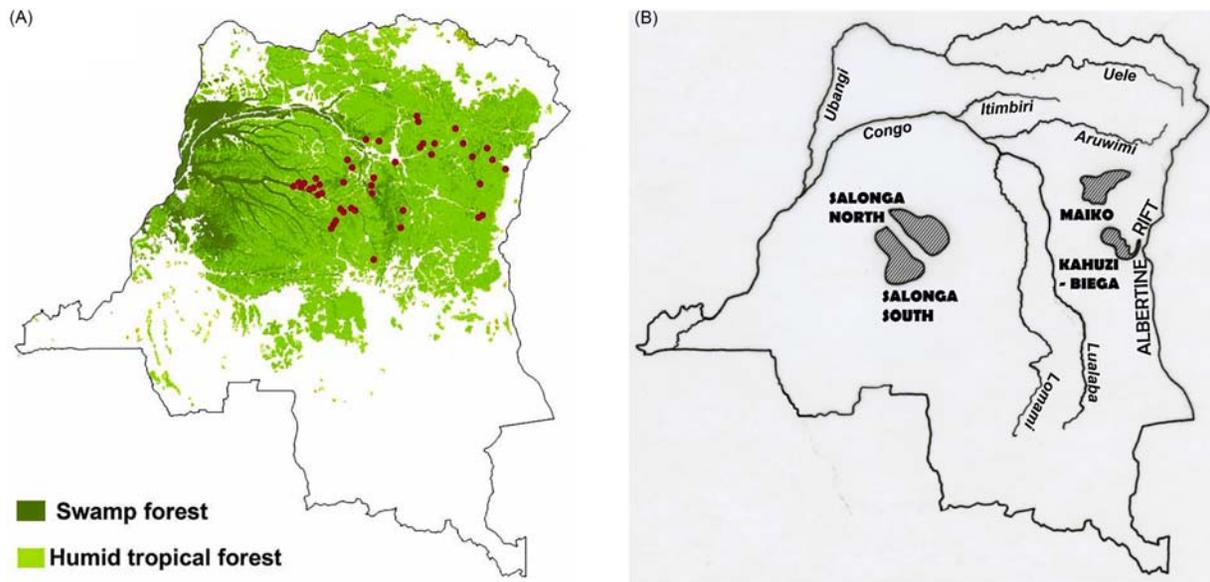


Fig. 4 (A) Localities where Congo Peafowl occurred historically and swamp forest and humid tropical forest vegetation belts in the DR Congo. (B) DR Congo: Position of important rivers, mountain range and National Parks. (A): Original map from: FACET—Forêts d’Afrique Centrale Evaluées par Télédétection (2010) *South Dakota State University & University of Maryland* (eds.). Redrawn by Alain Reygel. (B) Drawn by Alain Reygel.

All this pertains to the question “what in historical times, before man opened up the primary forest?” Attempts to model the original Congo Peafowl distribution, based on actual vegetation and climatological data did not yet give conclusive results. Indeed, modeling is limited by the quality of information available: most biodiversity data are incomplete and possibly characterized by biased sampling. Even though the diversity within the Congolian lowland rainforests remains to be fully mapped, the patterns are unlikely to be caused by undersampling alone. We do have a reasonable knowledge of its 20th century occurrences. The reason for its localized occurrence may well be explained by local extirpation.

Stidham (2008) described a fossil bone of Middle Stone Age, discovered at Plovers Lake Cave, South Africa, as belonging to Congo Peafowl. Because this species is now restricted to rainforests in the Congo Basin, this suggested that the species has experienced considerable geographic expansion a few tens of thousands of years ago. He thus concluded that the fossil indicates forested habitat in the vicinity of Plovers Lake Cave during the Pleistocene. But Manegold and Louchart (2009) refuted the identification of this fossil bone, and so also the hypothesis of forested areas, the typical habitat of the species, at this locality in southern Africa.

Biology

Congo Peafowl occurs in many different forest types but is often associated with slopes between watersheds with shallow soils supporting dry forest with an open understory. Its irregular distribution may correspond in part to the limited availability of this habitat type (Hart and Upoki, 1997). The species is not restricted solely to primary forest, the results show that old secondary forest adjacent to primary forest is used, at least for foraging (Mulotwa et al., 2010).

It does not appear to have a specialized diet and has been recorded eating fruit from common tree species throughout the region as well as insects and other invertebrates.

The breeding season may depend on local rainfall conditions. The birds are monogamous. In captivity they showed a most interesting sexual display. Both cock and hen bowed their head deeply, neck, back and spread-out tail at an angle of 45 degrees (Van Bemmelen, 1961). The nest is made on a horizontal tree stem, a few meters above the ground, eggs number 2–4 and the chicks roost on low branches. The male guards the nest and defends the brood (this is not the case in *Pavo*). Both parents are in continuous “twitter” contact with the chicks.

Field study

When the approximate range of a species is known, density becomes the parameter to extrapolate the population size. This scientific data are essential to specify its category of vulnerability and helps guide conservation strategies. The IUCN recommends obtaining such field data in the DRC for an accurate assessment. The systematic scanning of the environment is unfortunately not feasible for the evaluation of the density of this discreet and shy species which would escape or hide at the slightest noise, thus making it difficult or even impossible to detect and count individuals; therefore we have to make do with random checks.

Some historical work yielding incomplete results has been carried out. Between 1993 and 1995 the occurrence and status were assessed at sites in the eastern DRC, based on interviews with local hunters and forest surveys (Hart and Upoki, 1997). The survey region covered approximately 125,000 km² and was bounded by the Lomami River to the west, the Albertine Rift highlands to the east, the Aruwimi River to the north and Kahuzi Biega Park to the south (see Fig. 4). Congo Peafowl had been extirpated or were only doubtfully present at 16 of 65 sites where survey coverage was adequate and where the species was reported to have occurred in the past. Occurrence of the species was confirmed or probable at the remaining 49 sites. It was reported as locally common (> five reported encounters since 1990) at only 12 sites and was considered seriously threatened at 19 of the 65 sites. Fortunately, habitat loss was not extensive in Maiko National Park where the species appeared to be locally common in these survey years.

Salonga National Park (SNP; 1° 00'—3° 20' S; 20° 00'—22° 30' E) is the largest African rain forest reserve, entirely located in the center of the bird's range in the central Congo River basin (Fig. 4); it was created in 1970 to protect flagship endemic species such as the Congo Peafowl and the Bonobo *Pan paniscus*. It was inscribed in 1984 by IUCN. The conservation outlook for this site has been assessed as "critical" in the latest assessment cycle due to heavy losses of emblematic species to large-scale poaching for ivory and bushmeat over the last decades. Local people are living within SNP and draw most of their primary needs from forest products. They practice activities such as picking, gathering, collecting honey, handicrafts, traditional medicine and collecting firewood, as well as taking game. Fortunately, massive intrusion is still limited, SNP lying in an isolated region accessed primarily by water or air. In their early zoological exploration of SNP, Dupain and Van Krunkelsven (1996) found the Congo Peafowl. Emile Mulotha started to work on this species in SNP for his doctoral thesis. His fieldwork was carried out between June 2004 and November 2005. But Emile died sadly in a plane accident in 2011.

The estimated total area of the park is about 36,560 km², in two blocks, separated by a gap about 40–45 km wide (Fig. 4). The northern block is c. 17,000 km², and the southern block is c. 19,000 km². Altitude varies between 350 m and 700 m, rising gradually from west to east. The study area was in the southern block at an altitude of c. 360 m above sea level. The study plot comprised two contiguous parcels of forest, 2 km² of undisturbed primary forest (UPF) and 2 km² of old-growth secondary forest (OSF; c. 34 years' regeneration). Six parallel transects of 4 km in length and 200 m apart were established across the boundary between the two forest types, such that half the length of each transect fell within UPF and half within OSF. At intervals of 200 m along each transect, a numbered stick was planted as a signpost, thus creating a grid of 100 squares of 200 × 200 m, with 50 squares each in UPF and OSF. To generate Congo Peafowl sightings within the grid, two transect lines were selected randomly each month, and walked with a velocity of approximately 1 km/h. The distance to every Congo Peafowl seen along the transect line was noted. Any droppings and feathers seen during the transect walks were collected, and their locations noted. In total, 140 km of transect was walked in each habitat type. To supplement the transect data, some grid squares were chosen at random each month and searched thoroughly for droppings and feathers (resulting in data for 27 squares in UPF and 35 in OSF). The observer was highly experienced in identifying Congo Peafowl droppings and feathers in the field and took care to avoid confusion with those of other Galliformes that also occur in SNP (in particular Crested Guineafowl *Guttera pucherani*).

In a 10 × 10 m quadrat around the location of each individual bird sighted or droppings/feathers collected, EM recorded forest type, litter cover, canopy cover, forest understory (open or closed), distance to the nearest watercourse, height and diameter at breast height for the two biggest trees and the species richness of dominant plants. The variables were chosen as they are seasonally stable, easy to measure, and representative of the habitat characteristics that describe the immediate environment of a bird's location. Fecal analysis involving the identification of fragments surviving digestion was used to determine food items eaten throughout the year and across microhabitats in each forest type.

EM detected Congo Peafowl, either by sighting a bird, or by collecting feathers or droppings on 256 occasions, 79 in UPF and 177 in OSF. Forest with an open understory generated 208 of the 256 detections, while the remaining 48 were in forest with a closed understory. Congo Peafowl were sighted on 31 occasions, all of which were during transect surveys. This equated to one sighting per 9.03 km of transect walked, a low return on effort for the transect surveys. The species lives in groups whose size varies from 1 to 6 individuals. The density of Congo Peafowl in secondary forest (2.4 and 2.79 individuals per km²) is higher than in primary forest (1.14 and 1.43 individuals per km²; this appears low compared to the average density of other Galliformes).

This species has been reported to occur only in primary forest in the past, although Hart and Upoki (1997) related several accounts of using secondary forest by their informants. Our data show that use of regenerating forest was relatively intense, although it must be noted that the secondary forest investigated has been undisturbed for more than 30 years and is in close proximity to primary forest. The intense use of regenerating forest could be associated with the rich food source from the abundant fruiting of secondary forest plants. Leaf litter was thicker in OSF than in UPF, which could also play an important role in attracting birds to OSF. Leaf litter invertebrates comprise the majority of animal items in the diet.

In this study, detections of Congo Peafowl or its signs occurred mainly at locations less than 3 km from a watercourse, although detections were never made in swampy areas. This corresponds with statements in the literature that the species occurs in reasonable proximity to a water source but avoids swamp forest or places likely to flood.

Congo Peafowl were more common (easier to detect?) in forests with open understory and a dense canopy. Some factors seemingly favor the choice of degraded microhabitat and open undergrowth. These tend to be present close to a stream, with good litter cover (containing an abundance and diversity of invertebrates); and a sufficiently closed canopy layer can help as protection against predators.

Analysis of droppings permitted identification of 14 items of animal origin and 11 of plant origin. This demonstrates that the species has a broad unspecialized omnivorous diet. A preliminary comparative analysis of the droppings of Congo Peafowl and

Crested Guineafowl shows that the spectrum of the diet of Congo Peafowl is broader. Food common to both species sharing the same microhabitats at SNP amounts in this study only to four animal and two vegetable categories. Therefore, food competition between the two species seems to be limited.

It will be important to establish in future studies whether the birds are breeding in secondary forest, or whether undisturbed forest is acting as a daily source for the birds seen in the regenerating forest. One hypothesis is that patches of secondary or regenerating forest, by connecting fragments of primary forest, might allow easy daily movements between them.

Conservation

According to the IUCN RED List, the Congo Peafowl deserves the qualification “Vulnerable.” Threats are multiple: destruction of forest for logging, agriculture (shifting cultivation), aquaculture, energy production and mining, leading to habitat loss. Human intrusions and disturbance are frequent; war, civil unrest and military exercises also count. But, no doubt, the major threat throughout the region is captures in snares set for small game, especially mammals, but these snares are taking this bird as well.

Of utmost importance for in situ conservation is better knowledge of a species distribution. For the Congo Peafowl we can reasonably say that this is rather well-known. Further assessments of its habitat requirements is needed. IUCN suggests research to assess the socio-economic importance of bush meat and to evaluate the potential for sustainable use and for livelihood alternatives. This includes continuing education campaigns designed to mitigate bush meat hunting.

In the past, ex situ conservation was considered a promising safeguard, when the species started to breed at Antwerp Zoo. Sadly, breeding success in captivity has been very low and in some years the population declined. It was hoped to reduce this decline by introducing as many available hens as possible to a few breeding locations, but efforts have been limited by difficulties such as the species’ susceptibility to disease, which would seemingly, to the contrary, argue for spreading the breeding stock. There are plans for captive breeding within SNP, in the natural range of the species (Collar and Butchart, 2014). But, because of this difficulty with the captive population, in situ conservation is more important.

The successful conservation greatly depends on maintaining sufficiently dense populations in protected areas, where there is a possibility that hunting can be limited or banned. Currently, probably important populations exist in the Maiko, Kahuzi-Biega and Salonga National Parks, and potential exists there for long-term conservation. A seemingly moderate population may also occur in the Okapi Wildlife Reserve National Park (Hart and Upoki, 1997). It has not been observed recently in or near Yangambi, a well-studied field station of the University of Kisangani and we ignore the situation in the northern and in the southern parts of the species’ range. It goes without saying that nature reserves and national parks where the species occurs would need much more capacity in the number of staff, in order to allow surveys to be carried out.

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Further Reading

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