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The World's Most Imperiled Raptors Present Substantial Conservation Challenges

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ABSTRACT.—Potential extinction of raptor species is especially important given their outsized roles in ecosystems and human cultures. We examined Red List data for raptor species listed as critically endangered by the International Union for the Conservation of Nature. Our goal was to highlight the plight of these critically endangered raptor species while identifying the reasons for their imperiled status, the most important countries for their conservation, and the actions needed for their persistence. We categorized the 17 critically endangered raptor species into two groups—Accipitrid vultures and species with small populations. Accipitrid vultures had relatively large populations and ranges, and were listed under Criterion A due to precipitous population declines. The threat listed for the most Accipitrid vultures was "pollution," reflecting poisoning as the principal cause of declines. Conversely, the small population species were listed under Criteria C and D and were most threatened by "agriculture and aquaculture." Countries in Africa and south Asia were hotspots of critically endangered raptors. The conservation action listed for the most species was "education and awareness" followed by "land protection" and "law and policy." The most-listed monitoring category was "population trends." The Multi-species Action Plan to Conserve African-Eurasian Vultures should be implemented to prevent extinction of Accipitrid vultures. Conversely, species with small populations are generally isolated and must be managed individually. Conservation of the world's most imperiled raptor species is an important facet of assuaging the sixth mass extinction.

KEY WORDS: *bird of prey*; *critically endangered*; *extinction*; *island species*; *Raptors MOU*; *Red List*; *vulture.*

LAS AVES RAPACES MÁS AMENAZADAS DEL MUNDO PRESENTAN IMPORTANTES DESAFÍOS DE CONSERVACIÓN

RESUMEN.—La extinción potencial de las especies de rapaces es especialmente importante debido a su papel principal en los ecosistemas y las culturas humanas. Examinamos los datos de la Lista Roja de especies de rapaces catalogadas en peligro crítico por la Unión Internacional para la Conservación de la Naturaleza. Nuestro objetivo fue resaltar la difícil situación de estas especies de rapaces en peligro crítico al tiempo que identificamos las razones de su estado de amenaza, los países más importantes para su conservación y las acciones necesarias para su persistencia. Clasificamos las 17 especies de rapaces en peligro crítico de extinción en dos grupos: buitres accipítridos y especies con poblaciones pequeñas. Los buitres accipítridos tuvieron poblaciones y áreas de distribución relativamente grandes, y se incluyeron en el Criterio A debido a las rápidas disminuciones poblacionales. La amenaza listada para la mayoría de los buitres accipítridos fue la "contaminación", lo que refleja el envenenamiento como la causa principal de las disminuciones. Por el contrario, las especies con poblaciones pequeñas se incluyeron en los Criterios C y D y estuvieron más amenazadas por "la agricultura y la acuicultura". Los países de África y el sur de Asia fueron puntos calientes

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de rapaces en peligro crítico. La acción de conservación enumerada para la mayoría de las especies fue “educación y concienciación”, seguida de “protección de la tierra” y “leyes y políticas”. La categoría de seguimiento más mencionada fue “tendencias poblacionales”. El Plan de Acción Multi-específico para la Conservación de los Buitres de África y Eurasia debería implementarse para evitar la extinción de los buitres accipítridos. Por el contrario, las especies con poblaciones pequeñas generalmente están aisladas y deben manejarse individualmente. La conservación de las especies de rapaces más amenazadas del mundo es una faceta importante para aliviar la sexta extinción masiva.

[Traducción del equipo editorial]

INTRODUCTION

The current rate of extinction rivals those of other mass extinction events (Ceballos et al. 2010, 2015, 2017). Over the past 500 yr, more birds are known to have gone extinct (140 species) than any other group of vertebrates (Ceballos et al. 2015, McCallum 2015). Thus, the sixth mass extinction (Ceballos et al. 2010, 2015, 2017) is especially salient for bird conservationists.

The loss of such biodiversity will likely have major consequences for human and ecosystem health (Dirzo et al. 2014), because some taxa have outsized ecosystem functions. For example, abundance and diversity of raptors (*sensu* McClure et al. 2019) is associated with increased biodiversity (Sergio et al. 2005, 2006). Raptors are often used as indicators of environmental health (Sergio et al. 2008), and provide cultural and ecosystem services (Markandya et al. 2008, Donázar et al. 2016, O’Bryan et al. 2018, Grilli et al. 2019, Aguilera-Alcalá et al. 2020).

Raptors are also of great conservation concern: 18% of raptor species are threatened with extinction and over half are experiencing global population declines (McClure et al. 2018). Indeed, 38% of raptor species that are listed as least concern by the International Union for the Conservation of Nature (IUCN) are in decline (BirdLife International 2021). This dire situation has rendered raptors as more threatened and declining faster than most other groups of birds (McClure and Rolek 2020). In the midst of these population losses, many raptors are also understudied, with 10 of 559 (2%) raptor species receiving the bulk of the research attention and one-fifth remaining essentially unexamined (Buechley et al. 2019).

Species listed as critically endangered by the IUCN are at the highest risk of extinction in the wild. Our goal is to highlight the plight of these critically endangered raptor species while identifying the reasons for their imperiled status, the most important countries for their conservation, and the actions needed for their persistence. Our results should therefore inform immediate efforts to prevent raptor extinctions.

METHODS

Birdlife International undertakes Red List assessments of the world’s bird species as the Red List authority for birds. For information regarding the methodology of these Red List assessments, see documentation from the IUCN Standards and Petitions Subcommittee (2019). We first accessed and analyzed Birdlife International’s database of these assessments (datazone.birdlife.org; BirdLife International 2021). We then examined data for species within the orders Accipitriformes, Cariamiformes, Cathartiformes, Falconiformes, and Strigiformes (i.e., raptors; McClure et al. 2019) that were listed as critically endangered.

For most species, the data we recorded from Red List assessments include estimates of the number of mature individuals within the population, extent of occurrence (EOO), and the population trend over either the past three generations or 10 yr, whichever is longer. These three generations could be observed in the past, projected into the future, or be a combination of both. Population trends can also be suspected, inferred, or estimated. Birdlife International (2021) also reports the estimated quality of these estimates as either “good,” “medium,” or “poor.” We noted the countries in which each species was purported to occur, considering species as present in countries where they were extant and non-vagrant.

We also recorded the threats listed per species. Threats were listed following the definitions of Salafsky et al. (2008). Threat categories included “agriculture and aquaculture” (hereafter, agriculture); “biological resource use,” which includes hunting and collecting, belief-based use, and logging; “natural system modifications,” which include fire management, dam construction, and other ecosystem modifications; “pollution,” which includes poisoning via pesticides and veterinary drugs such as diclofenac (Oaks et al. 2004); “invasive and

Table 1. The common and scientific names of the 17 critically endangered raptor species as well as their listing criteria on the International Union for the Conservation of Nature's Red List (BirdLife International 2021).

Common Name	Scientific Name	Criteria
Annobon Scops-Owl	*Otus feae*	B1ab(ii,iii,v); C2a(ii)
California Condor	*Gymnogyps californianus*	C2a(i); D
Cuban Kite	*Chondrohierax wilsonii*	C2a(ii)
Flores Hawk-Eagle	*Nisaetus floris*	C2a(ii)
Hooded Vulture	*Necrosyrtes monachus*	A2acd+3cd+4acd
Indian Vulture	*Gyps indicus*	A2bce+4bce
Madagascar Fish-Eagle	*Haliaeetus vociferoides*	C2a(ii)
Pernambuco Pygmy-Owl	*Glaucidium mooreorum*	B1ab(ii,iii,iv,v); C2a(i,ii); D
Philippine Eagle	*Pithecophaga jefferyi*	A2cd; C2a(ii)
Red-headed Vulture	*Sarcogyps calvus*	A2abce+3bce+4abce
Ridgway's Hawk	*Buteo ridgwayi*	C2a(i)
Ruppell's Vulture	*Gyps rueppelli*	A2abcd+3bcd
Siau Scops-Owl	*Otus siaoensis*	D
Slender-billed Vulture	*Gyps tenuirostris*	A2ce+4ce
White-backed Vulture	*Gyps africanus*	A2bcd+3bcd+4bcd
White-headed Vulture	*Trigonoceps occipitalis*	A2bcd+3bcd
White-rumped Vulture	*Gyps bengalensis*	A2bce+4bce

other problematic species and genes" (hereafter, problematic species); and finally "transportation and service corridors" (hereafter, service corridors), which include roads and powerlines.

We further recorded the conservation actions needed per species. Again, these actions followed the definitions of Salafsky et al. (2008). Action categories included "education and awareness"; "land/water management" (hereafter, land management); "land/water protection" (hereafter, land protection); "law and policy"; "livelihood, economic and other incentives" (hereafter, economic incentives); and finally "species management," which includes *ex situ* conservation and reintroductions among other actions directly focused on the species of concern.

We also recorded from Red List assessments the research needs per species. These research needs are divided into two main categories, each containing subcategories. The first category is "research," which contains subcategories: "actions"; "harvest, use, and livelihoods"; "life history and ecology"; "population size, distribution, and trends" (hereafter, populations); "taxonomy"; and "threats." The second category is "monitoring," which contains subcategories: "habitat trends"; and "population trends." We calculated the number of species for which each threat, action, and research category was listed and divided the species into two groups based on clear differences in listing criteria: (1) Accipitrid vultures (i.e., vultures in the family Accipitridae) and (2) other species, which we call "small population species."

RESULTS

There were 17 species of critically endangered raptors as of 2022 (Table 1). Nine of these species—all of them Accipitrid vultures, except the Philippine Eagle (*Pithecophaga jefferyi*)—were listed under Criterion A (population size reduction). Eight species were listed under Criterion C (small population size and decline), three species were listed under Criterion D (very small or restricted population), and two species were listed under Criterion B (geographic range). Note that species can be listed under multiple criteria (Table 1).

The species with the lowest number of mature individuals (ranging from 0 to 49) was the Pernambuco Pygmy-Owl (*Glaucidium mooreorum*; Table 1) and the species with the greatest number of mature individuals (30,000) was the Indian Vulture (*Gyps indicus*; Fig. 1). The six species with the greatest numbers of mature individuals were all Accipitrid vultures (Fig. 1). Seven species had poor quality estimates of the number of mature individuals, seven had medium quality estimates, and only the California Condor (*Gymnogyps californianus*) had a good quality estimate of the number of mature individuals. Neither the White-backed Vulture (*Gyps africanus*) nor Hooded Vulture (*Necrosyrtes monachus*) had any estimate of mature individuals (Fig. 1).

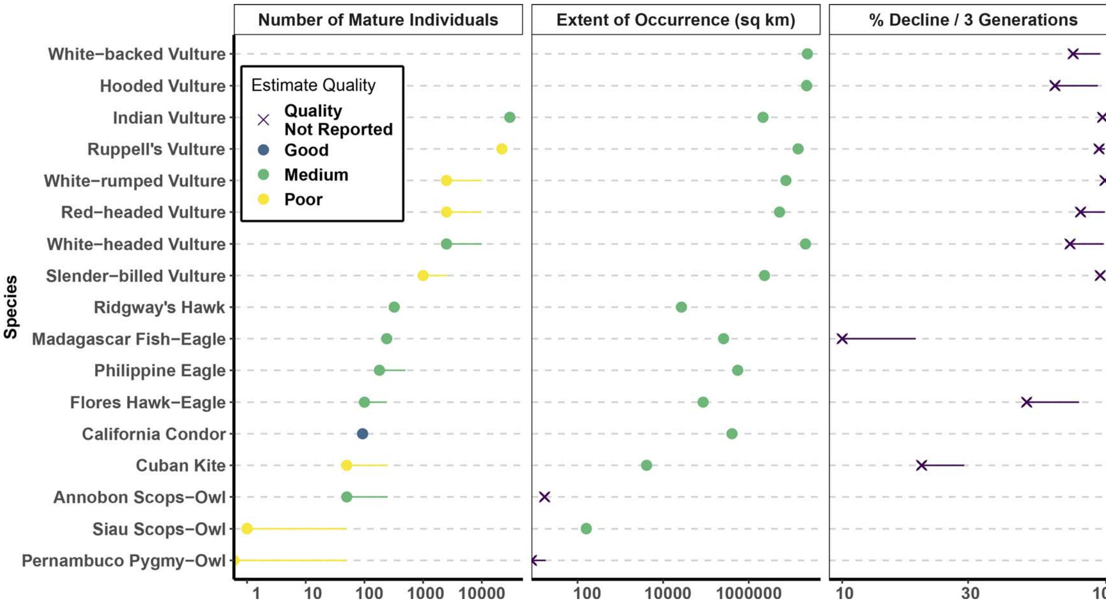

Figure 1. The number of mature individuals, extent of occurrence, and percent decline over three generations for the 17 critically endangered raptor species. Missing points indicate that no estimate was available. Points indicate minimum values and lines indicate maxima.

Regarding distributional range size (i.e., extent of occurrence), the species with the smallest range was the Pernambuco Pygmy-Owl with an extent of occurrence from 0 to 18 km^2 (Fig. 1). The largest range size was the White-backed Vulture, which had an extent of occurrence of 23,400,000 km^2 (Fig. 1). The eight species with the largest extents of occurrence were all Accipitrid vultures (Fig. 1).

The species declining at the fastest rate over three generations (99%) was the White-rumped Vulture (*Gyps bengalensis*), and the species declining the least was the Madagascar Fish-Eagle (*Haliaeetus vociferoides*; 10%–19%). The eight species declining the fastest were all Accipitrid vultures (Fig. 1). There were no estimates of population trend for Ridgway's Hawk (*Buteo ridgwayi*), Philippine Eagle, California Condor, Annobon Scops-Owl (*Otus feae*), Siau Scops-Owl (*Otus siaoensis*), or Pernambuco Pygmy-Owl. This lack of population trends is partly owing to increasing (i.e., Ridgway's Hawk and California Condor) or stable (Siau Scops-Owl) species not having estimates.

The countries harboring the most critically endangered raptor species (four) were India and several countries across Africa (Fig. 2). Overall, southeast Asia and Africa were hotspots of critically endangered raptor species, whereas Europe and Australia harbored no critically endangered raptors (Fig. 2). North and South America each harbored one critically endangered raptor species, and the Caribbean harbored two. Pacific Islands (i.e., Indonesia and the Philippines) harbored three critically endangered raptor species (Fig. 2).

The most-listed threat to Accipitrid vultures was pollution, followed by biological resource use, whereas the most-listed threat to small population species was agriculture (Fig. 3). The most-listed action for both Accipitrid vultures and small population species was education and awareness, followed by land management, and law and policy (Fig. 3). The research category listed for the most species was populations, and the most-listed monitoring category was population trends (Fig. 3).

DISCUSSION

Our results highlight daunting challenges for conservationists attempting to prevent raptor extinctions. There are essentially two groups of critically endangered raptors that simultaneously confront conservationists with the declining and small population paradigms (Caughley 1994). These two groups consist of Accipitrid vultures, which are listed due to drastic population declines (Criterion A); and the rest of the critically endangered raptor

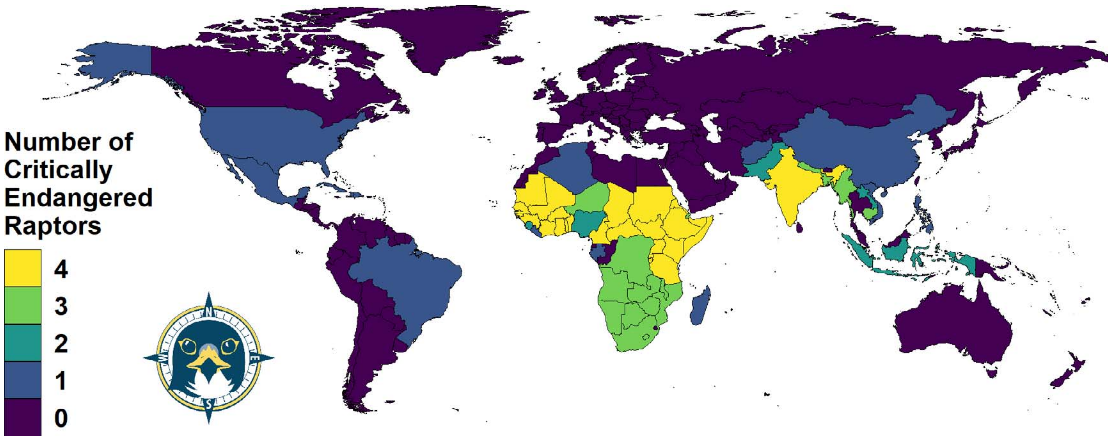

Figure 2. The number of critically endangered raptor species present per country. We considered a species to occur within a country if it was listed on the International Union for the Conservation of Nature's Red List (BirdLife International 2021) as extant and non-vagrant within that country.

species, which are generally listed due to small population size (i.e., the small population species; Criteria C and D).

Accipitrid Vultures. The critically endangered Accipitrid vultures have relatively large populations and ranges compared to the small population species (Fig. 1). However, the drastic population declines observed for these species present unique and pressing challenges. The African (Ogada et al. 2016) and Asian (Pain et al. 2008) vulture crises (see below) each resulted in the listing of four vulture species as critically endangered. These crises are

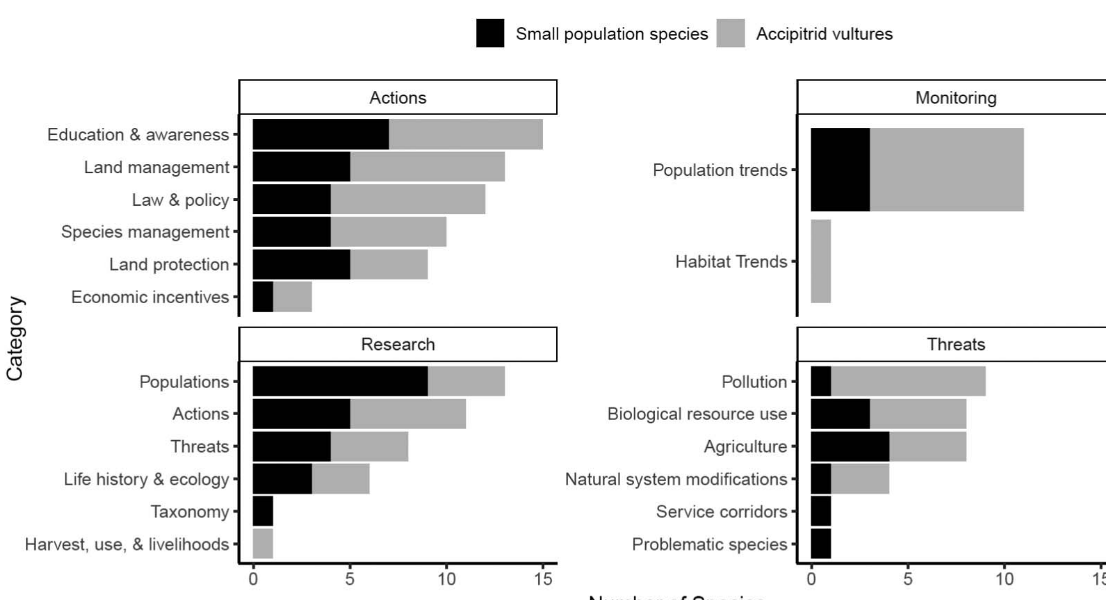

Figure 3. The number of critically endangered raptor species for which each category of conservation action (Actions), research and monitoring needs, and threats are listed on the International Union for the Conservation of Nature's Red List (BirdLife International 2021).

clearly reflected in the distribution of critically endangered raptors among the world's countries, with Africa and southeast Asia being hotspots of critically endangered raptor species (Fig. 2).

The two vulture crises mostly arose from disparate forms of poisoning (Pain et al. 2008, Ogada et al. 2012, Botha et al. 2017). Such poisoning threats are reflected in our results with pollution being the major threat to Accipitrid vultures (Fig. 3). In Asia, the source of poison is mostly diclofenac (Oaks et al. 2004) and other non-steroidal anti-inflammatory drugs used in veterinary medicine (Pain et al. 2008). Fortunately, a ban on the use of veterinary diclofenac in 2006, and the research and development of meloxicam as a non-toxic alternative seem to have resulted in the stabilization or increase of some populations in India and Pakistan (Chaudhry et al. 2012, Galligan et al. 2014, McClure et al. 2021b).

There are various forms of poisoning threatening vultures across Africa (Botha et al. 2017). Sentinel poisoning occurs when poachers poison the carcasses of large mammals to prevent circling vultures from alerting authorities to their crimes; and poison baits can unintentionally kill vultures when carcasses are poisoned in efforts to kill nuisance mammalian carnivores (Roxburgh and McDougall 2012, Botha et al. 2017). African vultures are also often poisoned for belief-based use (i.e., traditional medicine; McKean et al. 2013, Ogada et al. 2016, Botha et al. 2017). Assuaging such various forms of poisoning requires a multi-faceted approach involving education campaigns and governmental legislation. The Multi-species Action Plan to Conserve African-Eurasian Vultures (i.e., the Vulture MsAP; Botha et al. 2017) is a guidance document published by the Coordinating Unit of the Convention on Migratory Species' Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (hereafter Raptors MOU) that was developed in consultation with stakeholders and experts. This document aims to rapidly stop population declines of Accipitrid vultures and provides a framework for implementing such action across national, multinational, and nonprofit entities. We recommend that implementation of the Vulture MsAP be considered a major priority by the conservation community.

Small Population Raptor Species. The other group of critically endangered raptors generally suffers from small population size and range (Fig. 1). These species thus experience problems common to those of small-populations—their numbers are reduced to such a level as to be threatened by environmental, demographic, and genetic stochasticity (Lande 1993, Caughley 1994). Indeed, stochasticity can threaten small populations with extinction even if anthropogenic threats are effectively managed (Brito and Fernandez 2000). A meta-analysis of published minimum viable population estimates revealed that the average minimum population size for birds is roughly 3700 mature individuals (95% CI = 2544, 5244; Traill et al. 2007). The most abundant small population species is the Ridgway's Hawk, with a global population of 322 mature individuals (Fig. 1). Some species such as the Cuban Kite (*Chondrohierax wilsonii*) have not been seen in nearly a decade (Gallardo and Thorstrom 2019). The Pernambuco Pygmy-Owl is considered possibly extinct (Butchart et al. 2018), with a global population size estimated as ranging from 0 to 49 (Fig. 1) and a highly restricted range (Da Silva et al. 2002). The Pernambuco Pygmy-Owl has not been observed since 2001 (Butchart et al. 2018) and was only first described in 2002 (Da Silva et al. 2002). With such small populations and restricted ranges, these species are highly susceptible to extinction via stochastic events.

Seven of the nine small population species are island endemics. Our results therefore bolster recent calls for increased conservation of island raptor species (McClure et al. 2020b, Pizzarello and Balza 2020). Island raptors tend to be more threatened than other raptors even after controlling for confounding factors including range size and forest dependency (Buechley et al. 2019). Species endemic to islands face many threats such as habitat destruction and invasive species (Johnson and Stattersfield 1990, Loope et al. 2001, Brooks et al. 2002, Paxton et al. 2018). It is therefore unsurprising that agriculture was the most-listed threat and that land protection and land management were important conservation actions for small population species (Fig. 3). However, the only critically endangered raptor threatened by a nuisance species is the Ridgway's Hawk, which is severely affected by parasitic nest flies (Hayes et al. 2019). Invasive pest eradication on islands is therefore not yet necessary for prevention of raptor extinctions, although it remains important for many other species (Parkes and Panetta 2009).

Unlike for the Accipitrid vultures (Botha et al. 2017), there is no single overarching plan to conserve the world's small population raptor species, and approaches must be more tailored to specific species. The actions listed most for these species include education and awareness, land protection, and land management (Fig. 3). These actions should address threats including biological resource use (e.g., hunting, logging) and agriculture. Several species need direct management (Fig. 1). For example, captive breeding and reintroduction are ongoing for the California Condor (Finkelstein et al. 2012), and the Ridgway's Hawk is the subject of translocation and nest management activities (McClure et al. 2017, Hayes et al. 2019). Such conservation action has resulted in population increases for these two species, such that they might be downlisted in future Red List assessments (BirdLife International 2021). The California Condor and Ridgway's Hawk thus demonstrate that targeted management action can substantially improve conservation status. Other small population raptor species thus need immediate, targeted, and intense conservation action.

The only critically endangered raptor species for which taxonomy is listed as a research priority is the Annobon Scops-Owl. Several authorities consider this taxon to be a subspecies of the African Scops-Owl (*Otus senegalensis*; McClure et al. 2020a). Because species-level taxa tend to receive more conservation action than subspecies (Hazevoet 1996, Karl and Bowen 1999, Penhallurick and Wink 2004), the decision to list this taxon as a species on the Red List likely increases the attention to the Annobon Scops-Owl. Similarly, the Cuban Kite was only recently recognized as a species by the American Ornithological Society (Chesser et al. 2021), despite being recognized by BirdLife International for several years. Such delay might have affected the conservation attention afforded to this species. Importantly, the Puerto Rican Sharp-shinned Hawk (currently *Accipiter striatus venator*) likely numbers fewer than 100 individuals (R. Thorstrom unpubl. data). Recent genetic and morphological analyses suggest that this taxon should be considered a species (Catanach et al. 2021). Given the rarity of the Puerto Rican Sharp-shinned Hawk and its drastic population decline due to Hurricane Maria (Gallardo and Vilella 2017), this taxon would likely be listed as critically endangered if considered a species. We therefore recommend a taxonomic reevaluation of the Puerto Rican Sharp-shinned Hawk so that this taxon can be properly prioritized for conservation action. Future taxonomic work should therefore help prioritize conservation efforts by settling the debate about the taxonomic level of small population raptor taxa.

Conservation, Research, and Monitoring Priorities. Our results support recent studies demonstrating the Global South is important for raptor research and conservation (Fig. 2; McClure et al. 2018, 2020a; Buechley et al. 2019, Santangeli et al. 2019). Indeed, the only critically endangered raptor species in the Global North is the California Condor. Many of the countries we highlight in the Global South as having relatively high numbers of critically endangered raptor species are underfunded for conservation (Waldron et al. 2013). Investment in conservation programs in the Global South is therefore needed to prevent raptor extinctions.

Law and policy is listed as a priority action for 12 critically endangered raptors, including all critically endangered Accipitrid vultures. For species with relatively large ranges that cross national borders, international instruments are needed to ensure conservation. The Raptors MOU is administered under the United Nations' Convention on Migratory Species. This legally nonbinding international agreement commits signatory countries throughout Africa and Eurasia to conserve migratory raptors. All critically endangered Accipitrid vultures are listed as covered by the Raptors MOU (Coordinating Unit of the Raptors MOU 2015). Critically endangered raptor species with small populations generally do not range across international borders (except California Condor and Ridgway's Hawk); thus they are not covered by international agreements such as the Raptors MOU. Countries with small populations of endemic raptors must therefore take the initiative to implement policies and take action to conserve these critically endangered species.

The most pressing research and monitoring targets for critically endangered raptors are populations and population trends, respectively (Fig. 3). Such a need for better population estimates is reflected in the fact that 47% of reported estimates of population size were of poor quality and population sizes for two species are not reported (Fig. 1). Indeed, with one-fifth of raptor species being virtually unexamined (Buechley et al. 2019) it is possible that some species are imperiled without knowledge of the scientific community. Further, both the Raptors MOU and Vulture MsAP call for increased systematic monitoring of raptor species (Coordinating Unit of the Raptors MOU 2008, Botha et al. 2017). There is therefore a clear need to better monitor raptors across the globe. Toward this end, several raptor research and conservation entities are collaborating in the Global Raptor

Impact Network (GRIN; www.globalraptors.org; McClure et al. 2021a). GRIN collects data via mobile application and direct solicitation then analyzes it to specifically calculate and track population measures used by the Red List (i.e., population size, trend, and range). For example, Sutton et al. (2021) used GRIN data to demonstrate that the IUCN range estimate for the Harpy Eagle (*Harpia harpyja*) was 11% too large. The Philippine Eagle Foundation is currently using GRIN to revise population and range estimates for the critically endangered Philippine Eagle (C. McClure unpubl. data). Such data collection and analysis should be applied to all of the critically endangered raptors.

Although many raptors are experiencing global population declines (McClure et al. 2018), this study focused on the critically endangered raptor species. The critically endangered raptors are the highest priority regarding prevention of extinction in the short term. However, a long-term perspective must also be adopted in which population declines, even of non-threatened species, are reversed. Indeed, the sixth mass extinction is one of declining overall biodiversity, with many common species in decline (Ceballos et al. 2017, Rosenberg et al. 2019). Preventing the extinction of raptor species is an important, yet difficult, facet of assuaging the current biodiversity crisis.

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