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Review

Priorities for research and action to prevent a New World vulture crisis

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ABSTRACT

Proactive approaches are typically more cost-effective than reactive ones, and this is clearly the case for biodiversity conservation. Research and conservation actions for Old World vultures typically followed large population declines, particularly in Asia and Africa. These are clear examples of reactive intensive conservation management. We here contend that there are signs of a potential upcoming continental vulture crisis in the New World. New Word vultures share many of the threats that have decimated their Old World counterparts, such as toxicosis from poisoning and lead. At the same time, we show that quantitative data on key demographic and conservation action aspects are largely lacking for many New World vultures, particularly those restricted to the Neotropics. This knowledge gap prevents us from quantifying population declines, and in turn, to design effective management actions to mitigate and prevent further declines. Essentially, if the current knowledge gaps are not filled rapidly, we will miss the opportunity to apply proactive conservation. We here propose a set of actions to prevent a potential vulture crisis in the Americas.

1. Introduction

The current biodiversity crisis, often referred to as the sixth mass extinction, has triggered a series of calls for action and systemic changes at the international policy and individual level (IPBES, 2019). For such actions to have an impact, modern conservation is fast progressing towards an evidence-based approach, whereby scientific evidence informs decision making and implementation of actions on the ground (Sutherland et al., 2020; Sutherland et al., 2004). Unfortunately, after several calls for filling evidence and ecological knowledge gaps over a decade ago (Cook et al., 2010; Ferraro and Pattanayak, 2006), the situation has not much improved, especially for some taxa and ecosystems (Christie et al., 2020; Conde et al., 2019; Joppa et al., 2016; Mammola, et al., in press). Lack of ecological knowledge and conservation-evidence can jeopardise our chances of averting the current biodiversity crisis. On the one hand, the scarcity of robust and long-term studies on population trends, demography, and range size (among others), greatly limits our ability to detect species or ecosystems at risk and in need of conservation attention (Bland et al., 2012). This, in turn, affects our capacity to prioritize efforts and potentially apply proactive, rather than reactive, conservation measures (Hoffmann et al., 2010; Rodrigues et al., 2006). On the other hand, lack of an evidence-base for conservation often results in inefficient allocation of resources, e.g. prioritizing less effective or even counter-productive actions (Cook et al., 2010; Ferraro and Pattanayak, 2006; Junker et al., 2020). Overall, under the current pervasive lack of ecological and conservation knowledge, practitioners and decision makers are often operating "in the dark", borrowing the words of Cook et al. (2010).

Vultures are the only obligate scavengers among all terrestrial vertebrates, and have potential to deliver critical ecosystem services, such as organic waste decomposition and sanitation, climate change mitigation and ecotourism, among others (Buechley and Şekercioğlu, 2016; Grilli et al., 2019). Therefore, conserving vultures has wide-reaching implications for ecosystem health and human wellbeing (Buechley and Şekercioğlu, 2016; Plaza et al., 2020; Santangeli et al., 2019). Across all species on Earth, vultures represent among the most striking examples of both conservation successes and failures. Over the past few decades, vultures have experienced some of the most dramatic declines in

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population abundances and conservation status among vertebrates (Buechley and Şekercioğlu, 2016; McClure et al., 2018). In the case of Asian vultures, for example, the conservation community belatedly reacted by quantifying the magnitude of the decline when it was already manifest (Williams et al., 2020). These critical research and conservation efforts have been instrumental in saving vultures in Asia from going extinct (Prakash et al., 2012), but only after the populations of some species declined by over 99% (Green et al., 2004).

On a global level, vulture declines have not been ubiquitous across species and regions. While most of the Old World vultures, 14 of 16 species, are globally threatened or near threatened (hereafter threatened refers to Red List status: Near Threatened, Vulnerable, Endangered, Critically Endangered) according to the International Union for Conservation of Nature (IUCN) (Botha et al., 2017), most of the New World vultures (including condors), 5 of 7 species, are not currently listed as threatened (McClure et al., 2018). The only threatened New World vultures are the California (*Gymnogyps californianus*) and Andean (*Vultur gryphus*) condors, the first being listed as Critically Endangered and the latter being recently up-listed to Vulnerable. These two species' distributions cover parts of North and South America, suggesting that threats for scavengers are prevalent across the New World. In fact, the Least Concern IUCN status of New World vulture species, especially the King vulture (*Sarcoramphus papa*), and Lesser (*Cathartes burrovianus*) and Greater (*Cathartes melambrotus*) yellow-headed vultures, is based on extremely limited and fragmented information, bringing to question the reality of their actual statuses.

The unintentional poisoning threat, i.e. vulture mortalities following ingestion of poisons aimed to kill carnivores, has decimated Old World vulture populations (Botha et al., 2017). Unintentional poisoning is now ramping up across the Americas (Plaza et al., 2019), together with other important regional threats, such as environmental lead contamination (Finkelstein et al., 2012; Plaza and Lambertucci, 2019). Thus, there is an urgent need to quantify the current available ecological and conservation related knowledge (e.g.. on population demography and threats) on these species, highlight knowledge gaps, and pave the way to prevent a potential New World vulture and condor crisis. Considering the risk of not having enough data to understand the threats, evaluate population trends and design effective management actions, we here review the available scientific literature on New World vultures to identify knowledge gaps in each species' ecology and conservation. We then highlight commonalities of threats known among Old and New World vultures and propose actions to prevent a potential vulture crisis in the Americas.

2. Methods

2.1. Systematic literature search

We performed a literature review searching for all common and Latin name combinations (n = 29 keywords: *Turkey Vulture OR Lesser Yellow-headed Vulture OR Greater Yellow-headed Vulture OR American Black Vulture OR King Vulture OR California Condor OR Cóndor Californiano OR Cóndor de California OR Andean Condor OR Cóndor Andino OR Zopilote aura OR Urubu à tête rouge OR Zopilote sabanero OR Urubu à tête jaune OR Black Vulture OR Zopilote común OR Urubu noir OR Zopilote rey OR Sarcoramphe roi OR Cóndor californiano OR Condor de Californie OR Cathartes aura OR Cathartes burrovianus OR Cathartes melambrotus OR Coragyps atratus OR Gymnogyps californianus OR Sarcoramphus papa OR Vultur californianus OR Vultur gryphus*) for the seven New World vulture species. The use of multi-lingual search terms (i.e. the vernacular species name in both English and local language) helped to minimize language biases that affect most global literature reviews (Nuñez and Amano, 2021). We searched the title, abstract and keywords in both the Web of Science (Clarivate Analytics) and Scopus (Elsevier B.V.) on 4th October 2021. The searches in the two databases yielded 903 unique documents after removal of duplicates. We further reduced the database to 700 documents when we excluded non-relevant studies, such as from other regions than the New World or other disciplines (e.g., computer science).

2.2. Metadata extraction

We read the 700 documents taken forward after the initial screening (title and abstract first, then if relevant the whole document) and assigned them to one of eight (non-mutually exclusive) research subject areas: *conservation actions* (studies measuring and reporting on the effectiveness of a conservation intervention; monitoring was not included as a conservation action), *threats* (studies addressing one or multiple threats to the species), *population trend* (studies monitoring temporal variations in number of individuals or trends in demographic parameters) and *population size* (studies reporting number or density of counted birds), *habitat* (studies exploring habitat(s) used), *demography* (studies reporting demographic parameters, such as survival or breeding success), *range size* (studies focusing on the distribution or occurrence of a species or estimating range size) and *movement* (studies on movement ecology). A single study could be assigned to zero, one, or multiple subject areas. Moreover, we assigned each study to one or multiple vulture and condor species, and to one or multiple countries where the study was performed. Country metadata were extracted only for the studies which were previously assigned to at least one subject area. Once again, to minimize language driven biases (Nuñez and Amano, 2021), we strived to classify all of the studies irrespective of the language. The majority of studies were in English, with some in Spanish, and a minority in Portuguese (see the full list with metadata in Appendix S1).

2.3. Data visualisation

To visualise the number of studies per species and topic, we used the packages 'ggplot2' (Wickham, 2016) and 'circlize' (Gu et al., 2014) in R (R Core Development Team, 2021). The numbers of studies refer to those studies that were classified to one or more subjects, as detailed above. We mapped the variation in study coverage (across all subjects combined) by country using ArcMap 10.8 (© ESRI).

2.4. Threat mapping

We used the Latin name of the worlds' 23 vulture and condor species, following the IUCN taxonomy, to extract the IUCN-listed threats for each species. This was done automatically using the R package "rredlist" (Chamberlain, 2018). IUCN uses a hierarchical system based on three levels to classify threats, so that Level One is the most general and includes Level Two, and Level Two in turn includes Level Three, the most specific threat classes. As an example, the threat 5 "Biological resource use" at Level One, includes multiple Level Two classes, such as 5.1 "Hunting & collecting terrestrial animals", and Level Two classes in turn may include multiple Level Three classes, such as 5.1.1 "Intentional use". We here used the Level One (most general) threat classes of the IUCN threat classification scheme (Version 3.2: https://www.iucnredlist.org/resources/threat-classification-scheme) which lists 12 threat classes. Among these 12 classes, one, geological events, was not associated with any of the focal species of this study, resulting in 11 threat classes. Next, for the Old World vultures, we derived the proportion of the 15 species for which a specific threat is present. No threats were listed for *Gypohierax angolensis*, as this species is Least Concern. It was thus excluded from this threat mapping exercise. Among the New World species, only two (California and Andean condor) have IUCN threats listed (the other five species are classified as Lest Concern, therefore their threats are not assessed, and not listed). For these two condor species we simply present results on a scale of 1 = threat listed for the given species, or 0 = threat not listed.

3. Results and discussion

3.1. Current knowledge

Research on New World vultures is largely biased in space, with the US representing about half (49%) of all studies, largely owing to research on the California condor. The US is followed by Argentina (15% of all studies), where research has largely been focused on the Andean condor (Fig. 1). Research is largely lacking for several species and research subjects (Fig. 2). Vultures restricted to the Neotropics (King vulture, Lesser and Greater yellow-headed vulture), all IUCN Least Concern, have relatively few publications (23, 9, and 2 studies, respectively; Fig. 2). The cumulative number of studies on these three species (34) represents only 7% of research on New World vultures, while they represent 43% of all New World vulture species and 13% (3/23) of vultures of the World. Conversely, the remaining four species, the California and Andean Condor, Turkey and Black vulture had much higher number of studies (n = 123, 97, 150, and 100 studies, respectively). Across all considered research subjects, research on threats was dominant, with 145 studies (29% of the total), followed by population size, movement, range size and habitat (n = 88, 82, 55, and 53, respectively). Conversely, studies on conservation actions, demography, and population trends were relatively scarce (with 35, 30, and 16 studies, respectively), amounting to just 16% of all studies.

3.2. Population demography

The identification of extinction risk and the development of population recovery strategies heavily depend on demographic data. Specifically, information on population size and trend, and range size, is key to assess conservation status, according to the IUCN criteria A – population size reduction, B – geographic range, C – small population size and decline, D – very small or restricted population, and to a lesser extent criterion E – quantitative analysis (extinction risk; www.iucnredlist.org). While 189 studies (38% of the total) focused on the four subjects related to population demography, i.e. population size and trend, demographic parameters (e.g. survival and fecundity), and range size, there is an evident research bias between the individual subjects and the seven species (Fig. 2). For example, only 16 studies focused on population trends, with the majority of these being focused on the California condor (n = 10). Only three studies reported population trends for Andean condor, two for the Black vulture, and one for the Turkey vulture. Meanwhile, no studies focused on population trends of King vulture or Lesser and Greater yellow-headed vultures. Similar between-species biases are evident for the other population demography related subjects, such as range and population size, as well as demography (e.g. survival and fecundity). An extreme case is the Greater yellow-headed vulture, which lacks any study on demography (Fig. 2).

Overall, we found that for all species but the Critically Endangered California condor (*Gymnogyps californianus*), information on population demography is lacking. This knowledge gap hampers our ability to detect early signs of decline, reliably classify the IUCN threat statuses, and establish proactive rather than reactive conservation actions.

3.3. Threats

Identifying and quantifying threats represents a first critical step for conservation (Groom et al., 2006). This helps quantify extinction risk and identify solutions (Sutherland et al., 2014). Studies addressing threats to the New World vultures were among the most numerous (n = 145, representing 29% of all studies). However, the understudied Neotropical vultures have only one (King vulture and Lesser yellow-headed vulture) or no (the Greater yellow-headed vulture) studies on threats. While we did not classify the specific threats, it is most likely that these results are largely driven by studies on the impacts of toxicosis, such as lead poisoning (Finkelstein et al., 2012; Kelly and Johnson, 2011; Plaza et al., 2020).

3.4. Conservation actions

Scanning for solutions and quantifying their effectiveness have become fundamental pillars of modern conservation science, whereby a set of actions are typically compared in terms of their ecological impacts and costs. This process allows avoiding unnecessary waste of (often scarce) conservation resources while maximizing the impact of interventions (Santangeli and Sutherland, 2017; Sutherland et al., 2011; Sutherland et al., 2012). Therefore, conservation science heavily relies on the body of available scientific evidence for informing decisions and addressing the current biodiversity crisis.

We found that the total number of studies measuring and reporting the effectiveness of a conservation intervention for any of the New World vulture species was relatively low (n = 35; 7% of studies). This is surprising given the conservation relevance and attention devoted to vultures, both historically (e.g. California condor) and more recently (e.g. Andean condor). Indeed, studies on conservation actions for the California condor represent almost half (17 out of 35) of the studies on this subject from across all seven species. The Least Concern Turkey and Black vultures had seven studies on conservation actions, while the Vulnerable Andean Condor had only three. Again, the three Neotropical species had only one study (Greater yellow-headed vulture) or none (King and Lesser yellow-headed vulture). This highlights the paucity of information that is so essential in informing management.

3.5. Habitat and movement

The above research subjects, such as population demography and conservation actions, are directly linked to applied species management. However, other ecological aspects, such as habitat and space use, may still be relevant for informing conservation, at least indirectly (Courchamp et al., 2015). Studies on movement (including space use; n = 82) and habitat (i.e. habitat use; n = 53) were well represented, totalling about one quarter (27%) of all studies. Again, the three Neotropical species had less than four studies per species and per each of the two subjects, whereas the other species had generally over ten studies for each of the two subjects (Fig. 2). The relatively high number of movement and habitat use studies is likely the result of several biologging projects focused on vultures over the past few decades (Alarcon and Lambertucci, 2018).

3.6. Another potential continental vulture crisis

The lessons from Europe, Asia, and Africa are clear: threats can emerge suddenly, spread rapidly, and trigger catastrophic vulture declines that necessitate rapid responses (Green et al., 2004; McClure et al., 2018; Ogada et al., 2016). This is also reflected in the historic (e.g. California condor) and ongoing (e.g. Andean condor) declines throughout the Americas. We show that a large number of threats (6 out of 11) associated with at least one Old World vulture species are also shared by either one or both of the two threatened New World condors (Fig. 3). Among the main threats to Old World vultures are biological resource use (e.g., hunting and trapping, including secondary poisoning from lead ammunition) and pollution (including poisoning via pesticides). Lead poisoning, in particular, is also shared by both Condor species, while pollution by the California condor only, at least according to the IUCN threat classification information. However, pollution, e.g. from poisoning via pesticides, has also been recently reported for the Andean Condor (Plaza et al., 2019), and likely affects most of the New World vulture species. Two other important threats to Old World vultures, such as transportation and service corridors (e.g., collision and electrocution with power lines) and energy production and mining (e.g., wind turbine collision mortality), are also present for the California condor and likely imminent threats for the Andean condor (Plaza and

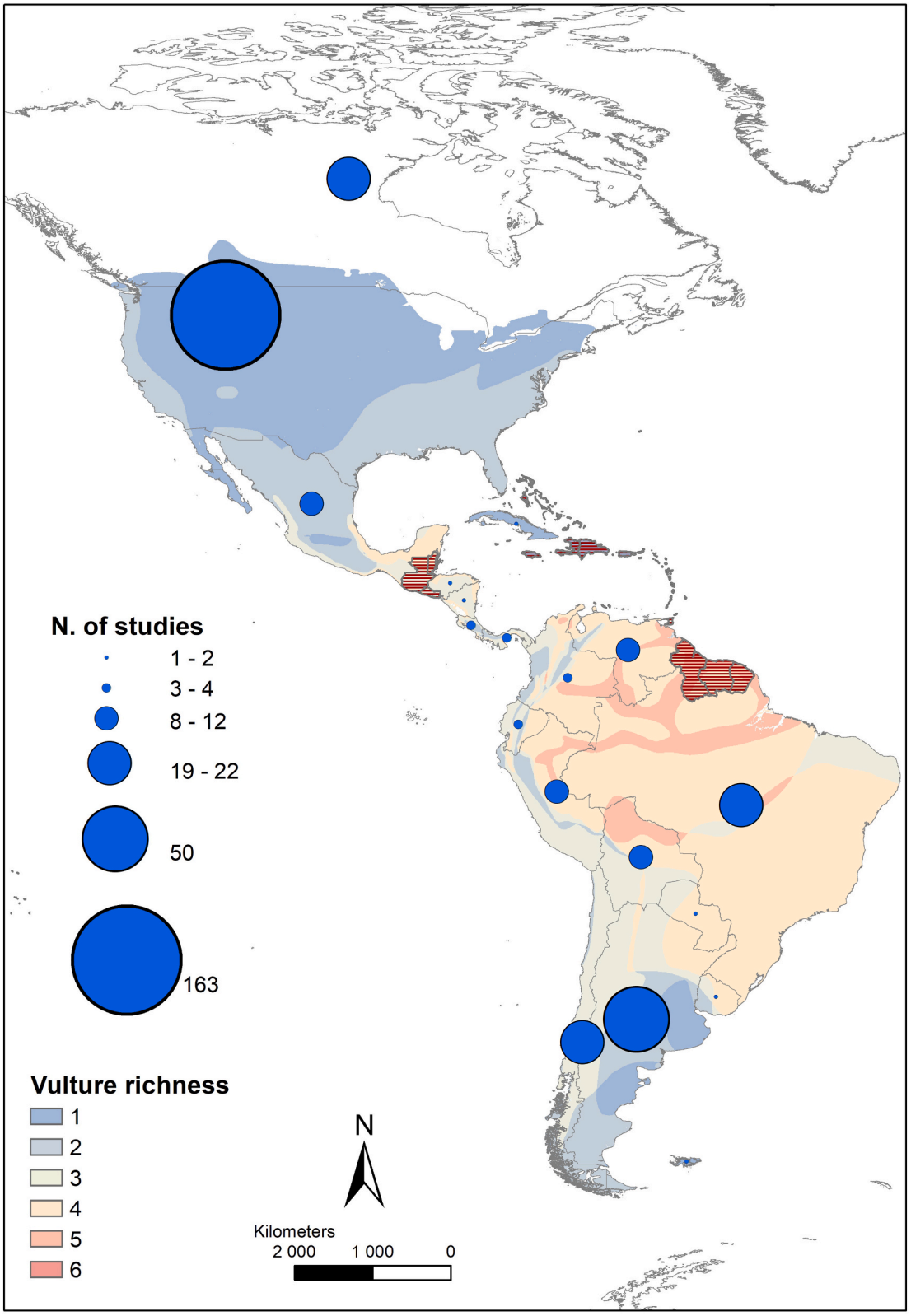

Fig. 1. The distribution of the available scientific literature (filled blue circles) across all the vulture and condor species in the New World. The two largest circles represent the two countries USA and Argentina, with highest number of studies (163 and 50), and are thus shown with their exact values rather than range of values for the studies. Color gradient in the background represents the number of species (vulture and condor richness) across the New World. Countries within the vulture and condor range for which no studies exist are depicted by red hashed patterns. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

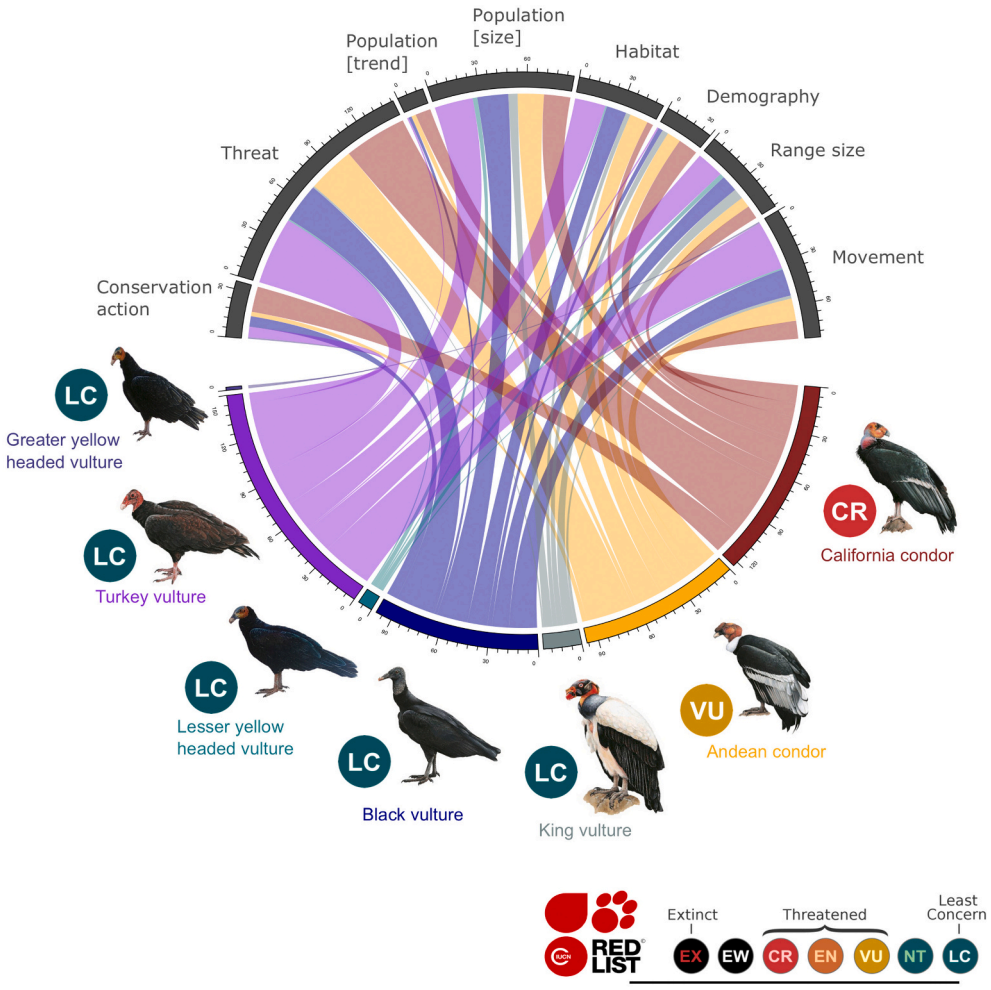

Fig. 2. Available scientific literature for each New World vulture species (bottom half of the circle), organized by eight research subjects (top half). Vulture images reproduced from: www.birdsoftheworld.org.

Lambertucci, 2020). Overall, the current situation suggests that the threats that have been and are afflicting vultures in the Old World are ubiquitous across continents and require careful attention in the New World.

To this end, the recent and widespread decline (estimated to range between 30 and 49% over three generations; www.birdlife.org) of the Andean condor may represent only the tip of the iceberg. Currently, two of the three least known New World vultures are thought to have declining populations (King and Greater yellow-headed vulture), while the Lesser yellow-headed vulture is assessed to have a stable population according to BirdLife International (www.birdlife.org). These negative population trends, while highly uncertain, indicate that there may be regional- to continental-level threats affecting vultures, especially in the Neotropics, for which the magnitude and potential impacts are largely unknown.

Rapid nature appropriation and land conversion to make space for intensive land uses, such as cattle ranching or infrastructure development (Van Asselen and Verburg, 2013), will inevitably boost the magnitude and scope of the existing biodiversity threats in Latin America. The expansion of intensive beef farming in the region largely reduces the main food source to vultures, as livestock carcasses are no longer made available to scavengers under these intensive production regimes (Plaza and Lambertucci, 2020; Vale et al., 2019). Moreover, the expansion of cattle ranching often results in human-wildlife conflicts, which fuel the use of poisons to eliminate carnivores (Lambertucci et al., 2021; Michalski et al., 2006), among other species, thereby endangering scavengers. Cases of mass poisoning involving Andean condors have been reported from Argentina (up to 34 individuals in one poisoning event), Bolivia, Chile and Peru, while several poisoning events were also registered in Colombia and Ecuador where there are just a few hundred of individuals alive (Plaza and Lambertucci, 2020, 2021). Similarly, toxicosis due to lead, pesticides, and rodenticides will likely increase with human encroachment and human land use intensification, further threatening New World vultures and condors (Plaza et al., 2019).

We thus contend that threats are prevalent but demographic information and continuous monitoring schemes are lacking. This suggests that, if a continental vulture crisis emerges in the New World, we will be unable to detect and address it in a timely manner, and this is particularly true for the Neotropics. For example, the recent up-listing of the Andean Condor to Vulnerable (BirdLife International, 2022), underscores worrying and potentially widespread threats for the rest of the guild. Some of the New World vulture species could already be declining similarly to the sympatric and better studied Andean Condor, but the current knowledge gaps make those declines largely unnoticed.

3.7. Actions to prevent a New World vulture crisis

The increasing threats and lack of knowledge on many New World vultures, particularly in the Neotropics, represent a conservation challenge, but also an opportunity to preempt a likely crisis. There is expertise in both North and South America, and a knowledge-base built over decades of research and conservation on iconic species, like the

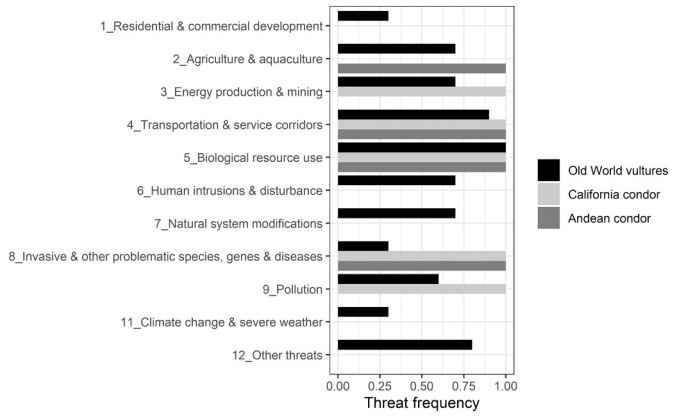

Fig. 3. The frequency of each IUCN Level 1 threat (including all threats of any impact) afflicting vultures and condors for the Old World Vultures (proportion of species, out of 15 [IUCN threats not listed for the Palm-nut vulture], for which a specific threat is present), as well as for the threatened California and Andean condors (here the values are 0 = threat not listed, or 1 = threat listed for the given species). Other New World vultures are currently not threatened and hence lack a threat listing by IUCN. Practical examples of the types of listed threats with relevance to vultures: Threat 1 (numbers here refer to the Y axis labels from top to bottom) class includes e.g. tourism and recreational infrastructures developed in vulture sensitive areas; 2, e.g. changes in livestock farming regimes that reduce the food base for vultures; 3, e.g. wind turbine collision mortality; 4, electrocution and collision with power lines; 5, unintentional or deliberate killing, e.g. for belief-based use; 6, recreational activities causing disturbance, e.g. near breeding colonies; 7, habitat changes that may reduce the food-base; 8, competition with alien species, like with feral dogs for carcasses; 9, poisoning due to pesticide use and other drugs, like diclofenac; 11, droughts that alter patterns of carcass food availability.

California and Andean condors, as well as from the Old World (Botha et al., 2017). Thus, we call for the development and implementation of a multi-species action plan for the New World vultures and condors following the recent successful example in the Old World. There, all the best available knowledge and expertise was mobilized to define a strategic plan for action to conserve the African and Eurasian vultures, and to gain conservation momentum (Botha et al., 2017). Increasing the research focus on basic population demography, such as population size and population trend (e.g., via systematic counts, genetics, and even citizen-science data; Perrig et al., 2019), fecundity, survival, and range size, is paramount for increasing the robustness of Red List status assessments. This is particularly needed for the Neotropical vultures, for which large knowledge gaps exist. At the same time, we urge the development of social-ecological system research focused on quantifying and understanding threats, their drivers, and underlying mechanisms.

To fill existing knowledge gaps, we call on the research community focused on raptors to consider shifting research efforts towards the least researched species, particularly the Neotropical vultures, even if they are not currently threatened. For example, a framework now exists to prioritize investment across all raptor species by weighing both conservation status and research history (Buechley et al., 2019). To best achieve this, international raptor organizations (e.g., The Peregrine Fund, Raptor Research Foundation and the Mohamed Bin Zayed Raptor Conservation Fund) and government funding bodies could invest in filling existing knowledge gaps on species. Threat monitoring and assessment could also be performed by leveraging the biomonitoring potential of some of the more ubiquitous and widespread species, e.g., the Turkey vulture (Ballejo et al., 2021), following for example the recent case study developed on African vultures (Thompson et al., 2021). Finally, as managers and local practitioners are the ultimate users of scientific knowledge and evidence, we suggest that, in critical circumstances, they could borrow information from closely related species when designing conservation interventions. While this is not an ideal case, if monitoring is performed following action implementation, the resulting data could inform species conservation within an adaptive-management framework.

4. Conclusions

Over the past few decades, we have witnessed unprecedented catastrophic declines of the entire avian obligate scavenger guild at a global scale. Such declines have emerged first in Europe (Donázar, 1993), then Asia (Green et al., 2004), and most recently in Africa (Ogada et al., 2016). The case of the California condor population recovery represents a unique conservation success story, although one associated with many challenges and still under intensive management. However, the recovery of decimated vulture and condor populations can be an extremely costly and challenging endeavour, see e.g. how challenging is the restoration of Asian vulture populations (Chaudhry et al., 2012; Galligan et al., 2020). We here alert that there are clear signs of a potential new continental vulture crisis in Latin America. While such a crisis could be imminent in this region, we do not have the knowledge base to detect it in a timely manner, not to mention address it before it is too late. As obligate scavengers, vultures provide critical nature's contributions to people, benefitting human societies throughout the Americas with their waste disposal services (Grilli et al., 2019). Failure to conserve them will represent a severe cost to societies, both financially and culturally (Buechley and Şekercioğlu, 2016). Hence, the time to prevent a New World vulture crisis is now.

Declaration of competing interest

All the authors declare they have no any financial or non-financial conflict of interest with relevance to this study.

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Appendix A. Supplementary data

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