Assessing African Vultures as Biomonitors and Umbrella Species

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African vulture populations are rapidly declining, yet funding and other resources available for their conservation are limited. Improving our understanding of which African vulture species could best serve as an umbrella species for the entire suite of African vultures could help conservationists save time, money, and resources by focusing their efforts on a single vulture species. Furthermore, improving our understanding of the suitability of African vultures as biomonitors for detecting environmental toxins could help conservation authorities to detect changes in ecosystem health. We used a systematic approach based on criteria selected *a priori* to objectively evaluate the potential of each of the 10 resident African vulture species as (i) an umbrella species for all of the African vulture species, and (ii) an avian biomonitor. For each criterion, we scored the respective African vulture species and summed the scores to determine which species was best suited as an umbrella species and as an avian biomonitor. Our results showed that, overall, certain aspects of vulture ecology (large population sizes, large body sizes, long lifespans, and their ability to be monitored over numerous seasons) support their suitability as biomonitors, while other ecological traits, including their diets and the public's perceptions of vultures, could diminish their suitability. The White-backed Vulture (*Gyps africanus*) was the best fit of the 10 vulture species in our assessment as both an avian biomonitor and an umbrella species for all African vulture species. Meanwhile, significant knowledge gaps for other species inhibit their utility as biomonitors. Due to their large home-range sizes, African vultures may only

be useful as biomonitors at a regional scale. However, there could be value in using the White-backed Vulture as an umbrella species, as an aid to conserve the entire suite of African vulture species.

INTRODUCTION

In Africa and worldwide, governments, scientists, managers, and communities are increasingly interested in monitoring levels of toxicants in the environment (Burger, 2006; Maes et al., 2016; Cortinovis and Geneletti, 2018). This is partly because of commitments of countries to multilateral environmental agreements designed to prevent pollution of the environment with toxic chemicals and thereby protect the health of wildlife, domestic animals, and people (Thompson and Blackmore, 2020; Dulsat-Masvidal et al., 2021). "Biomonitoring" is a form of environmental monitoring where an organism is used to provide information about quantitative aspects of the environment (**Table 1**). The use of various species as biomonitors, therefore, has a huge potential value in these countries and ecosystems.

Raptors (including vultures) have been widely used as biomonitors in Europe and elsewhere (Monclús et al., 2020). Passive monitoring of contaminants can be done using samples from dead raptors (e.g., internal tissues, gastric contents, feathers, and preen oil/gland), while active monitoring can be done with samples from trapped live birds and nests (e.g., blood, plasma/serum, deserted or addled eggs, regurgitated pellets or prey remains, preen oil, and feathers, Espín et al., 2021). Studies have highlighted the usefulness of raptors as biomonitors of heavy metals (which impair the immune systems of Black Kites (*Milvus migrans*; Blanco et al., 2004), organochlorines including dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyl (PCB), [which affect reproduction in White-tailed Eagles (*Haliaeetus albicilla*; Korsman et al., 2012)], and lead intoxication associated with hunting [which reduces the breeding success of Bonelli's Eagles (*Aquila fasciata*; Gil-Sánchez et al., 2018)]. There are currently plans underway for pan-European biomonitoring using raptors (Dulsat-Masvidal et al., 2021). However, despite the widespread use of raptors as biomonitors, very few studies have tested the suitability of vultures as biomonitors (Badry et al., 2020), and none have focused on the African vultures.

Another way in which a species may be used in the support of conservation is as an "umbrella species." Various categories have been suggested to qualify the value of a species in this way (Lambeck, 1997; Noss, 1999; **Table 1**). The most sensitive species (i.e., those quickest to detect or respond to slight changes) in some categories (e.g., area-, dispersal-, resource-, and process-limited species) could be considered as "umbrella species" for other species in the same category (Noss, 1999), as their requirements for population persistence are believed to encapsulate those of a suite of associated species (Carignan and Villard, 2002). Identifying the requirements of an umbrella species (**Table 1**) may be used for conservation planning, as

TABLE 1 | Categories of potential indicator species (Lambeck, 1997; Noss, 1999; Carignan and Villard, 2002; Markert et al., 2003).

Category	Definition
Bioindicators	Organisms (or communities or parts of organisms) containing information on *qualitative* aspects of the environment.
Biomonitors	Organisms (or communities or parts of organisms) that contain information on *quantitative* aspects of the environment.
Flagship species	Species which are usually large, charismatic, and can easily attract public support for conservation programmes.
Keystone species	Species that are ecologically essential. Their strong interactions with other species generate effects that are disproportionately large relative to their biomass.
Narrow endemic species	Species that are restricted to geographic ranges, and which are rare within that range.
Species strongly linked with certain habitat features	Species that are closely linked with certain habitat features.
Umbrella species–*the following four categories can all be regarded as umbrella species*	
Area-limited species	Species that need vast areas of suitable habitat for viable populations to persist and whose requirements for persistence are thought to encapsulate those of a range of associated species.
Dispersal-limited species	Species that are restricted in their ability to move between patches, or which encounter a high mortality risk when attempting to do so.
Resource-limited species	Species that need certain resources (such as large snags, nectar sources, fruits, etc.) that may be in critically short supply either temporally or spatially.
Process-limited species	Species that are sensitive to the spatial characteristics, rate, level, or timing of some ecological processes such as fire, floods, grazing, competition with alien species, or predation.

implementing conservation strategies for an umbrella species should benefit co-occurring species (Fleishman et al., 2000; Roberge and Angelstam, 2004; Branton and Richardson, 2011; Maslo et al., 2016). Consequently, using an umbrella species may save conservation professionals money and time by allowing them to focus their efforts on one, instead of on a suite of, species (Roberge and Angelstam, 2004). To the best of our knowledge, there are no studies that test the suitability of vultures as umbrella species. African vulture populations are declining rapidly (Ottinger et al., 2021; Williams et al., 2021), and the funding available and time left to save these birds are both limited. So, it could be extremely helpful if conservationists could

TABLE 2 | Status and range of the 10 vulture species commonly found in Africa.

African Vulture species	Status[a]	Range[b]
1. Palm-nut Vulture *Gypohierax angolensis*	LC	Africa
2. Bearded Vulture *Gypaetus barbatus*	NT	Africa, Asia and Europe
3. Egyptian Vulture *Neophron percnopterus*	EN	Africa, Asia and Europe
4. Hooded Vulture *Necrosyrtes monachus*	CR	Africa
5. White-backed Vulture *Gyps africanus*	CR	Africa
6. Rüppell's Vulture *Gyps rueppelli*	CR	Africa and Europe[c]
7. Griffon Vulture *Gyps fulvus*	LC	Africa, Asia and Europe
8. Cape Vulture *Gyps coprotheres*	EN	Africa
9. White-headed Vulture *Trigonoceps occipitalis*	CR	Africa
10. Lappet-faced Vulture *Torgos tracheliotos*	EN	Africa and Middle East

We used the common and binomial names and taxonomic ordering of the IOC World Bird List, v10.1 (Gill et al., 2020). [a]"Status" refers to the global threat category allocated in the IUCN Red List of Threatened Species (IUCN, 2021), where LC, Least Concern; NT, Near Threatened; EN, Endangered; CR, Critically Endangered. [b]"Range" is as determined from maps in Botha et al. (2017). [c]Vulture Conservation Foundation (2019).

focus their efforts on a single African vulture species, which could serve as an umbrella species for all of the African vultures.

Aims and Objectives

Firstly, given the increasing European focus on the use of raptors as biomonitors, we hypothesized that African vultures could also be useful as biomonitors. We, therefore, aimed to identify whether the respective African vulture species would be well-suited for use as avian biomonitor species, by comparing each African vulture species to all bird species, within the limits of available knowledge for each bird species. Secondly, in recognizing the dire conservation status of African vultures and that time and funds for their conservation are limited, we hypothesized that one vulture species could be used as an umbrella for all (or most) of the other African vulture species. Therefore, we aimed to evaluate each African vulture species in terms of its potential to act as an umbrella species for all African vulture species.

MATERIALS AND METHODS

Study Species

To assess whether the respective African vulture species would be appropriate for use as biomonitors, we considered all 10 species that occur regularly in Africa (**Table 2**; Mundy, 2016).

We excluded the Cinereous Vulture (*Aegypius monachus*) from our analyses because its core range is in Asia, Europe, and the Arabian Peninsula, and its occurrence in Africa is irregular (Copete, 2018a,b; Daboné et al., 2021). We included the Palm-nut Vulture (*Gypohierax angolensis*) because, although its diet includes a large proportion of plant matter (Mundy et al., 1992; Carneiro et al., 2017), it is widespread throughout Africa (IUCN, 2021; **Table 2**), and there is no genetic (Lerner and Mindell, 2005) or anatomical (Chapin, 1932) evidence to support its exclusion.

In the following assessments of the 10 African vulture species as avian biomonitors, and as umbrella species for all African

vultures, our methods were based on data from the peer-reviewed scientific literature to ensure objectivity and repeatability of our results. Where published data were lacking, we relied on expert opinions which were pooled and the consensus was used, and we highlighted this approach in the **Supplementary Materials** (**Supplementary Tables 1**, **2**).

Assessing African Vultures as Avian Biomonitor Species

To achieve our first aim of identifying whether African vultures (either as a group of species or as individual species) could be used as biomonitors, we compiled a list of criteria considered to be important when selecting an avian species as a potential biomonitor, following Landres et al. (1988) and Fleishman et al. (2000). We based our criteria for selecting an avian biomonitor on the list proposed by Hollamby et al. (2006), who provided their criteria based on a literature review and their own observations. They proposed 20 criteria for evaluating a candidate bird species' suitability as a biomonitor of environmental change based on the knowledge of its biological traits.

To make our scoring of the respective African vulture species as clear, repeatable, and objective as possible, we provide a quantitative classification scale for each criterion (**Supplementary Table 1**) with detailed information regarding (i) the variable used to measure each criterion; (ii) a description of the values for each score; (iii) the range of scores given for each criterion; (iv) the range of possible scores; and (v) the relevant table number where additional information is provided.

Seven of the 20 criteria suggested by Hollamby et al. (2006) related to the collection, transportation, or storage of the biological samples. We could not assess those seven criteria in this study without knowing which samples a researcher may collect as there is a great variety of samples that could be collected from vultures (e.g., Espín et al., 2021), and ideally, each one should be individually assessed in a separate study. We excluded those seven criteria from our analysis, retaining the other 13 criteria proposed by Hollamby et al. (2006); (**Table 3**).

We evaluated the 10 African vulture species (listed in **Table 2**) individually, for each of the criteria in **Table 3**, ranking the species from best- to worst-fit in terms of their suitability as biomonitors.

Assessing African Vultures as Umbrella Species

Our second aim was to evaluate the potential of each of the respective African vulture species as an umbrella species for all the African vulture species. Following the recommendations of Landres et al. (1988), we compiled a list of criteria for selecting an umbrella species (Seddon and Leech, 2008; **Table 4**). This method relies on information related to species' traits that are broadly similar to the traits proposed by Branton and Richardson (2011), and Maslo et al. (2016), for selecting an umbrella species.

We evaluated the 10 African vulture species (**Table 2**) individually for each of the criteria in **Table 4** ranking the species from best fit (usually represented with a score of "1") to worst fit

TABLE 3 | Criteria for identifying an avian biomonitor species (modified from Hollamby et al., 2006).

No.	Criterion
1	The population size must be large enough for sampling to not adversely affect it
2	The species' body size should be sufficient for the sample volume to meet analysis needs
3	The species should be long-lived
4	Size, age and sex differences within the species can be documented
5	The biology of the species should be characterized
6	The species can be monitored over numerous seasons or biological cycles
7	The species should be non-migratory and non-nomadic, at least for the part of their life cycle when sampling occurs
8	The species' diet can be determined for the ecosystem under consideration, and should be relatively consistent within and between ecosystems under study
9	The species' foraging range must be known
10	The species' reproductive cycle in the study area is known, and number of young hatched and reared can be quantitatively determined
11	The species should occupy a high trophic level in the food chain
12	The species can be sampled cheaply and relatively easily, in the ecosystem under examination
13	Public acceptance of the species as an indicator should be established

TABLE 4 | Criteria for selecting an umbrella species (modified from Seddon and Leech, 2008).

No.	Criterion
1	Natural history and ecology are well-known
2	Large home-range size
3	High probability of population persistence
4	Co-occurs with and represents species of interest, with threats common to both
5	Has management needs that benefit co-occurring species
6	Sensitivity to human disturbance
7	Ease of monitoring

(usually represented with a score of "10"). To make our scoring of the respective African vulture species as clear, repeatable, and objective as possible, we provide a quantitative classification scale for each criterion (**Supplementary Table 6**), with detailed information regarding (i) the variable used to measure each of the seven criteria, (ii) a description of the values for each score, (iii) the range of scores given for each criterion, (iv) the range of possible scores, and (v) the relevant table number where further detail is provided. The methods used to score the respective African vulture species against each criterion are presented in the **Supplementary Materials**. We then ranked the species, according to their scores, in terms of their suitability as an umbrella species for all the African vulture species.

RESULTS

Assessing African Vultures as Avian Biomonitor Species

Of the 10 African vulture species, the White-backed Vulture (*Gyps africanus*) was the best suited as a potential avian biomonitor species, and the Cape, Rüppell's and Lappet-faced Vultures tied as the second-best (**Table 5**). The Palm-nut Vulture was the worst suited as a biomonitor species.

As a group, African vultures scored well for some criteria. Relative to all birds, African vultures have large body sizes (criterion 2) and long lifespans (criterion 3); the various sizes, ages, and sexes can be distinguished (criterion 4); they can be monitored over numerous seasons (making them suitable for long-term monitoring, criterion 6); they are non-migratory and non-nomadic during the breeding season (criterion 7); and they also have well-known reproductive cycles (criterion 10).

Some African vulture species do not have large population sizes, and these species (the Griffon, Egyptian, and Bearded Vultures) scored poorly for criterion 1. While the biology and foraging ranges of most African vulture species are well-known, knowledge on these two aspects for the Palm-nut Vulture is relatively lacking, and so this species scored lower than the others for criteria 5 and 9.

Some African vulture species (e.g., the Palm-nut, Hooded, and Egyptian Vultures) scored poorly for criterion 8, because of the variation in their diets, while the *Gyps* vultures scored well, because of their fairly restricted diets (**Supplementary Materials**; **Supplementary Table 2**). Related to this, most African vulture species occupy a high-trophic level (**Table 5**), allowing the study of chemicals that bioaccumulate, and so most species scored well for criterion 11 (**Supplementary Materials**; **Supplementary Table 3**). There was variation in the scores for criterion 12, as we regarded some vulture species (particularly the more commensal species) easier and cheaper to trap for sampling (in ideal trapping scenarios) than the others. For criterion 13, we found no information on how the public views the use of vultures as bioindicators, and so all species scored poorly for this criterion (**Supplementary Materials**; **Supplementary Table 4**).

Assessing African Vultures as Umbrella Species

The White-backed Vulture was the best suited of all 10 African vulture species as a potential umbrella species for all African vultures (**Table 6**). The Rüppell's Vulture was the second-best, and the Cape Vulture was the third-best. The Bearded and Palm-nut Vultures were tied as the worst suited as umbrella species (**Tables 6, 7**).

In terms of knowledge on the natural history and ecology for each species (criterion 1), the White-backed Vulture scored the best with the most knowledge, and the Palm-nut and Griffon Vultures tied as the worst since the least is known about these two species (**Supplementary Materials**; **Supplementary Table 5**). According to the information from published studies, the White-backed, Rüppell's, Cape, and Lappet-faced Vultures have the largest home-range sizes, and so these four species scored the best for criterion 2, while

TABLE 5 | The 10 African vulture species, scored according to the assessment criteria that Hollamby et al. (2006) considered to be important when selecting an avian biomonitor species.

No.	Criterion	African vulture species*									
		WbV	CV	RV	LfV	HV	WhV	GV	EV	BV	PnV
1	Large population size	1	1	1	1	1	1	10	10	10	1
2	Large body size	1	1	1	1	1	1	1	1	1	1
3	Long-lived	1	1	1	1	1	1	1	1	1	1
4	Size, age and sex identifiable	1	1	1	1	1	1	1	1	1	1
5	Biology characterized	1	1	1	1	1	1	1	1	1	5
6	Can monitor over many seasons	1	1	1	1	1	1	1	1	1	1
7	Non-migratory and non-nomadic	1	1	1	1	1	1	1	1	1	1
8	Dietary range is restricted	1	1	1	1	5	5	1	5	1	5
9	Foraging range known	1	1	1	1	1	1	1	1	1	10
10	Reproductive cycle known	1	1	1	1	1	1	1	1	1	1
11	Species occupies high trophic level	1	1	1	1	5	1	1	5	1	5
12	Sampling is cheap and easily	1	5	5	5	1	5	5	1	10	5
13	Publicly accepted	10	10	10	10	10	10	10	10	10	10
	Total:	22	26	26	26	30	30	35	39	40	47
	Rank:	1	2	2	2	5	5	7	8	9	10

*Species names have been abbreviated: WbV, White-backed Vulture Gyps africanus; CV, Cape Vulture Gyps coprotheres; RV, Rüppell's Vulture Gyps rueppelli; LfV, Lappet-faced Vulture Torgos tracheliotos; HV, Hooded Vulture Necrosyrtes monachus; WhV, White-headed Vulture Trigonoceps occipitalis; GV, Griffon Vulture Gyps fulvus; EV, Egyptian Vulture Neophron percnopterus; BV, Bearded Vulture Gypaetus barbatus; PnV, Palm-nut Vulture Gypohierax angolensis. Species were scored on a 1 to 10 scale, where, for each criterion, "1" is the best score, and "10" is the worst. The column headed "Criterion" gives a brief description of the criteria listed in **Table 3**.

TABLE 6 | Assessment of the 10 African vulture species, according to the criteria of Seddon and Leech (2008) for an umbrella species.

No.	Criterion	African vulture species*									
		WbV	RV	CV	LfV	GV	HV	EV	WhV	BV	PnV
1	Natural history and ecology well-known	1	7	4	6	10	4	8	6	8	10
2	Large home-range size	1	1	1	1	10	5	10	10	10	10
3	High probability of population persistence	10	10	10	10	7	10	9	10	8	6
4	Co-occurs with and represents species of interest	4	6	10	4	8	4	5	7	10	8
5	Management benefits co-occurring species	5	5	5	5	6	5	5	6	5	7
6	Sensitivity to human disturbance	1	1	1	1	1	10	7	1	1	5
7	Ease of monitoring	3	1	1	8	1	6	1	8	10	6
	Sum of scores for all seven criteria:	25	31	32	35	43	44	45	48	52	52
	Rank as umbrella species for African vultures:	1	2	3	4	5	6	7	8	9	9

*Species names abbreviations are listed in **Table 5**. Species were scored on a 1 to 10 scale, where "1" is the best score, and "10" is the worst.

there were no data available for the Palm-nut Vulture that we presumed had the smallest home-range size, and was scored the worst for this criterion, along with the Egyptian, White-headed, and Bearded Vultures, which all have relatively small home-range sizes (compared with the other vulture species, **Supplementary Materials**; **Supplementary Table 7**). For the probability of population persistence (criterion 3), all the vultures scored poorly, however, the Palm-nut Vulture scored the best for this criterion (there is no evidence of declines for this species), while most of the remaining species scored a "10" (76–100% declines in the three generations, **Supplementary Materials**; **Supplementary Table 8**). For criterion 4, the Hooded, Lappet-faced, and White-backed Vultures scored the best, as their ranges most overlapped (and their threats were common to)

those of the other vulture species, while the Cape and Bearded Vultures scored the worst since their ranges overlapped little of the other vulture species' ranges (**Supplementary Materials**; **Supplementary Table 9**). For criterion 5 (has management needs that overlap those of other species), there was little variation in the scores for each species; the Palm-nut Vulture scored the worst (a "7"), while most other African vulture species scored better, with a "5" (**Supplementary Materials**; **Supplementary Table 10**). For criterion 6 (should be sensitive to human disturbance), the Palm-nut, Egyptian and Hooded Vultures scored the poorest (with scores of "5," "7", and "10," respectively, since they breed and/or forage in areas disturbed by people), while all the other species received a score of "1" since we regarded them as sensitive to human disturbance

TABLE 7 | Ranking of the 10 African vulture species in terms of their suitability as (i) an avian biomonitor species, and (ii) an umbrella species for all 10 African vulture species.

African vulture species	Ranking	
	Biomonitor species	Umbrella species
White-backed Vulture *Gyps africanus*	1	1
Rüppell's Vulture *Gyps rueppelli*	2	2
Cape Vulture *Gyps coprotheres*	2	3
Lappet-faced Vulture *Torgos tracheliotos*	2	4
Hooded Vulture *Necrosyrtes monachus*	5	6
Griffon Vulture *Gyps fulvus*	7	5
White-headed Vulture *Trigonoceps occipitalis*	5	8
Egyptian Vulture *Neophron percnopterus*	8	7
Bearded Vulture *Gypaetus barbatus*	9	9
Palm-nut Vulture *Gypoheirax angolensis*	10	9

These ranks are based on overall scores in **Tables 5**, **6**, where "1", the best (the most suitable species); and "10", the worst (the least suitable species).

(**Supplementary Materials**; **Supplementary Table 11**). Finally, in terms of the ease with which a species may be monitored (criterion 7), the Bearded Vulture scored the worst because of its inaccessible habitat, the tree-nesting species scored better, and the remaining cliff-nesting species scored the best (**Supplementary Materials**; **Supplementary Table 12**).

DISCUSSION

Assessing African Vultures as Biomonitors

Our assessment showed that of the 10 African vulture species, the White-backed Vulture was the species that was best suited as a biomonitor. It scored well for every criterion apart from "public acceptance of the species as a biomonitor" (criterion 13). As a group, the African vultures are suited for use as biomonitors in some respects: they have large body sizes and long lifespans; the various sizes, ages, and sexes can be distinguished; they can be monitored over numerous seasons, making them suitable for long-term monitoring; and they have well-known reproductive cycles.

Most African vulture species scored well for criterion 11 (they occupy a high trophic level, and so can be used to study chemicals that bioaccumulate), however, there may be intraspecific variation in their diets and feeding habits; some Hooded Vultures in West Africa forage along coastlines (Barlow, 2020), increasing their potential exposure to mercury (Diop and Amara, 2016) and persistent organic pollutants (Camacho et al., 2013), while Hooded Vultures in southern Africa do not display this beachcombing behavior. These differences in feeding habits and diet between regions must be considered if using vultures as biomonitors to study chemicals that bioaccumulate.

We found no differences between the respective vulture species in terms of how the public views them, despite there being numerous studies worldwide that have investigated people's perceptions of vultures (e.g., Phuyal et al., 2016; Cailly Arnulphi

et al., 2017; Cortés-Avizanda et al., 2018; Morales-Reyes et al., 2018; Duriez et al., 2019; García-Alfonso et al., 2019), including several in Africa (Santangeli et al., 2016; Craig et al., 2018; Deikumah, 2020; Mashele et al., 2021a,b). These studies tend to focus on the perceptions of people who live in communities bordering protected areas (e.g., Reson, 2012; Mdhlano et al., 2018), who bear the opportunity costs of conservation areas, i.e., disproportionate lost benefits from other land use (Adams et al., 2010). Fewer studies explore the perceptions of vultures among people in the Global North (George et al., 2016; Kluever et al., 2020) and/or urban areas (e.g., Campbell, 2009), who are wealthier and more likely to fund research or conservation work for vultures. We believe that there is a need for vulture attitude and perception studies in urban communities.

We scored all the African vulture species well for criterion 7 (they are all non-migratory and non-nomadic during the breeding season), but their home ranges, even during the breeding season when movements of adults are more constrained, are vast compared with those of many other bird species. Therefore, toxins in the tissues of African vultures could only be used to show trends in environmental pollution (e.g., in lead toxicity, Garbett et al., 2018; van den Heever et al., 2019) at massive (regional) scales, after which, other species (with smaller home ranges) would have to be used as biomonitors to pinpoint where environmental pollution is occurring on a finer scale, so that clean-up measures may be initiated. For this reason, and because all African vultures scored poorly on the criterion "Public acceptance of the species as an indicator" due to the lack of knowledge on this subject (Hollamby et al., 2006, p. 15), we believe that African vultures are, at present and relative to other species of birds, not ideally suited as avian biomonitors.

Assessing African Vultures as Umbrella Species

Our assessments showed that the White-backed Vulture is the African vulture species that is best suited for use as an umbrella species for all 10 African vulture species. The White-backed Vulture is the most suited as a potential umbrella species for all African vultures because: (i) its natural history and ecology are the best known of all 10 vulture species; (ii) it has one of the largest home-ranges of all the vulture species; (iii) it is the most widely distributed across Africa (i.e., it co-occurs with and represents the other vulture species); (iv) its management needs will benefit co-occurring species; (v) it is sensitive to human disturbance; and (vi) it is among the easiest to monitor (mainly due to its nests being the easiest of all the tree-nesting vulture species' nests to monitor; Thompson et al., 2018). Using the White-backed Vulture as an umbrella species for all African vultures may assist conservation practitioners in Africa to save time, money, and effort while still working toward their mandates of protecting all vulture species and the ecosystem services they provide (Safford et al., 2019). Where nesting areas of various vulture species overlap, nest monitoring efforts and studies of breeding success and productivity could focus on the White-backed Vulture. Similarly, focusing on addressing the threats to White-backed Vultures will address many of the

management needs of co-occurring vulture species (Ogada et al., 2016; Botha et al., 2017; Murn and Botha, 2018; Thompson et al., 2020). The use of the White-backed Vulture as an umbrella species may augment other vulture conservation tools, such as identifying priority areas for conservation (Santangeli et al., 2019), retrofitting unsafe energy infrastructure (Perold et al., 2020), reducing wildlife poisoning, and its effects (Gore et al., 2020), reducing the trade in vultures for bushmeat and traditional medicine (Buij et al., 2016; Boakye et al., 2019), phasing out lead ammunition (Margalida et al., 2013), and encouraging hunting (which both preserves habitat and provides food for vultures) where appropriate (Mateo-Tomás and Olea, 2010). However, we should not overlook the conservation needs of any vulture species whose distributions, diets, and other natural history traits (**Table 6**) are not well-represented by the White-backed Vulture.

Constraints

Dulsat-Masvidal et al. (2021) highlighted the legislative constraints when using raptors as biomonitors in Europe. In Africa too, vultures are protected by various international, regional, and sub-regional legal instruments (Thompson and Blackmore, 2020), which may make their use as biomonitors more challenging. Future assessments of species as potential avian biomonitors should include the requirement for non-threatened status. Any assessments of vultures as biomonitors or as umbrellas should also be periodically revised, to incorporate increases in knowledge, and changing public and expert opinion.

In our evaluation of the African vultures as biomonitors, we excluded specific criteria proposed by Hollamby et al. (2006) that relate to chemicals because this evaluation cannot be done until the chemicals to be studied have been chosen, and that does not fall within the remit of this study. Three of the criteria (numbers 6, 15, and 17) proposed by Hollamby et al. (2006) relate to the sensitivity of a candidate species to a particular chemical. While it is implicit that biomonitors must be sensitive to the chemicals under study, this has not been evaluated here, and the inclusion of these three (and the remaining excluded) criteria of Hollamby et al. (2006) could produce different results in terms of which vulture species is best suited as a biomonitor.

The disadvantage of selecting the White-backed Vulture as an umbrella for all the African vultures is that, like many other vulture species, it has a low probability of population persistence. If the White-backed Vulture is used as an umbrella species, then the Palm-nut Vulture may need additional, complementary monitoring, and conservation actions, since the Palm-nut Vulture's diet, habitat and threats are not well-covered by the White-backed Vulture.

The criteria against which we scored the respective African vulture species were partly based on qualitative data, provided by pooling of expert opinion. We acknowledge that there may be uncertainty in the predictions made using expert-based models (Johnson and Gillingham, 2004); however, we believe that our elicitation of expert knowledge was done rigorously, allowing us to rank the species in a cost-effective manner when quantitative data for certain criteria were lacking (Kuhnert et al., 2010). While this means that our datasets are not ideally suited for conducting sensitivity analyses (Thabane et al., 2013), we can

still comment on the ways in which differences in scoring could affect the ranking of species. With regards to how knowledge gaps may have affected our scoring and ranking of species as biomonitors, an increase in knowledge regarding the biology (criterion 5) and the foraging range (criterion 9) of the Palm-nut Vulture could improve its score as a biomonitor from 47 to 34, which would change its ranking from 10th to 7th. Similarly, if awareness campaigns caused the public acceptance of a particular vulture species as a biomonitor (criterion 13) to change from "unknown" to a 91–100% acceptance rate, then the species' score for this criterion would change from 10 to 1, changing its ranking which could elevate the Cape, Rüppell's, Lappet-faced, Hooded or White-headed Vultures into 1st place.

In terms of how knowledge gaps may have affected our scoring and ranking of species as umbrellas, the down-listing of the global status of the Cape Vulture in December 2021 from endangered to vulnerable could change its scoring for criterion 3 from "10" to "8," although this change alone will not alter its ranking as tied third-best umbrella. However, the rank of a species could be affected by an increase in knowledge about its natural history and ecology (criterion 1), for example, an increase in the number of publications on the Palm-nut Vulture could elevate its rank as an umbrella species above its current 9th place. An increase or decrease in a species' range could change the scoring of the species for criterion 4 (co-occurs with and represents species of interest, with threats common to both). Finally, criterion 7 (ease of monitoring) was scored by expert opinion, and, if other experts had scored this criterion, could be slightly different, based on their experience. We highlight that this study is an initial step in testing African vultures as umbrellas and biomonitors with data that are currently published and the combined experiences of experts who work with African vultures.

CONCLUSION

Our results showed that the African vultures are not well-suited as avian biomonitors, but various vulture species are regarded as flagship species (Carrete and Donázar, 2005; Pesic et al., 2012; Gangoso et al., 2013; Krüger, 2013, 2014), and the usefulness of vultures as cultural keystone species may also be worth exploring (Markandya et al., 2008). Cultural keystone species are plants and animals that can be used to measure human health and well-being, because of their vital link to a particular culture (Cristancho and Vining, 2004; Garibaldi and Turner, 2004). Vultures are recognized worldwide for the ecosystem services (cleaning, nutrient cycling, cultural) they provide (Gangoso et al., 2013; Grilli et al., 2019; Morales-Reyes et al., 2019), for their aesthetic value (Becker et al., 2005; Morelli et al., 2015; Aguilera-Alcalá et al., 2020), and for their important roles in African traditional medicine (Buij et al., 2016). The use of African vultures as cultural keystone species could bridge gaps between ecological and socio-cultural systems that undermine current vulture conservation efforts (Horgan et al., 2021).

Vultures are obligate scavengers with a crucial role as highly specialized sanitarians (Mendoza et al., 2018). In some cases (particularly in West Africa), the presence of vultures may

highlight unhygienic habits such as open-air abattoirs and garbage sites[1], but usually, the role of vultures as keystone species (Mills et al., 1993; Buechley et al., 2018) means that their loss (and the loss of the irreplaceable cleaning services they provide) may result in mesopredator release, trophic cascades, zoonotic disease epidemics, and considerable economic, environmental, and One Health costs (Markandya et al., 2008; Plaza et al., 2020; Ottinger et al., 2021; van den Heever et al., 2021). From a positive perspective, the selection of a single vulture species for use as an umbrella species for all the African vultures may greatly reduce the costs of monitoring vulture populations and implementing conservation interventions. We recommend that if conservation authorities, practitioners, and researchers wish to use a single vulture species as an umbrella species for all African vultures, they should focus on the White-backed Vulture.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

WB conceived the idea for this study. WB, LT, and MO designed the study. LT, SK, BC, MO, LS, and JD contributed to the materials and methods section of the manuscript and compiled the tables presented in the **Supplementary Material**. LT wrote

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[1]Daboné, C., Oueda, A., Thompson, L. J., Adjakpa, J. B., and Weesie, P. D. M. (unpublished data) Trade in vulture parts in West Africa: Burkina Faso may be one of the main sources of vulture carcasses. *Bird Conserv. Int.*

the first draft of the manuscript. All the authors contributed to the revision of the manuscript and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2021.729025/full#supplementary-material

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