Bird Conservation International (2022) 32:173–187. © The Author(s), 2021. Published by Cambridge University Press on behalf of BirdLife International
doi:10.1017/S0959270921000307

Pursuit of 'sustainable' development may contribute to the vulture crisis in East Africa

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(Received 02 November 2020; revision accepted 23 June 2021)

Summary

The United Nations Sustainable Development Goals aim to improve livelihoods and maintain functioning ecosystems, and include the provision of electricity and the prevention of desertification. We show that the pursuit of those two goals can lead to developments that put critical ecosystem functions at risk. Vultures are scavengers that provide sanitary ecosystem services, but their populations across Africa are declining due to poisoning, electrocution, and collision with power infrastructure. The extent to which the pursuit of sustainable development threatens vultures in Africa is unclear. We surveyed 227 km of powerlines in Ethiopia, which revealed bird mortality (0.15 vulture carcasses / km) at power infrastructure constructed under a National Electrification Programme to provide universal electricity access by 2025. We also interviewed 190 local pastoralists in 10 areas about livelihood challenges, which revealed that the bush *Prosopis juliflora*, which was originally introduced to prevent desertification but then invaded north-eastern Ethiopia, increased livestock predation and motivated the use of poison to control predators. Actions to increase universal access to electricity and to reduce desertification therefore have undesired side-effects that increase vulture mortality through electrocution and poisoning. To avoid negatively affecting local vulture populations and the services they provide, we urge governments to use infrastructure designs that minimise the risk of electrocution and assist pastoralists to protect their livestock and reduce the risk of poisoning to vultures and other wildlife.

Keywords: electrocution, collision, desertification, poisoning, human-wildlife conflict, Ethiopia

Introduction

Many nations aim to improve the livelihoods of their people by following the United Nation's Sustainable Development Goals. Among these goals are the ambitions to provide universal access to clean and affordable electricity (Goal 7) and to reduce land degradation through the prevention of desertification (Goal 15). Implicit in the term 'sustainable' is, however, the ambition to maintain critical ecosystem services by protecting natural biodiversity that provides these services, which may potentially lead to conflicts among different goals (Cord *et al.* 2017, Kiesecker *et al.* 2019).

One critical service provided by biodiversity is the recycling of dead biological material and the prevention of the spread of diseases (Whelan *et al.* 2008, Morales-Reyes *et al.* 2015). Obligate scavengers like vultures consume vast quantities of dead biological material and therefore facilitate the rapid removal of animal carcasses that could otherwise harbour diseases (DeVault *et al.* 2003, Moleón and Sánchez-Zapata 2015, Plaza *et al.* 2020). In Africa, most vulture species have declined by >80% over the past decades owing to human-caused mortality such as poisoning, direct persecution, and electrocution and collision with electricity infrastructure (Ogada *et al.* 2015, Safford *et al.* 2019). The loss of specialist scavengers like vultures may lead to an increase in more generalist scavengers like feral dogs or rodents, which may negatively affect the livelihoods and well-being of humans (Ogada *et al.* 2012, Buechley and Şekercioğlu 2016), and may increase the transmission risk of zoonotic diseases (Gibb *et al.* 2020). Attempts to achieve sustainable development goals and improve people's livelihoods should therefore strive to minimise risks affecting local vulture populations and the services they provide (Safford *et al.* 2019, Serrano *et al.* 2020).

Despite the laudable ambition of most sustainable development goals, the concept underlying the goals has been criticised because it relies on perpetual economic growth and may ignore planetary boundaries (Steffen *et al.* 2015, Naidoo and Fisher 2020). In particular, the growth of power generation through renewable technologies has raised concerns that well-intended international agreements may have negative consequences for biodiversity if implemented at large scales (Kiesecker *et al.* 2019). For example, the expansion of renewable wind energy generation has been shown to have potential negative consequences on biodiversity due to collision mortality (Marques *et al.* 2014, Thaxter *et al.* 2017, Serrano *et al.* 2020), yet these effects on biodiversity are rarely considered in the engineering field (Katzner *et al.* 2019, Veers *et al.* 2019). Collision mortality not only occurs at power generating infrastructure, but also along power distribution networks, as birds and bats can collide with power lines (Jenkins *et al.* 2010, Bernardino *et al.* 2018). Poorly designed power distribution infrastructure can also lead to electrocution of birds when they perch on uninsulated support structures (Lehman *et al.* 2007, Angelov *et al.* 2013), and collision and electrocution are among the key anthropogenic mortality causes for vultures in Europe and Africa (Guil *et al.* 2011, Ogada *et al.* 2015, Eccleston and Harness 2018).

Although the problem of electrocution and collision has been known for almost 50 years (Markus 1972, Nikolaus 1984), many current infrastructure designs used to pursue the sustainable development goal of universal access to electricity in Africa do not prevent wildlife mortality risks of electrocution and collision (AEWA 2012, Gärtner and Stamps 2014, Government of Ethiopia 2019). For example, the Government of Ethiopia launched a National Electrification Programme in November 2017, which aims to provide universal electricity access nationwide by 2025 for the benefit of all its citizens (Government of Ethiopia 2019). During this expansion, one million rural households are being connected to centralized electricity every year by the construction of above-ground power distribution lines. Although a major funding agency anticipated this expansion to pose a 'minimal' risk to birds (World Bank 2018), the environmental safeguards of this funder have been questioned (Rich 2013, Morley *et al.* 2021). Ethiopia is one of the most important areas for the conservation of vultures globally, but there is large uncertainty over the potential unintended consequences of the National Electrification Programme on Ethiopia's vultures (Santangeli *et al.* 2019, Buechley *et al.* 2021b).

The universal access to electricity is expected to reduce the demand on fuelwood and therefore also contribute to a second sustainable development goal: reducing the risk and consequences of desertification (Mirzabaev *et al.* 2019). Desertification affects large areas of eastern Ethiopia and has so far been addressed by the introduction of exotic plants expected to stabilise the soil and provide fuelwood (Zollner 1986, Haregeweyn *et al.* 2013). One of the plant species used to combat desertification is *Prosopis juliflora*, a shrub species from Central and South America that has been introduced in many arid regions of the world, where it has frequently become invasive (Kaur *et al.* 2012, Heshmati *et al.* 2019, Mirzabaev *et al.* 2019). This plant is a highly competitive shrub that displaces native plants (van Klinken *et al.* 2006) and can cause brain damage in cattle (Tabosa *et al.* 2006), consequently reducing food availability for livestock (Coppock *et al.* 2005, Witt 2010). In Ethiopia, *P. juliflora* was originally planted in the 1970s, and has invaded natural grassland and acacia shrublands in large regions of eastern Ethiopia through dispersal by livestock droppings (Haregeweyn *et al.* 2013). Because dispersal is facilitated by rural villages and linear landscape features, the plant is expected to spread further to currently uninvaded areas (Shiferaw *et al.* 2019b). Although some people derive value from using *P. juliflora* for firewood, the majority of pastoralists in north-eastern Ethiopia resent the plant because it negatively affects their livestock (Mehari 2015, Bekele *et al.* 2018, Shiferaw *et al.* 2019a). The *P. juliflora* invasion has many negative consequences on the livelihoods of rural pastoralists, but so far, no link between this invasive plant and vulture populations has been described (Coppock *et al.* 2005, Argaw 2015, Bekele *et al.* 2018).

Here we suggest with the case of eastern Ethiopia that the pursuit of the two above-mentioned sustainable development goals may increase the direct and indirect threats to vultures and may therefore undermine goals that aspire to safeguard biodiversity and ecosystem services. We conducted quantitative surveys to collect direct evidence of bird mortality and interviewed rural stakeholders to understand whether their routine solutions to overcome general problems in livestock farming may pose a mortality risk to vultures.

Methods

Study area

We focused our study on the north-eastern lowlands of Ethiopia in the regional states of Oromia and Afar between 8.67–11.92°N and 39.42–43.60°E (Figure 1). This area is known as a priority area for the conservation of vultures (Arkumarev *et al.* 2014, Oppel *et al.* 2015, Santangeli *et al.* 2019) and is at the forefront of the expansion of *Prosopis juliflora*, with >12% of the surface area covered by the species 35 years after its introduction (Haregeweyn *et al.* 2013, Shiferaw *et al.* 2019b). The Afar Region covers an area of 14 million ha where rural pastoralism is the dominant source of livelihood (Shiferaw *et al.* 2019a), and many people live in small rural settlements that are not yet connected to the electricity grid. Our work was concentrated along the major access route, the highway leading from Addis Ababa to Djibouti between Welencheti (8.67°N, 39.42°E) and Hayu (11.91°N, 41.57°E), including minor side roads. The main highway runs parallel to the Awash River, a partly underground river that has been dammed into a series of lakes and is the key invasion corridor for *P. juliflora* (Haregeweyn *et al.* 2013, Shiferaw *et al.* 2019b).

The highway along the Awash river is also the main electricity transmission line corridor where one to several high-voltage power lines transport electricity over large distances. Besides these high-voltage transmission lines, many low- to medium-voltage power distribution lines branch out from the main corridor to reach small communities in the vicinity. In Ethiopia, 20–25% of inhabitants live >5 km from the nearest power distribution network, and many of these communities will be connected by small to medium-voltage distribution lines within the National Electrification Plan by 2025 (Government of Ethiopia 2019). Ethiopia's electricity is generated mostly (>90%) from hydropower, but by 2030 the contribution of wind and solar power is expected to increase (Gärtner and Stamps 2014). Additional energy generation facilities are planned in our study region, namely four solar power generation facilities in Metahara (to be completed in 2021) and Welencheti (in 2022), which will require further infrastructure to distribute the generated electricity into the national grid (Government of Ethiopia 2019).

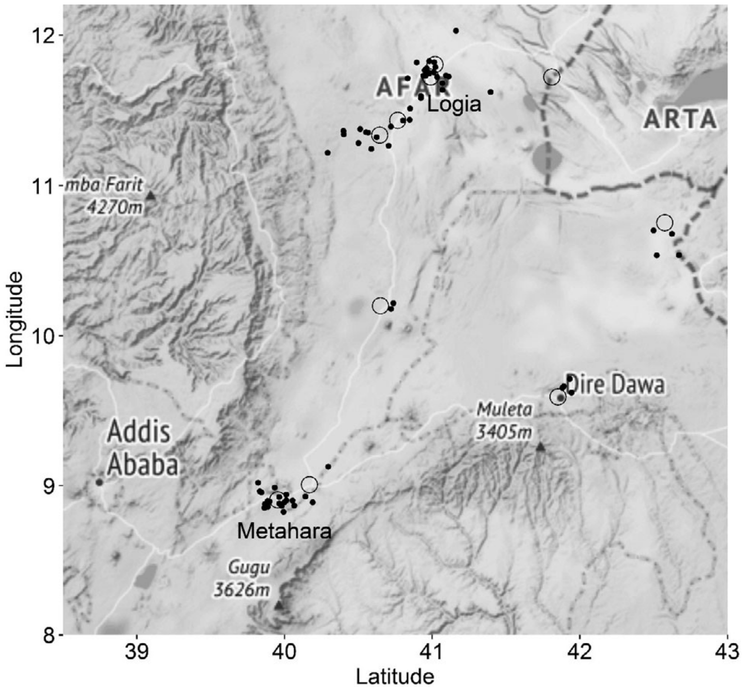

Figure 1. Map of the study area in north-eastern Ethiopia showing places where we conducted surveys of powerlines to detect bird mortality (black dots, $n = 67$), and conducted interviews with rural stakeholders (unfilled circles, $n = 68$ interviews in 10 areas) in 2019.

Surveys to find bird carcasses

Electrocution at and collision with power distribution infrastructure is a recognised major threat to many large birds in Africa, and frequently occurs in the vicinity of sites that regularly attract large numbers of birds, such as rubbish dumps, abattoirs, and permanent water bodies (Jenkins *et al.* 2010, Angelov *et al.* 2013, Bernardino *et al.* 2018). To quantify the extent of electrocution and collision mortality we therefore conducted surveys under power distribution lines that were expected to pose a high risk due to their location near permanent water or food sources or roosting sites. We surveyed low- to medium-voltage distribution lines that were supported by single poles with a cross-bar and conducting wires propped up above the support structure (Figure 2), as these designs are the most dangerous for electrocution (Lehman *et al.* 2007, Eccleston and Harness 2018). This design is also used by the National Electrification Programme in Ethiopia (Figure 2), and similar lines connecting up to 1 million new households to electricity are anticipated to be built every year until 2025 (Government of Ethiopia 2019).

Surveys were conducted by two or more observers walking or slowly driving under each powerline and searching the ground and any adjacent vegetation where scavengers may have dragged collision or electrocution victims (Costantini *et al.* 2017). Any carcass or remnants of a carcass were identified to species, and the likely cause of death was recorded as electrocution or collision based on the location of the carcass and any recognisable injuries. Species and causes of mortality that could not be identified were recorded as 'unknown'. The length of surveys ranged from 100 m to 35 km depending on the length and accessibility of powerline sections that met our criteria of high electrocution and collision risk. The start and end points of each survey, and the length of each surveyed line, were recorded with GPS. We performed surveys during the day

Figure 2. New power poles erected in 2019 as part of the National Electrification Programme near the Metahara Export Abattoir, a reliable food source for vultures. Based on mortality at other powerlines in this area, and the dangerous design of this new infrastructure, globally threatened vultures will likely be killed by this line every year. Inset shows detail of support structure of an already existing line with a Black Kite *Milvus migrans*.

between 07h00 and 18h00 hrs local time on 12 days in January, eight days in June, one day in October, and five days in December 2019. Because high mortality observed during a primary survey could have potentially been caused by chance, we re-surveyed two areas repeatedly (near Metahara and Logia; Figure 1) to exclude that the high mortality found under those lines during the first survey had occurred solely by chance. In Logia, a dangerous line that was constructed in 2017 under the National Electrification Programme was surveyed three times (January, June, December 2019), while in Metahara a new line was still under construction in December 2019. We therefore surveyed similar already existing lines in the vicinity in January, June, and October 2019 to document whether high mortality occurred only at certain times of the year. These repeated surveys occurred long enough apart that double counting due to carcass persistence was extremely unlikely (Barrientos *et al.* 2018), and we therefore present the average mortality rate separately for each month and location.

We summarise and present results as the relative number of victims per km of powerline, but caution that this will be a minimum figure as factors that influence detection and persistence probability of carcasses are not accounted for by our method (Bellan *et al.* 2013, Etterson 2013, Korner-Nievergelt *et al.* 2015). Carcass consumption and removal by scavengers, carcass loss through burial in wind-drifted sand, and inability to detect carcasses due to vegetation are the key factors that may affect the number of detected victims (Costantini *et al.* 2017, Barrientos *et al.* 2018). While the powerlines we searched were in relatively similar semi-desert and savannah habitats, with similar scavenger communities, it was not possible to quantify carcass loss rates, so our estimates must therefore be considered as minimum rates.

Interviews with livestock owners

We conducted interviews with people inhabiting rural Afar and Oromia primarily to quantify the frequency of use of poisonous substances, because many vultures in Africa are inadvertently killed when carcasses laced with poison are used to eliminate livestock predators (Ogada *et al.* 2015, Murn and Botha 2018, Safford *et al.* 2019). We therefore conducted interviews with people who either own livestock, or may have other conflicts with wildlife (e.g. raiding or trampling crops) that could conceivably be resolved with poison (Santangeli *et al.* 2016, Craig *et al.* 2018). However, our interview questions had an open and general design, and in each interview rural people were asked only two general questions: (1) what are your main problems in raising livestock or growing crops? and (2) what solutions do you routinely employ to overcome these problems? We did not ask specifically for the use of poison, and we did not ask specifically for the effects of *P. juliflora* invasion, because we were not aware of the potential effects of *P. juliflora* when we designed the interviews.

We selected people in 10 general areas of north-eastern Ethiopia (Figure 1) who owned livestock or grew crops and were willing and temporally available to participate in the research. Interviews were conducted between 24 January and 18 December 2019 in a semi-structured conversation in the local language of rural people by a local associate who translated responses back to researchers. All participants were informed of the research prior to the interview commencing, no names or other identifying characteristics were recorded, and all participants were given the opportunity to discontinue the conversation at any time (St John *et al.* 2014). The procedures were approved by the Human Ethics Research panel of the RSPB in 2018. Interviews were either conducted with individuals or with groups consisting of 2–12 people, and the age group, gender and education level of participants was noted.

Answers were categorised into six different themes to portray problems (habitat availability, climate, invasive species, disease, predation, other), and into eight different types of solutions (migration, guarding/chasing, fencing, shooting, trapping, poisoning, medicine, and other solutions). The frequency of answers was summarised per interview regardless of the number of people participating in the interview, because group interview participants provided a single collective answer and not independent answers.

Results

Bird electrocution and collision

We conducted 67 transect surveys to search for electrocution and collision victims under powerlines, covering a total of 227 km. During these surveys we found a total of 79 bird carcasses of 11 species, including 34 carcasses of four globally threatened vulture species (0.15 vultures / km; Table 1). Spatial distribution of mortality was aggregated, with few carcasses found along lines in open desert habitat, but large numbers of carcasses found near areas that routinely attract large numbers of birds, such as rubbish dumps, water sources, or abattoirs.

The highest encounter rate of bird carcasses per km of powerline occurred next to abattoirs in Metahara and next to the rubbish dump in Logia along a new power distribution line that had been built in 2017. Repeated surveys along those lines indicated that at least 0.67–10 dead birds / km could be found three times per year (Table 2). In December 2019, a new 5-km power distribution line with the typical hazardous pole design was under construction next to the Metahara export abattoir (Fig. 2), where our surveys found very high mortality in every month we surveyed.

Interviews with livestock owners

We interviewed a total of 190 people during 68 distinct interviews in 10 areas of north-eastern Ethiopia. The majority of participants (57%, Table S1 in the online supplementary material) were men 30 years of age or older with no formal education, and only 16% of participants had formal primary or secondary school education. Our interviews revealed that 87% of respondents experienced problems with carnivores that occasionally attacked their livestock, 43% highlighted drought and climate as problem and 38% mentioned diseases transmitted by ticks. The threat of carnivores was exacerbated by the invasive species *Prosopis juliflora*, which was highlighted in

Table 1. Number of bird carcasses encountered along 227 km of surveyed low- and medium-voltage power distribution lines in eastern Ethiopia in 2019. 'IUCN' indicates the global threat classification for each species on the IUCN Red List; CR = Critically Endangered, EN = Endangered, NT = Near Threatened, LC = Least Concern.

Species		IUCN	Collision	Electrocution	Other cause of death
Hooded Vulture	*Necrosyrtes monachus*	CR	1	8	2
White-backed Vulture	*Gyps africanus*	CR	4	2	0
Rüppell's Vulture	*Gyps rueppelli*	CR	4	2	0
Egyptian Vulture	*Neophron percnopterus*	EN	4	6	1
unidentified vulture	*Gyps* sp.		3	0	0
Verreaux's Eagle Owl	*Bubo lacteus*	LC	0	1	0
Yellow-billed Kite	*Milvus aegyptius*	LC	1	5	2
Marabou Stork	*Leptoptilos crumenifer*	LC	5	3	1
Abdim's Stork	*Ciconia abdimii*	LC	0	3	0
Sacred Ibis	*Threskiornis aethiopicus*	LC	1	2	0
Lesser Flamingo	*Phoeniconaias minor*	NT	1	0	0
Hamerkop	*Scopus umbretta*	LC	1	0	0
unidentified bird			10	5	1
TOTAL			**35**	**37**	**7**

Table 2. Encounter rate (dead birds / km) of bird carcasses along powerlines at Metahara and Logia in different months of 2019. Note that these encounter rates are minimum estimates of mortality because they do not account for carcass disappearance.

Location	Month	Survey effort (km)	No. of bird carcasses	Bird carcasses / km	No. of vulture carcasses	Vulture carcasses / km
Metahara	Jan	10.5	25	2.39	11	1.05
	Jun	3.5	10	2.86	9	2.57
	Oct	0.5	5	10.00	5	10.00
Logia	Jan	1.5	6	3.00	2	1.00
	Jun	1.5	1	0.67	1	0.67
	Dec	1.5	5	3.33	3	2.00

36.8% of interviews. This evergreen bush provides cover for carnivores, and the expansion of *P. juliflora* was therefore reported to facilitate more frequent attacks by carnivores on livestock.

Given that predation by carnivores was the most frequently stated problem, many of the reported solutions revolved around how livestock could be protected from predators. The most common solution to control the problem of predators was shooting (68%), but this practice was again complicated by the invasion of *P. juliflora*, which provided predators cover and rendered shooting more difficult. As a consequence, 45.6% of interviews revealed that some people have used poison to kill predators, especially since *P. juliflora* reduced visibility and limited the effectiveness of shooting.

A broad range of poisons were used, ranging from medicine that was administered to reduce tick infestation of livestock (e.g. Diazinon), through a range of easily available pesticides (e.g. Malathion), rodenticides, to soil extracts obtained from intensive pesticide applications in cropland. Many people were aware that poisoning could have negative consequences on other wildlife, and that the availability of poison had declined, making it harder to use this approach: 16% of respondents that mentioned poison as a solution indicated that poison was used more frequently in the past. The solution to infectious diseases transmitted by ticks was medication which used to be readily available from pastoral and agricultural offices. This medication could also be misappropriated as poison in carcasses to kill predators. Some people (5%) complained that there was no longer sufficient support from pastoral and agricultural offices to provide tick medication, potentially leading to a higher incidence of infectious diseases.

Discussion

The pursuit of sustainable development goals may undermine essential environmental services to the detriment of the human population if biodiversity impacts are not adequately considered in design and delivery of associated projects. We show that the expansion of dangerous electricity infrastructure and the invasive plant *Prosopis juliflora* pose direct and indirect lethal threats to globally threatened vulture populations in Ethiopia, and thus jeopardize the provision of valuable ecosystem services by these scavengers (Ogada 2014, Safford *et al.* 2019). The threat of dangerous electricity infrastructure could be easily mitigated by altering the design of new infrastructure and by retrofitting already existing infrastructure (Guil *et al.* 2011, López-López *et al.* 2011, Badia-Boher *et al.* 2019). The indirect threat of poisoning that is exacerbated by the expansion of *P. juliflora* will, however, require the development of socio-economic solutions to fundamental livelihood problems of pastoralists living in rural Ethiopia (Coppock *et al.* 2005, Argaw 2015, Bekele *et al.* 2018, Shiferaw *et al.* 2019a).

Our study shows actual mortality, but we cannot derive an accurate estimate for the potential impact on Ethiopia's vulture populations, as the sizes of these populations are poorly known (Buechley *et al.* 2021b). Extrapolations to understand the country-wide death toll are also extremely speculative due to the non-homogenous distribution of vultures, which is unlikely to completely overlap with areas where electricity infrastructure will be constructed (Buechley *et al.* 2021b). Nonetheless, if we use cost extrapolations of planned power grid densification, intensification, and extension schemes (Government of Ethiopia 2019), we coarsely estimate that by 2030 an additional 21,826 km of low- and medium-voltage power distribution lines may be constructed in Ethiopia. If these lines use the same hazardous design as the lines in our study area (Figure 2), and if we extrapolate our overall average carcass encounter rate of 0.15 dead vultures / km across this newly established network, the potential death toll could be >3,000 vultures every year along this new network alone. Similarly, the two newly built lines (5 km in Metahara, 1.5 km in Logia) from where we have direct observations (Table 2) could alone be responsible for the mortality of at least 30 globally threatened vultures every year if our average carcass encounter rates are extrapolated over an entire year. We caution that these extrapolations are highly speculative and rely on untested assumptions, such as a uniform distribution of vultures and risk, and that vulture carcasses did not persist for many months and were therefore counted repeatedly. The extrapolated number is therefore surrounded by large uncertainty. Nonetheless, the order of magnitude of extrapolated mortality suggests potentially enormous negative effects that poorly designed power infrastructure constructed for universal access could extol on vulture populations.

We urge funders and policy makers to revise the design requirements for infrastructure and develop infrastructural standards that reduce risk for biodiversity and resulting ecosystem services. Such legally backed standards will guide deployment of safe infrastructure beyond the National Electrification Programme in Ethiopia. Our study shows that in certain areas, the dangerous design of new power distribution lines causes the loss of vultures. Deployment of similar infrastructure near attractive feeding or roosting areas across the country will likely cause bird mortality that could be orders of magnitude larger than our localised study suggests and could have disastrous consequences to Ethiopia's resident vultures and to migratory populations wintering in Ethiopia (Arkumarev *et al.* 2014, Buechley *et al.* 2018, Phipps *et al.* 2019). Numerous guidelines exist on how to design and deploy bird-safe electricity infrastructure (AEWA 2012, BirdLife International 2015, Martín *et al.* 2019), which are both feasible and affordable in Africa. For example, an equally hazardous powerline near Port Sudan (Angelov *et al.* 2013) was replaced with bird-safe infrastructure in 2014 solving bird electrocution problems.

Modification of electricity transport infrastructure not only benefits biodiversity, but also the goal to provide reliable electricity to human households. Bird electrocution causes power outages which can result in substantial economic costs (D'Amico *et al.* 2018, Moreira *et al.* 2018). Avoiding electrocution of birds through better designed electricity infrastructure would therefore result in economic benefits and improved quality of power supply.

Besides the risk of electrocution, we further show that the risk of inadvertent poisoning has likely increased by the spread of the invasive plant *P. juliflora*. Although some people derive value from using *P. juliflora* for firewood, the majority of pastoralists in Afar would willingly contribute to its removal (Tilahun *et al.* 2017). Our interviews revealed that pastoralists used to control livestock predators with weapons, but due to the invasion of *P. juliflora* they are more likely to use poison as predators are no longer visible in dense *P. juliflora* stands. Out of nine individually marked Egyptian Vultures that perished in our study region in Ethiopia between 2016 and 2020, at least three (33%) died from poisoning (Buechley *et al.* 2021a, Oppel *et al.* 2021), which suggests that poisoning poses a real risk to vulture populations, although the magnitude of that risk is difficult to quantify (Ogada 2014). While the use of lead shot to kill animals may also have negative consequences on scavengers through the ingestion of lead fragments, poison residues in carcasses are more likely to cause mortality than the ingestion of lead fragments. Poison use may have been more common in the past when toxic substances were more easily available, but the spread of the invasive *P. juliflora* may increase the propensity to use poison and further increase the detrimental effect on Africa's predators and scavengers. We therefore reiterate the recommendation that the import, manufacture, sale, and use of toxic substances needs to be more effectively regulated and enforced to minimize mortality risk to wildlife (Ogada *et al.* 2015, Botha *et al.* 2017).

Solutions to reduce the incidence of poisoning are complicated and will require community-specific approaches (Perry *et al.* 2020), such as a diversification of household income sources to reduce total dependency on livestock (Davies and Bennett 2007, Romañach *et al.* 2007, Tsegaye *et al.* 2013). Potential improvements to protect livestock from wild predators are enclosures (Lichtenfeld *et al.* 2015), protective collars (Khorozyan *et al.* 2020), distraction displays (Radford *et al.* 2020), or guard dogs (Khorozyan and Waltert 2019, McManus *et al.* 2015; van Bommel and Johnson 2012), but many of the pastoralists we interviewed already use enclosures, and dislike dogs because they are considered as 'impure' under their Muslim faith (Subasi 2011). Alternatively, improvements to veterinary care (without using non-steroidal anti-inflammatory drugs that cause kidney failure in vultures) and access to water and food resources may increase the health of livestock populations and could directly reduce predation risk (Khorozyan *et al.* 2015). Lastly, the economic impact of livestock predation could be offset by other sources of income (Jackson and Wangchuk 2004, Romañach *et al.* 2007). The ultimate cause of livestock predation by natural predators, however, is the loss of natural habitats and wildlife populations that serve as principal prey for predators (Kebede *et al.* 2012, Amaja *et al.* 2016). Large scale restoration of natural habitat and wildlife populations may therefore be one of the best mitigation strategies against livestock predation. In the meantime, however, it will be important to raise awareness of rural stakeholders to the devastating consequences of poison use on non-target species which provide critical ecosystem services for the community (Ogada 2014, Ogada *et al.* 2015). Education campaigns can help to reduce the use of poisonous substances against wildlife and thus benefit vulture populations (Sanz-Aguilar *et al.* 2015, Ntemiri *et al.* 2018, Badia-Boher *et al.* 2019).

In summary, the pursuit of sustainable development goals is expected to improve the well-being and livelihoods of people in many countries. However, the direct and indirect consequences of any measures to improve human livelihoods should be carefully evaluated before implementation to prevent the erosion of valuable ecosystem services that will ultimately reduce human well-being.

Supplementary Material

To view supplementary material for this article, please visit http://doi.org/10.1017/S0959270921000307.

Acknowledgements

This work was carried out in the framework of the LIFE+ project "Egyptian Vulture New LIFE" (LIFE16 NAT/BG/000152, www.LifeNeophron.eu) funded by the European Union and co-funded by the A. G. Leventis Foundation and the BirdLife GEF/UNDP Migratory Soaring Birds project. We appreciate the support during fieldwork by Lubomir Peske, Clementine Bougain, Paul Apeverga, Sulaiman Muhammad, Mekonnen Kassa, Samson Zelleke, Behailu Abraham, Nora Juhar, and Amin Seid. Permission to conduct research in Ethiopia was granted by the Ethiopian Wildlife Conservation Authority and we appreciate the support of Dr Fanuel Kebede. We thank Joelene Hughes, Sorrel Jones, Michael McDonald, Richard Bradbury, Andrea Santangeli and Vanessa Berrie for helpful discussions on how to design questionnaires and evaluate responses. The manuscript was greatly improved by constructive comments from Evan Buechley, Antoni Margalida, and an anonymous reviewer.

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