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A conservation criminology-based desk assessment of vulture poisoning in the Great Limpopo Transfrontier Conservation Area

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ABSTRACT

Vulture declines are uniquely problematic for socio-ecological systems because they are nature's most important scavengers. Intentional and unintentional poisoning, human-wildlife conflict, energy infrastructure, belief-based use, and illegal hunting activities remain threats to vulture populations across Africa. Conservation stakeholders have identified evidence that a number of vulture species in particular ecosystems are being systematically targeted by poisoning with potentially significant effects on human, wildlife, and ecosystem health. We explored the extent to which an interdisciplinary, expert team-based approach linking conservation and criminology could help inform efforts to prevent poisoning of Africa's vultures. We used the case of illegal vulture poisoning and conservation in the Great Limpopo Transfrontier Conservation Area (GLTFCA), a known poisoning site, as an exemplar. We used an interdisciplinary framework, conservation criminology, to guide a desk assessment of how the local environment may create opportunities for illegal poisoning. Our assessment was conducted as a science team and included multiple iterations and structured discourse. The assessment identifies different elements of vulture poisoning and the opportunity factors that can both underly the problem and inform prevention strategies and tactics. We discuss controlling tools and weapons, extending local guardianship, denying benefits, reducing frustration and stress, and assisting compliance to help prevent illegal poisoning. Results provide insights into

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harm prevention using evidence-based theory and illustrate the positive potential of interdisciplinary team science for vulture conservation. With additional application, monitoring and evaluation, strategies and tactics explored in this desk assessment may be revised and implemented and portend other benefits for vulture conservation beyond poisoning; the spread of beneficial influence could be a welcome force multiplier for this important scavenger guild.

Vultures are among the most threatened groups of birds worldwide (Ogada et al., 2012b; Buechley and Şekercioğlu, 2016). The International Union for Conservation of Nature (IUCN) currently lists 69% of all vulture species as Threatened or Near Threatened, and the majority of these are classified as Endangered or Critically Endangered (BirdLife International, 2015). Worldwide, vulture declines are being driven by poisoning, electrocutions and collisions with energy infrastructure, harvest for illegal trade and bushmeat, and land-use changes, among other human-related activities (Botha et al., 2017; Buij et al., 2016; Meretsky et al., 2000; Pain et al., 2003; Thiollay, 2006). Vulture declines are problematic for socio-ecological systems because they are nature's most important scavengers. They provide a significant ecological service by disposing of carcasses more rapidly and efficiently than any other vertebrate scavenger (DeVault et al., 2003; Ogada et al., 2012a), which is likely to reduce the prevalence of disease transmission within ecosystems.

Africa's vulture populations are emblematic of worldwide loss in biodiversity in that in just three generations, seven species have declined by at least 80%, four species have been uplisted to Critically Endangered and two species to Endangered (BirdLife International, 2015; Botha et al., 2017). The range and extent of threats facing Africa's vultures are more varied compared to those of south Asia, but all are directly or indirectly associated with anthropogenic factors. Various forms of unintentional and intentional acute poisoning are known to be the primary drivers of declines in Africa (Ogada et al., 2016).

1. The criminogenic scope and scale of vulture poisoning in Africa

Intentional and unintentional poisoning remain serious threats to vultures despite many African countries having legislation that specifically addresses the use of poison for killing wildlife (e.g., Ogada, 2014). Agricultural and pest control chemicals may be regulated for legal use but are either unintentionally or intentionally used to kill vultures (Botha et al., 2017; Ogada et al., 2012a); chemicals remain readily available and are known to be traded through licit and illicit channels in both small and large quantities. Research on white-backed vultures (*Gyps africanus*) suggests poisoning has substantial demographic impacts and variations in exposure to poisoning can produce measurable demographic differences in spatially adjacent sub-populations (Monadjem et al., 2018). Poisoning may occur concomitantly with human-wildlife conflicts (Mfunda and Røskaft, 2011), belief-based uses (Buij et al., 2016; Williams et al., 2014), and collisions with, and electrocutions on, energy infrastructure (Boshoff et al., 2011; Jenkins et al., 2010).

Vultures, and other scavengers, are often at risk of intentional and unintentional poisoning because of human-wildlife conflicts. The existence of mammalian carnivores adjacent to and within human communities can place significant financial and emotional strain on livestock owners and game ranchers when their animals are depredated. Livestock owners may illegally lace fruit, meat, animal carcasses, and waterholes with poison, such as highly toxic pesticides, to kill animals such as lion (*Panthera leo*), cheetah (*Acinonyx jubatus*) or black-backed jackal (*Canis mesomelas)* in retaliation for depredation, or proactively to prevent depredation (Hübschle, 2019). Wide-spread crop damage from large mammals such as elephants (*Loxodonta africana*), buffalo (*Syncerus caffer*), and hippopotamus (*Hippopotamus amphibius*) can also result in wildlife poisoning, which, in turn, causes the death of scavengers, including vultures (Botha et al., 2017).

The cross-border trafficking of pesticides is a concern in southern Africa; chemicals banned in their source countries (e.g., United States, European Union) are deposited at bargain prices (Hübschle, 2019). The types of poisons used in the Great Limpopo Transfrontier Conservation Area (GLTFCA), for example, across all reported incidents include aldicarb, carbamate, carbofuran, methamidophos, organophosphate, and strychnine (Hübschle, 2019). Sometimes, these chemicals are counterfeited and smuggled by criminal networks into South Africa from Mozambique and Zimbabwe (Hübschle, 2019). The impacts of these chemicals can cascade across ecosystems as they indiscriminately poison nontarget carnivores, insects, and scavengers including vultures. These chemicals present significant human and environmental threats beyond those to vultures (Moshi et al., 2015). Hübschle (2019) reported at least one confirmed human death from exposure to poison in Sengwe Corridor, with several more deaths unverified. Livestock can suffer from weight loss after ingesting poisoned water or food (Hübschle, 2019). We know human-wildlife conflicts cluster in space and time according to socio-ecological, temporal, and spatial qualities in the environment (Carter et al., 2012), and wildlife species are differentially vulnerable to conflicts with humans (Kahler and Gore, 2015). Recorded poisoning incidents can also cluster (Fig. 1).

Belief-based use is an umbrella term that incorporates a wide range of culturally-grounded medicinal, psychological, spiritual, ritual, and occult practices that require the harvest and consumption of vultures or their body parts (e.g., claws, bones, skulls, kidneys, skin). Belief-based use contributes to almost 30% of vulture deaths that have been recorded across the African continent (Ogada et al., 2016). Many species of birds and their body parts are harvested for market trade; the birds are

often killed directly with poisons or collected as a by-product of poisoning events associated with other activities (e.g., human-wildlife conflict, poaching). Belief-based use of wildlife often tracks temporal dimensions of culture, such as holidays or life-cycle events (e.g., holding a vulture skull can enable one to predict the future, wearing vulture skin during circumcision as part of the ritual process) (Craig et al., 2018). McKean et al. (2013) reported that there are an estimated 59,000 vulture-part consumption events in South Africa each year, involving an estimated 1250 hunters, traders, and healers. Multidisciplinary inquiry incorporating market surveys and direct observations and documenting belief-based use and demand for vulture products is spatially concentrated in Western and southern Africa (e.g., Craig et al., 2018; Williams and Whiting, 2016). The literature suggests that the limited reporting of vulture belief-based use in Northern, Eastern, and Central Africa (e.g., Kendie et al., 2018; Nikolaus, 2011; Odino et al., 2014; Ogada and Buij, 2011) should not be interpreted as a lack of vulture belief-based use or a non-existent belief-based use trade. As with human-wildlife conflict, indiscriminate risks from chemical- use to kill

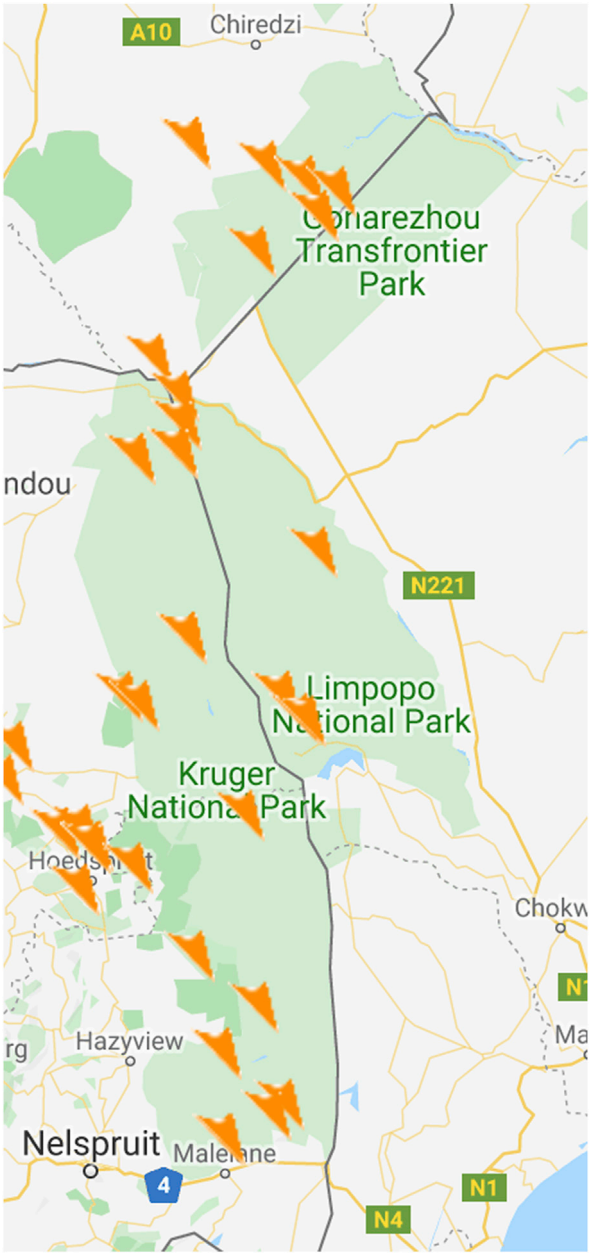

Fig. 1. The African Wildlife Poisoning Database provides open-access data of recorded vulture poisoning incidents in the Great Limpopo Transfrontier Conservation Area (1986–2019), which indicate some degree of spatial clustering. Each lightning strike indicates a single poisoning event, at which the death of multiple species may be recorded.

vultures for belief-based purposes have substantial human-health implications because traders, healers, and end-users of vulture parts may come into contact with poisons during belief-based use of vultures.

The dramatic increase in elephant poaching for ivory in southern Africa, in particular to supply the global illegal wildlife trade, has preceded and been linked to huge increases in mass poisoning events of vultures (e.g., Groom et al., 2013); elephant poaching for ivory is highly concentrated in space and time (Wasser et al., 2015). Vultures "circle" in the skies above a carcass when scavenging. This circling behavior serves as one of many sentinels for law enforcement authorities, who can use vultures as a cue to help them locate illegal hunting activities and potentially enhance their ability to apprehend illegal hunters via surveillance and/or forensic science (Ogada et al., 2015; Funda, 2019). Some poachers in East Africa have adapted their process of crime commission; they deliberately lace elephant carcasses with fast-acting toxic pesticides to prevent vultures from signaling to law enforcement and other authorities the presence of a dead animal, an action referred to as "sentinel poisoning" (Ogada, 2014; Ogada et al., 2015). Between 2012 and 2014, 11 sentinel poaching incidents were recorded across seven, predominantly southern African countries, where 155 elephants were killed and de-tusked and 2044 vultures were poisoned (Ogada et al., 2016). A significant number of vultures can be killed at a single poisoned elephant carcass. Until recently, the highest mass mortality recorded to date was >500 vultures found dead in Bwabwata National Park, Namibia in 2013 after feeding on a single poisoned elephant carcass (Ogada et al., 2016). In June 2019, 537 vultures, of five species, were killed by elephant poachers in northern Botswana (de Greeff, 2019). Vulture mortalities from poisoning events associated with elephant poaching for ivory have increased more rapidly than other types of poisoning (e.g., retaliating for human-wildlife conflict) accounting for one third of all vulture poisonings recorded in Africa since 1970 (see Fig. 1 in Murn and Botha, 2018). Sentinel poisoning has particularly acute and negative impacts on local vulture populations, and unchecked sentinel poisoning will likely cause spatially-explicit local extinction of white-backed vultures in Kruger National Park, South Africa, in less than 60 years (Murn and Botha, 2018).

Since 2014, lion poaching for belief-based use has added a new aggravation for local vulture conservation. This is according to lion ecologists that study populations in the Great Limpopo Conservation Unit, which overlaps with a portion of the GLTFCA. In Mozambique's Limpopo National Park, the targeted poaching of lions for body parts accounted for 61% of known human-caused mortality between 2011 and 2018 (total lions = 17), with a clear increase in pressure in 2014; approximately half of lions killed for retaliatory purposes have been recorded with body parts removed (Everatt et al., 2019). Lion skeletons, bones, heads/face, paws, teeth, stomach fat, and claws have all been removed for trinkets or muthi (i.e, traditional medicine). Everatt et al. (2019) documented evidence of a slight shift over time in the types of body parts being removed, from skin and meat being dominant prior to 2014 and faces and paws after 2014. They found poison was the most common means of killing lions, and in Machampane, Mozambique, poisoning accounted for 61% of all mortalities.

The impact and range of poisoning on Africa's vulture populations, and thus socio-ecological systems, is significant. Human decisions and behaviors underlie these poisoning activities and are a primary source of risk to these populations. To be sure, not all stakeholders are interested in conserving vultures or are concerned with impacts associated with poisoning scavengers. Further, we note that neither in this paper, nor in the team science exercises preceding the article, were we explicitly advocating for the criminalization of those involved in vulture poisoning, nor necessarily for increased law enforcement activities, as this may be detrimental to rural populations who are dependent on bushmeat (Bowen-Jones et al., 2003). However, the ripple effects present in the socio-ecological system within which vultures reside pose increased risks to human populations due to the potential proliferation of disease and other outcomes resulting from the removal of these efficient scavengers. Regulations exist to control risks associated with poison, yet violations of the rule of law persist. Such noncompliance undermines conservation activities, designed to conserve vultures and other wildlife species, and support for sustainable rural livelihoods such as avitourism endeavors or building wildlife economies (Biggs et al., 2011; Space for Giants, 2019).

Most of these aforementioned scientific aspects of vulture poisoning have until now been restricted to the purview of conservation biology and applied ecology disciplines; harms and risks associated with human-wildlife conflicts, intentional poisoning and poaching have been delineated by conservation biology experts and communicated with conservation professionals. Criminology is just starting to be applied in conservation crime/environmental harm contexts (see for example Lemieux, 2014; Moreto and Pires, 2018, Moreto, 2018, Petrossian, 2019; Gibbs et al., 2010; Gore, 2017; Brisman and South, 2019; Hübschle and Shearing, 2018). Criminological explorations of conservation problems are yielding new and diverse theoretical insights, many with effective practical implications for on-the-ground conservation strategies and tactics (e.g., Kahler, 2018; Hübschle and Shearing, 2018). Such conservation crime-based assessments have the ability to complement other conservation interventions guided by social marketing (e.g., Smith et al., 2010)Smith et al., 2010, risk communication (e.g., Gore and Knuth, 2009) or community-based management (Hübschle and Shearing, 2020). Finally, conservation criminology-based assessments can offer new outcome evaluation measures. To these ends, we conducted a conservation criminology-based desk assessment of the illegal poisoning of Africa's vultures, using the case of vulture poisoning and conservation in the GLTFCA as an exemplar.

2. The Great Limpopo Transfrontier Conservation Area

The Great Limpopo Transfrontier Conservation Area is an integrated conservation area across three international boundaries, South Africa, Zimbabwe, and Mozambique. Gazetted in 2002, the creation of the Park was first conceived in 1990. The core area comprises the Great Limpopo Transfrontier Park, one of the first formally established peace parks in southern

Africa, which links three National Parks: Mozambique's Limpopo, South Africa's Kruger, and Zimbabwe's Gonarezhou. It also links Zimbabwe's Sengwe communal land and South Africa's Makuleke region, which lie between Gonarezhou and Kruger National Parks. The GLTFCA measures almost 100,000 km^2 and includes the Great Limpopo Transfrontier Park as well as the Banhine and Zinave National Parks, the Massingir and Corumana areas and interlinking regions in Mozambique (Fig. 2). The GLTFCA comprises various private and state-owned conservation areas in South Africa and Zimbabwe bordering the transfrontier park (Peace Parks Foundation, 2019); it has a number of strategic objectives enumerated in the International Treaty, including fostering transnational collaboration and cooperation, promoting alliances that include diverse stakeholders, enhancing ecosystem integrity, developing transborder ecotourism, facilitating sustainable development, and facilitating exchanges for joint management of the ecosystem. Anti-poaching remains a programmatic priority for the GLTFCA; and the Joint Management Board set up a wildlife poisoning task team in 2016 in response to registered concerns that poisoning was emerging as a major threat to conservation efforts (Hübschle, 2019). Hübschle's (2019) analysis of poisoning events in the GLTFCA reported great variation in frequency of recorded poisoning incidents between 2008 and 2019, with a slight increasing trend.

We chose the GLTFCA as our focal site for this desk assessment because multiple poisoning-related threats to vultures converge in space and time with conservation efforts there. Firstly, there are large numbers of breeding vultures in the area (Murn and Botha, 2016; Murn et al., 2013). Secondly, vultures are illegally harvested for trade in the area, and the use of vulture body parts in belief-basedpractices is prevalent there (McKean et al., 2013; Mdhlano et al., 2018; Mashele, 2020). Finally, it is an area of broad concern for wildlife poisoning events among multiple stakeholders (Murn and Botha, 2018). For example, among the total number of birds reported poisoned in Gonarezhou, Kruger, and Limpopo National Parks between 2008 and 2019, vultures comprised 99%, 78%, and 90%, respectively (Hübschle, 2019). In much of Southern Africa (i.e., Botswana, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe), from April 2009 to April 2019, there were 99 reported wildlife poisoning incidents, with a total of 6932 vultures killed and/or harmed (Africa Wildlife Poisoning Database, 2019). Indeed, as we were finalizing this article, a mass poisoning event occurred in Botswana involving more than 500 vultures, and the event is apparently tied to a spike in elephant poaching for the illegal ivory trade (de Greef, 2019). Of the 99 known vulture poisoning incidents throughout Southern Africa, 15 (15%) occurred in the GLTFCA (Africa Wildlife Poisoning Database, 2019). Note that these are the records contained in the African Wildlife Poisoning Database as of April 2019 and are an underestimate of the frequency of these incidents.

Four vulture species are known to breed in the GLTFCA (Murn et al., 2013; Thompson et al., 2017). A fifth vulture species, the Cape Vulture (*Gyps coprotheres*), forages in the area, but does not breed there (Wolter et al., 2016). All vulture species commonly recorded in the GLTFCA are classified as either globally Endangered or Critically Endangered by the IUCN (IUCN, 2019, Table 1).

2.1. Environmental and conservation criminology

Inherent to the case of illegal vulture poisoning is environmental risk. Environmental risks are the possibility of loss, damage, or other negative outcomes to bio-socio-physical systems, and can arise from disturbances like deforestation, climate change, invasive species, and homogenization or loss of biodiversity. Such human-oriented environmental risks are complex and can be a cause and a consequence of social conflicts, which are not evenly distributed across landscapes. People are not uniformly vulnerable to environmental, and social justice risks, and decision making about environmental and social justice risk management can incorporate layperson perceptions as well as expert assessments. Because environmental risks involve socio-ecological systems, it is often useful to employ interdisciplinary approaches for identifying, reducing and addressing associated harms. Conservation criminology is one interdisciplinary approach integrating principles and practices from conservation biology and natural resource management with criminology and decision science. In this regard, conservation criminology works to capitalize on the strengths and compensates for the weaknesses associated with environmental criminology and situational crime prevention (Gibbs et al., 2010; Gore et al., 2013; Gore, 2017). Conservation criminology informed this desk assessment of illegal vulture poisoning in several overarching ways. In terms of conservation biology and natural resource management, we considered specific vulture species of conservation concern, the key drivers of conservation threats, the impact of threats on wild populations, variation in ecosystem susceptibility, conservation regimes operating in different communities, and public attitudes, perceptions, and values associated with vulture conservation and management. Risk and decision science promoted thinking about different types of risk perceptions and assessments to vultures and people from poisoning, decision-making by local people to use vultures and vulture parts during belief-based use activities, communication of risks to different stakeholders associated with poisonous chemicals, and public perceptions of poisons. Criminology and crime science informed our assessment via consideration of the illegal use, distribution and trade of regulated chemicals, and illegal taking of wildlife for the wildlife trade or human-wildlife conflict. Then, we incorporated insight about how the natural environment creates opportunity structures that underlie vulture poisoning.

Environmental criminology is an umbrella term for a group of criminological theories arguing that crime events can be understood in terms of environmental influences. Further, crime patterns can be analyzed through the socio-ecological, temporal, and spatial qualities of these environments and other immediate circumstances that help make commission of crime possible. Environmental criminology suggests prioritizing a focus on crime events and how and why these events unfold rather than on individual's criminality or criminal motivations (e.g., Petrossian, 2019). One theory within environmental criminology is Rational Choice Theory (see Cornish and Clarke, 1986). Rational Choice Theory deals with the way that

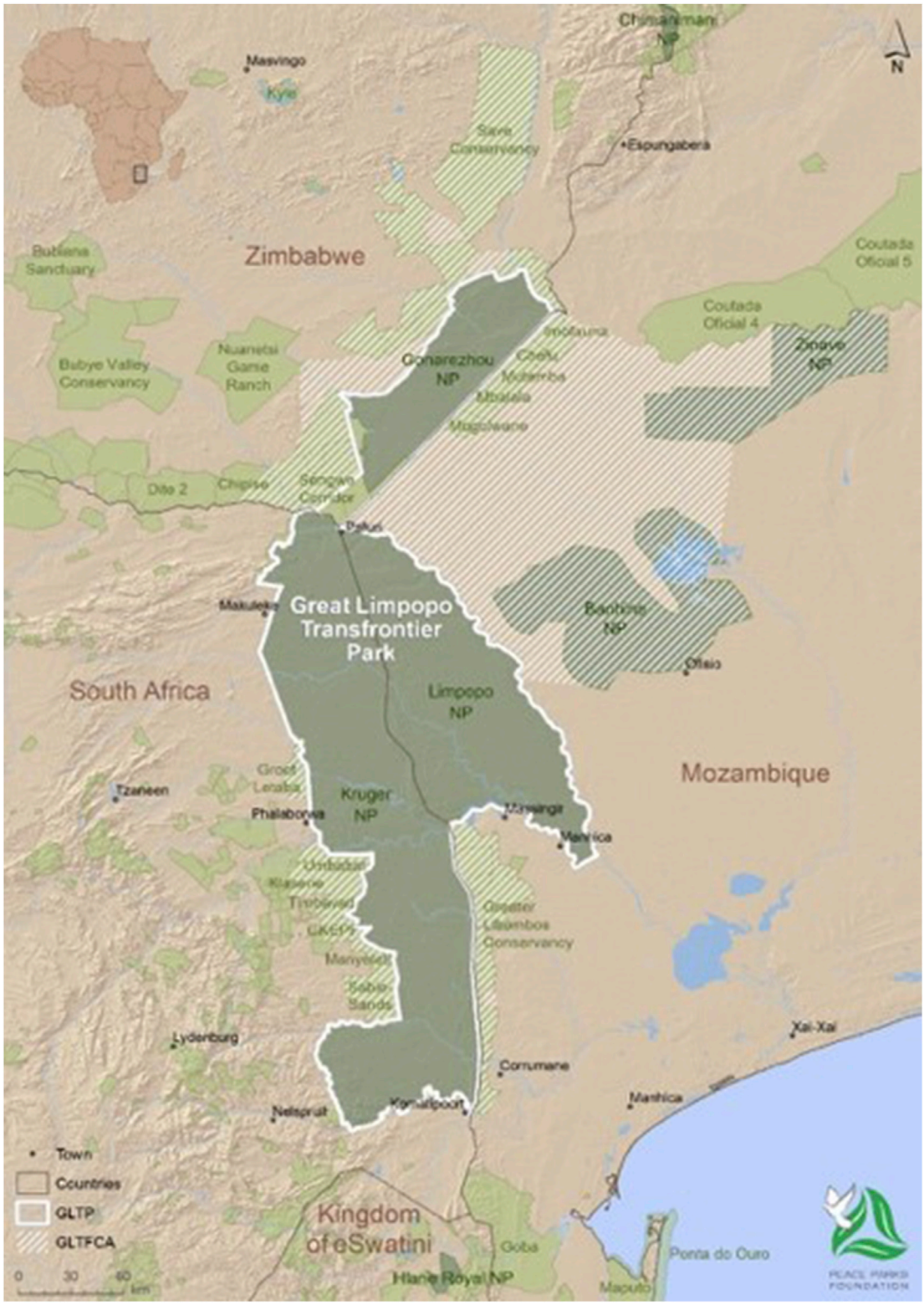

Fig. 2. The Great Limpopo Transfrontier Conservation Area is managed as an integrated unit across three international boundaries and a suite of other private, public, and indigenous/communal lands (Peace Parks Foundation, 2019).

Table 1
Vulture species commonly found in the Great Limpopo Transfrontier Conservation Area. For each species listed the International Union for Conservation of Nature (IUCN) regional Red List Status (i.e., South Africa, Lesotho and eSwatini combined) (Taylor et al., 2015) is equivalent to the global status (IUCN, 2019), where EN = endangered, and CR = critically endangered. * denotes the species is known to breed in the GLTFCA. The general threat categories and poisoning threats are those used and referenced by the IUCN.

Species	IUCN Status	Conservation Characteristics	IUCN General Threat Categories	IUCN Poisoning Threats
Cape Vulture (*Gyps coprotheres*)	EN	Gregarious, cliff-nesting species occupying breeding colonies year-round, endemic to Southern Africa, population currently stable to increasing	Residential & commercial development, agriculture & aquaculture, energy production & mining, transportation & service corridors, biological resource use, human intrusions & disturbance, natural system modifications, invasive species, climate change & severe weather	Inadvertent poisoning through ingestion of poison left for pests, contamination of their food supply (e.g., livestock administered anti-inflammatory drug diclofenac)
Hooded Vulture (*Necrosyrtes monachus*)*	CR	Wide-ranging tree-nesting scavenger occupying multiple habitats including forests, and cities	Agriculture & aquaculture, biological resource use, invasive species, pollution	Non-target poisoning, sentinel poisoning, unintentional poisoning with carbofuran pesticides at livestock baits being used to poison predators
Lappet-faced Vulture (*Torgos tracheliotos*)*	EN	Afro-tropical species ranging across Africa and into Middle East in savanna, plains, deserts and open mountain slopes, solitary tree nester	Agriculture & aquaculture, transportation & service corridors, biological resource use, human intrusion & disturbance, natural system modifications, pollution	Accidental poisoning from strychnine used by many farmers for predator control and increased use of agricultural pesticides, intentional poisoning for traditional medicine, sentinel poisoning, diclofenac poisoning from ingesting treated livestock carcasses
White-headed Vulture (*Trigonoceps occipitalis*)*	CR	Wide-ranging tree-nesting species avoiding human habitation and restricted to protected areas	Agriculture & aquaculture, human intrusion & disturbance, biological resource use, pollution, invasive species	Indirect poisoning at baits set to kill predators, sentinel poisoning, diclofenac poisoning from ingesting treated livestock carcasses
White-backed Vulture (*Gyps africanus*)*	CR	Gregarious, wide-ranging lowland species of open wooded savanna, nesting in loose colonies	Agriculture & aquaculture, transportation & service corridors, biological resource use, pollution	Deliberate and accidental poisoning for belief-based use and to prevent birds from drawing attention to poaching activities

criminal decisions are made by individuals, including decisions about involvement in specific types of crime and decisions about specific criminal events. Potential offenders weigh the costs and benefits of making both of these decisions. Rational choice theory assumes behavior is purposive and rational. However, it is not perfect and offenders sometimes make poor choices and only evaluate immediate risks and rewards.

Crime Pattern Theory deals with the ways that offenders seek and find opportunities for crime in the course of their everyday lives; this concept is focused on the community level. Crime Pattern Theory assumes offending is closely related to places where communities spend their time (e.g., where we pray, play, eat, live, work) and the pathways between them. Offenders choose their targets based on routine pathways they use to move between activity nodes. Crime happens at the intersection of the activity space of offenders, victims, and targets. Success or failure impacts the crime template and routine of offenders. Crime can concentrate in “hotspots” or places, like a street or park, that have an unusually high rate of reported crimes or calls for police assistance. Hotspots can be acute or chronic and develop based on characteristics of the location. For example, hotspots may attract large numbers of people for reasons unrelated to criminal motivation, they may afford criminal opportunities that are well known to offenders, or they may have insufficient regulation of bad behavior. Understanding

crime-place relationships, particularly crime concentrations, helps to provide tactical advice on investigations and deployment of resources for crime prevention and evaluation (Cornish and Clarke, 2003; Wortley and Mazerolle, 2008).

Routine Activity Theory deals with the ways that opportunities arise and decline as a result of societal change. A crime event requires the convergence in time and space of three elements: a likely offender, a suitable target, and absence of a capable guardian. These three elements are specific to the local conservation context. Thus, preventing crime requires "reducing" one of these three elements—any single one, depending on the context, resources, capacity, or political will. Sometimes, likely offenders are addressed through alternative livelihood programs or education and communication efforts. Sometimes, suitable targets can be addressed through ex-situ conservation programs. Sometimes, the absence of a capable guardian is addressed by enhancing capacity for informal guardians. Informal guardians are people that are available and locally-based, knowledgeable, and willing to intervene in direct or indirect ways. A guardian's willingness to intervene and choice of intervention depends on four factors: 1) a sense of responsibility toward the target (theirs or intimate connection), 2) physical competence to intervene, 3) the availability of tools for protection, and 4) the severity of the crime.

Adapting elements of environmental criminology to our conceptual framework thus proposes: 1) opportunity can be a cause of crime (harm), 2) crime (harm)-specific focus is fundamental for understanding the role of situational factors in crime, 3) crime (harm) is concentrated in space and time, and 4) crime (harm) can be reduced (sometimes immediately and dramatically) by situational, environmental, structural, and agency-related changes.

Conservation and environmental criminology can offer action-oriented implications for preventing intentional vulture poisoning events. Specifically, we know situational crime prevention (SCP) can be achieved via interventions targeting two categories of situational factors—reducing the physical opportunities needed to commit a crime and increasing the risks of being caught (see Cullen and Agnew, 2006). Enhancing effective strategies that "increase incentives to comply" with conservation rules is desirable when they provide additional options to expand guardianship, increase transparent conservation practices, and provide incentive-based options to communities (Kahler, 2018). Moreover, the work of Hübschle and Shearing (2018, 2020) shows the importance of rural communities as fulcrum institutions in conservation and wildlife protection. Indeed, these connections are reflected in the United Nations' Sustainable Development Goal 15 (i.e., protect, restore, and promote sustainable use of terrestrial ecosystems). Situational crime prevention (Clarke, 1980) suggests that when thinking about crime, interventionists ideally focus on the specific situations and opportunities that are likely to make the commission of a crime easy. Further, crime opportunities are not distributed randomly in time and space. Certain locations are more crime prone than others and crime occurs during specific time periods (Petrossian, 2019). SCP advances the premise that at the base of every harm is an offender's decision point, weighing the risks and benefits of a behavior in the absence of effective controls and in the presence of a suitable target. Thus, there are always three ingredients that all harms share across space and time: a motivated offender, a suitable victim or target, and a lack of guardianship. When considering these three, 25 SCP techniques can be developed in support of decreasing one or all of the three elements of a crime event (Clarke, 1983) (Table 2); these tactics may also form the basis of a desk assessment. Kahler (2018) proposed, tested, and evaluated an expanded suite of SCP techniques for conservation. The expanded suite better reflected the dominant paradigm in conservation biology and linked it to sustainable development and livelihood preservation, whereby contested illegality, agency, and structure are incorporated into the theoretical framing.

Crime prevention is not a panacea (Clarke, 2013; Smith and Clarke, 2012), and it has not been widely applied in conservation. One critique from traditional crime spaces is that although SCP creates opportunities for prevention specifically tailored for community-level and locally-targeted problems; these strategies and solutions may be less compatible with national-level approaches. SCP is rarely a "one size fits all" type of intervention, although it has the ability to be scaled across contexts. Another critique is that many of SCP's techniques can be considered "hard" and are based on the classical deterrence theory that assume offender agency, hedonism, and rationality. Classical teachings support that individuals want to avoid

Table 2
The twenty-five techniques of situational crime prevention aim to increase the effort and risks of crime as well as reduce rewards, provocation and excuses (Smith and Clarke, 2012). An extended conservation-focused version includes five additional techniques designed to increase incentives for compliance with both the rule of law and rules in use (Kahler, 2018). Our desk assessment of illegal vulture poisoning in the Great Limpopo Transfrontier Conservation Area was loosely informed by these 30 techniques. Not all these strategies may be relevant to the conservation context and in some instances techniques may have collateral impacts in conservation that are generally known to be avoided if possible (e.g., fences and fines approaches to conservation). Foundational references provide comprehensive definitions of each strategy and technique.

Increase Effort	Increase Risks	Reduce Rewards	Reduce Provocation	Remove Excuses	Increase Incentives
1. Harden targets	6. Extend guardianship	11. Conceal targets	16. Reduce frustration and stress	21. Set rules	26. Leverage local communities as guardians
2. Control access to facilities	7. Assist natural surveillance	12. Remove targets	17. Avoid disputes	22. Post instructions	27. Increase transparency of governance
3. Screen exits	8. Reduce anonymity	13. Identify property	18. Reduce emotional arousal	23. Alert conscience	28. Increase use of science in decision-making
4. Deflect offenders	9. Utilize place managers	14. Disrupt markets	19. Neutralize peer pressures	24. Assist compliance	29. Enhance livelihood alternatives
5. Control tools/ weapons	10. Strengthen formal surveillance	15. Deny benefits	20. Discourage imitation	25. Control drugs and alcohol	30. Increase risk of detection

negative outcomes so they intentionally choose to conform to avoid the costs of punishment. In traditional economic theory, the concept of rational choice simply means that if economic conditions change, individuals will change their behavior in response. Some SCP techniques seek to thwart an offender by making it impossible for the crime to be committed no matter what the motivation, mindset, or emotions of the offender. However, SCP does include some "soft" techniques that do not rely on offender rationality or agency to reduce crime and are instead based upon other theories of human behavior. SCP also demands specificity. In other words, SCP's concern is the opportunity structure, not the social structure, associated with crime. Some argue that SCP will lead to displacement of crime (see Guerette and Bowers, 2009 for cogent evaluation of SCP-related displacement as well as diffusion of benefits). The most common type of crime displacement is the shifting of crime from one place to another (i.e., spatial displacement) as a result of an intervention of some kind. Displacement may also occur in respect to time, target selection, one type of offense to another, or a change of tactics. Past studies have provided evidence (Guerette and Bowers, 2009) that the literature supporting situational crime prevention is strong enough to outweigh displacement criticism. To date, there have been few successful studies across the globe on reducing wildlife poisoning using situational crime prevention techniques or using the techniques for a desk assessment; the benefits of SCP to assess and prevent illegal vulture poisoning remain equivocal. Importantly, some scholars advocate for alternative views on crime through alternative lenses to environmental criminology such as chaos theory (e.g., social justice may overcome the global criticality of environmental crises [Takemura, 2010]) or ecocide (e.g., destruction of natural environment to the extent that they are unable to support life [South, 2010]). It is beyond the scope of this manuscript to compare and contrast these theories, however we note our selection of SCP to inform this desk assessment over other approaches because of its empirical support in other criminogenic contexts, crime-specific strengths, and complementarity to other conservation strategies, particularly community-based conservation (Moreto and Pires, 2018).

3. Methods

We used iterative, mixed, and team-of-expert based methods (Morss et al., 2018; Salas et al., 2018; Singleton et al., 1993) to help achieve our objective of a conservation criminology-based desk assessment of vulture poisoning in the GLTFCA. In November 2017, a 20+ member team of academic and non-governmental researchers, government policy makers, and conservation managers from the United States, South Africa, and Kenya converged at the United States-based National Socio-Environmental Synthesis Center (SESYNC) for the first of four in-person meetings intended to study the socio-environmental dimensions of "Saving Africa's Vultures." In this regard, our approach was emblematic or comparable to many "gap analyses" of conservation problems. We liberally adapted the Delphi method to help us achieve our objective; the method leverages expert-based elicitation and iterative opportunities for feedback both in-person and electronically (Trochim and Donnelly, 2001). We also based our assessment on a common conceptual design to facilitate interdisciplinary productivity (Morss et al., 2018; Tobi and Kampen, 2018). Our expert affiliations included scientists and scholarly leaders in community-based conservation, environmental toxicologists, avian conservationists, statistical modelers, anthropologists, ethicists, Geographic Information System specialists, and economists. Because of the variety of professional expertise, and the varied lived experiences, the geographical breadth of our team, the data available to us via our personal and professional networks, and our desire to neither levy collective judgement condoning nor criminalizing local livelihood activities, we chose to focus our efforts on the activity of poisoning over the offenders engaged in the poisoning. We recognized the use of poison can be legal in some circumstances; considering the suite of possible violations of the rule of law and rules in use (Gore et al., 2013) was of interest to us because we felt it best reflected the "in real life" context of vulture conservation in the GLTFCA. Fortunately, several team members had detailed knowledge of the modus operandi, drivers, and push/pull factors associated with poisoning in the region, so our work had more than a criminological perspective.

First, we met in person as a large group for one day, discussed harms associated with vulture poisoning, conservation criminology as a guiding approach, and situational crime prevention as a potential strategy. This large group meeting helped enable a common group understanding and vernacular along with delineation of our objective; our lived personal and professional experiences promoted modifying terminology, crime prevention structure and organization to best suit our team and our collective interdisciplinary "in-real-life" knowledge of vulture poisoning in the GLTFCA. In this regard, a criminologist, ecologist, ethicist, or conservationist may not see the proposed strategy wholly reflect their singular disciplinary dogma. We discussed and identified many of the problems of concern associated with intentional poisoning. To be more specific, we considered the consequences of poisoning for the vultures and people, discussed measures to prioritize consequences, and considered how long intentional poisoning has been taking place. We also worked to identify and understand events and conditions that precced and accompany poisoning as well as resources that may be of assistance in developing a deeper understanding of the problem. We considered what we knew about why the problem is occurring and how the poisoning is currently being addressed.

Second, we broke into self-selected small groups of about 4–7 individuals and began to scaffold possible response strategies and tactics to prevent illegal poisoning. We discussed at length the suite of possible solutions that would help support removing the causes of illegal poisoning. We also considered which stakeholders were best positioned to implement possible solutions and how they might do so. These discussions included brainstorms of new interventions and constant consideration of the local community context, feasibility, efficacy, and cost. Some small group discussions involved concept mapping with white boards and colored markers and projected computer screen images to support collaborative note taking. Small group-work results were consolidated into a single cloud-based Google Doc Editor for team editing.

Third, the team dispersed and engaged in weekly Skype calls, where the desk assessment was edited, revised, and discussed over the course of approximately six months. The lead author consolidated all electronic, small group, Skype, and Google Doc comments and presented a complete draft assessment to the entire group during the next in-person meeting. The assessment was discussed as a group, revisions were made in real-time using the Google Doc projected onto a large screen, and different small groups were reconvened to further refine and revise the strategy. The final assessment was shared electronically, and the large group of authors had two opportunities to revise and edit the assessment as this manuscript was co-drafted. In at least these regards, our assessment is based on multidisciplinary intelligence and analysis. Our approach reflected guiding principles identified for effective collaborative manuscript development in interdisciplinary science teams—transparency, inclusivity, protection and promotion, accountability, efficiency, and productivity (Kowarsch et al., 2016; Oliver et al., 2018). Finally, we engaged local experts with extensive on-the-ground experience with wildlife poisoning in the GLTFCA to seek their input about tactics with the best changes of successful implementation.

4. Results

Our objective was to conduct a conservation criminology-based desk assessment of illegal vulture poisoning in the GLTFCA using a team-based and iterative approach. Results are presented as *potential tactics* for implementation and organized according to six situational crime prevention framework strategies. Documented examples are provided based on open source data available on the African Wildlife Poisoning Database Poisoning Map Tool (Table 3).

Increase Effort. Poisoning vultures is a relatively easy activity that does not require extensive skill or physical effort. As noted by the IUCN, agriculture and aquaculture-based threats are categories of risk relevant to all of Africa's vulture species and thus traverse the continent. Agricultural chemicals are widely available, affordable, and accessible; they are not rigorously regulated and have a long shelf life. In general, border and park officials are thought to have insufficient awareness of chemicals used in wildlife poisoning events and lack mechanisms to identify, safely confiscate and dispose of chemicals during their regular patrols. Existing efforts to manage human-wildlife conflicts are often developed in collaboration with communities and private landowners bordering the GLTFCA, however efforts can fail when compensation schemes for livestock killed or crops damaged by wildlife are ineffective, slow to be implemented, or farmers lack incentives, financial or otherwise, to report rather than poison, problem wildlife. In summary, killing vultures with poison can be an indiscriminate activity. Because of the ubiquity, efficacy, and efficiency of poison, controlling and reducing access to poisons was identified by the team as being most important for increasing efforts to address wildlife poisoning. Tactics which fall under this strategic pillar include:

- Efficient, user-friendly, and enforced licensing systems or certification schemes for chemical sales;
- Awareness and sensitization campaigns promoting safe storage, use, and disposal of unused chemicals and pesticides;

Table 3
Six strategies of situational crime prevention of vulture poisoning in the Great Limpopo Transfrontier Conservation Area may be accomplished using different tactics in specific spaces. Some tactics were intentionally dropped from the desk assessment recommendations after the group deemed them unsuitable given the conservation context (e.g., drugs and alcohol).

Strategic Pillar	Tactic(s) from Desk Assessment	Noteworthy Spaces for Implementing Tactics (based on African Wildlife Poisoning Database)
Increase Effort	Control tools and weapons (e.g., bans of chemical sales in very small quantities; chemical traceability efforts through high and low tech systems)	Human population centers close to park boundaries or transnational borders such as those adjacent to Gonarezhou National Park (e.g., Massangena and Malvernia, Mozambique; Rutenga, Zimbabwe)
Increase Risks	Extend guardianship (e.g., engagement and capacity building of community groups; whistleblower reporting supported by resources surrendered by offenders)	Nature reserves, communal lands, wilderness camps, private lands and game ranches bordering GLTFCA, such as those west and north of Kruger National Park (e.g., Mnisi Tribal Authority Lands)
Reduce Rewards	Deny benefits (e.g., deny full compensation when poison is involved; communication programs in muthi markets)	Muthi markets in Durban (e.g., Markets of Warwick, Victoria Street Market) and Johannesburg (e.g., Faraday Market), South Africa and Maputo, Mozambique (e.g., Xipamanine and Xiquelene Markets)
Reduce Provocation	Reduce frustration and stress (e.g., effective human-wildlife conflict mitigation and compensation; benefit sharing from wildlife economy)	Farm and ranching communities bordering GLTFCA (e.g., Lydenburg, South Africa, particularly communities without fencing and communal conservancies)
Remove Excuses	Assist compliance (e.g., chemical disposal options; poison response plans in high and low tech formats; awareness raising of potentially lethal impact of poisons on domestic animals, people, children, ecosystems)	Fuel stations on major road bordering GLTFCA and close to game reserves, clinics and hospitals in human population centers, park headquarters/gates
Increase Incentives	Leverage local communities as guardians (e.g., sustainable community-based conservation; developed extension functions)	Communal conservancies bordering GLTFCA such as Naivasha Community Conservancy, Zimbabwe and communities surrounding Massingir Dam, Mozambique

- Prohibition of the sale of chemicals and highly hazardous pesticides in small quantities in paper/plastic straws in informal markets;
- Efficient and effective detection, screening, and traceability of chemicals through labeling, signature markers, monitoring and reporting via whistleblower, electronic, paper, and sniffer dog systems; and
- Continued systematic and frequent monitoring of vultures using color-marking and satellite/GSM tags, with data being standardized and shared widely.

Increase Risks. The risks to offenders for engaging in illegal poisoning of vultures remain generally low; offenders are unlikely to be caught or sanctioned. Officials often do not directly acknowledge wildlife poisoning as an environmental crime (Hübschle, 2019). It is unlikely that laws or rules associated with agricultural chemicals will be changed in the near term. However, by design, the land-use mosaic surrounding the GLTFCA includes a diversity of private, public, and communal functions. Although traditional faith and belief systems have long been a heritage of the region, they are not always included in conservation-related issues. There remain opportunities for engaging traditional healers and belief practitioners as well as traditional cultural institutions, like chiefs and their advisory councils or age/status-cohort groups. These influencers can be powerful allies for promoting compliance with anti-poisoning efforts as they are known at times to be friends, family, teammates, or coworkers of offenders; they observe offenders and may be aware of potential future offending. Community and traditional institutions that have authority over various places and spaces adjacent to the GLTFCA can be engaged in collectively punishing and sanctioning offenders if the criminal justice system is insufficient, for example in Mozambique's remote Machampane Wilderness Camp, where white-backed vultures have been poisoned. Importantly, any such measures and methods of crime control should be permissible within appropriate rule of law systems and global human rights frameworks. Enhancing guardianship is key for increasing risks from illegal poisoning. Tactics which fall under this strategic pillar include:

- Low cost, user-friendly whistleblower numbers for mobile phone messaging with reward system for reporting that is supported by resources surrendered by convicted offenders that parallels reporting databases and verified to avoid false planting of poisons;
- Awareness and sensitization campaigns which engage all forms of media, promoting the human health risks of poisoning, with advertisements at markets, bus stations, and taxi ranks, for example in towns such as Hoedspruit, where white-backed and Cape vulture poisoning has been documented, as well as Massingir, Mozambique;
- Engagement and capacity building of existing community groups (e.g., women's groups, farm-watch groups, school children, cross-faith clergy, local chiefs, traditionaltra councils) to serve as local guardians of the GLTFCA, including anti-poisoning activities, for example in South Africa's Ndlovumzi Nature Reserve, where hooded vulture poisoning has been documented; and
- Effective, efficient and sustainable engagement of the medical, clinical, and public health community to monitor and report human and animal mortalities resulting from poisoning and also to maintain chain of custody.

Reduce Rewards. Individuals that poison vultures may derive different types of benefits from the activity, for example expressed belief-based use or reduced human-wildlife conflict. It is possible that individuals practicing or administering muthi (i.e., traditional African medicine) are unaware of the potential negative side-effects of consuming poisoned animal parts. Communities in rural areas adjacent to the GLTFCA may lack capacity or resources to implement human-wildlife conflict mitigation programs that do not involve lethal control. This may help explain documented lion poisoning south of Pafuri in South Africa or around Massingir Dam in Mozambique (although as Everatt et al., 2019 noted, belief-based use of lions is a potentially growing threat). Benefits associated with poisoning may be reduced through tactics including:

- Modifying human-wildlife conflict mitigation programs that provide compensation for depredated livestock to withhold full compensation in instances where poison was involved; and
- Locally appropriate education and communication about human health risks from muthi in multiple languages (e.g., isiZulu, isiTsonga, Shona, Venda, Portuguese, Afrikaans, English) at urban muthi markets such as those in Durban and Johannesburg and rural muthi traders operating in the GLTFCA

Reduce Provocation. Illegal poisoning of vultures is often linked to human-wildlife conflict; particularly cases where individuals or communities experiencing conflict remain frustrated about decision-making processes they feel are uninclusive or perceive there to be unjust benefit sharing from wildlife economy programs designed to incentivize conservation. People may dispute each other over different solutions to conflict (e.g., lethal versus nonlethal control of carnivores depredating livestock). It is important to mitigate the problem of depredation by carnivores before it occurs , encourage better livestock husbandry through optimally designed holding pens, and collaboration with herders so they can inform authorities when issues arise. When individuals or communities poison vultures directly or indirectly (as discussed above vis-à-vis human-wildlife conflict), their behaviors may be imitated by others who are similarly frustrated by a lack of government response to their needs or are involved in disputes with wildlife. Reducing frustration from human-wildlife conflict may be accomplished with tactics such as:

- Transparent and inclusive awareness and sensitization programs building capacity for safe, just, and effective solutions to human-wildlife conflict that does not involve poison;
- Support benefit sharing from wildlife economy initiatives, such as ecotourism in and around Pafuri, on the border of South Africa, Mozambique, and Zimbabwe, where hooded and white-backed vulture poisonings have been documented; and
- Poison buyback programs, perhaps linked to corporate social responsibility campaigns.

Remove Excuses. There exist chemical permitting systems and laws, legislation about permitted use of animal products for belief-based use, and rules for human-wildlife conflict mitigation and compensation schemes (Thompson and Blackmore, 2020). Across the suite of existing policies and laws, consistent enforcement and clear communication rules can be supported, as can consistency in legislation and penalties across range countries. In many instances, the poisoning risks to human and animal health are known and can be more effectively communicated. Old communication materials may be revised or new materials developed and translated into appropriate local languages to effectively communicate human health risks as well as domestic animal risks of handling chemicals and poisoned animal products. Poisoning workshops and training sessions can be developed and formalized as part of an accredited course or competency certificate. Additional tactics for assisting compliance with rules about poisoning wildlife include:

- Support safe, secure, and low/no cost chemical disposal and/or buy back schemes in easily accessible areas in cities such as South Africa's Lydenburg, where Cape vulture poisoning has been documented, as well as in entry gates to parks throughout the GLTFCA such as Mozambique's Massangena; and
- Awareness and sensitization of poison response plans—national, regional or otherwise— for law enforcement officers, informal guardians, traditional healers, and public health/clinic workers, distributed in paper, electronic, and mobile app formats.

Increase incentives. A significant obstacle to reducing the use of poisons is that the benefits from reduced use provide little direct incentive for those that engage in poisoning. Indirect mortality, where vultures are not the target of poisoning, further distance individual behavior from its consequences. Incentive-focused tactics can contribute to increased transparency with local communities, help enable open discussions, and enhance sharing and understanding of different opinions. The United States Agency for International Development's Famine Early Warning System Network, United States Department of Agriculture , United States Fish and Wildlife Service Division of International Affairs, and Kenya's International Livestock Research Institute are well-known examples of these types of extension programs. Incentives can be designed that align with the economic and social interests of local communities using tactics that include:

- Supporting sustainable community-based conservation in areas adjacent to the GLTFCA where policies that encompass traditional value systems and indigenous knowledge are implemented through shared responsibility between multiple institutions, including local guardian programs; and
- Developing extension functions to expressly provide farmers and ranchers with prompt responses based on experience and expertise. Enhancing communication between agricultural extension officers, veterinarians and conservationists in the field could provide further information useful for these materials and products. In this way they will be supporting the overall effort by serving as informal guardians.

5. Discussion

No other functional guild of animals is dominated by a group of so few, and yet such endangered species as vultures (Santangeli et al., 2019). In socio-ecological systems already experiencing harms associated with the illegal wildlife trade and human-wildlife conflicts, the collateral impacts from vulture poisoning on humans and animals may be overwhelming at best and irreversible at worst. The literature is providing new evidence that, unlike declines of other species like white rhinoceros (*Ceratotherium simum)* that face conservation threats from human pressure, declines in obligate apex scavengers such as vultures are likely to drastically alter ecological food webs (e.g., mesoscavenger release hypothesis that proposes mid-sized and less-efficient scavenger populations, referred to as mesoscavengers, can increase in abundance in the absence of competition from larger more efficient scavengers) with implications for carrion removal and disease regulation services (O'Bryan et al., 2019). Preventing poisoning-related harm to vultures is more efficient and effective than *responding* to such events because the impacts of poisoning are often fatal for the birds and other affected wildlife, and not always detectable and potentially unresolvable for humans. Further, Article 11 of the Convention on Biological Diversity encourages parties to adopt measures that are economically and socially sound and act as incentives for conservation and sustainable use of biological resources (UNEP, 1992).

We conducted a conservation criminology-based desk assessment of illegal poisoning of vultures in the GLTFCA. Helping to describe and characterize the conservation, risk, and criminogenic dimensions of the problem advances thinking about strategies and tactics that can be most effective and efficient at prevention. The desk assessment herein can also complement formal, ground-level crime site analyses should they be conducted (e.g.,Hübschle, 2019). Although not a formal crime

analysis, this interdisciplinary and team-based assessment provides novel insight into an as yet unexplored conservation criminology issue. Strategies and tactics are unlikely to be reviewed by all readers as being universally applicable or feasible. However, the goal of the assessment is to provoke thinking, discourse, and interdisciplinary innovation for this conservation crime problem. Financial, human-power, cultural, and other factors would need to be considered alongside a crime-site analysis. Here, we discuss how our desk assessment might be used to inform implementation as well as evaluation of crime prevention tactics.

This multidisciplinary, iterative, and interdisciplinary team-of-experts based exploration linking conservation and criminology produced novel descriptive insight about different tactics that can be used to help prevent the situations that give rise to poisoning of Africa's vultures using the case of vulture poisoning in the GLTFCA. Concomitantly considering the conservation, criminological, and risk dimensions of vulture poisoning in the GLTFCA builds on the rapidly expanding literature on vulture poisoning in Africa. The majority of this literature focuses on building new evidence about explicit risks from poisoning and/or human behaviors associated with those risks (e.g., Monadjem et al., 2018). This meaningful knowledge base lacks interdisciplinary perspectives on the illegality of the activity and how harm can be prevented using evidence-based best practices. For example, many of the highly hazardous pesticides and chemicals mentioned in this article are either legal or their use is socially legitimate; as an example aldicarb and derivatives are legal in Zimbabwe while banned in Mozambique and South Africa with implications for cross-border trafficking and trade (compare with Hübschle, 2019). In particular, the criminological dimension provides new insight into how to reduce noncompliance with rules by focusing on the harm or crime itself and NOT the people involved. In this regard, we neither condone nor criticize the activities of people in pursuit of their livelihoods. Rather, we focus on the harm of poisoning itself. There is utility in this approach because of the preventative implications, but prevention does not attend to responding to higher-level global drivers of poisoning, such as wildlife trafficking, dumping of highly-toxic chemicals by pharmaceutical corporations in the Global South, and overall structural inequalities.

Practically, the tactics characterized herein may inform efforts to reduce illegal vulture poisoning. Importantly, these activities offer opportunities to engage a wide variety of stakeholders and leverage quantitative and qualitative data (e.g., Clarke, 1997). Crime prevention strategies and tactics are most effective at reducing crime rates when they are specific. Some of the tactics were intentionally dropped from our downstream analysis (e.g., control drugs and alcohol) because of our groups' perceived unsuitability of this tactic to the problem. Thus, local cultural institutions, community-based groups, law enforcement authorities, market traders, conservation organizations, extension officers, and others are ideal conceptual and practical collaborators. Collaborators may contribute different financial and human-power resources. How, when and why different stakeholder groups are engaged will depend on the local and situational contexts (Clarke, 1997). This desk assessment is specific to the GLTFCA and our expert group has broad on-the-ground experience in the area, however, more nuanced contexts would bolster any efforts to leverage insights herein to prevent future poisoning events. In particular, engaging local stakeholders will help match the underlying reasons for poison use – human-wildlife conflict, belief-based use, or sentinel poisoning – with specific harm prevention tactics. More specifically, we know the cultural context can be very site dependent. Some communities retain strong traditional beliefs for vulture use whereas others believe harming or even touching vultures is taboo. Ultimately, communities, chemical/agroindustrial companies, commercial farmers, and other place-specific stakeholders must be involved in solution sets.

Existing poisoning databases may be used to help refine, monitor, and evaluate the crime prevention strategies and tactics. For example, The African Wildlife Poisoning Database is a joint project between the Endangered Wildlife Trust and The Peregrine Fund and aims to collect and collate data of historical and current wildlife poisoning incidents that occur across Africa. Data can be used to determine wildlife poisoning clusters, assist in targeting such areas for Wildlife Poisoning Response Training, and determine the impact of training on mortality trends when incidents happen. Prevention strategies' efficacy and impacts could be monitored by trapping and tagging adult vultures to track their movements and behavior within the GLTFCA. Being the most abundant and widespread vulture species, white-backed vultures would be particularly useful to tag; annual mortality could be monitored, evaluated, and compared over time to assess any response to SCP strategies. The appropriate settings and sensors on tracking units can also detect mortality signals or extended periods of inactivity which could be used to trigger rapid response activities. This type of monitoring has the potential to significantly reduce mortality rates of vultures and other wildlife. Collectively, we recognize a primary necessity for effective vulture conservation is effective collaboration—in data sharing and beyond. Without full collaboration across agencies, NGOs, universities, individuals, and faith-based and local communities, including sharing data from population monitoring efforts, poisoning events, and all other types of mortality events, vulture conservation is unlikely to succeed. More comprehensive and collaboratively-derived data can be effectively communicated to decision makers in support of their efforts to protect and reverse the downward population trend in these endangered scavengers.

Vulture conservation is a dynamic and complex endeavor whose efficacy is undermined by intentional and unintentional poisoning, such as in the GLTFCA. Conservation criminology is not relevant to all aspects of vulture conservation but the desk assessment presented here helps advance thinking about poisoning problems in more precise terms. This assessment helps focus attention for problem solving and provides practical strategies to attempt to shift the current paradigm. The range of strategies and tactics presented here may prevent poisoning from occurring in the first place, and thus the associated risks of poisoning to socioenvironmental systems may also be prevented. Suggested interventions such as Wildlife Poisoning Response Planning and Training and the use of wildlife tracking can also contribute to rapid action when incidents occur and help reduce mortalities suffered by animals exposed to this threat. We know crime prevention efforts can result in a "halo" or

"bonus" effect, where benefits associated with the implementation of crime prevention activities are diffused to other sociocultural harms and contexts (Clarke, 1997). With additional application, monitoring, and evaluation, the strategies and tactics explored in this desk assessment may be replicated, revised and implemented and portend other benefits for vulture conservation beyond poisoning (e.g., in Zululand, South Africa). Even a small paradigm shift and spread of beneficial influence could be a welcome force multiplier for this important scavenger guild.

Declaration of competing interest

We declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e01076.

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