

A multispecies assessment of wildlife impacts on local community livelihoods

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Abstract: Conflicts between the interests of agriculture and wildlife conservation are a major threat to biodiversity and human well-being globally. Addressing such conflicts requires a thorough understanding of the impacts associated with living alongside protected wildlife. Despite this, most studies reporting on human-wildlife impacts and the strategies used to mitigate them focus on a single species, thus oversimplifying often complex systems of human-wildlife interactions. We sought to characterize the spatiotemporal patterns of impacts by multiple co-occurring species on agricultural livelihoods in the eastern Okavango Delta Panhandle in northern Botswana through the use of a database of 3264 wildlife-incident reports recorded from 2009 to 2015 by the Department of Wildlife and National Parks. Eight species (African elephants [*Loxodonta africana*], hippopotamuses [*Hippopotamus amphibious*], lions [*Panthera leo*], cheetah [*Acinonyx jubatus*], African wild dogs [*Lycaon pictus*], hyenas [*Crocuta crocuta*], leopards [*Panthera pardus*], and crocodiles [*Crocodylus niloticus*]) appeared on incident reports, of which 56.5% were attributed to elephants. Most species were associated with only 1 type of damage (i.e., either crop damage or livestock loss). Carnivores were primarily implicated in incident reports related to livestock loss, particularly toward the end of the dry season (May–October). In contrast, herbivores were associated with crop-loss incidents during the wet season (November–April). Our results illustrate how local communities can face distinct livelihood challenges from different species at different times of the year. Such a multispecies assessment has important implications for the design of conservation interventions aimed at addressing the costs of living with wildlife and thereby mitigation of the underlying conservation conflict. Our spatiotemporal, multispecies approach is widely applicable to other regions where sustainable and long-term solutions to conservation conflicts are needed for local communities and biodiversity.

Keywords: carnivore, conflict, conservation, herbivore, human-wildlife interactions, management

Una Evaluación Multiespecie de los Impactos de la Fauna sobre el Sustento de la Comunidad Local

Resumen: Los conflictos entre los intereses de la agricultura y la conservación de fauna son una gran amenaza para la biodiversidad y el bienestar humano en todo el mundo. Para tratar estos conflictos se requiere un entendimiento exhaustivo de los impactos asociados con la convivencia con fauna protegida. A pesar de esto, la mayoría de los estudios que reportan sobre los impactos humano-fauna y las estrategias que se usan para mitigarlos se enfocan en una sola especie, lo que simplifica demasiado los complejos sistemas de interacciones humano-fauna. Buscamos caracterizar los patrones espaciotemporales de los impactos por múltiples especies coocurrentes sobre el sustento agrícola en la franja oriental del Delta del Okavango al norte de Botswana

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Article impact statement: Impacts of protected wildlife on local community livelihoods can vary and overlap across species, spatial scales, and time of the year.

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mediante el uso de una base de datos de 3,264 reportes de incidentes con fauna registrados entre 2009 y 2015 por el Departamento de Vida Silvestre y Parques Nacionales. Ocho especies (elefante africano [*Loxodonta africana*], hipopótamo [*Hippopotamus amphibious*], león [*Panthera leo*], chita [*Acinonyx jubatus*], licaón [*Lycaon pictus*], hiena [*Crocuta crocuta*], leopardo [*Panthera pardus*] y cocodrilo [*Crocodylus niloticus*]) aparecieron en los reportes de incidentes, de los cuales el 56.5% estaba atribuido a los elefantes. La mayoría de las especies estuvo asociada sólo con un tipo de daño (es decir, daño a cultivos o pérdida de ganado). Los carnívoros fueron los principales implicados en los reportes de incidentes relacionados con la pérdida de ganado, particularmente hacia el final de la temporada seca (mayo-octubre). Al contrario, los herbívoros estuvieron asociados con los incidentes de pérdida de cultivos durante la temporada de lluvias (noviembre-abril). Nuestros resultados ejemplifican cómo las comunidades locales pueden enfrentar diferentes dificultades en su sustento por parte de diferentes especies durante diferentes periodos en el año. Tal evaluación multiespecie tiene consecuencias importantes para el diseño de las intervenciones de conservación enfocadas en la resolución de los efectos de la convivencia con la fauna y por lo tanto la mitigación del conflicto de conservación subyacente. Nuestro enfoque multiespecie espaciotemporal puede aplicarse ampliamente a otras regiones en donde las comunidades y la biodiversidad local necesitan soluciones sustentables y a largo plazo para los conflictos de conservación.

Palabras Clave: carnívoro, conflicto, conservación, herbívoro, interacción humano-fauna, manejo, modelos aditivos generalizados

摘要: 农业和野生动物保护之间的利益冲突已对全球的生物多样性和人类福祉造成了重大威胁。要解决这些冲突,就必须深入了解与受保护的野生动物共存所带来的影响。尽管如此,大多数关于人兽冲突影响的研究报告以及缓解这些影响的策略都聚焦于单一物种,因而过度简化了人类与野生动物相互作用的复杂系统。本研究利用博茨瓦纳野生动物管理部门和国家公园在2009年至2015年记录了3,264条野生动物事件的数据库,描述了多物种共存的时空格局对博茨瓦纳北部的奥卡万戈三角洲东部农业生计的影响。报告中记录了八种野生动物的事件,分别是非洲象 (*Loxodonta africana*), 河马 (*Hippopotamus amphibious*), 狮子 (*Panthera leo*), 猎豹 (*Acinonyx jubatus*), 非洲野狗 (*Lycaon pictus*), 鬣狗 (*Crocuta crocuta*), 豹 (*Panthera pardus*) 和鳄鱼 (*Crocodylus niloticus*), 其中有56.5%的记录都来自非洲象。大多数物种只与一种类型的破坏有关(作物损失或牲畜损失)。食肉动物事件报告主要涉及牲畜损失,特别是在旱季结束的阶段(五月到十月),而食草动物则与雨季(十一月到四月)的作物损失事件有关。我们的研究结果说明了当地社区如何在一年的不同时间面对来自不同物种的不同生计挑战。对于旨在处理与野生动物共存的成本,从而减轻潜在保护冲突的保护干预措施来说,本研究的多物种评估对其设计具有重要意义。我们的多物种时空方法还广泛适用于其它需要为当地社区和生物多样性提供可持续和长期的保护冲突解决方案的地区。【翻译:胡怡思;审校:聂永刚】

关键词: 食肉动物, 冲突, 保护, 食草动物, 人与野生动物, 相互作用, 广义可加模型, 管理

Introduction

Conflicts between the interests of agriculture and those of wildlife conservation are increasingly common (e.g., Shackelford et al. 2015; Fischer et al. 2017; Egli et al. 2018) and currently represent one of the biggest challenges for biodiversity conservation worldwide (Díaz et al. 2019). These conflicts—also known as “conservation conflicts” (Redpath et al. 2013)—are detrimental not only to biodiversity conservation, but also to economic development, social equality, and resource sustainability in areas where they occur (Woodroffe et al. 2005; Redpath et al. 2013; Rasmussen et al. 2018). Developing sustainable solutions to decrease and mitigate such conflicts is vital to ensure long-term coexistence between human livelihoods and biodiversity conservation (Kremer & Merenlender 2018).

Conservation conflicts often arise as a result of antagonistic interactions between wildlife and human activities (Young et al. 2010; Redpath et al. 2013). Such human-wildlife impacts (HWI) include livestock depredation by carnivores, crop and property damage by her-

bivores, and the subsequent retaliatory killing of problem individuals or species by humans. How these HWI affect the well-being of local communities is context and species dependent, but consequences can include loss of income and food (Kaswamila et al. 2007), higher exposure to injury from wild animals (Barua et al. 2013), and disrupted social activities, such as school attendance (Mackenzie et al. 2015). Understanding patterns and drivers of HWIs is an important component of managing conservation conflicts (Redpath et al. 2013). For instance, a better understanding of HWIs can enable the development of technical solutions, such as scaring devices or compensation payments, to minimize negative interactions between people and wildlife (e.g., Pozo et al. 2017a; Ohrens et al. 2019). Addressing the latter can in turn reduce conflict between the interests of conservation and those of other human activities (Baynham-Herd et al. 2018).

Despite this, most studies reporting on HWIs and the strategies used to mitigate them have focused on single species or trophic groups (e.g., Loveridge et al. 2017; Struebig et al. 2018; Ndava et al. 2019; Ohrens et al.

2019). Yet, human activities often affect multiple wild species (Allen 2015; Laguna et al. 2015). For example, Laguna et al. (2015) describe a system in northern Patagonia where introduced sheep (*Ovis aries*) compete with native guanacos (*Lama guanicoe*) for pasture and fall prey to a native predator, the puma (*Felis concolor*). In this scenario, optimizing the productivity of sheep herding activities requires an understanding of both competitive and predatory processes.

An additional level of complexity occurs when impacts associated with multiple species vary seasonally and spatially (Gross et al. 2018; Mukeka et al. 2019). Yet, such multispecies, spatiotemporal assessments are absent from the literature, which has instead tended to focus on single species (e.g., Wilson et al. 2015). This oversimplification of HWI situations risks hindering the development of cost-effective management strategies aimed at decreasing costs associated with living with wildlife (Kansky et al. 2016; Baynham-Herd et al. 2019). Moreover, implementing mitigation strategies for only 1 species is unlikely to reduce potential negative attitudes toward wildlife in general if other species are also perceived to be a problem in the same area (Lescureux & Linnell 2010; Suryawanshi et al. 2013; Redpath et al. 2015). In other words, the additive negative impact of multiple species on the livelihoods of local communities may outweigh the benefit of managing a single species. Reporting and accounting for this complexity in negative human-wildlife interactions is therefore critically important to providing realistic and effective solutions to decrease the impacts of wildlife on local communities and ultimately to improve peoples' perceptions of biodiversity conservation.

We characterized seasonal and spatial patterns of reported impacts by multiple species in Botswana's eastern Okavango Delta Panhandle. More specifically, we examined whether the number of reported impacts varies significantly across months of the year and whether this variation shows common patterns across study villages, damage types, and species. To do this, we used data from a database of reported wildlife incidents. We took this approach because a focus on single-species management risks undermining conservation and a more holistic approach to assessing HWIs, accounting for co-occurring species and human livelihoods, is needed for sustainable and long-term management.

Methods

Study Site

Our study area was in northern Botswana, on the eastern side of the Okavango Delta Panhandle, which is delimited by the Namibian border to the north, the Okavango River in the south, and the northern buffalo fence to the

southeast (Fig. 1). Unprotected areas were part of the study site, which was composed of a mixture of agricultural land, human settlements, and savannah shrubland (Pozo et al. 2017b). This landscape is home to a wide range of protected African wildlife, including African elephants (*Loxodonta africana*), hippopotamuses (*Hippopotamus amphibius*), lions (*Panthera leo*), cheetah (*Acinonyx jubatus*), African wild dogs (*Lycaon pictus*), hyenas (*Crocuta crocuta*), leopards (*Panthera pardus*), and crocodiles (*Crocodylus niloticus*), all of which we included in our analyses. Wildlife species disperse throughout the eastern panhandle, including across areas where people live.

Subsistence agriculture in the form of crop production and livestock herding is the main livelihood in the study area. Most of the 16,000 people living in the eastern panhandle are based in 1 of 13 villages distributed along the Okavango River (CSO 2011) (Fig. 1). Deep Kalahari sands cover most of the region; fertile soils are near the Okavango River. Local farmers cultivate fields from November to April across an area extending from the river's edge up to 14 km inland (Songhurst 2017). Local farmers keep livestock in both villages and smaller cattle posts scattered across the study area. Average herd size is 12 head of cattle per farmer, and livestock is typically protected overnight in *kraals* (i.e., thorn branch or thick wooden branch enclosures) (LeFlore et al. 2019).

Reporting Protocol for the Problem Animal Control Program

In 2009, the government of Botswana introduced to the eastern Okavango Delta Panhandle a Problem Animal Control (PAC) program to decrease conflicts between local farmers and livestock herders and protected wildlife. Under this program, the Department of Wildlife and National Parks (DWNP) office in the village of Seronga (Fig. 1) encourages people from the 13 villages in the study area to report PAC incidents to the DWNP, including damage to crops, livestock or property, and death of people and protected wildlife. People in the eastern panhandle report wildlife incidents to the village chief, the police department, DWNP officials in their villages, or directly to the DWNP office in Seronga within 7 days of the incident (Songhurst 2017). For each incident report, an officer from the DWNP undertakes a visit to the affected person or site and verifies the level of impact (e.g., amount of crop area destroyed and number of animals killed) before initiating the compensation process (Noga et al. 2018; LeFlore et al. 2019).

Data Collection

We collated records of incidents involving wildlife reported from 2009 to 2015 at the DWNP office in Seronga. We digitally transcribed each incident report from archive books, recording the date of the incident

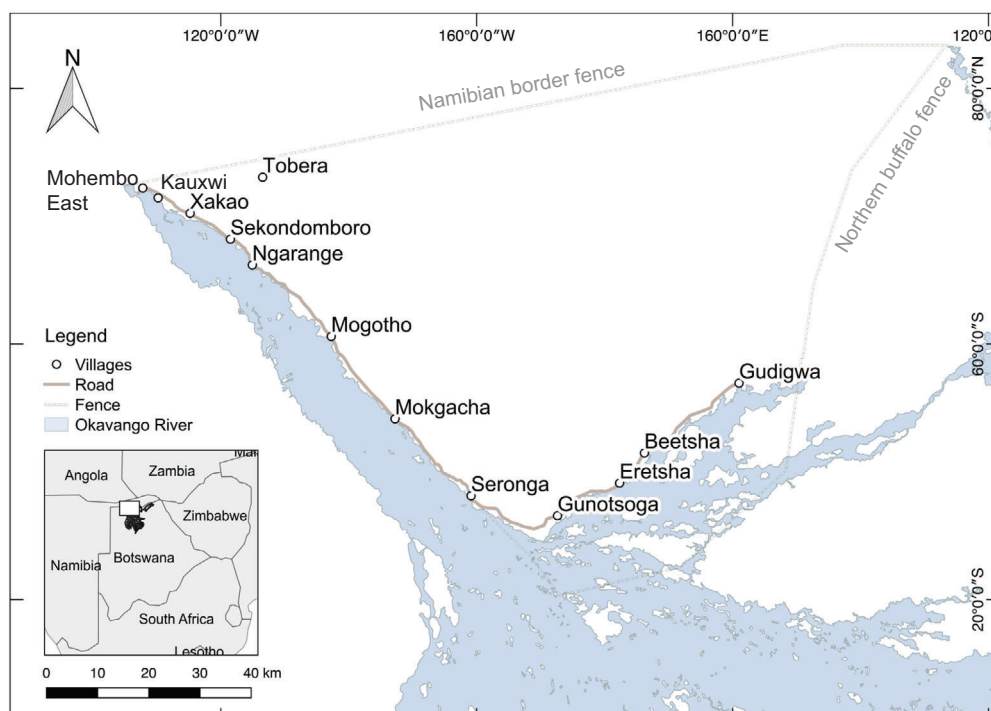


Figure 1. Study area in the eastern Okavango Delta Panhandle, northern Botswana and the 13 villages distributed along the Okavango River (light blue) from which wildlife damage reports originated. The inset shows the location of the study area in northern Botswana.

(including day, month, and year), species involved, closest village to the reported location, and type of damage incurred (i.e., crop, livestock, people, or property damage).

Data Analyses

We used hierarchical generalized additive models (Pedersen et al. 2019) to assess annual trends in the number of reported incidents across villages, damage types, and species involved. For each of these grouping factors, we built and compared 3 different model structures. For model 1, we assumed no variation across factor levels (i.e. individual villages, damage types, or species). Model 2 allowed annual trend to vary independently across factor levels, and model 3 allowed for variation across factor levels, but had a penalty for deviations from a global shared trend (Pedersen et al. 2019). In other words, for model 3 we assumed each factor-level curve has a shape similar to the others. To explore possible variation across villages within individual species, we compared the models (with village as grouping factor) for each of the most commonly reported species, namely, elephant, lion, and crocodile. We fitted separate models for each grouping factor because preliminary analyses indicated poor model convergence when all 3 were grouped together in 1 model.

All models included year (7 levels, 2009–2015) as a random effect and had a negative binomial error structure to account for overdispersion. Even though annual trends are cyclic by nature—signifying that the first and last month will show a degree of temporal correlation—we chose not to implement cyclic cubic regression splines constraining the extremities of estimated curves (Wood 2017) because preliminary analyses revealed considerable differences in the number of reports in December and January. For all models assessing the variation in the number of reports across villages, we included the log of the last village population size recorded in the region (CSO 2011) as an offset to account for variation in village size within the study area. Model structure and assessment of fit are detailed in Supporting Information. Model comparison was based on Akaike's information criterion (AIC), and subsequent inferences were made from the model with the lowest AIC value when the difference with the next best model (ΔAIC) was <4 (Burnham & Anderson 2002) or from model parameters averaged across models with $\Delta\text{AIC} < 4$. All models were fitted in the R package *mgcv* (Wood 2017).

Results

A total of 2886 incident reports were filed between January 2009 and December 2015 across the 13 study

Table 1. Number and percentage of incidents reported for all documented species and types of damage across the 13 villages in the eastern panhandle of Botswana from 2009 to 2015.

Species	No. reports (% of species-specific total)			
	crop loss	livestock loss	people injured	property damage
Cheetah	-	2 (100)	-	-
Crocodile	-	429 (99.8)	-	1 (0.2)
Elephant	1518 (93.1)	22 (1.3)	3 (0.2)	88 (5.4)
Hippopotamus	78 (90.7)	4 (4.7)	-	4 (4.7)
Leopard	-	106 (99.1)	1 (0.9)	-
Lion	-	449 (100)	-	-
Spotted hyena	-	17 (94.4)	1 (5.6)	-
Wild dog	-	165 (100)	-	-

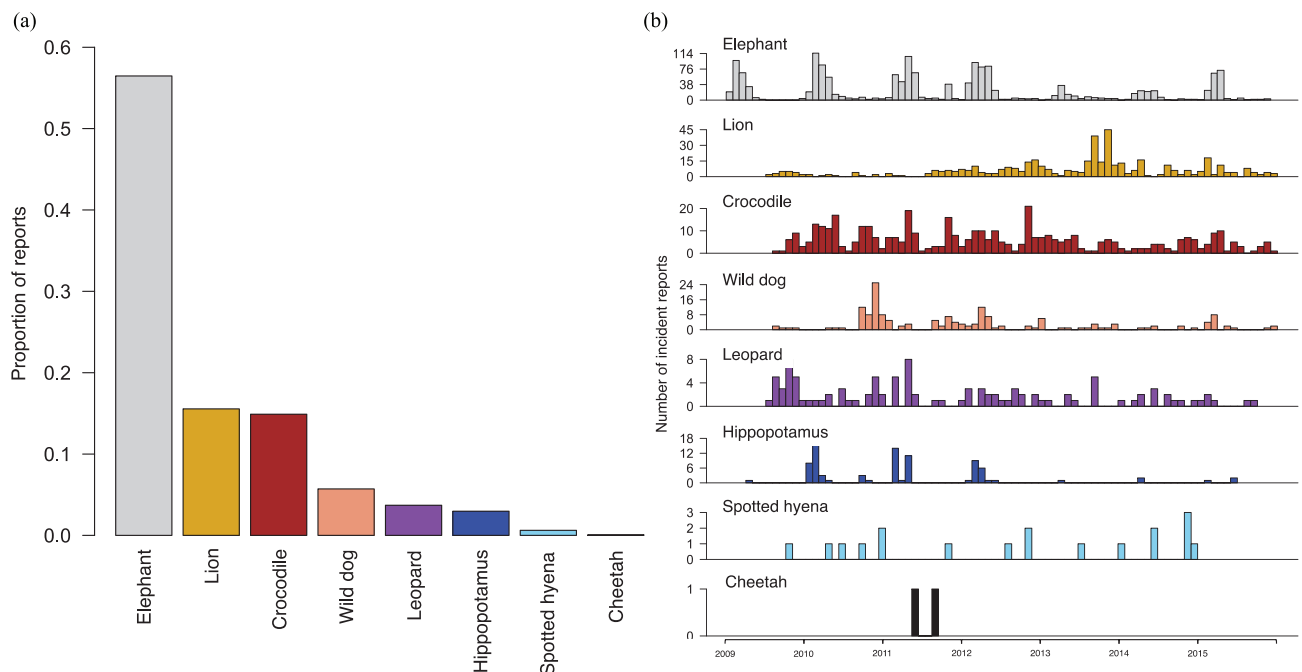


Figure 2. (a) Proportion of total wildlife damage reports and (b) time series of annual frequency of reports from 2009 to 2015.

villages. Reports involved 8 species and 4 types of damage (Table 1). Herbivores, including elephant and hippopotamus, were primarily associated with damage to crops and to a lesser extent damage to property. In contrast, all carnivore species (cheetah, crocodile, leopard, lion, spotted hyena, and wild dog) were associated with livestock loss. Incidents attributed to elephants accounted for 56.5% of all reports (Fig. 2). The mean number of incidents reported per village per year varied from 0 to 154 (mean of 32).

All model comparisons resulted in a single top model, on which inferences were subsequently made (Table 2). An annual trend in the number of incident reports across villages, damage types, and species indicated a peak in reporting during March; the maximum mean prediction was 56.2 reports (95% CI, 37.1–85.2) (Fig. 3a). In con-

trast, July had the lowest predicted number of reports; the predicted mean was 8.8 (95% CI, 5.7–13.5). Annual trends varied across villages (Fig. 3b), damage types (Fig. 3c), and species (Fig. 3d), but only the village grouping showed evidence of a global trend (model comparison in Table 2). Variation in the number of reports per 100 people across villages was highest in February (mean number of reports per 100 people [SD] = 0.41 [0.25]) and lowest in June (mean [SD] = 0.06 [0.03]). Reports from January to May were predominantly related to crop damage, whereas those from June to December concerned livestock loss. Reports involving elephants constituted the vast majority of reports from January to June. From July to December, however, impacts from lions and crocodiles were most commonly reported.

Species-specific annual trends in the number of reported incidents per 100 people also varied across

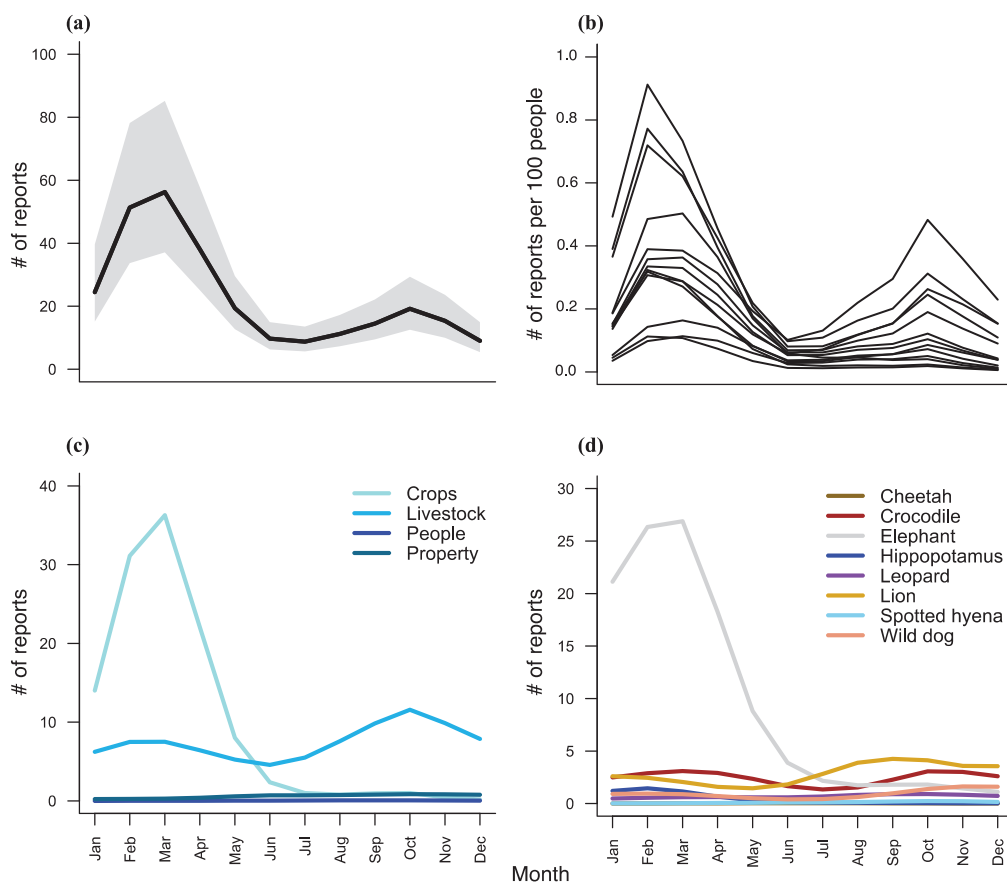


Figure 3. Annual trend in the number of incident reports (a) across all villages, damage types, and species (gray shading, 95% CI), (b) across villages, (c) across damage types, and (d) across species.

villages (Fig. 4), especially for lions. The predicted number of reports per 100 people varied across villages by a factor of 6.6 (in June) to 687.4 (December) for elephants; 376.7 (May) to 562.4 (December) for lions; and 151.5 (June) to 667.8 (December) for crocodiles. Village-level annual trends for lion and crocodile reports were best modeled as deviations from a shared global trend (Table 2). This was not the case for the trend in monthly elephant reports, which varied independently across villages. Although the intensity of elephant-damage reporting showed a clear peak in March, impact peaks for lions and crocodiles exhibited a bimodal distribution over the year. Low points were in May and July, respectively (Fig. 4).

Discussion

Our study has important implications for the management of wildlife, and by extension for conservation conflicts, in areas where multiple species affect different aspects of peoples' livelihoods, such as food production and security, basic infrastructure, and safety. We argue that it is important not to overlook the impact of all species, especially if they affect different aspects of peo-

ple's livelihood at distinct times of the year (Mukeka et al. 2019). A sole focus on mitigation strategies targeted at charismatic or priority species (Douglas & Veríssimo 2013; Redpath et al. 2015) may reduce, but not minimize, resentment toward wildlife—and conservation objectives in general—if impacts by other species remain unaddressed.

Our multispecies assessment showed that local communities in the eastern Okavango Delta Panhandle are affected by wildlife throughout the year. Although more than half of all PAC reports corresponded to incidents involving elephants, another 7 carnivore and herbivore species (i.e., hippopotamuses, lions, cheetah, African wild dogs, spotted hyenas, leopards, and crocodiles) also affected local livelihoods. In general, herbivore and carnivore species lead to distinct impact patterns across the year. Herbivores predominantly caused damage to crops during the wet season (November–April), and carnivores preyed on livestock most often during the dry season (May–October). Thus, our results illustrate how local communities can face distinct livelihood challenges from different species over the course of the entire year. Importantly, our findings on the spatiotemporal variability of HWIs by multiple species mirror those

Table 2. Summary and comparison of hierarchical generalized additive models testing the variation in the number of problem animal reports across villages, damage types, and species.

Species	Grouping factor	Model structure ^a	Deviance explained (%)	edf ^b	AIC
All	Village	1	19.2	14	4116.0
		2	35.7	44	3959.7
		3	40.1	43	3891.4
	Damage type	1	10.9	8	1771.0
		2	80.9	24	1379.6
		3	80.5	24	1385.0
	Species	1	13.3	11	2843.2
		2	71.4	36	2298.9
		3	70.9	35	2312.0
Elephant	Village	1	41.4	14	2563.3
		2	54.7	50	2451.3
		3	54.0	37	2483.2
Lion	Village	1	15.6	11	1455.8
		2	59.7	24	1194.9
		3	60.2	26	1185.7
Crocodile	Village	1	11.5	12	1460.3
		2	52.5	26	1175.9
		3	57.6	34	1134.3

^a Key: 1, no variation across factor levels; 2, variation across factor levels; 3, variation across factor levels with global shared trend. All models included year of study as a random effect and had a negative binomial error structure.

^b Effective degrees of freedom (used to measure the complexity of penalized smooth terms [Pedersen et al. 2019]).

reported by Mukeka et al. (2019) in Narok County, Kenya, suggesting that this is a phenomenon not limited to our study system.

The prevalence of herbivore-related incidents during the wetter months of the year coincides with the crop-growing period, when seasonal rains increase the productivity of the Kalahari sands. Agricultural crops often have higher nutrient content than natural resources favored by wild herbivores (Osborn 2004), which may attract them to crop fields near the Okavango River (Pozo et al. 2017a, 2018). In addition, crop fields are generally located between areas used by elephants during the day and the Okavango River, which elephants visit at night to minimize overlap with human activities (Pozo et al. 2017b, 2018). Although elephants inflicted most of the reported crop damage, hippopotamuses were also held responsible for damaging crops during the wet season (Kanga et al. 2013; Mekuka et al. 2019). In contrast, reports of carnivore incidents occurred during the drier months of the year. From July to November, the Okavango River gradually retreats to smaller bodies of water within the delta, forcing livestock to venture farther away from the riverbanks in search of forage (Weise et al. 2018). This behavior may increase encounters with wild carnivores, such as lions, and people may turn to hunting these more naïve prey when natural prey are scarce (Valeix et al. 2012).

Although previous studies show the importance of spatial (Sitati et al. 2003; Wilson et al. 2015; Mason et al. 2018) and temporal (Yurco et al. 2017) variation in HWIs, our results highlight the temporal dimension of this variation; annual trends in species-specific impacts differed across small spatial scales. Although village-level trends for some species, such as lions and crocodiles, shared a similar curve, the number of reports per month could still vary by several orders of magnitude across villages over the year. Although we did not focus on the village-level characteristics that might influence the number of reports—and instead put emphasis on the variation across villages—other studies have highlighted the importance of metrics, such as distance from the delta floodplain, proximity to wildlife corridors leading to and from the delta, number of livestock, and variations in human attitudes toward wildlife as possible factors affecting the spatial distribution of incidents (Pozo et al. 2018; LeFlore et al. 2019, 2020).

It is important to acknowledge the possible biases associated with the voluntary reporting of HWIs. For instance, compensation for damage by some species and not others may influence the rate of incident reporting (Jackson et al. 2008; Gusset et al. 2009; Songhurst 2017). Wild dogs are rare in the study area relative to hyenas, yet the former species accounts for far more incidents than the latter (Gusset et al. 2009; LeFlore et al. 2019), potentially because the government compensates livestock depredation by wild dogs but not by hyenas. A similar bias may influence the number of reports of depredation by lions (LeFlore et al. 2019). At the time of study, the PAC program paid owners 100% compensation for losses due to lions, but only 35% in the case of depredation by leopard, wild dog, or cheetah (DWNP 2013), which creates an incentive to report lions. There are other biases to consider within the PAC program. For example, it is probable that farmers in the study area are reporting less than expected because the process to receive compensation is considered long, difficult, and inadequate by local communities (Pozo et al. 2017a; Noga et al. 2018; LeFlore et al. 2020). In an area where public transport is not available, people have to report wildlife incidents to the village chief, the police department, DWNP officials, or directly to the DWNP main office within 7 days of the incident occurring (Songhurst 2017). After this, an officer from the DWNP has to visit households affected and verify the level of impact they had before the compensation process can be initiated (Noga et al. 2018; LeFlore et al. 2019). Combined with the labor-intensive nature of agricultural activities in the study area, this lengthy initiation process could have influenced the likelihood of PAC reporting. This has made the implementation of compensation schemes controversial and hard to monitor in Botswana and in many other countries (Nyhus et al. 2005). More generally, we acknowledge that the number of reported PAC incidents in a region—although

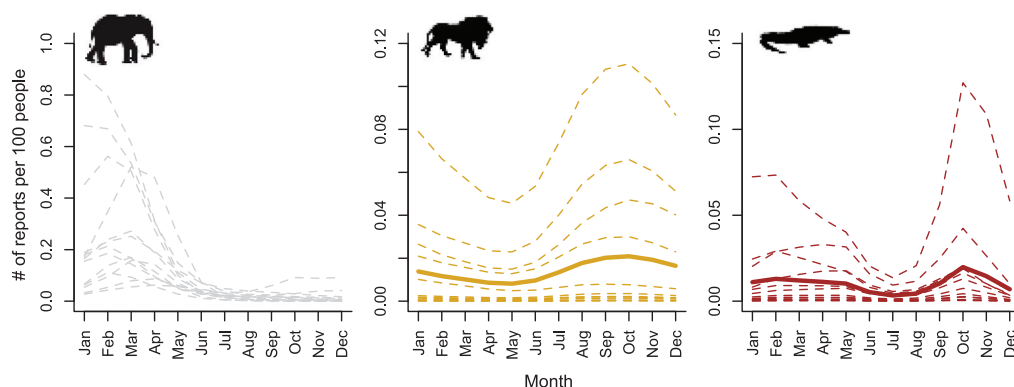


Figure 4. Annual trend in the number of incident reports per 100 people across 13 villages for elephants, lions, and crocodiles (dashed lines, annual trends per village; continuous line, shared global trend across villages [absent for elephant]). The y-axes differ.

a useful indicator of conflict—is unlikely to capture the complexity and multidimensionality of conservation conflicts. However, it is often the only source of information in affected areas, and we used it as a conservative long-term indicator of the conflict status in the eastern Okavango Panhandle (Pozo et al. 2017a).

Our study shows the need to adopt a holistic management of HWIs that accounts for multiple species and acknowledges the diversity and needs of people. Current mitigation methods only for elephant conservation in the Okavango delta require considerable effort and financial investment from local farmers (Noga et al. 2015, 2018). These methods include planting less palatable crops, building chili fences, setting up crop guards, building beehive fences, and implementing land-use planning techniques (e.g., Noga et al. 2015; Pozo et al. 2017b; Pozo et al. 2018). On top of this, farmers must also build livestock enclosures (kraals) and change herding practices to protect cattle against depredation by large carnivores that occurs at different times of the year (Weise et al. 2018; LeFlore et al. 2019). The additive effect of these 2 different mitigation strategies likely increases the cost to local communities, making tolerance for local wildlife and support for conservation improbable (Blackie & Sowa 2019; LeFlore et al. 2020). Thus, future management of HWIs should be developed in close partnership with local communities, with the aim of proposing cost-effective mitigation solutions that can address multiple types of HWIs. Such an approach has been implemented in the context of fisheries management, for which the interests of different stakeholders on the use of different resources are integrated and modeled in search of a compromise (Mapstone et al. 2008). For example, in our case study, discussions could center on how efforts or subsidies aimed at minimizing different types of HWIs could be allocated seasonally based on their relative occurrence.

Multispecies assessments, such as the one presented in this study, can provide a basis for mitigation efforts

and management decisions that are not only physically and economically feasible, but also promote collaboration among local stakeholders, government institutions, and conservation groups. We argue that holistic HWI assessments can help deliver fair and realistic solutions to local stakeholders, as well as benefit the conservation of wildlife they interact with. Although our focus was a case study in the eastern Okavango Delta Panhandle, our findings are widely applicable to other scenarios in which human activities are affected by a range of wild species.

Acknowledgments

We are thankful to the government of Botswana for granting access to and use of the data presented in this study. In particular, we thank M. Flyman and M. Mweze of DWNP for their support. We are also thankful to the Ecoexist Project and CLAWS Conservancy for guidance and support in the field. We thank P. Sheller and Ngami Data Services for GIS data. R.P. was funded by the National Commission for Scientific and Technological Research (CONICYT, Chile), the Ecoexist Project (Botswana), and the ANID/FONDAP/15110009 Center for Climate and Resilience Research (CR2) Project (Chile). E.L. was funded by a J. William Fulbright Research Scholarship, the University of Massachusetts Amherst Graduate School, and the Mellon Mays Graduate Initiative through the Social Science Research Council. In addition, A.B.D. was funded by an Early Career Fellowship from the Leverhulme Trust. N.B., R.P., A.B.D., I.J., J.C., J.M., and S.R. were funded by the European Research Council under the European Union's H2020/ERC grant agreement 679651 (ConFooBio).

Supporting Information

A description of generalized additive model structure and assessment of fit (Appendix S1) is available online. The

authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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