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RESEARCH ARTICLE

A mixed-methods assessment of human-elephant conflict in the Western Okavango Panhandle, Botswana

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Abstract

1. Human-wildlife conflict, where interactions have negative impacts on both people and animals, is complex with underlying drivers and broad ecological and social impacts. From individual incidents and perceptions, to contemporary patterns and long-term trends, a range of information about human-wildlife conflict can help understand and manage challenges. However, many studies focus on a single data type or spatiotemporal scale.
2. In the Western Okavango Panhandle in Botswana, people in rural farming communities share and compete for resources with a growing African savanna elephant population. Few previous studies have focused on human-wildlife interactions in this region. We assessed spatiotemporal trends in human-elephant conflict using reported conflict incidents (2008–2016), surveys of individual perceptions of conflict encompassing the late 1990s–2016, and detailed field raid assessments from 2016. We found complementary patterns among the data types at different geographic and spatial scales.
3. We found that the number of annual HEC incidents have increased over time, although not evenly across space, with increases primarily in the northern region of the Panhandle. Crop raiding presents both chronic and acute challenges for farmers, with the amount of damage incurred per incident largely dependent on the size of elephant group involved rather than factors within the farmers' control such as guarding or types of crops grown.
4. Our results provide a characterization of contemporary conflict incidents and long-term trends, despite scarce historical data. Combining the reporting and assessment data with surveyed local ecological knowledge offered a multidimensional understanding of human-wildlife conflict for a region where this information was lacking. It is an important precursor to effective and collaborative conflict management and mitigation.

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5. When possible, this mixed-methods approach may facilitate understanding for complex human-wildlife interactions and support the diverse communities and stakeholders involved with conflict-related challenges.

KEYWORDS
coexistence, crop raiding, human-elephant conflict, human-wildlife conflict, human-wildlife interactions, indigenous knowledge, local ecological knowledge

1 | INTRODUCTION

Understanding, mitigating and managing human-wildlife interactions is a complex global challenge (IPBES, 2019). Increased pressure from human activities, coupled with shifts in wildlife distribution and behaviour linked to climatic and land use changes, has increasingly brought people and wildlife into closer proximity and competition for limited resources (Abrahms, 2021; Durant et al., 2022; Salerno et al., 2021). This can result in localized and widespread biodiversity loss, diminished human health and wellbeing, and decreased support for conservation initiatives (Kansky et al., 2014; Ngorima et al., 2020; Talukdar & Choudhury, 2020). Large terrestrial herbivores are especially prone to negative interactions with humans due to their substantial dietary and space-use requirements (Pascual-Rico et al., 2021; Ripple et al., 2015). This presents a particular challenge for many rural communities living in mixed-use landscapes in sub-Saharan Africa that include African savanna elephants *Loxodonta africana*.

African savanna elephants are a species of conservation concern that vary widely in their population size and co-occurrence with people (Gobush et al., 2020). Human-elephant interactions can have negative consequences for humans, and disproportionately impact the residents of socioeconomically vulnerable and under-resourced rural communities (Salerno et al., 2021). Foraging of cultivated crops by elephants, typically called "crop raiding", is a common type of HEC. Cultivated crops represent highly nutritious but risky food resources for elephants (Ahlering et al., 2011; Vogel et al., 2019) and can lead to property damage and life-threatening encounters between elephants and people. Here, we use the term "crop raiding" not to indicate malicious intent by elephants but rather to succinctly capture the negative impacts that crop foraging has for farmers. Not all encounters are antagonistic (Buchholtz, Fitzgerald et al., 2019; Buchholtz, Redmore et al., 2019), and indeed the concept of "convivial conservation" posits that peaceful cohabitation between people and wildlife in shared landscapes is possible (Buscher & Fletcher, 2020; Keil, 2016). However, human-elephant conflict (HEC) can undermine coexistence as a result of the direct and indirect adverse impacts to both humans (e.g. loss of income and earning potential, injuries and fatalities, food insecurity, increased exposure to disease and gender-based violence, Barua et al., 2013; Khumalo & Yung, 2015; Manoa et al., 2020; Mayberry et al., 2017; Nyumba et al., 2020; Salerno et al., 2020) and elephants (e.g. increased poaching and retaliatory killing, physiological stress that disrupts cognition and behaviour and lowers female reproductive success, disturbance to social structure, and loss of genes from large, reproductively-fit adults, Ahlering et al., 2011; Ball et al., 2022; Campbell-Staton et al., 2021; Chiyo et al., 2011; Compaore et al., 2020; Gobush et al., 2008; McComb et al., 2001; Shannon et al., 2013).

These considerable impacts of HEC mean that it is a social and ecological challenge that requires data at multiple scales to inform effective management and mitigation. Without knowledge and data related to human-wildlife interactions, it can be difficult to fully understand the system's patterns and drivers and how they may change over time (Gross et al., 2022; Tiller et al., 2021). HEC is often analysed using Western quantitative approaches such as estimating elephant population size, recording the number of conflict incidents, and measuring damaged area and economic losses (Deodatus & Lipiya, 1991; Prakash et al., 2020; Hoare, 1999; Pozo et al., 2018; Sukumar, 1991). Methods for gathering additional data from local community perspectives, including questionnaires and interviews with people experiencing conflict, have also been incorporated in more recent studies (ex: Browne-Nuñez & Jonker, 2008; Ngorima et al., 2020; Sampson et al., 2019). Rural and Indigenous communities frequently have extensive observations of and experiences with local wildlife and ecological processes, and their knowledge of HEC dynamics over time may best be interpreted through interpersonal, qualitative methods (Gilchrist et al., 2005; Kohler et al., 2019). While their worldviews and lived experiences are valuable on their own, documenting and integrating Indigenous and local ecological knowledge within HEC research (a "multiple evidence base approach", Tengö et al., 2014), can provide a more robust understanding of HEC dynamics and support more effective mitigation (Meinecke et al., 2018).

Data that cover the relevant spatial and temporal scales to understand both current conflict conditions and long-term drivers is often lacking. Local knowledge can be highly effective in extending the temporal scope of quantitative studies by drawing on people's memories (Parker et al., 2007). Since HEC patterns and experiences can vary widely across spatial scales (Sitati et al., 2003; Wilson et al., 2015), dialogue with local communities can also provide a nuanced understanding of important fine-scale socioecological interactions (Buchholtz, Fitzgerald et al., 2019; Buchholtz, Redmore et al., 2019; Buchholtz, Fitzgerald, et al., 2020; Buchholtz, Stronza, et al., 2020). Additionally, interviews can initiate dialogue that may facilitate the development and implementation of participatory research, which can foster more locally relevant and impactful conservation and social outcomes (Fisher et al., 2021; Skroblin et al., 2021).

Despite the advantages of this holistic approach, particularly in understudied areas, local ecological knowledge is often overlooked, and research that links empirical HEC measurements with people's experiences of HEC is relatively limited.

In the Okavango Delta of northwest Botswana, subsistence farming communities share and compete for resources with a growing population of African savanna elephants (Buchholtz, Fitzgerald et al., 2019; Buchholtz, Redmore et al., 2019; Chase et al., 2016; Songhurst et al., 2016; Thouless et al., 2016). The Okavango Delta is a key area for elephant conservation, but has also been identified as a HEC hotspot (Botswana Department of Environmental Affairs, 2008). While numerous studies of human-elephant interactions have been conducted in the Eastern Panhandle of the Delta, far less is known about HEC dynamics in the geographically-distinct Western Panhandle. There are limited empirical studies and long-term monitoring data quantifying HEC or its impacts on communities in the region that could inform evidence-based conservation and mitigation strategies.

We aimed to quantify and characterize HEC in the Western Panhandle using a mixed-methods approach. Our main objectives were to characterize current and long-term trends in HEC, specifically patterns in conflict timing, type, severity and spatial variation. We achieved these objectives through combining data across spatial and temporal scales including incident reports, agricultural field surveys, and farmer interviews.

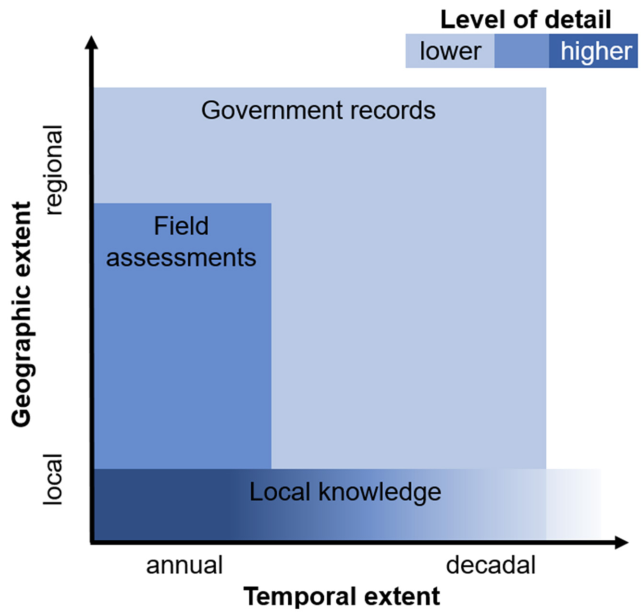


FIGURE 1 Conceptual diagram illustrating the potential for variation in geographic (spatial) extent, temporal extent, and level of detail provided by different data sources. These reflect the general patterns within our specific study area, but could be adapted and interpreted for other systems to highlight the way that different sources can complement each other, or where one source may be more relevant than another depending on the spatiotemporal extent and level of detail needed to meet objectives.

2 | METHODS

2.1 | Overview

Human-wildlife conflict (HWC) is a multifaceted challenge, and a variety of data exist to help us better understand the drivers, experiences and patterns of conflict. In this study, we focused on data from three sources that span different spatial and temporal scales: government reports, farmer interviews and field assessments. We used incident reports from the Botswana Department of Wildlife and National Parks (DWNP), which span the geographic extent of the Western Panhandle from 2008 to 2016, to quantify regional interannual HEC trends. We conducted semi-structured interviews with farmers about local HEC and used this knowledge to characterize HEC patterns; these surveys were geographically limited but encompassed farmers' memories and experiences from the 1990s to 2016. Finally, we used field assessments of elephant crop raiding incidents across eight villages during the 2016 growing season to analyse spatial patterns and conflict type and severity.

We expected these different data types to provide different information with varying levels of detail across spatial and temporal scales. Although the primary purpose of our study was to use these different data types to identify well-supported patterns of HEC, rather than use them to 'test' each other, we can use a conceptual diagram to understand their differences and better recognize how they can complement each other (Figure 1).

2.2 | Study area

The Western Okavango Panhandle (hereafter, Panhandle) represents the region directly west of the Okavango River in northern Botswana and extends down to the alluvial fan of the Okavango Delta (Figure 2). This area includes Ngamiland wildlife management areas and concessions (NG1, 2, 3, 6, 7, and 10) and covers approximately 15,000 km^2. The region is dominated by shrub savanna and sandy soils, with seasonal floodplains and riverine forest habitat along the Delta. The climate is divided broadly into the wet season (November to April, 95% of rainfall = 627 mm, Statistics Botswana, 2016) and the dry season (May to October). The Okavango River and associated wetlands provide the only permanent water in the region, and ephemeral low-lying pans fill with water during the wet season.

Both the human and elephant populations in the Okavango Delta have experienced dramatic growth since the Angolan and Namibian civil wars in the late 1990s, which led to the influx of thousands of refugees who are now permanent Botswanan citizens (Lefko-Everett, 2004), and a parallel emigration of elephants from Angola and Namibia into northern Botswana (Chase & Griffin, 2011). The elephant population in the Panhandle was estimated at 2242 elephants in 2013 (95% CI range 0–5370, sampling intensity 1.56%; Botswana DWNP, 2013). Limited aerial surveys in the Panhandle in the last decade make it difficult to estimate interannual variation and trends in the elephant population that could affect conflict. People in the Panhandle predominantly live along the A35 road that

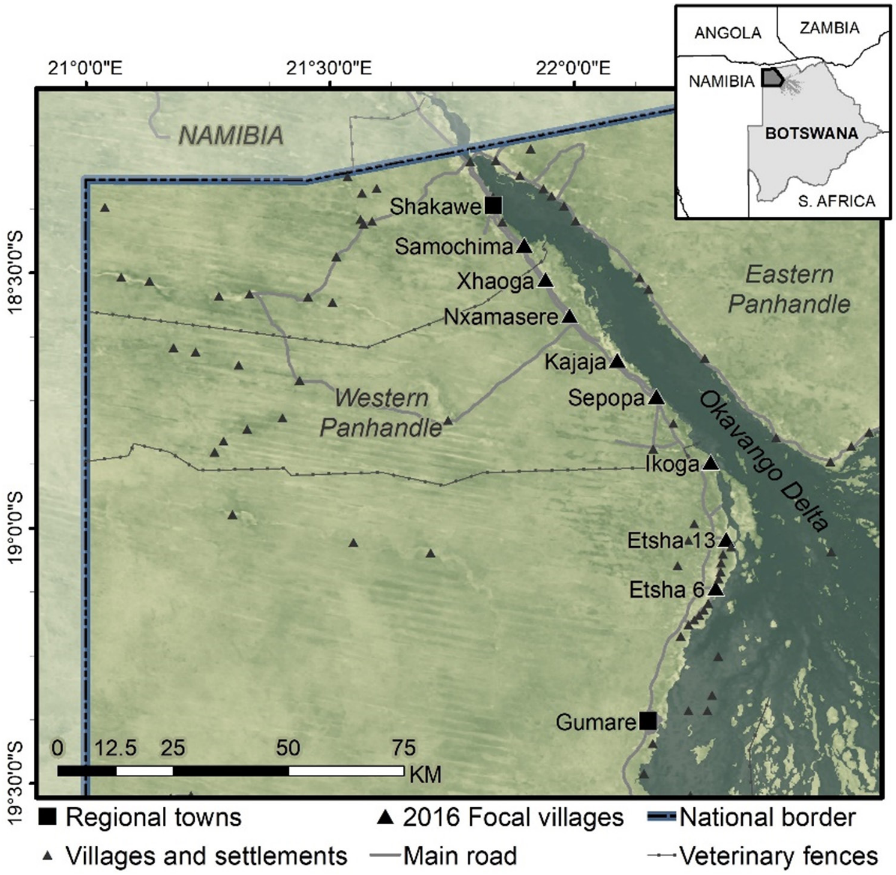


FIGURE 2 The Western Panhandle of the Okavango Delta, Botswana, including regional towns and the eight 2016 focal villages for field surveys. Farmer interviews occurred in the village of Nxamasere.

roughly follows the banks of the Okavango River wetland (Figure 2). The eight villages assessed for this study in 2016 were: Samochima, Xhaoga, Nxamasere, Kajaja, Sepopa, Ikoga, Etsha 13 and Etsha 6. They range in size from 137 people (Kajaja) to 5234 people (Etsha 6; Statistics Botswana, 2012; Table 2). The Western Panhandle has one of the highest poverty levels in the country (World Bank Group, 2015), making people especially vulnerable to the economic impacts of HEC such as crop loss. Panhandle residents rely on subsistence agriculture and livestock for their nutrition and livelihoods (see Box 1).

2.3 | Human-elephant conflict incidents: Longitudinal data

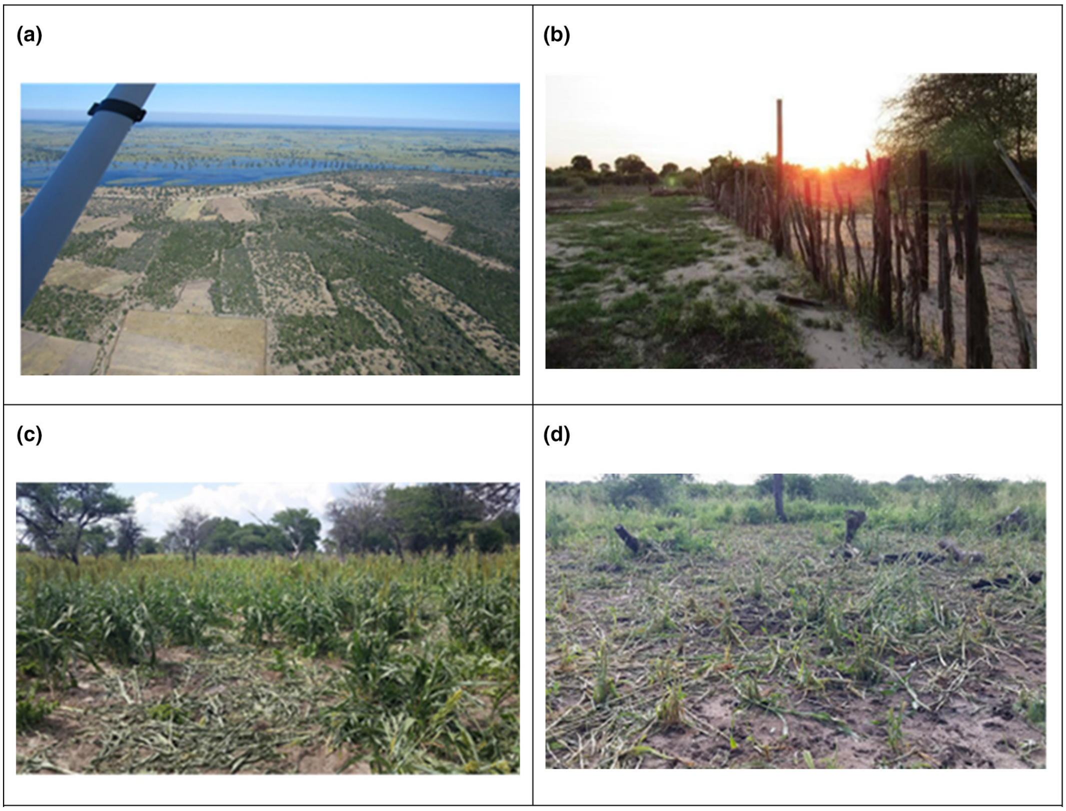
We collated longitudinal data on HEC from records kept by the regional DWNP offices in Shakawe and Gumare. Types of incidents included direct and indirect crop damage, livestock injury or death, property damage (e.g. fences, water tanks (jojos), buildings), and serious human injuries or death. Farmers are responsible for reporting incidents to officers at the DWNP, who then assess the damage as time and resources allow and complete Field Reports. Field Reports contain varying levels of information and detail; summaries of this information are used to record incidents from Field Reports in cumulative Compensation and Occurrence Logs. We copied incident records from hand-written Field Report binders and Compensation and Occurrence Logs from 2008 (the earliest records available) to 2016 and transcribed them into a digital format. DWNP aims to provide compensation for incidents based on severity of incident and standardized rates.

We analysed this longitudinal data using linear regression to characterize annual trends in HEC incident numbers and location. Since records varied in their level of precision for incident location (e.g., field description, ward name, village name), we attributed all incidents to the village-level for analyses and assessments of HEC variation among villages. These details were used to determine the relative location of HEC in the Panhandle (demarcated as north or south of the latitude of 18°69′56.01″S) and allowed us to investigate broad spatial HEC trends. Total cultivated area in 2016 was roughly equivalent in the north and the south regions of the Panhandle (north = 2,292,702 m^2, south = 2,319,815 m^2).

2.4 | Human-elephant conflict incidents: 2016 data

Detailed data on reported elephant crop raiding incidents were collected during the agricultural growing season from February to June 2016. This data supplemented, but did not replace, DWNP

BOX 1 Subsistence agriculture is common in the Western Panhandle. Major crops include staple grains like sorghum, maize and millet, and cash crops such as watermelon and sweet reed. The growing season for crops primarily falls from November to May, although timing is rainfall-dependent. Fields may have a guard hut, and these are used either as a seasonal residence throughout the growing season or to sleep in intermittently while protecting the field from elephants. (a) Fields lie outside of the village and vary in size. Proximity to the Okavango Delta can put fields directly in the path of elephants travelling to the river. (b) Fences around fields to exclude free-ranging livestock, such as pole and wire fencing, are typically ineffective at excluding elephants. Electric fencing is rare. (c) When elephants enter fields, crops such as sorghum are damaged through consumption and trampling. (d) Crop loss can be exacerbated when elephants knock over fences, which allows livestock to enter and further consume and trample crops. Photo credits: E. K. Buchholtz 2016.



assessments. Community enumerators from the eight study villages in the Panhandle were hired and trained through the non-governmental organization Ecoexist. Ecoexist is based in the Eastern Okavango Panhandle and is an NGO focused on "reducing conflict and fostering coexistence between elephants and people" (www.ecoexistproject.org). Farmers who experienced elephant crop raiding would report the incident to the community enumerator, local community council official, or police or DWNP officer. The enumerator would then visit the incident with co-author E.K. Buchholtz and field assistant S. Kerumotsemang to assess the damage. These assessments would take place as soon as possible after the incident was reported, often the same day, in order to get the most accurate measure of the damage and the conditions. Every reported incident was assessed, including if elephants raided the same fields on multiple occasions. We collected data based on standardized methods described by Hoare (1999) and Songhurst (2017), and included: characteristics of the field; farmer; types of crops grown; types of protection or mitigation used; elephant-related damage; and any elephant-related demographics, in addition to a short narrative description of the incident provided by the farmer (see full data sheet in Supporting Information Table S1). We identified the sex of the raiding elephants when possible, using visual observations of elephants or spoor (elephant track) measurements.

We used a linear mixed model to examine what factors could explain variation in the amount of crop damage per reported incident. We included field characteristics (field size; whether grains, cash crops, or both were grown; location in north or south of the region), mitigation and raid history (whether the field was guarded the night of the incident; if the field had been raided in 2015), and elephant group characteristics (male or female group; number of elephants).

We used village as the random effect and let intercepts vary. We used the LME4 package to calculate the model and estimates (Bates et al., 2015) and the PBKRTEST package to estimate likelihood-based p-values and degrees of freedom (Halekoh & Højsgaard, 2014). We also calculated summary statistics for field report data, including: location; number of previous raids; average field size; crop types damaged; total damage area; and elephant demographics. For all statistical analyses in this study, we used R v3.6.2 (R Core Team, 2021).

2.5 | Farmer interviews

We conducted semistructured interviews with farmers in the village of Nxamasere during June and July 2016. This village was selected due to its central location, ongoing rapport and trust with both the farmers and the *dikgosi* (chiefs/heads of villages), and reliable communication with the Village Development Council. The goal of the interview was to understand people's experiences farming, how elephants and crop raiding impact their farming, and their perception of the local elephant population in terms of size, demographics, and behaviour (full script in Supporting Information Table S2).

The interviewees were selected by making a list of all of the farmers in the village with the cooperation of the *dikgosi* and Village Development Council, and contacting them to set up the interview if they were willing and able. Farmers were selected to represent households, with interviews from 40 farmers recorded and analysed in this study of the approximately 65 independent households in Nxamasere. A majority of farmers interviewed were females aged between 40–69 years old, and had been farming for their whole lives (Supporting Information Table S3). Farmers were met in a location of their choosing, usually in the village *kgotla* yard (center square), or at their fields or homes. They were provided with a written and verbal description of the study and provided verbal consent prior to the interview to accommodate limited literacy. Interviews followed approved materials and ethics by the Texas A&M University Institutional Review Board (College Station, Texas, USA—Protocol IRB2016-0279D). All interviews were conducted in Setswana or Simbukushu, with translation by S. Kerumotsemang, and written transcription of responses into English. No financial compensation was provided.

Interview responses were quantified for both open- and closed-ended questions. Thematic analysis was conducted on open-ended questions prior to quantifying them using the methodology outlined by Braun and Clarke (2006). These themes were defined and applied by co-author M.E. McDaniels, who did not conduct the interview and was therefore more impartial to the responses. First, all open-ended responses were read and then re-read thoroughly, to ensure familiarity with and understanding of the data. Next, initial codes and labels were developed based on phrases that encapsulated common responses to the questions. These codes were then broadened into overarching and comprehensive themes and applied to each response. This allowed the number of responses falling into each theme to be quantified. Depending on the question, multiple themes could be applied to a response. Themes and responses were then summarized for interpretation.

3 | RESULTS

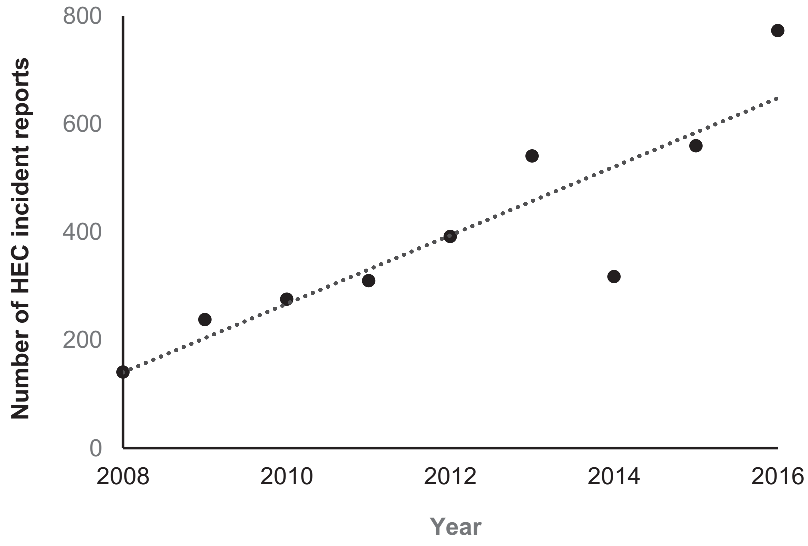
3.1 | Human-elephant conflict: Annual and seasonal trends

There was an increase in the annual number of HEC incidents in the Panhandle between 2008 and 2016, based on DWNP longitudinal report data ($R^2 = 0.79$, Figure 3a). HEC incidents ranged from 141 in 2008 to 773 in 2016, peaking in 2016. Although lower than the trendline, HEC levels in 2014 did not qualify as an outlier. HEC accounted for half of all HWC incidents reported to DWNP during the nine-year period (HEC: $n = 3549$, HWC: $n = 7015$).

The trend of increasing HEC incidents over time observed in DWNP reports was supported by farmers' interview responses, with most farmers responding that HEC levels had increased over the last 8–10 growing seasons (Figure 3b). Farmers primarily attributed the increase to a growth in the elephant population and changes in elephant behaviour (47.6%). One respondent said that "as time went on, elephants are more," and others said that "there are a lot more elephants now because of reproducing" and "elephants are reproducing at a higher rate." One respondent specifically stated that more elephants were coming from Namibia into the Panhandle since the end of the civil war. Some farmers believed that elephants had become less fearful over time, with one saying that "it used to be easier…you could just make noise and the elephants would leave the fields, but now they stay longer" and another saying that "now, even if I try to chase them out the elephants will just stay around the field like cattle". Some farmers attributed variation in HEC trends to rainfall levels. Generally, they indicated that years with lower or later rainfall and longer droughts resulted in a greater number and intensity of conflict incidents, with one farmer stated that "It [HEC] only depends on the rainfall." However, there was not a consensus on the magnitude or direction of how rainfall and drought impacted elephant presence and movement.

HEC incidents exhibited strong seasonality, with three-quarters of incidents reported to DWNP from 2008 to 2016 occurring between February and May (74.77%, Figure 4a). These months overlap with the wet season in the Panhandle, which spans from November to April, and the growing season for staple grains such as millet and sorghum, which are planted after the rainy season begins and ripen from April through June. March through June showed the highest levels of interannual variation in HEC incidents, with several outliers in February through May in the years 2008, 2013, 2015 and 2016. The total number of annual HEC incidents varied more in the late wet season than in the late dry season. The 2016 field survey data was closely aligned with the DWNP data (Figure 4b). During the growing season there were 251 individual crop raiding incidents, and the majority of incidents occurred from March through May ($n = 226$), with a peak of 113 incidents in April.

(a)



(b)

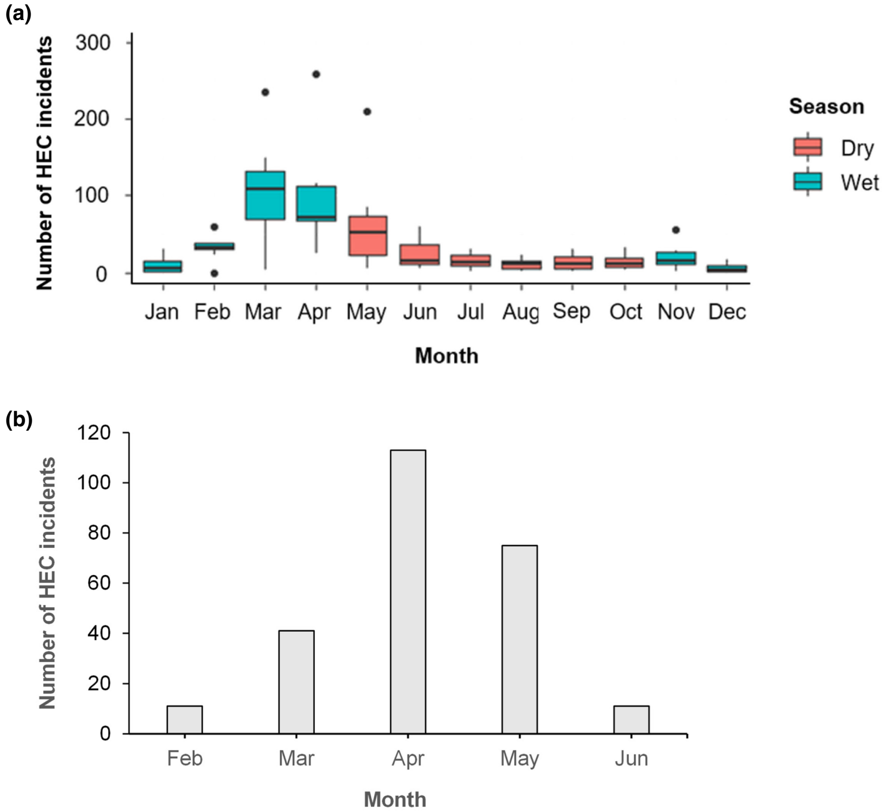
Response	*Count*
Increased	**14**
Due to increased numbers of elephants	5
Due to change in elephant behavior	5
Varies annually	**6**
Related to rainfall levels	2
Related to number of elephants	4
Related to protection of fields	1
Other	**1**
Decreased	**0**

Farmer responses to the question about the past eight to ten growing seasons, "Over that period of time, have crop raids been increasing, decreasing, or changing year-to-year with no clear pattern?"

FIGURE 3 Annual trends of HEC incidents in the Western Okavango Panhandle. (a) An increasing annual trend in incidents ($y = 63.8x - 127{,}969$, $R^2 = 0.79$) based on reports to the Botswana Department of Wildlife and National Parks from 2008–2016 ($n = 3549$). (b) Farmer interview responses about annual HEC trends and causes (farmer respondents: $n = 21$).

The timing of HEC from farmer surveys corresponded with both the DWNP incident reports and 2016 field survey data. Farmers used a combination of specific months, crop stages, and rainfall conditions to describe the timing of HEC. They reported that crop raiding primarily occurred from February through June, and was most frequent in April and May (Figure 4c,d). Most raids began when crops were at an intermediate stage, and peaked when crops were ripe. A few farmers related higher HEC with low or delayed rainfall.

Most farmers said that they experienced crop raiding in 2016 (84.21%, $n = 32$), and over one-quarter of these respondents experienced raiding one to two times during the season (28.1%, $n = 9$). Of the fields surveyed in 2016, most incurred raids (80.19%, $n = 170$). A quarter of farmers who experienced crop raiding in 2016 said elephants had raided their fields three times during the season ($n = 8$); an additional nine farmers described the frequency of raids as "many", with some occurring on a weekly basis (21.8%). Most surveyed fields raided in 2016 were only raided once ($n = 118$). The remaining 52 fields accounted for 133 separate incidents. Fields that incurred multiple raids sustained an average of 2.56 raids, with a maximum of five repeat crop raiding events in one field. On average, there were 14 days between repeat raids, with 20% of repeat raids occurring within 3 days of the first raid ($n = 26$), and 26% occurring within a week ($n = 34$). A majority of farmers experienced



(c)

Response	*Count*
Related to month	**16**
February - March	8
April - May	7
September	1
Related to crop stage	**15**
Intermediate	11
Ripe	4
Related to rainfall and water levels	**5**
No specific start because elephants are around all the time	**7**

Farmer responses to the question, "What time of year or at what point in the season do elephants start to come into fields?"

(d)

Response	*Count*
Related to month	34
February - March	7
April - May	20
June - July	7
Related to crop stage	**9**
Intermediate	1
Ripe	8
Related to rainfall and water levels	3
Frequent at all times	**3**

Farmer responses to the question, "When is the time or point in the season when there are the most elephants or the most frequent raids?"

FIGURE 4 Temporal patterns for the beginning and frequency of HEC incidents in the Western Okavango Panhandle. (a) Seasonal frequency of HEC incidents from DWNP incident reports from 2008–2016. Outliers are displayed as black circles. (b) Monthly frequency of crop raiding incidents assessed in 2016. (c) Farmers responses with a variety of indicators to describe the timing of elephants' presence in fields and (d) the seasonal frequency of elephants and raids.

at least one conflict event prior to 2016 (87.18%, $n = 34$), and most of those respondents said that HEC had occurred every year since 2010 (61.76%, $n = 21$). One farmer said that since 1996, elephants had been raiding their crops. They "couldn't remember a year since then where elephants did not cause some damage, but before 1996 elephants were not raiding crops."

3.2 | Human-elephant conflict: Incident type and severity

The most common type of HEC incident reported to DWNP between 2008 and 2016 was crop and field damage (87.66%, n = 3111). One-third of incidents included property damage (33.79%, n = 1319), mostly involving fences and fence poles, water pumps, and jojo water tanks. Property damage, typically damage of fences and fence poles surrounding fields, co-occurred with about one-fifth of crop and field damage incidents (19.86%). Injury to or death of livestock made up 2.08% of reports. Between 2008 and 2016, 10 recorded incidents resulted in "human life-threatening" impacts.

The extent of crop damage during a single incident ranged from 2 m^2 to 76,748 m^2 (mean 1610.6 m^2) during 2016 based on assessed fields. Eight of the fields that were assessed in 2016 sustained 100% crop loss. During interviews, 13 of the farmers who had experienced crop raiding prior to 2016 reported that elephants had damaged 100% of their fields in past raids, and four farmers said that elephants had damaged 100% of their fields for two or more seasons.

The amount of damage done in a single night was more likely to be due to the number of elephants than to other variables, such as what type of crop was grown, where the field was located, whether it had been guarded the night of the raid, or if it had been raided the previous year (Table 1). The size of the field and number of elephants were both positive and statistically significant factors correlated with the amount of damage in crop raiding incidents. Including a random effect variable for village increased the R-squared value (marginal R^2 = 0.20, conditional R^2 = 0.31).

Elephant herds that raided fields during 2016 varied in size and demographic makeup. Most crop raiding incidents were attributed to single elephants or groups with less than four individuals (n = 166). Most raids involved male elephants (n = 186), with group size averaging 2.3 individuals, while under one-fifth of raids involved female herds (n = 43) averaging 6.9 individuals. Most raids by both male groups and female herds resulted in fence damage (90.70% vs 89.25%, respectively). Female herds tended to damage a greater proportion of total field area than male groups; an average raid by a female herd resulted in damage to nearly a quarter of a field's total area (23.08%), compared to just 4.26% by male groups. Both female herds and male groups had a strong likelihood of raiding fields that had been previously raided within the last year (72.97% female raids, 78.57% male raids). In addition to damaging crops, nearly half of all raids by female herds also included injury or death to livestock (46.51%), compared to around one-quarter of male raids (24.19%).

Several farmers described changes in the demographics of the elephant groups that raided their crops (n = 13), reporting that the size of raiding herds was larger. One farmer said "even now there are family herds [raiding], when there used to be only bulls." Other farmers added that "families" and "groups" were coming more frequently, "even coming with their babies now", and that raiding herds "come sometimes in high numbers… sometimes more than five individuals". Another farmer said that "…with families they [elephants] will even threaten your life…now elephants are in large numbers, and you can chase out a whole group but a new group can then come in." This farmer went on to say "The more elephants in a group, the more damage caused."

3.3 | Human-elephant conflict: Spatial variation

Between 2008 and 2016, HEC increased in the northern portion of the Panhandle, and there was a fluctuating trend in the southern portion according to DWNP reports (Figure 5). HEC in the north had a statistically significant positive exponential trend over the study period, with a peak of 524 reports in 2016 (R^2 = 0.86). HEC in the south did not have a statistically significant trend and peaked in 2009 with 142 reports (R^2 = 0.18). The largest disparity between HEC reports in the north and south occurred in 2016 (524 reports vs 179 reports, respectively). The distribution of crop raiding incidents in the 2016 agricultural field surveys somewhat aligned with the long-term trends; just over half of crop raids occurred in the north (55.38%, n = 139, Table 2). Most raids were concentrated in the three northernmost villages of Nxamasere, Samochima, and Xhaoga, with nearly a quarter of raids occurring in Xhaoga. More fields incurred repeat raids in the north than the south, and a higher proportion of all raids in the north were repeat raids.

The long-term annual frequency and the proportion of fields raided in 2016 surveys varied at the scale of individual villages,

TABLE 1 Linear mixed model for total crop-raiding damage per incident based on reported incidents during 2016 for eight villages in the western Okavango Panhandle, Botswana. Random effect of villages (n = 8), observations = 210, intraclass correlation = 0.13.

Covariates	Estimates	CI	p	df
(Intercept)	−2966.93	−6454.91 to 521.05	0.09	14.62
Field size (m2)	0.08	0.01 to 0.14	0.016*	194
number of elephants	744.21	310.62 to 1177.80	0.001**	200.91
females present	1578.53	−1240.24 to 4397.29	0.271	199.56
field located in north	−1687.24	−6102.39 to 2727.92	0.392	6.52
raided in 2015	−120.32	−1954.21 to 1713.57	0.897	200.92
only grain crops grown	2921.72	−1756.76 to 7600.20	0.22	200.77
only produce crops grown	721.39	−6045.67 to 7488.45	0.834	197.63
guarded	1487.32	−554.11 to 3528.74	0.152	200.35

*p ≤ 0.05; **p ≤ 0.01.

according to DWNP and 2016 field survey data (Table 2). The villages reporting the highest numbers of incidents differed each year, and the total number of incidents reported per village also varied each year (supporting information Table S4). In the 2016 field surveys, villages in the south experienced the maximum, second highest, and lowest proportion of fields raided on a per-village basis (100%, 90.00% and 53.33%). The percentage of fields raided in each village in the south had a greater variability than villages in the north (σ(south) = 0.20, σ(north) = 0.03).

3.4 | Farmer interviews: Incident reporting

Farmers who experienced crop raiding in 2016 reported the incident to DWNP and/or Ecoexist (27 reported to DWNP; 24 reported to Ecoexist; 20 reported to both). Of those that reported only to Ecoexist, we also informed DWNP. However, only one-quarter of farmers said that DWNP had assessed the reported damages by the time of our survey (25.93%, *n* = 7). Several farmers said that they were discouraged from reporting field damage because of inaction by the DWNP. One respondent said that "always the wildlife department takes a long time for them to come, and then again a long time to compensate". Another said "[I am] trying to report all the problems, but the DWNP responds late, so [I am] just giving up", and "because even with reports from DWNP the government doesn't do anything".

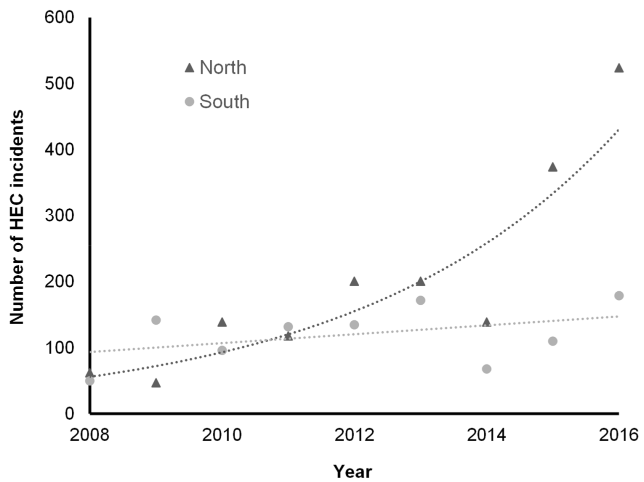


FIGURE 5 Interannual variation in the levels of reported HEC incidents in the northern ($y = [(3 \times 10^{-221})(e^{0.25x})]$, $R^2 = 0.86$) and southern ($y = 6.73x - 13{,}427$, $R^2 = 0.18$) portions of the Panhandle from 2008 to 2016.

4 | DISCUSSION

Human-wildlife conflict is a multidimensional issue, and in regions where data is limited, it can be difficult to form a comprehensive understanding of the conflict and its impacts. We used three different data types to characterize the complexity of HEC in the Western Okavango Panhandle of Botswana, which we found differs in timing, location, type and severity of conflict incidents. This work provides an example of HWC research that uses a mixed-methods approach to develop a retrospective characterization of long-term trends in an area with limited historical wildlife conflict and population data. Drawing from a variety of data sources allowed us to build an understanding of past and current trends in HEC and elephant demographics that no single data source could provide.

HEC in the Panhandle, as reflected in reported incidents and farmers' experiences, significantly increased between 2008 and 2016. We found that reported HEC incidents nearly tripled in less than 10 years and farmers perceived conflict and crop raiding as escalating issues. These trends are important to know, because there is limited information for the sizes and interactions of human and elephant populations that could otherwise be used to infer conflict trends. Governmental records that date back to 2008 and span the spatial extent of the western Panhandle are therefore valuable for capturing regional trends. Farmers' experiences likewise indicate more frequent incidents, reflecting the increasing trend over time. The increasing pattern of annual HEC highlights the growing challenge that conservation, management, and mitigation efforts must address.

Not all conflict incidents are equal, and it is important to consider the type, severity and frequency of conflict. Characterizing the variation in conflict incidents allows us to recognize the different

TABLE 2 Total crop raiding incidents from 2016 field surveys in eight villages across the Panhandle.

	Village	Population	Total number of fields per village	Unraided fields	Number of raid incidents	Percent of fields raided	Percent of total 2016 raids
North	Samochima	1,145	27	4	32 (17 repeat raids)	85.19%	12.75%
	Xhaoga	889	41	8	58 (39 repeat raids)	80.49%	23.11%
	Nxamasere	1,584	30	6	37 (22 repeat raids)	80%	14.74%
	Kajaja	247	10	2	12 (6 repeat raids)	80%	4.78%
South	Sepopa	2,824	20	2	24 (8 repeat raids)	90%	9.56%
	Ikoga	1,270	30	14	23 (12 repeat raids)	53.33%	9.16%
	Etsha 6	5,237	29	6	35 (19 repeat raids)	79.31%	13.94%
	Etsha 13	2,694	25	0	30 (10 repeat raids)	100%	11.95%

Lighter grey shading indicates villages in the northern region and darker grey shading indicates villages in the southern region.

outcomes for people and elephants associated with the conflict and to effectively mitigate and manage those impacts (Meinecke et al., 2018). Farmers in the Panhandle experienced direct crop loss and property damage in 2016, ranging from a single trampled path through their field to over 76,700 m^2 of elephant foraging and trampling. Eight fields experienced 100% crop loss due to elephant incidents in 2016 alone. The severity of incidents, in terms of crop area damaged, was most strongly correlated with the number of elephants in the group based on 2016 data as well as farmer responses. Multiple farmers also reported that the challenge in trying to limit the damage caused by elephants has increased as elephants seem more desensitized to deterrents than they used to be. We did not find any statistical correlation between less damage done in fields that were actively guarded by farmers on the night of the incident. There was not a strong correlation with the type of crop grown, either; between farmers' experiences and the 2016 field assessments, this suggests some of the primary ways that farmers can attempt to reduce elephant crop raiding damage may have limited effect.

A key finding from both the farmer interviews and field assessments was the relationship between crop damage and the type and size of elephant group involved. Smaller groups, often bachelor herds or single bulls, presented a chronic challenge, occurring more frequently but resulting in less damage on average. Crop raiding by larger, female family groups was less common, but more acute, with a higher likelihood of injuring or killing livestock in addition to damaging crops. Farmers in Nxamasere reported that they had experienced crop raiding every year, at least once or twice a season. In 2016, we found that 80% of the fields were raided at least once, with 52 fields incurring repeat raids during the season. Both chronic and acute impacts can reduce field and farmer resilience throughout the growing season and can lead to food insecurity and loss of income. Previous studies showing that the financial impacts of property damage and trampling of non-target crops can be more costly than the crops consumed (Inogwabini et al., 2013; Naughton-Treves, 1998). This is further exacerbated by our finding that most raids occurred in fields that had been previously raided within the last year.

Conflict and its impacts vary seasonally, as well as in severity and frequency. All three data sources highlighted the strong seasonality of HEC. Farmers said that crop raiding began when crops were at an intermediate stage or ripe. Crops may be more attractive to elephants than wild forage at this stage because of their high nutritional value, despite wild forage also maturing during the rainy season (Chiyo et al., 2005; Gross et al., 2018). If social or climatic factors alter crop planting, this might also shift crop ripening timelines and therefore HEC occurrence. To best anticipate upcoming HEC patterns, mitigation efforts should therefore take into account how farmers adapt and vary crop timing.

We found the number and severity of HEC incidents were not uniform across the Panhandle but varied spatially. Data from the DWNP and field surveys showed that while HEC was increasing, it did not impact villages equally within or between years. Incidents increased exponentially in the northern region between 2008 and 2016, while incidents had no statistically significant trend in the south, although the number of incidents was more variable year-to-year there. Even within the northern and southern regions, there was variation in crop raiding frequency and intensity. Due to this variation, regionally-aggregated HEC levels could obscure local patterns necessary to manage different communities' needs. Spatial context for HEC has proved important in studying and predicting local patterns, for example in the configuration and connectivity of the landscape (Buchholtz, Fitzgerald et al., 2020; Buchholtz, Stronza, et al., 2020) and the distribution of fields and underlying anthropogenic and environmental variables (e.g. distance to water, presence of roads) on conflict incidents (Songhurst & Coulson, 2014). The regional patterns we found in the Panhandle could be the result of a variety of environmental, biological and anthropogenic covariates, warranting further research into the different trends in reported HEC incidents in the northern and southern Panhandle. Understanding spatial and temporal variations in HEC and elephant spatial ecology can be useful in the flexible allocation of resources for conflict management, for example through coordinating the distribution of elephant deterrents at different times for different locations, or increasing the presence of DWNP officials in villages that experience greater levels of HEC. It can also provide an early warning of the displacement of conflict from one village to another as new HEC mitigation strategies or farming techniques are implemented (Sitati & Walpole, 2006).

The mixed-methods approach emphasized some of the utility, strengths, and limitations of the different data sources. The DWNP PAC records provided nearly a decade of HEC levels across the Western Panhandle, which broadened the temporal and geographic scope of our study. However, during the study period, compensation payments were often delayed by months or years and did not serve as a strong incentive to report incidents. HEC incident reports to DWNP were considered to be an underestimate of overall HEC because of low levels of reporting, and therefore the results of all analyses are likely conservative estimates (DeMotts & Hoon, 2012). They offer general insight into the magnitude and trends of HEC at a regional scale that we would not have been able to replicate otherwise.

In contrast, interviewing individuals within a single central village provided a geographically limited but otherwise detailed source of knowledge about elephant behaviour, crop raiding, and patterns of HEC over time. It must be interpreted carefully to not extrapolate farmers' experiences in Nxamasere beyond the relevant spatial extent, however, it provided a valuable insight into the patterns of HEC that people experience and their understanding of why those patterns have arisen. As primary knowledge holders in the region, farmers' experiences of elephant behaviour and HEC revealed details about the timing, frequency, and long-term magnitude and trends of elephant demographics and HEC. Without these conversations, we would not have been able to obtain this information at a local level from other data sources. This mirrors other studies showing that people that interact with wildlife hold local ecological knowledge of conflict dynamics and species' habitat usage (Buchholtz, Fitzgerald et al., 2020; Buchholtz, Stronza, et al., 2020; Gilchrist et al., 2005; Meijaard et al., 2011).

Lastly, the field assessment data from a single season provided more in-depth data for HEC incidents as they occurred. This allowed us to record actual incident frequency, which is not recorded by the DWNP, as well as specific variables about the field, damage, elephants, and farmers involved. Repeated efforts to collect this data annually would provide stronger statistical support for understanding the drivers of HEC (Songhurst et al., 2016).

Future studies should examine the underlying anthropogenic and environmental drivers of HEC in the Panhandle and consider variables of field location and elephant movement in predicting conflict occurrence and intensity. New strategies that may improve human-elephant coexistence in the Western Panhandle, such as maintaining elephant movement corridors, protecting clusters of fields, and utilizing various mitigation techniques such as chilis, buffer crops and beehive fences, should be implemented through a co-design process with local residents and their ecological knowledge, with further collaboration through pilot and assessment phases. HEC remains a complex challenge in conservation and community development. A thorough understanding of the underlying patterns and processes driving HEC is key to finding long term solutions to reduce HEC.

As human populations, land use, and other factors that influence where people and wildlife interact change over time, it is crucial to understand and mitigate negative impacts and conflict. By combining existing data sources with interviews and field assessments, we aimed to capture regional patterns in conflict dynamics and context. This approach can be applied in other regions and systems, especially when there are limited historical data or monitoring. It is an important precursor to effective and collaborative conflict management and mitigation. Where possible, this mixed-methods approach may support understanding complex human-wildlife interactions and support the diverse communities and stakeholders involved with conflict-related challenges.

AUTHOR CONTRIBUTIONS

Erin K. Buchholtz and Megan McDaniels conceived the ideas and designed methodology; Erin K. Buchholtz collected the data; Megan McDaniels analysed the data; Megan McDaniels led the writing of the manuscript. All authors contributed to the manuscript during the writing and revising process.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

Field assessment data is archived in the Dryad Data Platform (https://doi.org/10.5061/dryad.bnzs7h4fka) and is available at https://datadryad.org/stash/share/JICkcj3szQggaf6oxWkwTS4rb5Y_12_cCCfRQhkOKeU. Data from DWNP is only available by contacting DWNP. Farmer interview data are not publicly available to protect the privacy of interviewees but may be shared with reasonable request to E. Buchholtz.

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REFERENCES

Abrahms, B. (2021). Human-wildlife conflict under climate change. *Science*, *373*(6554), 484–485. https://doi.org/10.1126/science.abj4216

Ahlering, M. A., Millspaugh, J. J., Woods, R. J., Western, D., & Eggert, L. S. (2011). Elevated levels of stress hormones in crop-raiding male elephants: Elevated stress in crop-raiding elephants. *Animal Conservation*, *14*(2), 124–130. https://doi.org/10.1111/j.1469-1795.2010.00400.x

Ball, R., Jacobson, S. L., Rudolph, M. S., Trapani, M., & Plotnik, J. M. (2022). Acknowledging the relevance of elephant sensory perception to human-elephant conflict mitigation. *Animals: An Open Access Journal from MDPI*, *12*(8), 1018. https://doi.org/10.3390/ani12081018

Barua, M., Bhagwat, S. A., & Jadhav, S. (2013). The hidden dimensions of human–wildlife conflict: Health impacts, opportunity and transaction costs. *Biological Conservation*, *157*, 309–316. https://doi.org/10.1016/j.biocon.2012.07.014

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Botswana DWNP. (2013). *Aerial census of animals in Botswana: 2013 dry season report*. Botswana Department of Wildlife & National Parks.

Botswana Department of Environmental Affairs. (2008). *Okavango Delta management plan* (pp. 1–216). Botswana Department of Environmental Affairs.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Browne-Nuñez, C., & Jonker, S. (2008). Attitudes toward wildlife and conservation across Africa: A review of survey research. *Human Dimensions of Wildlife*, *13*, 47–70. https://doi.org/10.1080/10871200701812936

Buchholtz, E., Fitzgerald, L., Songhurst, A., McCulloch, G., & Stronza, A. (2020). Experts and elephants: Local ecological knowledge predicts landscape use for a species involved in human-wildlife conflict. *Ecology and Society*, *25*(4), 26. https://doi.org/10.5751/ES-11979-250426

Buchholtz, E. K., Fitzgerald, L., Songhurst, A., McCulloch, G., & Stronza, A. (2019). Overlapping landscape utilization by elephants and people in the Western Okavango Panhandle: Implications for conflict and conservation. *Landscape Ecology*, *34*(6), 1411–1423. https://doi.org/10.1007/s10980-019-00856-1

Buchholtz, E. K., Redmore, L., Fitzgerald, L. A., Stronza, A., Songhurst, A., & McCulloch, G. (2019). Temporal partitioning and overlapping use of a shared natural resource by people and elephants. *Frontiers in Ecology and Evolution*, *7*, 117. https://doi.org/10.3389/fevo.2019.00117

Buchholtz, E. K., Stronza, A., Songhurst, A., McCulloch, G., & Fitzgerald, L. A. (2020). Using landscape connectivity to predict human-wildlife conflict. *Biological Conservation*, *248*, 108677. https://doi.org/10.1016/j.biocon.2020.108677

Buscher, B., & Fletcher, R. (2020). *The conservation revolution: Radical ideas for saving nature beyond the Anthropocene*. Verso Books.

Campbell-Staton, S. C., Arnold, B. J., Gonçalves, D., Granli, P., Poole, J., Long, R. A., & Pringle, R. M. (2021). Ivory poaching and the rapid evolution of tusklessness in African elephants. *Science (New York, N.Y.)*, *374*(6566), 483–487. https://doi.org/10.1126/science.abe7389

Chase, M. J., & Griffin, C. R. (2011). Elephants of south-East Angola in war and peace: Their decline, re-colonization and recent status: Elephants in war and peace in SE Angola. *African Journal of Ecology*, *49*(3), 353–361. https://doi.org/10.1111/j.1365-2028.2011.01272.x

Chase, M. J., Schlossberg, S., Griffin, C. R., Bouché, P. J. C., Djene, S. W., Elkan, P. W., Ferreira, S., Grossman, F., Kohi, E. M., Landen, K., Omondi, P., Peltier, A., Selier, S. A. J., & Sutcliffe, R. (2016). Continent-wide survey reveals massive decline in African savannah elephants. *PeerJ*, *4*, e2354. https://doi.org/10.7717/peerj.2354

Chiyo, P. I., Cochrane, E. P., Naughton, L., & Basuta, G. I. (2005). Temporal patterns of crop raiding by elephants: A response to changes in forage quality or crop availability? *African Journal of Ecology*, *43*(1), 48–55. https://doi.org/10.1111/j.1365-2028.2004.00544.x

Chiyo, P. I., Lee, P. C., Moss, C. J., Archie, E. A., Hollister-Smith, J. A., & Alberts, S. C. (2011). No risk, no gain: Effects of crop raiding and genetic diversity on body size in male elephants. *Behavioral Ecology*, *22*(3), 552–558. https://doi.org/10.1093/beheco/arr016

Compaore, A., Sirima, D., Hema, E. M., Doamba, B., Ajong, S. N., Di Vittorio, M., & Luiselli, L. (2020). Correlation between increased human-elephant conflict and poaching of elephants in Burkina Faso (West Africa). *European Journal of Wildlife Research*, *66*(1), 24. https://doi.org/10.1007/s10344-019-1329-8

DeMotts, R., & Hoon, P. (2012). Whose elephants? Conserving, compensating, and competing in northern Botswana. *Society & Natural Resources*, *25*(9), 837–851. https://doi.org/10.1080/08941920.2011.638362

Deodatus, F. D., & Lipiya, A. K. (1991). *Vertebrate pest impact around Kasungu National Park January–June 1990*. https://scholar.google.com/scholar_lookup?title=Vertebrate+pest+impact+around+Kasungu+National+Park%2C+January+-June+1990&author=Deodatus%2C+F.D.&publication_year=1991

Durant, S. M., Marino, A., Linnell, J. D. C., Oriol-Cotterill, A., Dloniak, S., Dolrenry, S., Funston, P., Groom, R. J., Hanssen, L., Horgan, J., Ikanda, D., Ipavec, A., Kissui, B., Lichtenfeld, L., McNutt, J. W., Mitchell, N., Naro, E., Samna, A., & Yirga, G. (2022). Fostering coexistence between people and large carnivores in Africa: Using a theory of change to identify pathways to impact and their underlying assumptions. *Frontiers in Conservation Science*, *2*, 127. https://www.frontiersin.org/articles/10.3389/fcosc.2021.698631

Fisher, J. T., Grey, F., Anderson, N., Sawan, J., Anderson, N., Chai, S.-L., Nolan, L., Underwood, A., Maddison, J. A., Fuller, H. W., & Frey, S. (2021). Indigenous-led camera-trap research on traditional territories informs conservation decisions for resource extraction. *FACETS*, *6*, 1266–1284. https://doi.org/10.1139/facets-2020-0087

Gilchrist, G., Mallory, M., & Merkel, F. (2005). Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. *Ecology and Society*, *10*(1) https://www.jstor.org/stable/26267752

Gobush, K. S., Edwards, C. T. T., Balfour, D., Wittemyer, G., Maisels, F., & Taylor, R. D. (2020). IUCN red list of threatened species: Loxodonta africana. *IUCN Red List of Threatened Species*. https://doi.org/10.2305/IUCN.UK.2021-2.RLTS.T181008073A204401095.en

Gobush, K. S., Mutayoba, B. M., & Wasser, S. K. (2008). Long-term impacts of poaching on relatedness, stress physiology, and reproductive output of adult female African elephants. *Conservation Biology*, *22*(6), 1590–1599. https://doi.org/10.1111/j.1523-1739.2008.01035.x

Gross, E. M., Lahkar, B. P., Subedi, N., Nyirenda, V. R., Lichtenfeld, L. L., & Jakoby, O. (2018). Seasonality, crop type and crop phenology influence crop damage by wildlife herbivores in Africa and Asia. *Biodiversity and Conservation*, *27*(8), 2029–2050. https://doi.org/10.1007/s10531-018-1523-0

Gross, E. M., Pereira, J. G., Shaba, T., Bilério, S., Kumchedwa, B., & Lienenlüke, S. (2022). Exploring routes to coexistence: Developing and testing a human–elephant conflict-management framework for African elephant-range countries. *Diversity*, *14*(7), 525. https://doi.org/10.3390/d14070525

Halekoh, U., & Højsgaard, S. (2014). A Kenward-Roger approximation and parametric bootstrap methods for tests in linear mixed models – The R package pbkrtest. *Journal of Statistical Software*, *59*, 1–32. https://doi.org/10.18637/jss.v059.i09

Hoare, R. E. (1999). *Data collection and analysis protocol for human-elephant conflict situations in Africa* (p. 41). WWF International and IUCN African Elephant Specialist Group.

Inogwabini, B. I., Longwango, M., Bakanza, A., & Bokika, J. C. (2013). Crop damage done by elephants in Malebo region, Democratic Republic of Congo. *Pachyderm*, *54*, 59–65.

IPBES. (2019). Global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services. *Zenodo*. https://doi.org/10.5281/zenodo.6417333

Kansky, R., Kidd, M., & Knight, A. T. (2014). Meta-analysis of attitudes toward damage-causing mammalian wildlife: Attitudes to damage-causing wildlife. *Conservation Biology*, *28*(4), 924–938. https://doi.org/10.1111/cobi.12275

Keil, P. G. (2016). Elephant–human Dandi: How humans and elephants move through the fringes of forest and village. In P. Locke & J. Buckingham (Eds.), *Conflict, negotiation, and coexistence: Rethinking human–elephant relations in South Asia* (0). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199467228.003.0012

Khumalo, K. E., & Yung, L. A. (2015). Women, human-wildlife conflict, and CBNRM: Hidden impacts and vulnerabilities in Kwandu conservancy, Namibia. *Conservation and Society*, *13*(3), 232–243.

Kohler, F., Holland, T. G., Kotiaho, J. S., Desrousseaux, M., & Potts, M. D. (2019). Embracing diverse worldviews to share planet earth. *Conservation Biology*, *33*(5), 1014–1022. https://doi.org/10.1111/cobi.13304

Lefko-Everett, K. (2004, September 1). *Botswana's changing migration patterns*. Migrationpolicy.Org https://www.migrationpolicy.org/article/botswanas-changing-migration-patterns

Manoa, D., Mwaura, F., Thenya, T., & Mukhovi, S. (2020). *A review of the visible and hidden opportunity costs of human-wildlife conflict in Kenya*. *9*, 228.

Mayberry, A. L., Hovorka, A. J., & Evans, K. E. (2017). Well-being impacts of human-elephant conflict in Khumaga, Botswana: Exploring visible and hidden dimensions. *Conservation and Society*, *15*(3), 280–291.

McComb, K., Moss, C., Durant, S. M., Baker, L., & Sayialel, S. (2001). Matriarchs as repositories of social knowledge in African elephants. *Science*, *292*(5516), 491–494.

Meijaard, E., Buchori, D., Hadiprakarsa, Y., Utami-Atmoko, S. S., Nurcahyo, A., Tjiu, A., Prasetyo, D., Nardiyono, Christie, L., Ancrenaz, M., Abadi, F., Antoni, I. N. G., Armayadi, D., Dinato, A., Ella, Gumelar, P., Indrawan, T. P., Kussaritano, Munajat, C., Priyono, C. W. P., Purwanto, Y., Puspitasari, D., Putra, M. S. W., Rahmat, A., Ramadani, H., Sammy, J., Siswanto, D., Syamsuri, M., Andayani, N., Wu, H., Wells, J. A., & Mengersen, K. (2011). Quantifying killing of orangutans and human-orangutan conflict in Kalimantan, Indonesia. *PLoS ONE*, *6*(11), e27491. https://doi.org/10.1371/journal.pone.0027491

Meinecke, L., Soofi, M., Riechers, M., Khorozyan, I., Hosseini, H., Schwarze, S., & Waltert, M. (2018). Crop variety and prey richness affect spatial patterns of human-wildlife conflicts in Iran's Hyrcanian forests. *Journal for Nature Conservation*, *43*, 165–172.

Naughton-Treves, L. (1998). Predicting patterns of crop damage by wildlife around Kibale National Park, Uganda. *Conservation Biology*, *12*(1), 13–168.

Ngorima, A., Brown, A., Masunungure, C., & Biggs, D. (2020). Local community benefits from elephants: Can willingness to support anti-poaching efforts be strengthened? *Conservation Science and Practice*, *2*(12), e303. https://doi.org/10.1111/csp2.303

Nyumba, T. O., Emenye, O. E., & Leader-Williams, N. (2020). Assessing impacts of human-elephant conflict on human wellbeing: An empirical analysis of communities living with elephants around Maasai Mara National Reserve in Kenya. *PLoS ONE*, *15*(9), e0239545. https://doi.org/10.1371/journal.pone.0239545

Parker, G. E., Osborn, F. V., Hoare, R. E., & Niskanen, L. S. (2007). *Human-elephant conflict mitigation: A training course for community-based approaches in Africa—Trainer's manual* (p. 39) [Trainer's Manual]. Elephant Pepper Development Trust, Livingstone, Zambia and IUCN/SSC AfESG https://www.iucn.org/sites/dev/files/import/downloads/heccombaptmen.pdf

Prakash, T. G. S. L., Wijeratne, A., & Fernando, P. (2020). Human-elephant conflict in Sri Lanka: Patterns and extent. *Gajah Journal of Asian Elephant Specialist Group*, *51*, 16–25. https://www.academia.edu/42879886/Human_Elephant_Conflict_in_Sri_Lanka_Patterns_and_Extent

Pascual-Rico, R., Morales-Reyes, Z., Aguilera-Alcalá, N., Olszańska, A., Sebastián-González, E., Naidoo, R., Moleón, M., Lozano, J., Botella, F., von Wehrden, H., Martín-López, B., & Sánchez-Zapata, J. A. (2021). Usually hated, sometimes loved: A review of wild ungulates' contributions to people. *Science of the Total Environment*, *801*, 149652. https://doi.org/10.1016/j.scitotenv.2021.149652

Pozo, R. A., Cusack, J. J., McCulloch, G., Stronza, A., Songhurst, A., & Coulson, T. (2018). Elephant space-use is not a good predictor of crop-damage. *Biological Conservation*, *228*, 241–251. https://doi.org/10.1016/j.biocon.2018.10.031

R Core Team. (2021). *R: A language environment for statistical computing (3.6.2)*. R Foundation for Statistical Computing.

Ripple, W. J., Newsome, T. M., Wolf, C., Dirzo, R., Everatt, K. T., Galetti, M., Hayward, M. W., Kerley, G. I. H., Levi, T., Lindsey, P. A., Macdonald, D. W., Malhi, Y., Painter, L. E., Sandom, C. J., Terborgh, J., & Van Valkenburgh, B. (2015). Collapse of the world's largest herbivores. *Science Advances*, *1*(4), e1400103. https://doi.org/10.1126/sciadv.1400103

Salerno, J., Bailey, K., Gaughan, A. E., Stevens, F. R., Hilton, T., Cassidy, L., Drake, M. D., Pricope, N. G., & Hartter, J. (2020). Wildlife impacts and vulnerable livelihoods in a transfrontier conservation landscape. *Conservation Biology*, *34*(4), 891–902. https://doi.org/10.1111/cobi.13480

Salerno, J., Stevens, F. R., Gaughan, A. E., Hilton, T., Bailey, K., Bowles, T., Cassidy, L., Mupeta-Muyamwa, P., Biggs, D., Pricope, N., Mosimane, A. W., Henry, L. M., Drake, M., Weaver, A., Kosmas, S., Woodward, K., Kolarik, N., & Hartter, J. (2021). Wildlife impacts and changing climate pose compounding threats to human food security. *Current Biology*, *31*(22), 5077–5085.e6. https://doi.org/10.1016/j.cub.2021.08.074

Sampson, C., Leimgruber, P., Rodriguez, S., McEvoy, J., Sotherden, E., & Tonkyn, D. (2019). Perception of human–elephant conflict and conservation attitudes of affected communities in myanmar. *Tropical Conservation Science*, *12*, 1940082919831242. https://doi.org/10.1177/1940082919831242

Shannon, G., Slotow, R., Durant, S. M., Sayialel, K. N., Poole, J., Moss, C., & McComb, K. (2013). Effects of social disruption in elephants persist decades after culling. *Frontiers in Zoology*, *10*(1), 62. https://doi.org/10.1186/1742-9994-10-62

Sitati, N. W., & Walpole, M. J. (2006). Assessing farm-based measures for mitigating human-elephant conflict in Transmara District, Kenya. *Oryx*, *40*(3), 279–286. https://doi.org/10.1017/S0030605306000834

Sitati, N. W., Walpole, M. J., Smith, R. J., & Leader-Williams, N. (2003). Predicting spatial aspects of human-elephant conflict. *Journal of Applied Ecology*, *40*(4), 667–677. https://doi.org/10.1046/j.1365-2664.2003.00828.x

Skroblin, A., Carboon, T., Bidu, G., Chapman, N., Miller, M., Taylor, K., Taylor, W., Game, E. T., & Wintle, B. A. (2021). Including indigenous knowledge in species distribution modeling for increased ecological insights. *Conservation Biology*, *35*(2), 587–597. https://doi.org/10.1111/cobi.13373

Songhurst, A. (2017). Measuring human-wildlife conflicts: Comparing insights from different monitoring approaches: Measuring human-wildlife conflict. *Wildlife Society Bulletin*, *41*(2), 351–361. https://doi.org/10.1002/wsb.773

Songhurst, A., & Coulson, T. (2014). Exploring the effects of spatial autocorrelation when identifying key drivers of wildlife crop-raiding. *Ecology and Evolution*, *4*(5), 582–593. https://doi.org/10.1002/ece3.837

Songhurst, A., McCulloch, G., & Coulson, T. (2016). Finding pathways to human–elephant coexistence: A risky business. *Oryx*, *50*(4), 713–720. https://doi.org/10.1017/S0030605315000344

Statistics Botswana. (2012). *2011 population and housing census: Population of towns, villages and associated localities* (p. 242). Census Office www.cso.gov.bw/cso

Statistics Botswana. (2016). *Botswana environment statistics—water and climate digest 2016*.

Sukumar, R. (1991). The management of large mammals in relation to male strategies and conflict with people. *Biological*, *55*(1), 93–102. https://doi.org/10.1016/0006-3207(91)90007-V

Talukdar, N. R., & Choudhury, P. (2020). Attitudes and perceptions of the local people on human–elephant conflict in the Patharia Hills reserve Forest of Assam, India. *Proceedings of the Zoological Society*, *73*(4), 380–391. https://doi.org/10.1007/s12595-020-00343-5

Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting diverse knowledge Systems for Enhanced Ecosystem Governance: The multiple evidence base approach. *Ambio*, *43*(5), 579–591. https://doi.org/10.1007/s13280-014-0501-3

Thouless, C. R., Dublin, H. T., Blanc, J. J., Skinner, D. P., Daniel, T. E., Taylor, R. D., Maisels, F., Frederick, H. L., & Bouché, P. J. C. (2016). *African elephant status report 2016: An update from the African elephant database* (Occasional Paper Series of the IUCN Species Survival Commission, No. 60). IUCN/Species Survival Commission Africa Elephant Specialist Group.

Tiller, L. N., Humle, T., Amin, R., Deere, N. J., Lago, B. O., Leader-Williams, N., Sinoni, F. K., Sitati, N., Walpole, M., & Smith, R. J. (2021). Changing seasonal, temporal and spatial crop-raiding trends over 15 years in a human-elephant conflict hotspot. *Biological Conservation*, *254*, 108941. https://doi.org/10.1016/j.biocon.2020.108941

Vogel, S. M., de Boer, W. F., Masake, M., Songhurst, A. C., McCulloch, G., Stronza, A., Henley, M. D., & Coulson, T. (2019). Do African savanna elephants (*Loxodonta africana*) eat crops because they crave micronutrients? *BioRxiv*, 673392. https://doi.org/10.1101/673392

Wilson, S., Davies, T. E., Hazarika, N., & Zimmermann, A. (2015). Understanding spatial and temporal patterns of human–elephant conflict in Assam, India. *Oryx*, *49*(1), 140–149. https://doi.org/10.1017/S0030605313000513

World Bank Group. (2015). *Botswana—Poverty assessment*. http://documents.worldbank.org/curated/en/351721468184754228/Botswana-poverty-assessment

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Data sheet for 2016 surveys of raided and unraided fields.
Table S2. Template of interview questions.
Table S3. Demographics of the 40 interview respondents in 2016.
Table S4. The top five villages with the highest levels of HEC reported from 2008 through 2016 across the Panhandle. The total annual number of HEC reports per village are indicated in parentheses.

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