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# Costs of elephant crop depredation exceed the benefits of trophy hunting in a community-based conservation area of Namibia

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**Abstract**

The Kazavango-Zambezi Transfrontier Conservation Area is home to the largest remaining elephant population in Africa but is also the site of high levels of human-elephant conflict through crop depredation. Offsetting the costs of coexisting with elephants in this area is critical to incentivizing elephant conservation within community-based conservation (CBC) areas, and trophy hunting has long been touted as a method for generating revenue for communities from wildlife. However, the idea that sustainable elephant hunting can offset the costs of crop depredation remains largely untested. We combined household survey data, financial records, and elephant population data to compare the potential benefits of sustainable hunting with the costs of crop depredation in a CBC area in northeastern Namibia. We determined that sustainable trophy hunting only returns ∼30% of the value of crops lost to the community and cannot alone offset the current costs of coexistence with elephants. As core institutions supporting the practice of conservation, CBC efforts must promote community management capacity to combine multiple wildlife-based income streams and build partnerships at multiple scales of governance to address the challenges of elephant management.

**KEYWORDS**
elephant conservation, environmental economics, food security, human-wildlife conflict, southern Africa, trophy hunting, wildlife management

## 1 | INTRODUCTION

Community-based conservation (CBC) is a potential pathway for maintaining human livelihoods and preserving wildlife populations outside of traditionally protected areas (PAs) in Africa (Western, Waithaka, & Kamanga, 2015). At its root, the CBC model in southern Africa is based on the premise that communities can be incentivized to

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conserve wildlife populations if they benefit economically from the presence of these populations (Galvin, Beeton, & Luizza, 2018; Hulme & Murphree, 2001). In theory, the success of CBC is predicated on two principles. First, community members must have proprietorship both in the retention of revenues generated through wildlife and the authority to set management practices within conservation areas. Secondly, wildlife must produce a substantial net benefit to the community. When paired with effective local governance, CBC can provide communities with a strong incentive to maintain long-term wildlife populations while also promoting human livelihoods (Hackel, 1999). In practice, however, CBC governing bodies—the community rule-making and management institution—are often simultaneously beholden to the policies set by higher levels of government and limited in the spatial extent of their decision-making authority, management capacity, and potential revenue sources, (Adams & Hulme, 2001; Ojha et al., 2016). For example, with limited photographic tourism potential, some Namibian CBC areas, known as conservancies, rely heavily on trophy hunting, yet their ability to benefit from hunting is limited by central government-controlled hunting quotas and adverse contractual arrangements with hunting companies (Bollig & Menestrey Schwieger, 2014; de Vette, Kashululu, & Hebinck, 2012). Consequently, CBC benefits are few, and member households often struggle to offset the costs of conservation, largely due to negative impacts from wildlife. Given these constraints and limitations on self-governance, it is unclear how effectively CBC governing bodies can address contemporary conservation issues, including the management and consumptive use of wildlife (Koot, 2019).

In southern Africa, managing savannah elephants (*Loxodonta africana*) presents a unique challenge to CBC. At a continental level, elephant populations are on a steep decline and face the very real threat of extirpation throughout much of their native range (Chase et al., 2016; de Boer et al., 2013). However, in some areas of southern Africa, elephant populations are stable or increasing, high in density, and range over large areas, including PAs and community lands (Lindsay, Chase, Landen, & Nowak, 2017; Salerno et al., 2020). The co-occurrence of human and elephant populations in CBC areas creates the potential for conflict, largely through crop depredation (Green et al., 2018; Hoare, 2015).

In CBC areas in southern Africa, agriculture, particularly for subsistence, is integral to supporting the livelihoods of many households (Davis, Di Giuseppe, & Zezza, 2017). Human-elephant conflict in these areas most often relates to crop depredation, but in other cases involves damaged structures and human injury or death (Pozo, Coulson, McCulloch, Stronza, & Songhurst, 2017). Elephants can destroy entire harvests in a single raiding event, creating

food insecurity in households (Salerno et al., 2020). Although guarding crops has a high opportunity cost and is dangerous for farmers, other methods of deterring human-elephant conflict (e.g., noise and scent deterrents, chili rope, and electric fences) are costly to implement and variably effective (Snyder & Rentsch, 2020). Ultimately, rural farmers have few viable methods for reducing the damages caused by elephants in their lands without extensive assistance from outside organizations (Shaffer, Khadka, Van Den Hoek, & Naithani, 2019).

Generating economic benefit from wildlife is central to CBC strategy, primarily through photographic tourism and trophy hunting. From the initial introduction of CBC, trophy hunting has been utilized as a mechanism to profit from elephants and incentivize wildlife conservation, particularly in remote or less scenic areas (Batavia et al., 2019; A. Dickman et al., 2019; Lindsey, Roulet, & Romanach, 2007). Trophy hunting occurs in roughly 23 African nations and has been promoted as an important tool for generating wildlife revenue, without which many Namibian CBCs would not be economically viable (Lindsey et al., 2007; Naidoo et al., 2016). A CBC's ability to generate high value from hunting, in terms of revenue, employment, and meat from hunted animals, can incentivize positive attitudes toward wildlife among community members (Störmer, Weaver, Stuart-Hill, Diggle, & Naidoo, 2019). However, equitable capture of revenue from trophy hunting remains a challenge, whereby farmers experiencing crop damage are not the ones to benefit (Cassidy, 2020), and unsustainable quotas can risk adversely affecting sensitive wildlife populations (Creel et al., 2016).

Elephants are a global public good with existence value shared by diverse stakeholders (Wang, Gong, & Mao, 2018), however, there is international debate on how elephants should be managed (Batavia et al., 2019; A. Dickman et al., 2019). Central to this conversation is the question whether and how much elephants should be commoditized. At the international level, elephant-rich nations, such as Namibia, South Africa, Zimbabwe, and Botswana, have petitioned CITES to reopen legal ivory markets, while global conservation efforts that have led to some nations, such as China, closing international and domestic ivory trade (CoP18 Prop. *11*, 2019; Gamso, 2019; Yu, Wetzler, Yang, Tang, & Zhang, 2017). The utility of trophy hunting is ingrained in this conversation and has drawn vocal supporters and detractors alike (Di Minin, Leader-Williams, & Bradshaw, 2016; Treves et al., 2019). Proponents of trophy hunting argue that hunting encourages the conservation of large wildlife populations, generates funds for conservation, and can be implemented in many areas where photographic tourism is unfeasible, safeguarding such areas from land conversion (Di Minin et al., 2016). These arguments suggest that elephant hunting would benefit CBC communities and

incentivize tolerance and sustainable management practices. However, the economic benefits of trophy hunting have not been balanced against the costs of coexistence with elephants within the CBC model (Schnegg & Kiaka, 2018). Currently, there is little evidence on whether elephant hunting alone can produce a net benefit to communities on CBC lands or not, which confounds understanding and planning regarding the role for hunting as an effective management tool in broader conservation landscapes (Treves et al., 2019).

We further explore the costs and benefits of elephants to CBC communities with a case study conducted in a conservancy in northeastern Namibia. By assessing the community-wide cost of crop depredation, the benefits generated through hunting, and the biological sustainability of elephant hunting, we test whether the economic benefits of elephant hunting alone can offset the community costs of crop depredation by elephants. Such analyses are necessary ingredients in understanding whether CBC governing bodies have the tools at their disposal to bridge the gap between the costs of living with wildlife felt by farmers and the higher level at which benefits can accrue (Cassidy & Salerno, 2020). Persistent imbalance in these costs, and between different levels of governance, may foster negative local attitudes toward elephants and in turn threaten support for elephant conservation (Biggs et al., 2017; Cooney et al., 2017; Dickman, 2010).

## 2 | METHODOLOGY

### 2.1 | Study area

We conducted this case study in Mashi Conservancy (Mashi), a 297 km$^2$ CBC area within the Zambezi Region of Namibia and part of the Kavango-Zambezi Transfrontier Conservation Area (KAZA, Figure 1). KAZA, the continent's largest terrestrial transfrontier conservation area (520,000 km$^2$), is jointly managed by five member nations (Namibia, Botswana, Angola, Zambia, and Zimbabwe), and is a mosaic of land cover and governance types, including national parks, urban areas, communal grazing- and farm-lands, and CBC areas. It is also home to Africa's largest contiguous elephant population, which is estimated at over 220,000 individuals (Lindsay et al., 2017; Nyambe, 2019). Though the KAZA Secretariat puts forth unified conservation and economic goals for the region, individual nations are still responsible for dictating their own wildlife policies, including establishing the legality of trophy hunting within their borders. In Namibia, trophy hunting is permitted in conservancies, private ranches, and certain state lands, with hunting revenues totalling N$ 36.4 (US$ 2.66, based on the average daily conversion rate between January 3rd, 2017, and November 29th, 2019) million in 2015 (Cooney et al., 2017).

Established in 2003, Mashi (Figure 1) is bordered by Mudumu National Park to the east, Bwabwata National Park and Botswana across the Kwando River to the west, and the Mayuni and Sobbe conservancies to the north. Mashi contains five villages, whose traditional authorities are each led by one *induna* (Mosimane & Silva, 2014). At least five ethnic groups are represented in Mashi (Mbukushu, Mafwe, Barotse, Subiya, and Bugakwe) with most households belonging to the Mbukushu and Mafwe groups (Kanapaux & Child, 2011). Trophy hunting in Mashi is conducted through a single hunting concession and annual quotas for specially protected animals, such
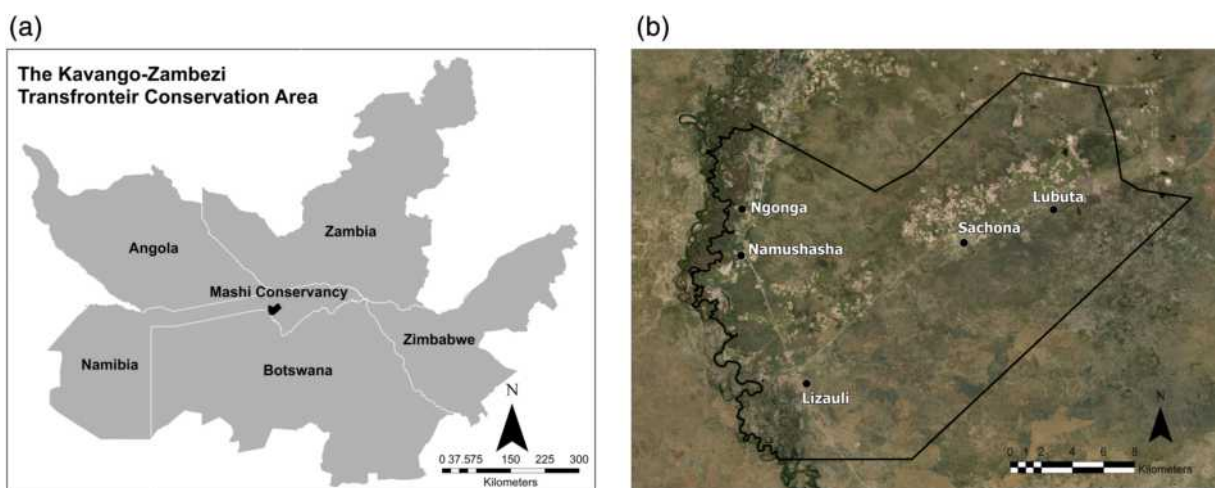


**FIGURE 1** (a) The Mashi Conservancy and five member nations of the Kavango Zambezi Transfrontier Conservation Area. Mashi Conservancy lays within the Zambezi Region (formerly Caprivi Strip) of Namibia. (b) Mashi Conservancy boundaries, Namibia, and its five member communities

as elephants, are set in conjunction with the central government (Boudreaux & Nelson, 2011). Due to its adjacent national parks, Mashi hosts several photographic tourism concessions, which do not conduct any hunting, and received payments from six tourism lodges during the study period. These concessions are legal arrangements that outline a profit-sharing agreement between Mashi and the private companies that operate within the conservancy's boundaries.

The conservancy is responsible for conducting periodic game counts, managing conservancy funds, and creating benefit sharing programs for the community. Until 2018, the conservancy disbursed N\$ 100 (US\$ 7.29) annually to all conservancy members. However, a restructuring of Mashi's central committee members in 2018 shifted the goals of their benefit sharing program, now focusing on funding infrastructure projects (e.g., installing solar water pumps and electrical infrastructure in Sachona and Lubuta in 2019) and no longer disbursing payments directly to households.

Within Mashi, households face high levels of unemployment and most are reliant on rainfed agriculture, natural resource collection, and government assistance to maintain their livelihoods (Kanapaux & Child, 2011). Food insecurity is prevalent throughout Mashi and exacerbated by crop depredation by wildlife (Salerno et al., 2020). Community members in Mashi are often negatively impacted by wildlife, with more than 75% of households experiencing some form of crop depredation from wildlife in 2007 and one individual being killed by elephants between 2017 and 2019 (Kanapaux & Child, 2011; Mr. Kadiba Shine, personal communication).

## 2.2 | Data collection

Our study incorporated data collected from three sources: livelihood and crop depredation data from household surveys, income and hunting reports from conservancy records, and elephant population and demography estimates derived from existing literature.

Before conducting research, we secured permission to work within Mashi from the KAZA secretariat, the Namibian Ministry of Environment and Tourism, each of the five area indunas in Mashi, and from conservancy executives. All human data collection in this study adhered to ethical standards reviewed and approved by the University of Colorado Institutional Review Board (#16-0126). We created a household livelihood survey instrument in 2016 and used input from conservancy and traditional authority members to confirm the relevance of the survey instruments. We conducted household surveys in all five villages from May to June during the dry season of 2017 (See Supplemental Information for further details); informed consent was given prior to each survey. Self-reported data generated from surveys are commonly used to estimate crop depredation in Africa (Ango, Börjeson, & Senbeta, 2017; Gontse, Mbaiwa, & Thakadu, 2018; Hariohay & Røskaft, 2015). While measuring perceived depredation rather than physical damage has potential sources of recall error and bias, a survey based methodology has a number of advantages: farmers are acutely aware of their lands and harvest and can accurately estimate crop depredation/damage; the simplicity of conducting surveys allows for a greater number of farmers to be included in the study; and direct measurements of crop depredation require monitoring throughout the entire growing season, which is infeasible across a wide area (Ango et al., 2017; Gontse et al., 2018; Kaminski & Christiaensen, 2014; Tzilkowski, Brittingham, & Lovallo, 2002).

To measure income and hunting in Mashi, we accessed conservancy records with assistance from the conservancy chairperson in 2017 and again in 2019. These records documented the annual number of animals hunted (i.e., offtake) and income gained through hunting. We recorded income generated through hunting and the number of elephants harvested annually from 2010 to 2018 (Table S1).

To estimate elephant population and age structure, we collected data on elephant vital rates (age specific birth and death rates) and population densities from previously published studies. We used these vital rates to calculate a baseline population growth rate for the Mashi elephant population. Female elephant vital rates were taken from a dataset derived from long-term observations of elephants in East Africa (Moss et al., 2011). Though this dataset was produced in a different region of Africa than our study site, Moss et al.'s (2011) study provides reliable long-term demographic data on a population of savannah elephants experiencing little immigration, emigration, or poaching, which is necessary for calculating the population growth that Mashi contributes to the regional elephant population (See Supplemental Information for further details). However, elephant populations in eastern and southern Africa, and across an array of environmental and age-structure conditions, have produced a wide range of observed population growth rates, which we incorporated into a later section of this analysis.

We used an estimate of the stable elephant density for the region ($0.61 \pm 0.32$ [*SD*] individuals/km$^2$) for the elephant density within Mashi (Robson et al., 2017). As the elephants found within Mashi are highly transient and intermix with a regional meta-population, we believe it is appropriate to apply a regional elephant density. Moreover, due to the conservancy's limited surveying efforts,

**TABLE 1** Summary, data sources, and calculations for variables used to calculate crops lost to and benefits generated from elephants in Mashi Conservancy in 2017

| Variable | Description and data source | Method of calculation |
|---|---|---|
| Total households: 883 households | Estimate of the number of households in Mashi conservancy<br>*Data: Personal communication and household surveys* | The total number of members of Mashi (2,256) was divided by the mean number of adults per-household in the household survey (2.56 adults/household). |
| Community loss:<br>US$ 157,000<br>N$ 2,150,000 | Total value of crops lost to the community due to elephants in Mashi<br>*Data: Personal communication and household surveys* | Mean household crop losses (kg/household) for maize, sorghum, millet, and beans/ground nuts were calculated from household survey data. These losses were then scaled to Namibian dollars using values (N$/kg) stated by local informants. The household value lost for each crop was then multiplied by the percentage of respondents that listed elephants as the main problem animal for depredation of the given crop. Lastly, this total household value of crop loss was multiplied by the number of households in Mashi to create an estimate of the community wide value of lost crops. |
| Value per-elephant:<br>US$ 14,900/elephant<br>N$ 204,000/elephant | The monetary value gained by the community for each hunted elephant<br>*Data: Personal communication, conservancy records and reports* (NACSO, 2018) | Mashi's contract with their hunting concessionaire stipulates that they will be paid US$ 14,900 (N$ 180,000) per-elephant hunted. Meat from hunted elephants, which is distributed to community members, is valued at N$ 24/kg and the chairperson of Mashi estimated that ∼1,000 kg of meat is distributed from each elephant. |
| Elephant population size (female elephants):<br>*Stable-* 91.2 ± 47.5 | Estimate of the female elephant population within Mashi<br>*Data*: Robson et al. (2017) | A density were given for the estimated stable (0.614 ± 0.322 elephants/km$^2$) elephant density in the Zambezi region. This density was multiplied by the area of Mashi (297 km$^2$) and divided by 2 to generate the female elephant population estimates. |
| Elephant population growth rate:<br>λ = 1.04 | Annual intrinsic population growth rate of female elephants<br>*Data*: Moss, Croze, and Lee (2011) | From previously published demographic data and vital rates, we created a 70 × 70 transition matrix for female elephants. Using the *popbio* package in R, we calculated the annual growth rate of this matrix. |
| Elephant offtake rates (male elephants/year):<br>*Current-* 6.67<br>*Sustainable-* 3.10 | The current elephant offtake rate in Mashi and sustainable rate based on population estimates.<br>*Data: Conservancy records* | From 9 years of conservancy hunting records, we calculated the current mean annual elephant offtake. Sustainable offtakes of male elephants were calculated from the stable female elephant population estimate by multiplying the density by growth rate raised to the tenth power, subtracting the original population, and dividing by 10. This process assumes an even sex ration among elephant calves and that reducing the number of adult males does not affect the vital rates of females. |

no estimates of Mashi's elephant population currently exist.

## 2.3 | Analysis

### 2.3.1 | Generating variables

We generated several derived variables from our data (Table 1). First, we generated an estimate of the total value of crops lost to the community due to elephants in Mashi. Despite knowing the total membership of Mashi (2,256 adult members), the number of households in the conservancy is unknown. This reported membership is similar to other estimates of Mashi's population (2017 WorldPop estimate: 2,859 individuals; 2011 Namibian census: 2,210 individuals) but is dramatically lower than the ∼4,000 population reported by Kanapaux and Child (2011) (NACSO, 2017; WorldPop, 2018). We utilized the conservancy's membership estimate as the smaller value provides a conservative estimate of CBC-wide crop depredation but acknowledge that the lack of an accurate population estimate is a confounding factor in this study. To calculate the number of households in the conservancy we divided conservancy membership (2,256) by the mean number of adults per-household in our household survey sample (Table 1). Most crop depredation was reported in the household survey in kilograms and we converted responses in hectares to kilograms using yield means provided by local key informants (500 kg/ha maize, 750 kg/ha millet and sorghum, 357 kg/ha beans and groundnuts). We converted the amount of crops lost to dollars using the local market value of each crop in 2019, as these values were not recorded in 2017 (N\$ 15/ US\$ 1.09 per-kg maize and millet, N\$ 16/ US\$ 1.17 per-kg sorghum, N\$ 35/ US\$ 2.55 per-kg beans and groundnuts). We then calculated the percentage of reports of elephants as the main problem animal for the depredation of each crop and scaled the value of lost crops by this amount before calculating the total value of crops lost per-household. Lastly, we multiplied the mean value of crops lost per-household by the estimated number of households in the community to create an estimate of the total value of crops lost within Mashi.

We generated an estimate of the community-level value gained from elephant hunting payments to the conservancy and meat distributed to community members. We calculated the stable populations of elephants within Mashi by multiplying the elephant density given by Robson et al. (2017) by the area of Mashi (297 km$^2$). From the elephant vital rates generated from Moss et al.'s (2011) data, we calculated the intrinsic annual population growth rate using the *popbio* package in the R statistical environment (R Core Team, 2017; Stubben & Milligan, 2007). Assuming that the elephants within Mashi are at a stable age distribution, we then calculated the 10-year production of female elephants in Mashi by multiplying the population estimates by the annual growth rate to the tenth power and removing the starting population. As there does not appear to be any sex ratio bias in savannah elephant calves, we assumed that the production of female and male calves is equal, as males are the only sex that is reportedly hunted in Mashi (Moss, 2001). As only adult elephants are hunted, we used aggregated demographic data provided by Moss et al. (2011) to calculate the probability of survival to 15 years for male calves and scaled the production of male calves by this amount to estimate the 10-year adult male production (Table S2). We used this production as the sustainable annual offtake and calculated the benefits of the elephant harvest by multiplying this offtake by the conservancy's per-elephant fee (N\$ 180,000/US\$ 13,100 per-elephant) plus the value of the meat produced by each elephant (N\$ 24/US\$ 1.75 per-kg [NACSO, 2018] and 1,000 kg meat/elephant reported by the Mashi conservancy chairperson) for a total value of US\$ 14,900 (N\$ 204,000) per-elephant. To contextualize the conservancy's earnings, in 2019, Mashi's hunting concession charged US\$ 40,000 (N\$ 548,000) per elephant hunt. Beyond the US\$ 13,100 conservancy fee, the remainder of that money goes to the privately-operated hunting concession and is not captured by the conservancy. Lastly, we subtracted the value gained from elephants from the value of crops lost to elephants to create an estimate of the net community-level value of elephants.

We combined two empirically bootstrapped distributions, one for community-level costs and the other for community-level benefits and used the distribution of their differences to assess our confidence in the net value that elephants provide (See Supplemental Information for further detail). This methodology allowed us to calculate our confidence in the estimations of household crop depredation and number of adults per household as the data for these values did not conform to any distribution (Figures S1 and S2). As there are no estimates of elephant population growth in Mashi based on observed data, the flexibility of bootstrapping allows us to incorporate previously published population growth rates, which vary widely (Table S3).

Lastly, we calculated alternative management regimes which would allow the income generated through elephant harvests to offset the costs of crop depredation. Using the estimated value of community-level crop depredation, we calculated how much income would have to be earned per-elephant to achieve parity for 1–20 elephants harvested per-year. We then repeated this process

for scenarios with 25, 50, and 75% reductions in the observed level of community-wide crop depredation.

# 3 | RESULTS

## 3.1 | Household characteristics

Only 92 of the surveyed households ($n = 241$) reported losing crops to wildlife, representing 38.2% of the total sample and 63.0% of households that planted crops in the previous year ($n = 146$). Respondents lost a mean ($\pm SD$) amount of 167 ($\pm 314$) kg maize, 11.9 ($\pm 65.0$) kg millet, 12.5 ($\pm 67.0$) kg sorghum, and 1.39 ($\pm 14.6$) kg of beans/groundnuts in the year prior to surveying, worth US$ 182, US$ 13.90, US$ 14.63, and US$ 3.55, respectively. These mean amounts represent a loss of 17.5, 2.10, 4.24, and 1.70% of an average household's maize, millet, sorghum, and beans/groundnuts harvest. Elephants were the main problem animal for 83.1% of maize, 100% of sorghum, 70.0% of millet, and 66.7% of bean/ground nut reports of crop depredation in our sample. These losses amounted to a per-household loss of US$ 465 for the estimated 337 households that experience crop depredation and a total community loss of US$ 157,000 due to elephants. From the mean number of adults per-household in the 241-survey sample (2.56, $SD = 1.25$) and the 2,256 adult members of Mashi, we estimated that there were 883 households in Mashi in 2017.

## 3.2 | Elephant demography

From our demographic matrix of female elephants, we calculated an intrinsic annual population growth of 3.90% ($\lambda = 1.039$). Though African elephant populations can maintain growth rate as high as 7% a year, this usually only occurs in young populations under ideal environmental conditions (Calef, 1988; Foley & Faust, 2010). Our calculated growth rate is similar to or greater than observed growth rates in areas with established elephant populations (Table S3). From this growth rate, we estimated that the stable elephant density estimate (0.61 elephants/km²) would produce 42.5 male calves over 10 years, or an annual sustainable offtake of 3.10 adult male elephants. From 2010 to 2019, an average of 6.67 elephants per-year were harvested in Mashi. At the current value of US$ 14,900 per-elephant (fee plus meat), the current offtake in Mashi produces US$ 99,400 annually, while the sustainable offtake would yield US$ 46,200 annually. Given current levels of crop depredation, the estimated sustainable offtake rate, and the current value gained per-elephant, the value of crops lost in Mashi

exceeds the value gained by the conservancy from hunting elephants by US$ 111,000 or ∼ US$ 329 for each of the estimated 337 households impacted by elephant crop depredation in Mashi.

## 3.3 | Bootstrap simulation and alternative management regimes

The costs of crop depredation were greater than the benefits of hunting in the majority of our bootstrap simulations. Of our 30,000 bootstrapped resamples, only 706 produced outcomes where the benefits from elephant hunting offset the community-level costs of crop depredation (Figure 2). The output of the bootstrap (mean = US$ 98,600, median = US$ 104,000, $SD$ = US$ 42,700) had a mean that was significantly different than zero, indicating an overall net cost for Mashi (95% CI of the mean: US$ 1,620–US$ 169,000).

Our estimates of alternative management regimes demonstrated that few feasible management scenarios would lead to parity between income from elephant hunting and the cost of elephant caused crop depredation. At the estimated sustainable offtake rate and current crop depredation level, Mashi would need to earn ∼US$ 50,700 per-elephant hunted to achieve parity, or ∼ 3.40 times the current fee. Conversely, given a community benefit of US$ 14,900 per-elephant (fee plus meat), Mashi could similarly increase its annual harvest beyond the sustainable rate of 3.10 to 10.5 elephants annually to generate the same revenue. The conservancy
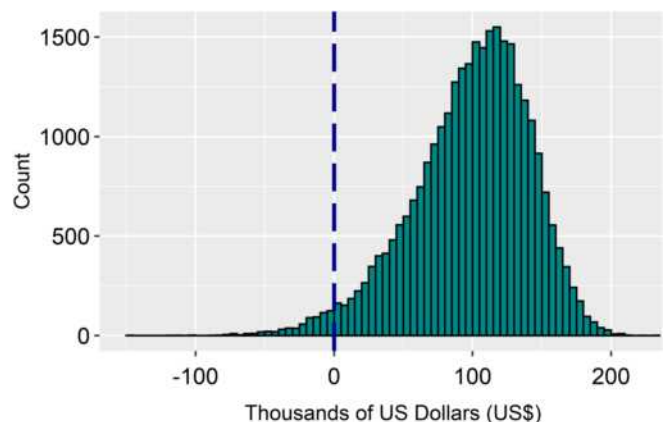


**FIGURE 2** Histogram of 30,000 bootstrap simulations of the difference between value generated by elephants and the community costs of crop depredation. The dashed vertical line separates outcomes where elephants generate more value than the costs of crop depredation (left) and outcomes where crop depredation outweighs the community value of hunted elephants (right). Positive values reflect the amount by which the costs of crop depredation exceeded the benefits gained from hunting

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could also achieve parity from the current benefit per-elephant at a sustainable offtake rate by reducing current crop depredation by 75%. To achieve parity between elephant benefits and costs while sustainably harvesting elephants, Mashi needs to either drastically reduce the amount of crops lost to elephants or to similarly increase the per-elephant benefit of hunting (i.e., hunt 4 elephants and gain at least US$ 39,300 per-elephant, Figure 3).

# 4 | DISCUSSION

Arguments in favor of hunting as a conservation tool cite benefits to communities and wildlife populations through providing management revenue, employment income and meat for communities, and incentives for preserving game animal populations (Cooney et al., 2017; Di Minin et al., 2016; Naidoo et al., 2016). As trophy hunting requires little initial investment and can be conducted in remote or less scenic areas, it has been used since the outset of CBC as a tool for generating benefits from wildlife in CBC areas, particularly where lucrative photographic tourism is less tenable (Lindsey et al., 2007). However, our case study demonstrates that sustainable hunting alone does not offset the costs of elephant crop depredation in a Namibian conservancy.

The challenges of generating value from hunting elephants in a rural landscape highlights some limitations inherent to the CBC model. Our analysis takes an idealized approach and assumes that CBC governing bodies have the capacity to distribute hunting revenues entirely and equitably to member households experiencing crop depredation. In practice, this is a persistent and often unsurmountable challenge as all hunting income must be filtered through policies of the central state as well as the conservancy governing body, resulting in fewer funds ultimately transferred to individual community members (Cassidy & Salerno, 2020; Galvin et al., 2018). For example, in 2019 Mashi had a total operating budget of ∼US$ 220,000 (which is considerably more than its hunting revenue alone), of which ∼US$ 138,000 (63%) was directed toward operational expenses, and from which US$ 4,380 was directed to offsetting crop depredation. Additionally, compensation payments are dispersed at a fixed rate of US$ 73.0 per hectare lost to wildlife, much less than the US$ 545 that we estimated could be generated from the yield of a hectare of maize. These figures suggest that the disparity between the costs and benefits of elephants is even greater at the individual household level than we have demonstrated in this study. Indeed, households in this region that suffer from crop depredation are significantly more likely to experience food insecurity (Salerno
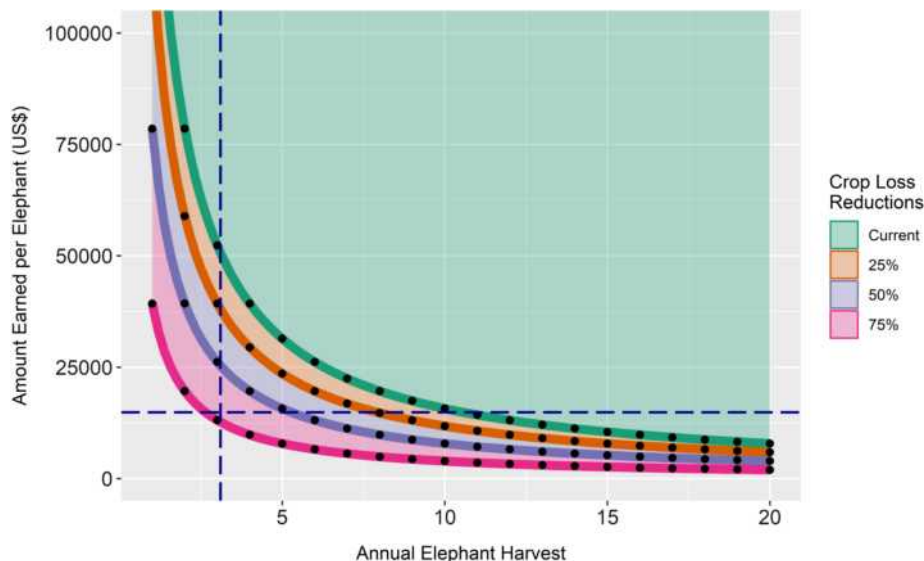


**FIGURE 3** Alternative elephant management scenarios possible within the Mashi Conservancy, Namibia, in 2017, allowing for changes in annual elephant harvest, value gained per-elephant, and reduction in crops lost to the community. Dark lines represent the point at which the value of elephants (as # of elephants harvested * value per-elephant) reaches parity with the costs of community-wide crop depredation for a given management scenario. Points represent whole elephant values along these lines. These lines follow the form of amount earned per-elephant = value of crops lost/number of elephants harvested. Shaded areas represent scenarios where the value of elephants exceed the costs of crop depredation. Differences in color represent the observed level of crop depredation in 2017 (green) and three levels of reduced crop depredation (orange, purple, pink). The vertical dashed line represents the estimated sustainable offtake of elephants at a stable density, derived from Robson et al. (2017), in Mashi Conservancy (3.10 elephants/year) and the horizontal dashed line represents the current value (2017) gained per-elephant from meat and conservancy payments (US$ 14,900/ elephant)

et al., 2020). Although meat provisioned from elephant hunts could potentially mitigate the effects of crop loss for some, the distribution of meat within conservancies is unlikely to be sufficient or equitable (Gargallo & Kalvelage, 2020). The conservancy additionally provides several other community benefits (e.g., funding schools and churches, creating electrical infrastructure), though these are unlikely to adequately offset the costs of crop depredation.

The current rate of elephant hunting in Mashi both exceeds our estimates for the conservancy's sustainable offtake and only offsets ∼60% of our estimate for crops lost to elephants in the community. These findings are based on a conservative approach: our calculation for sustainable hunting offtake in Mashi utilizes a greater elephant density than the conservancy's reported elephant density and also assumes an optimistic population growth rate. As our estimated growth rate was derived from a population of elephants that had little mortality from poaching or hunting, it is almost certainly higher than what is occurring in the Zambezi region of Namibia (Moss et al., 2011). In fact, the time series of elephant surveys used by Robson et al. (2017) showed no significant trend in elephant population size in the Zambezi region from 1989 to 2013. Moreover, our estimates of sustainable offtake rates exceed other sustainable rates in southern Africa (<10 bulls/year in a population of >1,000 individuals) and would be heavily contingent on the immigration of mature males into Mashi (Selier, Page, Vanak, & Slotow, 2014). As our analyses were biased toward optimistic elephant population growth, the true sustainable offtake of elephants in Mashi, and thereby the possible revenue generated from elephants, is likely lower than we estimated.

Since elephants are highly vagile, with 76% of elephant populations crossing national borders, Mashi may be able to hunt above the locally sustainable rate and still maintain their elephant population if they are subsidized by elephant populations from Mashi's two adjacent national parks (Lindsay et al., 2017). However, intentionally managing Mashi as an elephant population sink could be biologically problematic. High levels of hunting require close monitoring in and out of conservancy lands to ensure that it does not reduce the regional elephant population, as has occurred in other areas of Africa (Chase et al., 2016). Given that Mashi is just one of 15 conservancies in the Zambezi region and that conservancy land accounts for 27.8% of the region's 14,785 km$^2$ area, further investigation is required to determine if elephant production in the region's protected areas, such as national parks, could adequately subsidize elephant hunting in all of these conservancies. The process of estimating sustainable elephant offtakes at the conservancy

and regional levels highlights the challenge that conservation managers face in using limited resources and imperfect available data to determine the management of a complex species at multiple scales.

Trophy hunting is regulated by quotas proposed by individual conservancies and then vetted by state wildlife authorities, requiring coordinated management of elephants beyond conservancy borders. Hunting offtakes cannot be increased without the support of government wildlife experts who must balance conservancy quota requests with conservation goals for the nation's elephants. If Mashi's governing body were to push to increase hunting quotas, this could put the conservancy in conflict with the central government and would likely expose the limitations of conservancy-level decision-making.

Other avenues of gaining value from elephants, such as increase in revenue per elephant hunted, are similarly stymied by current CBC modalities. The per-elephant payments that Mashi receives are currently held static by contractual obligations to their resident hunting concessionaire. However, research suggests that hunters themselves support more equitable distribution of hunting revenues and are willing to pay a premium in situations where greater percentages of their fees are distributed to local communities (Fischer, Weldesemaet, Czajkowski, Tadie, & Hanley, 2015). This suggests that future increases in the per-elephant conservancy hunting fees could contribute toward parity between the costs and benefits of elephants. Increasing the revenue that CBCs gain from hunting could therefore offset the costs of crop depredation, though doing so would make the success of CBCs even more reliant on attracting international hunters—an increasingly narrow market.

While further increasing benefits from hunting may be challenging, the costs of crop depredation could be reduced. We observed a lower rate of wildlife-related crop depredation in our sample than we initially expected, given the high rates of crop depredation in 2007 reported by Kanapaux and Child (2011). Despite a possible reduction, or interannual variability, in crop depredation over the past 10 years, the current level of crop depredation still creates a large annual cost to the community. Past research has shown that crop depredation due to wildlife can be the most harmful effect that communities perceive from living near protected areas and can drive hostility toward wildlife (Dickman, 2010; Hartter & Goldman, 2011; Khumalo & Yung, 2015). Although reducing crop depredation may be a viable way to match the costs and benefits of elephants, about a 75% reduction in crop depredation would be needed to achieve parity with current payments from elephant trophy hunting at a sustainable offtake rate (Figure 3). Moreover, farming is an integral

part of rural lifestyles in Mashi, suggesting that some levels of crop depredation will always be present. Beyond materials and funding, organizing effective elephant deterrents also requires the capacity to ensure that community members have the willingness and training to adopt new deterrent methods (Snyder & Rentsch, 2020). Though conservancies likely cannot produce the funds on their own to implement expensive deterrents, such as electric or chili fences, conservancies can still play an essential role in implementing novel deterrents when provided with sufficient funding and support. This raises an important point about the role of CBC governance as a link between household-level needs and international conservation interests. CBC governing bodies must maximize benefits to household members by effectively transferring funds and minimizing administrative costs and losses (Calfucura, 2018), while coordinating improved mitigation strategies. Clearly, CBC governance must sit at the center of a tightly coupled cost–benefit model if trophy hunting in Namibian and southern African CBC programs is to be an effective conservation tool, though our findings question its effectiveness without substantial additional revenue or subsidies from international conservation interests.

Elephants are an important attraction for photographic tourism in Africa, and conservancies may be best served by integrating photographic tourism and hunting to the extent that their environmental resources allow (Naidoo et al., 2016). In analyzing Mashi's hunting revenue, we intentionally ignored any benefits created by elephants through photographic tourism for five reasons. First, this study endeavored to test whether hunting alone is a sufficient tool to offset crop depredation (Winterbach, Whitesell, & Somers, 2015). Second, although viable in Mashi, photographic tourism is a limited revenue stream in many CBC areas due to the lack of an economically viable photographic tourism industry, the resources required to build lodges, or scenic landscapes. Third, we lack sufficient data to estimate the percentage of photographic tourism that elephants account for in Mashi. Methodologies to attribute photographic tourism value to individual animals or species are often predicated on flawed assumptions (e.g., linearity between wildlife populations and photographic tourism value, misrepresenting the timeframe of wildlife valuation; Catlin, Hughes, Jones, Jones, & Campbell, 2013) and are beyond the scope of this paper. Fourth, Mashi is bordered by two national parks with large wildlife populations. These parks are the main attractor of tourists to Mashi, and the local photographic tourism industry is not purely contingent on maintaining elephant populations within the conservancy, unlike the hunting industry. Lastly, even within Mashi, with a developed photographic tourism industry and multiple tourism concessions, hunting still generates more conservancy revenue than photographic tourism (US\$ 116,000 from hunting and US\$ 101,000 from tourism in 2019) and remains the most direct way to commercialize wildlife.

If community members in Mashi continue to perceive or experience high costs from wildlife, hostility toward wildlife may arise, paving the way for retaliatory actions (Dickman, 2010). Hostility toward elephants due to conflict within conservancies in southern Africa could prove a major threat to global elephant conservation efforts (Biggs et al., 2017; Cooney et al., 2017). Addressing this cost of living with wildlife will require synergy across multiple levels of governance, and changes in the way CBC is managed at and between these different levels (Cassidy & Salerno, 2020). CBC governing bodies ultimately lack complete agency over their wildlife resources, as demonstrated by their need to conform to quotas placed by the central government to meet international conservation goals. Concurrently, the limited options for commoditizing wildlife available in CBC areas may not be sufficient for producing a positive value from wildlife with high costs of coexistence, as demonstrated in this study. What revenues that are produced from sources such as trophy hunting must still be filtered through the CBC governing body before they benefit community members. At this stage, CBC faces additional institutional challenges, such as equitable revenue sharing and power distribution that may further limit the benefits that are realized by community members. CBC governing bodies should continue to improve elephant deterrents, implement crop depredation compensation programs, and diversify revenue streams in lieu of overharvesting elephants. However, their success in offsetting the costs of coexisting with elephants, which are felt directly by community members, will likely be contingent on effective collaboration with outside actors, such as national governments, the KAZA secretariat, or international NGOs. While international conservationists may understand that elephant management is a large-scale issue that requires partnerships across multiple levels of governance, such understanding must be backed by investments that reflect their interests. Ultimately, the costs of coexistence with elephants must be shared in the same way that the benefits of elephants are shared globally. In doing so, these partnerships can meet CBC goals of improving human livelihoods and international goals of conserving elephant populations.

## CONFLICT OF INTERESTS
The authors declare no potential conflict of interest.

## AUTHOR CONTRIBUTIONS
Andrea E. Gaughan, Narcisa G. Pricope, Forrest R. Stevens, and Joel Hartter secured funding for this project in collaboration with Lin Cassidy and contributed to the research design. Michael D. Drake, Jonathan Salerno, and Lin Cassidy led the field data collection and Michael D. Drake, Jonathan Salerno, and Ryan E. Langendorf conducted the data analysis. Michael D. Drake led the manuscript preparation, to which all authors contributed. All authors assisted with multiple rounds of editing and approved of the publication.

## DATA AVAILABILITY STATEMENT
All relevant data used in this study, as well as the R script used to conduct the analysis and generate figures, are available as Supporting Information files.

## ETHICS STATEMENT
Ethical approval for the collection of data used in this study was approved by the University of Colorado Institutional Review Board (#16-0126). Permission to conduct research was granted by the Namibian Ministry of Environment and Tourism, Traditional Authorities, and local leadership in all study communities.

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## SUPPORTING INFORMATION

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