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Patterns of Primates Crop Raiding and the impacts on incomes of Smallholders across Mosaic agricultural Landscape of Wolaita Zone, Southern Ethiopia

--Manuscript Draft--

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Full Title:	Patterns of Primates Crop Raiding and the impacts on incomes of Smallholders across Mosaic agricultural Landscape of Wolaita Zone, Southern Ethiopia
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Keywords:	Anubis baboon; Grivet monkeys; Human-Wildlife Conflicts; non-human primate; Maize damage; Prevention method
Abstract:	Crop damage caused by non-human primates poses a significant challenge to wildlife conservation efforts. This study aims to assess primates foraging behavior and the extent of maize damage in 25 small (10x10m) maize fields, including both protected and non-protected fields. Data were collected over a twelve-month period spanning 2020 and 2021 in the Sodo Zuriya and Damot Gale regions in the Southern Highlands of Ethiopia. Farmers reported that olive baboons, porcupines, and grivet monkeys were the most notorious crop raiders. Baboons and grivet monkeys were found to attack maize more frequently in June, July, and August. Baboons primarily targeted maize in the morning, while grivet monkeys did so in the afternoon. Notably, primate raids were more common in maize fields located closer to the forest edge than in those situated farther away. The average maize yield losses due to nonhuman primate damage amounted to 43.14% and 31.4% in the protected and non-protected fields, respectively. Within this figure, 43.14% of the damage occurred in the protected fields situated 50 m from the forest edge. Conversely, non-protected fields experienced lower rates of damage: 14.42%, 13.18%, 3.7%, and 0.1% at distances of 50 m, 100 m, 200 m, and 300 m from the forest edge, respectively. Camera traps recorded 47 photos of baboons, 21 photos of grivet monkeys, and documented 8 primate crop foraging events. Consequently, our study concluded that maize fields positioned within 50 meters of the forest edge faced significant primate raids. Despite the utilization of wire mesh fencing, it displayed limited effectiveness in deterring olive baboons and grivet monkeys. Furthermore, while guarding is assumed to be an efficient protective strategy, our findings suggest its ineffectiveness when not implemented continuously.
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Response to Reviewers:	Title: Patterns of Primates Crop Raiding and the impacts on incomes of Smallholders across Mosaic agricultural Landscape of Wolaita Zone, Southern Ethiopia Manuscript Number: PONE-D-23-43746-R3 Response to Reviewers We are great full to the editors and reviewers for their insightful and valuable comments on our paper. We have carefully considered the comments and tried our best to address every one of them. We hope the manuscript after careful revisions meet your higher standard journal. The authors welcome further constructive comments if any. We provided the point by point responses. All modifications in the manuscript have been highlighted in yellow color. Sincerely, Yigrem Deneke

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Please review your reference list to ensure that it is complete and correct. If you have cited papers that have been retracted, please include the rationale for doing so in the manuscript text, or remove these references and replace them with relevant current references. Any changes to the reference list should be mentioned in the rebuttal letter that accompanies your revised manuscript. If you need to cite a retracted article, indicate the article's retracted status in the References list and also include a citation and full reference for the retraction notice.

Response

The following reference was removed from the manuscript in the first-round revision (R1):

The linear regression model results are reported as R2 values (proportion of variance accounted for), beta values (contribution to the model), t statistics (statistical significance of the contribution), and regression equations (the combination of variables best accounting for observed outcomes) (Sokal RR & Rohlf FJ, 1995). This was removed from the data analysis because the linear model only analyzes data with fixed factors. In contrast, the linear mixed model analyzes data with both fixed and random factors, along with the response variables.

The following nine references were added to the manuscript in the second-round revision (R2):

Hill, CM, Webber, AD, 2010; Hockings, KJ, Sousa, C, 2013; Freed, BZ, 2012; McGuinness, S, Taylor, D, 2014; Findlay, LJ, 2016; Gillingham, S, Lee, PC, 2003; Aharikundira, M, Tweheyo, M, 2011; Ango, TG, Börjeson, L, Senbeta, F, Hylander, K, 2014; Fang L, Hong, Y, Zhou Z, Chen, W, 2021. This is added to the manuscript because it includes important additional background information for this study.

The following reference was removed from the manuscript in the second & third-round revision (R2 &R3):

R core team. R, 2020. This reference was removed because the data were only analyzed using SPSS in the manuscript.

The following reference was added to the manuscript in the third round revision (R4):

R core team. R, 2024. I used the latest version of the R program because it is robust for analyzing various datasets. This reference is now included to highlight the effectiveness and reliability of R in handling the spatio-temporal datasets.

I have replaced Table 5 and text, Figure 5, and Figure 6, which were analyzed using SPSS, with new versions that can be analyzed using the R program.

I have included the number of field experts and local farmers participated in this study

I have included a relevant remarks in the conclusion section

I have included the following supporting documents in the manuscript (R3):

S2 file. The rate of maize damage by olive baboons in different crop phonological stages was analyzed in both protected and open/control fields using R code.

S3 file. The rate of maize damage by grivet monkeys in different crop phenological stages was analyzed in both protected and open/control fields using R code.

S4 table 2. A linear mixed model of the maize damage rate by primates, considering different spatio-temporal variables, was analyzed using R code.

Response to Reviewer 1

Reviewer #1: Thank you once again for inviting me to review furthers this manuscript. It is clear that the study is interesting and has some novelty. However, I think the authors need strong support for the statistical analysis part. With my previous comments, I was trying to encourage them to analyze their data in a robust way using LMM with the inclusion of random factors using R program instead of SPSS. The authors are stating that they used SPSS to do so and they even took out the R now from their data analysis section with this version. Still how they used the different statistical tools for the analysis is crude and not explicitly described. If the authors are willing to improve their manuscript by including these comments, I think the manuscript may be accepted for the publication without further review process.

Response: Thank you very much for the comments. I included the analysis done with R, running the analysis using LMM to account for both fixed and random factors and response variables. This analysis is clearly indicated in the supporting documents. The different statistical tools used for the analysis are also explicitly described in the data analysis section.

Reviewer #2: You corrected all the comments and suggestions that I gave you in the

	second round. Hence, I suggest to the editor that it be published in the journal. Good luck. Response: Thank you very much.
Additional Information:	
Question	**Response**
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Ethics Statement Enter an ethics statement for this submission. This statement is required if the study involved: • Human participants • Human specimens or tissue • Vertebrate animals or cephalopods	The work (VLIR-UOS, ET2019TEA485A102) was funded by the Flemish Interuniversity Council. I obtained written consent from local farmers and acquired a permit letter from the Wolaita Sodo Zone District and Sub-district Agriculture, Environment, Forest, and Climate Change Regulatory Office (Reference no. WZ/253/2013).

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Patterns of Primates Crop Raiding and the impacts on incomes of Smallholders across Mosaic agricultural Landscape of Wolaita Zone, Southern Ethiopia

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Abstract

Crop damage caused by non-human primates poses a significant challenge to wildlife conservation efforts. This study aims to assess primates crop foraging /crop raiding events and the extent of maize damage in 25 small (10x10m) maize fields, including both protected and non-protected fields. Data were collected over a twelve-month period spanning 2020 and 2021 in the Sodo Zuriya and Damot Gale regions in the Southern Highlands of Ethiopia, utilizing field experts and camera traps. Farmers reported that olive baboons, porcupines, and grivet monkeys were the most notorious crop raiders. Baboons and grivet monkeys were found to attack maize more frequently in June, July, and August. Baboons primarily targeted maize in the morning, while grivet monkeys did so in the afternoon. Notably, primate raids were more common in maize fields located closer to the forest edge than in those situated farther away. The average maize yield losses due to nonhuman primate damage amounted to 43.14% and 31.4% in the protected and non-protected fields, respectively. Within this figure, 43.14% of the damage occurred in the protected fields situated 50 m from the forest edge. Conversely, non-protected fields experienced lower rates of damage: 14.42%, 13.18%, 3.7%, and 0.1% at distances of 50 m, 100 m, 200 m, and 300 m from the forest edge, respectively. Camera traps recorded 47 photos of baboons, 21 photos of grivet monkeys, and documented 8 primate crop foraging events. Consequently, our study concluded that maize fields positioned within 50 meters of the forest edge faced significant primate raids. Despite the utilization of wire mesh fencing, it displayed limited effectiveness in deterring olive baboons and grivet monkeys. Furthermore, while guarding is assumed to be an efficient protective strategy, our findings suggest its ineffectiveness when not implemented continuously.

Key words: Anubis baboon, Grivet monkeys, Human-Wildlife conflicts, Non-human primate, Maize damage, Prevention method

Introduction

Crop raiding occurs when wild animals leave their natural habitats to pilfer crops grown by farmers for their own and their families' consumption [1, 2]. This concern has persisted since humans and wild animals began sharing landscapes and resources. In protected areas, the human-wildlife conflict is severe and presents a growing challenge mainly due to mismatches between conservation interests and the improvement of local residents' livelihoods [3, 4]. The frequency of crop raiding and the resulting damage may vary along a distance gradient from natural habitats into human-modified landscapes [5, 6]. A commonly reported pattern is that wild animals move from non-cultivated habitats to raid crops [7, 8]. Crops grown near forest edges are therefore more susceptible to raids than those farther away from the forests [4, 10-13, 20]. Moreover, the intensity of crop raiding depends on the type of crop raider species, crop species grown, and the season [14].

Therefore, finding ways to resolve conflicts between people and wildlife is essential for coexistence outside protected areas. Identifying successful methods will significantly enhance conflict resolution and wildlife conservation in general [4]. Current threats to wildlife stemming from conflict require strategies to manage and contain conflict for populations to persist [15]. Conflict resolution is also crucial in reducing the vulnerability of people who come into conflict with wildlife by minimizing the magnitude of wildlife damage sustained [16]. The success or failure of any mitigation technique is likely to be site and species-specific; determining the appropriate action depends on factors such as the species, location, timing, and historical and socio-ecological context [5, 17]. For instance, species' activity patterns and ranging behavior, which influence daily and seasonal damage patterns as well as the types of crops targeted, can significantly impact mitigation effectiveness [17].

Currently, wild mammals such as baboons, monkeys, bush pigs, porcupines, chimpanzees, and elephants have been identified across different regions of Africa as the most destructive crop raiders [18-21], causing substantial damage to many species of cereals, root crops, and fruits [5, 9]. Primates that attack subsistence farmers' crops are particularly concerning as they endanger farmers' livelihoods [18-20]. Studies on human-primate conflict have been conducted in various African countries, including Guinea-Bissau [22, 23], Madagascar [24], Rwanda [25], South

Africa [26], Tanzania [27], and Uganda [28-30]. These studies have acknowledged human-primate conflict as a serious issue with drastic impacts on the livelihoods of rural households. Subsistence farmers heavily rely on their agricultural production, making crop raiding by wildlife, such as primates, a serious threat to local food security. Additionally, the livelihood of local communities around protected areas mainly depends on agriculture, which is highly vulnerable to crop raiders [30, 31].

Similarly, various wild animals, including insect pests, small and large mammals, and birds, have been reported to raid crops in Ethiopia [18]. In southwestern Ethiopia, several large mammals such as olive baboons, bush pigs, giant forest hogs, vervet monkeys, porcupines, warthogs, colobus, and blue monkeys have been identified as significant crop raiders in both field crops and home gardens [6, 32]. However, the frequency and extent of crop raiding incidents may vary along a distance gradient from natural habitats into human-modified landscapes [5, 6]. Despite this variation, little is understood regarding the pattern and socio-economic impacts of crop raiding by wild primates in the biodiversity hotspots of Southern Ethiopia, including the Wolaita Damota Community Managed Areas. Therefore, our aim was to understand the pattern and extent of crop damage caused by primate species at different distances from forest edges surrounding the Damota Community Managed Areas. We hypothesized that the frequency of crop raiding by large wild primates and the corresponding magnitude of crop damage decrease with the distance from the forest edges and vary depending on the type of protection method employed in the crop fields. To achieve this, we aimed to determine the socio-economic impacts of crop raiding primates on farms located at four different distances (50m, 100m, 200m, and 300m) from the forest edges of the Damota Community Managed Areas. Subsequently, we quantified crop damage by primates in fields safeguarded with wire mesh, human guardians, scarecrows, thorny bushy maize fields, and in non-protected (open) maize fields. We also evaluated the efficacy of these preventive methods against primate crop raiding in the forest-agricultural landscape mosaic in Wolaita Damota Areas, Southern Ethiopia.

Materials and methods

Study area

The study was conducted in the Sodo Zuriya and Damot Gale districts, located approximately at 6.54°N 37.45°E through 6.9°N 37.75°E in the Highlands of Southern Ethiopia. The study sites included the Gurumu Woyde, Kokate Marachere, Konasa Pulasa, Damot Waja, and Dalbo Wogene sub-districts (Fig 1). The study area covers 380 km² and is primarily situated atop Mt. Damota. The Damota Community Managed Forest was established in January 2006 through collaboration between the Sodo community and World Vision Ethiopia. The aim was to restore and protect the montane high-forest on the slopes of Mount Damota. The land is collectively owned by five Sodo Zuriya and Damot Gale Communities, who secured the site and obtained land user-rights certificates from the Ethiopian Government in 2006. Furthermore, the Ethiopian government has supported the community's ownership of carbon rights trading, allowing them to earn revenue from carbon offsets. Additionally, cooperatives were established to manage the protected areas. According to the institute's assessment, the area also plays a role in global climate regulation [33]. This region experiences a dry period from October to March and a wet season from April to September, receiving 1450 to 1800 mm of rainfall, respectively [33]. The maximum rainfall occurs between June and September, with shorter rains falling in March and April [33]. The temperature ranges from 16°C to 24°C between the wet and dry seasons.

The Damota Community Managed Forest is characterized by rugged topography and diverse agro-ecology, fauna, and flora. The vegetation is marked by various types, including evergreen needle-leaved, deciduous needle-leaved, evergreen broadleaved, and deciduous broadleaved forests, mixed with shrubland, herbaceous vegetation, herbaceous wetland, moss and lichen, sparse/bare vegetation, and cropland [33]. Dominant plant species in this area include *Syzygium guineense* (woodland waterberry), *Juniperus procera* (African juniper), *Croton macrostachyus* (Broad-Leaved Croton), *Erica arborea* (briar root), *Olea europaea* (common olive), and *Acacia hockii* (Shittim Wood) [33]. The region is home to various large and medium-sized mammals, such as olive baboons (*Papio anubis*), grivet monkeys (*Chlorocebus aethiops*), duikers (*Sylvicapra grimmia*), common bushbucks (*Tragelaphus scriptus*), Guenther's dikdik (*Madoqua guentheri*), and porcupines (*Hystrix cristata*). Predators include golden jackals (*Canis aureus*), black-backed jackals (*Canis mesomelas*), leopards (*Panthera pardus*), African civets (*Civettictis *civetta*), and spotted hyenas (*Crocuta crocuta*) [33]. The entire area sustains a population of 16,342 people [34].

In Mount Damota, farmers typically possess very small plots of land. The range of landholding sizes spans from 0.06 to 1.75 hectares, with an average size of 0.5 hectares [35]. The Wolaita zone, characterized by a highland perennial farming system, supports a diverse array of crops [36]. According to [36], primary food crops in this region include maize, teff, various vegetables, and root and tuber species such as cassava, yam, potato, sweet potato, and taro. Additionally, tropical and temperate fruit tree crops like banana, avocado, mango, and apple are cultivated in the Wolaita Areas [36]. Maize fields in these areas tend to be quite small, often measuring around 10 x10 meters, and are interspersed with fields growing different crops. For the purposes of this study, maize fields were selected to assess the extent of damage caused by non-human primates.

Experimental setup

We set up our study using 25 maize fields. Ten maize study plots were situated 50 meters from the forest edge and were used to compare protective measures in the villages of Gurumu Woide and Kokate Marachare. The protected study plots were safeguarded using wire mesh, human guardians, scarecrows, and thorny bushes, while the non-protected fields remained open/control (Fig 2). Furthermore, we set up a total of fifteen non-protected maize study plots (Table 1), including Gurumu Woide, Kokate Marachare, Delbo Wogene, Damot Waja, and Konasa Pulasa. The study plots were located at varying distances: 100 meters, 200 meters, and 300 meters from the forest edge. The distances of each study plot farthest away from the forest edge were measured using the Garmin 72H GPS device. Distances from field edges to reference features or structures (e.g. trees, paths, or huts) were recorded to aid in distance estimation (Fig 3).

Each study field, we designated a study plot measuring 10m x 10m (Table 1). Within these study plots; we planted the high-yielding maize variety BH-546, well-suited for the region's agro-ecology. Maize seeds were sown early in the rainy season, typically in April, reaching the milky stage in late July and ripening by mid-August, with harvesting in September. Prior to sowing, oxen-drawn plows were used to prepare the fields by creating rows. Initially, 580 seeds were sown in each study plots in both the 2020 and 2021 maize cropping seasons. However, in one field (Field no. 25) seeds were removed or added by the farmer resulting in 532 seeds (19 rows x 28 seeds) during the 2020 maize cropping season and 627 seeds (19 rows x 33 seeds) during the 2021 maize cropping season. Each hole received one seed, with a planting distance of 40 cm x 30 cm, while maintaining a distance of at least 50 meter between one maize study plot and the next.

All cultivation practices, including fertilizer application, cultivation, and weeding, were carried out as usual. However, non-uniform germination of the sown maize seeds resulted in varying maize harvests across different plots. In this study, we collected data using (1) Field experts (2) Camera traps

Field experts

The data collection for Crop Foraging or Raiding Events (CFE/CRE) in primates was conducted by six field experts trained by researchers to ensure a thorough understanding of the subject. Each field expert monitored and assessed CFE/CRE incidents in both baboons and grivet monkeys. They actively participated in the project during two maize harvest seasons (from April to August in both 2020 and 2021). Additionally, these experts collaborated with twenty five local farmers during field observations and reporting. The overall data collection process was supervised by four researchers.

Researchers defined the primate crop foraging or crop raid event (CFE/CRE) to potential aspiring field experts as follows: *CFE /CRE is defined as when one or more individuals of a species entered (i.e. crossed a field boundary) and make trampling the field and left the field (CRE), and interacted with one or more maize stem and eat the stem (CFE). The CFE/CRE episode begins when the first primate enters the field; eat the stem and ends when the last primate leaves the farm. The duration is measured in seconds using a digital stopwatch. Primate age categories are adult (full species-sex-specific size), sub-adult (not fully grown, beyond infant development, exhibits independent behaviour frequently), or infant (developmentally small and dependent, carried frequently, maintains close proximity to adults).*

Field experts responded to the following questions: (1) What is the extent of primate damage to maize on protected and non-protected fields? (2) When and during which months do primates raid maize crops? (3) How long do primates typically stay during their maize raids? (4)

How frequently and at what times do farmers report primate incursions? (5) Which crop-feeding species have farmers reported encountering? (6) What is the extent of primate maize damage on fields located at a distance? (7) How many individual primates raided maize and entered fields? (8) In what proportion do multiple and single primate raid events occur? (9) How many individual primates typically visit maize fields? (10) In which age categories are maize crop-raiding primates typically found?

Data were also collected regarding the presence or absence of humans on fields, the nature of on-field human activity, the extent of guarding behavior, and responses to crop-raiding primates. Crop damage was determined by counting stems damaged by primates. Trained field experts assessed and counted the damage caused by primates to maize daily at 18:00 hours.

Camera traps

To gather information on the timing, frequency, and location of feeding behavior by olive baboons and grivet monkeys within the 25 study plots, we utilized Bushnell camera detection equipment (Browning trail camera Model No BTC-6HDX).

These motion-trigger cameras were configured to capture and store data, including the date, time, location, and temperature for each photo. The cameras were set to take only one photo per trigger, with a 2-second interval between triggers [37]. Cameras were securely housed and locked in metal cases. A potential CFE/CRE was recorded when one or more individuals olive baboons and grivet monkeys were merely present in the field [37]. An actual CFE was documented if the photo or video indicated physical manipulation and/or consumption of crop items [37, 38]. An interval of more than an hour between captured images was considered as an independent CFE [37]. During the course of this project, different camera traps were installed and dismantled on different days, resulting in varying numbers of trap days for each unit.

Cameras were installed on each study plot. We used 30mm x 30mm stainless steel wire mesh with a wire diameter of 1.6 mm and a height of 2.5 meters. For data storage, we utilized 16GB and 32GB Class 4 SDHC memory cards for each camera. Farmers monitored the camera traps to prevent theft. Data from the camera traps were collected from April to September in both 2020 and 2021, with cameras installed in each of the 25 maize fields for four consecutive trapping nights. We installed the cameras for 192 trapping days. During camera installation, we collected the following information: camera ID, GPS position, date, and altitude. Subsequently, we downloaded the photos and videos from the camera traps onto a laptop. We checked each photo/video for the presence of wildlife and other relevant information. We also investigated the presence of humans and dogs, among other factors. Photos containing baboons and monkeys that could damage the crop were numbered and placed in a digital folder. We cataloged all the saved photos/videos and associated information in a spreadsheet.

Data Analysis

We utilized SPSS Version 16 for Windows (SPSS Inc., Chicago, USA) to analyze the data. Tests were two-tailed, and results were deemed statistically significant when $p \leq 0.05$. The images captured by camera traps were interpreted to determine the frequency and timing of Crop Foraging/CRE Events (CFE/CRE). Descriptive statistics were employed to analyze crop feeding data. A chi-square test was conducted to examine the variation in maize damage by primates across different variables, including primate species raiding duration, multiple versus single raid events, primate CFE timing, and age-category of raiding in single or group. Median values were used to describe central tendency. For continuous variables, we conducted the Mann-Whitney U test, Spearman's Rank Correlation Coefficient, t-test, and F-test. Specifically, the Mann-Whitney U test compared primate CREs of raiding durations and different age categories of primate species on CREs. The Spearman correlation coefficient assessed the relationship between the number of individuals entering a field and the number at the forest edge prior to raiding. The independent sample t-test compared estimates of maize damage among variables such as the number of individuals raiding, Primate CREs, farm distance, duration of raiding, and crop phenology. The F-test compared estimates of maize damage between preventive and non-preventive strategies in the cropping seasons, as well as between single and multiple raids. The extent of primate assaults on maize in preventive and non-preventive maize fields during different crop phenological stages was analyzed using R (bplot function in the Rlab package) [39]. Similarly, linear mixed models were employed to analyze the different spatial-temporal variables. These models included fixed factors (distance, duration, and phenology) and random factors (Primate CREs, number of individuals raiding). The response variable was the rate of maize damage, and the analysis was conducted using R [39]. Maize damage was reported in three aspects: the average number of maize stems/cobs affected, the estimated amount of maize damaged in kilograms, and the proportion of maize damage caused by primates in relation to the expected harvest. To calculate monetary loss, we converted market prices for maize crop per kilogram to US dollars using the prevailing exchange rate at the time of the survey. Additionally, we estimated that the maize seeds in one maize stalk weighed approximately 0.2 kg after harvest.

Ethical statement

The study was approved by the institutional ethics committee, adhering to the established ethical guidelines of Wolaita Sodo University, under Reference No. WSU15/12/915. Subsequently, permission was obtained from the Wolaita Zone Agriculture, Environment, Forest, and Climate Change Regulatory Office, as well as the respective district authorities. Verbal consent was obtained from each study participant. All social data of the study participants were kept confidential and anonymized before analysis.

Result

Farmers-reported crop feeding or raiding species

All farmers consistently reported that baboons, porcupines, and grivet monkeys were the primary culprits responsible for the most severe crop damage to maize, and these species exhibited a high frequency of Crop Foraging/CRE Events (CFE/CRE). Additionally, some farmers (N = 10) suggested that bushbuck might also be involved in crop feeding or raiding. However, the reported CFE/CRE frequency of bushbuck in crop fields was notably low, occurring only 24 times (Table 2).

Farmer-reported maize damage assessments

The average percentage of maize cobs lost by olive baboons in wire mesh, human guard, scarecrow, and thorny bush setups was 8.23% (equivalent to 72.8 maize stems/cobs), 7.38% (65.3 maize stems/cobs), 9.82% (86.8 maize stems/cobs), and 9.45% (83.5 maize stems/cobs), respectively. These fields were located 50 meters from the forest edge. In non-protected fields, the average percentage of maize cobs lost by olive baboons were 10.04% (88.8 maize stems/cobs), 1.53% (13.5 maize stems/cobs), 0.4% (3.6 maize stems/cobs), and 0.1% (0.9 maize stems/cobs) located at 50 meters, 100 meters, 200 meters, and 300 meters from the forest edge, respectively (Table 3).

The average percentage of maize cobs lost by grivet monkeys in wire mesh, human guard, scarecrow, and thorny bush setups were 0, 1.83% (6.3 maize stems/cobs), 3.8% (13 maize stems/cobs), and 2.63% (9 maize stems/cobs), respectively. These fields were located 50 meters from the forest edge. In non-protected fields, the average percentage of maize cobs lost by grivet monkeys were 4.38% (15 maize stems/cobs), 11.65% (39.9 maize stems/cobs), 3.3% (11.3 maize stems/cobs), and 0, located at 50 meters, 100 meters, 200 meters, and 300 meters from the forest edge, respectively (Table 3).

In total, the average percentage of maize cobs lost by these two primate species in the protected fields was 43.14% (equivalent to 336.7 maize stems), located at 50 meters from the forest edge. The average percentage of maize cobs lost by primates in the non-protected fields was 14.42% (103.8 maize stems), 13.18% (53.4 maize stems), 3.7% (14.9 maize stems), and

0.1% (0.9 maize stems) located at 50 meters, 100 meters, 200 meters, and 300 meters, respectively.

Camera trap results

Our cameras recorded 47 photographs of baboons and 21 photographs of grivet monkeys, as summarized in Table 3. Of the 47 photographs of baboons, only 3 were confirmed as actual (CFE), while the remaining 44 were potential (CRE). Similarly, out of the 21 photographs of grivet monkeys, only 2 were confirmed as actual (CFE), with the remaining 19 being potential (CRE). Notably, the longest CRE event, recorded by camera ID A3 and E1, occurred in scarecrow and open maize fields (Table 4, Fig 4).

Farmers-reported extent of primate crop damage on protected and open/control fields

The average percentage of maize damaged by Olive baboons in both Gurumu Woide and Kokate Marachare study sites, as reported by farmers, was 23.62% in wire mesh, 21.03% with a human guard, 28.15% with a scarecrow, and 27.2% in thorny bush fields, respectively (Fig 5). The results of a one-way ANOVA indicated that the amount of damage in maize fields was significantly higher in thorny bush fields compared to the levels of damage from wire mesh, a human guard, and a scarecrow ($F=292.5$, $df=11$, $p < .001$, Fig 5).

The average percentage of maize damaged by grivet monkeys in the Kokate Marachare study site, as reported by farmers, was 0% in wire mesh, 24.14% with a human guard, 44.83% with a scarecrow, and 31.03% in thorny bush fields, respectively (Fig 6).The results of a one-way ANOVA indicated that the amount of damage in maize fields was significantly higher in thorny bush fields compared to the levels of damage from wire mesh, human guards, and scarecrows ($F=5.4$, $df=11$, $p < .005$, Fig 6).

Time or months of maize raided

According to farmers' responses, a higher frequency of maize cobs being plucked was reported in July, with 524 ± 3.8 maize cobs in the year 2020 and 539 ± 4.6 maize cobs in the year 2021. Moderate frequencies of maize raiding were reported in June and August, with 216 ± 4.6 and 64 ± 2.1 maize cobs in 2020, and 240 ± 5.2 and 25 ± 1.6 maize cobs in 2021, respectively. The lowest frequencies of maize raiding occurred in April, May, and September for both 2020 and 2021 (Fig 7).

Duration of crop-raiding events

The average raid duration ranged from 15.1 to 18 minutes, with a standard deviation of 0.66. There was significant difference in raid duration between species, as indicated by the Kruskal-Wallis test ($\chi^2 = 58.62$, df = 10, $P < 0.05$). Raid durations were significantly shorter when carried out by single individuals (median 1 minute, SD = 0.42) compared to raids by two or more individuals (median 3 minutes, SD = 2.42), as confirmed by the Mann-Whitney U test (n (single) = n (two+) = 38, U = 34.0, $p < 0.001$). The majority of Crop Raiding Events (CREs), approximately 70%, lasted between 0.1 and 12 minutes (Fig 8)

Farmers-reported CFE frequency and timing

Farmers observed that baboons typically fed on crops early in the morning, while grivet monkeys fed on crops throughout the day. According to farmers, neither baboons nor grivet monkeys were seen eating on crops at night. Baboon Crop Foraging Events (CFEs) occurred throughout the day but not in a uniform distribution, as revealed by photographic data from five locations (Chi-square goodness of fit: $\chi^2 = 32.36$, df = 12, $p < 0.001$). Similarly, Grivet monkey CFEs occurred throughout the day, also with a non-uniform distribution, based on photographic data from five locations (Chi-square goodness of fit: $\chi^2 = 35.86$, df = 8, $p < 0.001$). Morning CFEs were more common in baboons (6:00–7:00 a.m.) than afternoon CFEs (2:00–3:30 p.m.). In contrast, CFEs were more common in the early afternoon (11:00 a.m.–12:00 p.m.) for grivet monkeys than in the morning (6:00–7:00 a.m.) during both 2020 and 2021 years. Farmers reported no baboon CFEs in all five locations between 11:00 a.m. and 6:00 p.m. during both 2020 and 2021 years (Fig 9).

Determinants of maize damage by primates

In this study, the spatial-temporal variables affecting the incidences of maize damage by primates were analyzed using a linear mixed model. The model indicated that farms located 200 meters from the forest edge experienced significantly fewer maize raiding incidences compared to farms located 50 meters from the forest edge (t = -2.728, DF = 256.9, $P < 0.006$). The duration of maize raiding incidences was significantly longer, lasting 6.1-9 minutes, compared to durations of 0.1-3 minutes ($t = -1.993$, $DF = 182.9$, $P < 0.04$). Similarly, maize raiding incidences were significantly higher at both the fruiting stage ($t = -11.656$, $DF = 98.9$, $P < 2e-16$) and the maturity stage ($t = -13.53$, $DF = 176.05$, $P < 2e-16$) compared to the seedling stage (Table 5).

Primate crop raiding events

A total of 367 primates were observed at the forest edges immediately before or during Crop Raiding Events (CREs). Out of these, 367 individuals, accounting for 75%, ventured into fields (Table 6). This included all 75 CREs by Anubis baboons (79%) and 20 CREs by grivet monkeys (21%). Notably, Anubis baboons were significantly more likely to be found near the forest edge than grivet monkeys, as indicated by the Kruskal-Wallis test ($\chi^2 = 263.1$, $df = 15$, $p < 0.001$). The number of individuals entering a field showed a positive correlation with the number at the forest edge prior to raiding, which was confirmed by the Spearman's Rank Correlation Coefficient ($rs = 0.434$, $n = 95$, $p = 0.006$). This correlation persisted even when humans were present on the field, with a Spearman's Rank Correlation Coefficient of $rs = 0.324$, $n = 59$, and $p = 0.04$. Regarding the composition of CREs, the majority (36.1%) involved three or fewer individuals, while 47.8% consisted of a single individual or a pair. Only 16.1% of CREs involved more than five individuals (Fig 10). It's worth noting that baboons raided in significantly larger groups than other species, as shown by the Kruskal-Wallis test ($\chi^2 = 41.57$, $df = 5$, $p < 0.001$); however, most baboon raiding groups were small, with 78% comprising fewer than five individuals. On the other hand, grivet monkeys were more likely to raid alone, according to the Kruskal-Wallis test ($\chi^2 = 88.01$, $df = 5$, $p < 0.001$).

Multiple versus Single raid events

A significantly greater proportion of raids (64%; $n = 61$) occurred in groups rather than as single raids, as confirmed by the Chi-square test ($\chi^2 = 15.9$, $df = 4$, $p = 0.003$). Among the group raids, 67% consisted of either 2-CRE or 3-CRE groupings, indicating a diverse pattern of multiple-CRE profiles for both grivet monkeys and baboons (Fig 11). On the other hand, single raids accounted for 36% ($n = 34$) and were more likely to involve a single raiding individual. It's worth noting that the extent of maize crop damage per CRE differed significantly between single raids and group raids, as evidenced by the F-test ($F = 22.17$, $df = 1$, $p < 0.001$).

Primate field visit and crop raiding events

Seventy-five percent of primate field visits (comprising 22.3% baboons and 26.1% grivets) did not involve crop raiding at all, as illustrated in Fig 13. Among the visits that did include crop raiding, it was observed that 76% more baboon visits involved multiple crop-raiding events rather than a single event. In the case of grivets, 53% more visits involved multiple events, as confirmed by the Chi-square test (baboon - $\chi^2_1 = 11.63$, $df = 1$, $p < 0.001$; Grivet - $\chi^2_1 = 16.00$, $df = 1$, $p < 0.001$; Fig 12 & Fig 13).

Age categories composition of crop-raiding primates

Significantly more adults were observed on study plots during CREs compared to sub-adults, and more sub-adults were observed than infants. These differences were statistically significant (Mann-Whitney U tests: n (sub-adult) = 118, n (adult) = 216, $U = 1653.5$, $p < 0.001$; n (infant) = 33, n (sub-adult) = 118, $U = 952.0$, $p = 0.510$). This age category distribution was consistent for each primate species, as confirmed by a Chi-square test ($\chi^2 = 71.4$, $df = 1$, $p < 0.001$) (Table 7). Nearly 58% (n = 55) of raiders were single adults, and the majority of adults were present in 42% of CREs involving multiple individuals (n = 40). Baboons exhibited mixed age-category raiding groups significantly more frequently than grivet monkeys (Kruskal-Wallis test, $\chi^2 = 58.05$, $df = 5$, $p < 0.001$), and baboon raiding groups were more diverse (Kruskal-Wallis test, $\chi^2 = 10.88$, $df = 4$, $p = 0.028$). At least one infant was observed during six baboon raids. Most baboon and grivet raiders were accompanied by an adult during their raids. Almost two-thirds of baboon raiding groups included one or more sub-adults. All on-field adult and sub-adult primates damaged at least one crop stem. While infants occasionally interacted with crops by pulling or biting stems, they often traveled or rested near an adult female or engaged in play behavior with other infants or sub-adults, suggesting they were not anxious during CREs. Female primates with infants were particularly vigilant on fields; they were usually the first to return to the forest while carrying their infants and the first to flee in response to human actions. The sex of raiding individuals was not reliably determined for analysis; however, counts of male (n = 38) and female (n = 14) adult baboons on-field during CREs did not significantly differ ($\chi^2 = 29.45$, $df = 1$, $p < 0.001$). While significantly more maize stems were damaged by mixed-age groups than by adults-only groups, the former groups also comprised more individuals, traveled further onto fields, and raided for longer durations. These findings were supported by Mann-Whitney U tests (n (adults) = 10.0, n (mixed) = 36: stems U = 2840.5, p = 0.021; individuals U = 20.5, p = 0.367; maximum distance U = 24.5, p = 1.000; median distance U = 429.0, p = 1.000; duration U = 528.5, $p < 0.001$).

Discussion

Numerous primate species have been involved in crop raids, as documented in various studies [30, 40-44]. In this study, the average maize yield losses attributed to nonhuman primate damage were estimated at 340.8 kg per hectare. A study by [3] noted an average maize yield loss of 264.1 kg per hectare due to pests (baboons and pigs), representing 34.2% of the anticipated total yield. In the Budungo Forest Reserves of Uganda, a study by [9] reported that farmers observed 73% of crop damage caused by primates. Similarly, in another study [31] conducted in the Taita Hills of Kenya, characterized by a forest-agricultural mosaic landscape, farmers reported that 87% of the maize crop was attacked by primates.

In this study, the linear mixed model provides a parameter estimate of maize crop loss during primate Conflict-Raiding Events (CREs), incorporating spatio-temporal patterns relevant to maize raided by primate species. This is supported by reference [58], indicating that the fitted linear model is a good predictor for estimating the total number of crop loss events by wildlife. Conversely, in the study referenced [30], multiple regression models yield an improved estimate of maize crop loss during primate CREs by focusing on crop prevalence; maize was most frequently raided by olive baboons and vervet monkeys. Similarly, as stated in reference [30], the maize model maintains broad applicability while capturing a significant proportion of local stem damage. Considering that primate raiding behavior is often context-dependent [10], it is unlikely that CRE parameters contribute equally to maize crop loss during a raid [30].

Our study demonstrates the value of strategically positioned camera traps in providing insights into various aspects, including recording primate species, their targeted crop types and growth phases, daily and seasonal patterns of crop-feeding activity, and whether crop-feeding occurs individually or in groups [37]. Our identifications were likely biased toward more conspicuous individuals, primarily adult males [37]. Additionally, while camera traps may capture evidence of primate groups' presence in fields, they may not consistently provide photographic evidence of actual crop manipulation and consumption, as supported by reference [37]. Therefore, many events identified as Crop Foraging Events (CFEs) through camera traps may not indeed are actual CFEs.

To assess the severity of crop damage caused by primate feeding, we supplemented our research with additional methods, including farmers' reports. These reports helped monitor baboon and grivet monkey behavior, estimate daily maize damage, and assess post-harvest damage, as supported by references [12, 47].

The behavior of primates in the study area was influenced by their habits and foraging, with baboons on rocky cliffs and caves and grivet monkeys in large trees within the forest. Based on our field observation, Gurumu Woide has high forest fruit availability and an abundance of steep cliffs and caves suitable for the existence of a baboon troop. In contrast, Kokate, Konasa, Delbo, and Waja have lower forest fruit availability and fewer steep cliffs and caves for baboon survival. This may explain the reduced maize damage by baboons in these study sites. In this study, the distance traveled by both baboons and grivet monkeys to inspect and raid crops did not vary, as both species traveled up to 300 meters. During our observations in the caves, we found that baboons were located at far distances, approximately 400 meters from the first farmer fields.

Baboons raided the crops that are available close to the forest edge. Primates predominantly raided crops within 10 meters of the farm-forest edges [42, 48, 49]. However, baboons still visited farms located 300 meters from the forest edge, even though maize crop feeding events were infrequent at this distance. In Uganda, grivet monkeys ventured up to 55 meters into crop fields, while baboons reached up to 110 meters [50]. The highest distance observed was over 700 meters, notably in the Ngangao Forest in the Taita Hills, Kenya [31]. This variation may be influenced by the distribution of households and the number of farms investigated at different distances [31].

In this study, maize raids by primates were reported during the maturation of maize cobs. Our findings suggest that scarecrows and thorn bushes were generally ineffective in deterring the return of baboons or grivet monkeys to the fields. Our wire mesh (wire diameter of 1.6 mm and a mesh size of 30 mm x 30 mm, and a height of 2.5 meters) protection method reduced maize damage, but it did not deter baboons from raiding the crop, and they quickly habituated. Kokate

Marachare is one of our experimental study sites; in this site, the wire mesh fence was effective in discouraging olive baboons and grivet monkeys from attacking maize crops in fields located 50 meters from the forest's edge, but it was not effective in discouraging olive baboons in Gurumu Woide. We hypothesize that the presence of multiple baboons in the Gurumu Woide study site made them highly vigilant and determined to raid maize crops despite the crop fenced with wire mesh fences. In contrast, in Kokate Marachare, where only a single baboon was involved, hence the wire mesh fence most likely deterred them from crop raiding. According to a paper by [46], the net wire fences exhibited limited effectiveness against primate raiding in Budongo Forest Reserve, Uganda. Indeed, field guards were often absent due to other (social) activities, school attendance, etc. However, a study conducted by [3] found that continuous guarding is a principal strategy for effectively mitigating crop damage by pests. The extended protection duration was particularly necessary in villages at higher altitudes where maize takes longer to mature [3].

Both baboons and grivet monkeys are frequently observed foraging for crops in human-dominated settings in the study area, with baboons causing more damage than grivet monkeys. The time of day had differing effects on the crop-foraging patterns of the two species, with baboons foraging more frequently in the morning and grivet monkeys in the afternoon. This variation in the time of activity might be related to the presence of baboons, which appeared to deter grivet crop-foraging behavior [45]. Similarly, the time activity pattern varied in different areas; reference [51] recorded a peak in baboon crop foraging in Zimbabwe between 8 and 10 am, potentially driven by the need to find food upon waking. In contrast, a reference [10] found that primates in Uganda foraged on crops more frequently between noon and sunset than between sunrise and noon.

To access crops, baboons were observed using a 'sit and wait' strategy near the edge of crop fields [52]. The more time baboons and grivet monkeys spent close to the fields, the more likely they were to forage within crops. Furthermore, when they entered crops during these visits, they were more likely to enter multiple times. Crop raiding wasn't a behavior practiced by all members of primate social groups, with baboon raiding parties averaging five individuals [42]. In our study, more adults were observed on maize fields during CREs compared to sub-adults. This varies in different areas; in some studies, adult primates were the main crop raiders, as referenced in [42-45], while in other studies, sub-adults were identified as the primary raiders, as cited in [53-56]. However, this behavior was rare and observed only in baboons. Additionally, perceptions of risk may impact the age composition of primate raiding groups, with adult females with infants raiding the least frequently, likely due to increased caution, as suggested by [44, 57]. However, the diverse raiding group compositions among baboons, the presence of infants on fields, and high rates of raiding by baboons suggested that they were generally more comfortable on fields than other primate species.

Conclusion

The current significant crop losses underscore the necessity for continuous vigilance in maize fields, from sowing to harvest, to deter wild primate pests. The parameters of CRE (Crop Raiding Events) can serve as quantifiable standards for assessing the behavioral impact of techniques aimed at deterring primate crop raiding. Wire mesh fencing was found to have limited effectiveness in deterring baboons and grivet monkeys. Although guarding is assumed to be an efficient protective strategy, our study revealed its ineffectiveness when implementation lacks continuity. Thus, there was no completely effective method for preventing primates from crop raiding during this study. The linear mixed model was a relevant choice for analyzing the extent of maize damage by primates across various spatio-temporal factors. In general, understanding the spatio-temporal patterns of wildlife-induced crop deprivation and evaluating the key parameters related to CRE are crucial steps in mitigating the socio-economic impacts of primate pests originating from forest edges.

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Fig 1. Location map of the study area (created with ESRI ArcGIS Desktop 10.8)

Fig 2. Various prevention strategies (Wire mesh (A), Human guardian tower (B), Scarecrow (C), Thorny bush (D)) were assessed in eight experimental maize field sites to evaluate their effectiveness in deterring crop raiders. The study was conducted in maize field sites located in Gurumu Woide and Kokate Marachare (Photo credit: Yigrem Deneke).

Fig 3. Diagrammatic example of a field map used by observers. HSE = house. GH = guard hut. SH = storage hut. Solid black lines = field boundary. Green objects = trees.

Fig 4. The images above depict camera trap captures of various wildlife species observed in maize field sites located in Damota Mountain, Southern Ethiopia: (A) Anubis baboons (*Papio anubis*) (B) Grivet monkeys (*Chlorocebus aethiops*), (C) Porcupine (*Hystrix cristata*), and (D) Bushbuck (*Tragelaphus scriptus*)

Fig 5. The average of maize stems (≈number of cobs) damaged within 10m x 10m study plots by Olive baboons was examined in relation to various preventive methods at a distance of 50 meters from the forest edge during the 2020 and 2021 maize cropping seasons and crop phenology in the Gurumu Woide and Kokate Marachare (GW) sub-district. The boxplot illustrates a significant difference in crop damage among different prevention methods ($p < .001$).

Fig 6. The average of maize stems (≈the number of cobs) damaged within 10m x 10m study plots by grivet monkeys illustrates the relationship with various prevention methods at a distance of 50 meters from the forest edge during the 2020 and 2021 maize cropping seasons and crop phenology in the Kokate Marachare (KM) sub-district. The boxplot shows a significant difference in crop damage with different prevention methods ($p < .005$).

Fig 7. The frequency of primate maize crop raided during the 2020 and 2021 maize cropping seasons ($n = 95$)

Fig 8. Relative frequency of raid durations by primate CREs ($n = 95$).

Fig 9. The frequency of baboon and grivet monkey CFEs by time of day ($N = 95$) between April to September 2020 and 2021 years.

Fig 10. Relative frequency of raiding by primate CREs ($n = 95$)

Fig 11. The frequency distribution of CREs that were single raids or within a series of multiple-CREs for each of these two primate species ($n = 95$)

Fig 12. The number of baboon and grivet monkey field visits that did and did not involve crop-raiding events (CRE) on maize fields in the Highlands of Damota Mountain, April to September 2020 and 2021 years ($n=367$)

Fig 13. The number of baboon and grivet monkey field visits that involved single- and multi-crop raiding events on maize fields in the Highlands of Damota Mountain, April to September 2020 and 2021 years ($n=189$).

Table 1. Maize field and study plot size on the protective and non-protective maize fields

Study sites	Field number	Maize field size in hectare	Study plot size (10x10m)	Distance to forest edge	Preventive and non-preventive measures
Gurumu Woide	1	0.01	0.01	50m	Wire mesh
	2	0.06	0.01	50m	Human guard
	3	0.1	0.01	50m	Scarecrow
	4	0.1	0.01	50m	Thorny bushy
	5	0.1	0.01	50m	Open/control
	6	0.2	0.01	100m	Open
	7	0.3	0.01	200m	Open
	8	0.3	0.01	300m	Open
Kokate Marachare	9	0.2	0.01	50m	Wire mesh
	10	0.2	0.01	50m	Scarecrow
	11	0.2	0.01	50m	Thorny bushy
	12	0.2	0.01	50m	Open/control
	13	0.2	0.01	50m	Human guard
	14	0.3	0.01	100m	Open
	15	0.3	0.01	200m	Open
	16	0.3	0.01	300m	Open
Delbo Wogene	17	0.2	0.01	100m	Open
	18	0.2	0.01	200m	Open
	19	0.3	0.01	300m	Open
Damot Waja	20	0.06	0.01	100m	Open
	21	0.3	0.01	200m	Open
	22	0.3	0.01	300m	Open
Konasa Pulasa	23	0.01	0.01	100m	Open
	24	0.3	0.01	200m	Open
	25	0.3	0.01	300m	Open

Table 2. The comparison of farmer response frequency and CFE/CRE frequency of crop feeding/raiding species from April to September 2020 and 2021 years

Pest species	Number of farmers reporting the species	Frequency of CFE/CRE
Baboon (*Papio anubis*)	22	80
Grivet monkey (*Chlorocebus aethiops)*	17	45
Porcupine (*Hystrix cristata*)	25	75
Common bushbuck (*Tragelaphus scriptus*)	10	24

Table 3. Farmer observation and reported of maize damage assessments (580 maize stem expected per plot except field no. 25 (see the text)

Study sites	Field number	Distance to forest	measures	Olive baboons						Grivet monkeys					
				Maize cobs loss		% damaged		Av. damaged	Av.%	Maize cobs loss		% damaged		Av. damaged	Av. %
				2020	2021	2020	2021	2020/21	2020/21	2020	2021	2020	2021	2020/21	2020/21
Gurumu Woide	1	50m	Wire mesh	145	146	16.57	16.35	145.5	16.46	0	0	0	0	0	0
	2	50m	guard	127	128	14.51	14.33	127.5	14.42	0	0	0	0	0	0
	3	50m	Scarecrow	165	167	18.86	18.7	166	18.78	0	0	0	0	0	0
	4	50m	Thorny	160	161	18.29	18.03	160.5	18.16	0	0	0	0	0	0
	5	50m	Open/control	164	168	18.74	18.81	166	18.78	0	0	0	0	0	0
	6	100m	Open	48	54	5.48	6.05	51	5.77	0	0	0	0	0	0
	7	200m	Open	16	13	1.83	1.46	14.5	1.64	0	0	0	0	0	0
	8	300m	Open	4	5	0.46	0.56	4.5	0.51	0	0	0	0	0	0
Kokate	9	50m	Wire mesh	0	0	0	0	0	0	0	0	0	0	0	0
Marachare	10	50m	guard	4	2	0.46	0.22	3	0.34	12	13	3.56	3.74	12.5	3.65
	11	50m	Scarecrow	7	8	0.8	0.9	7.5	0.85	25	27	7.42	7.76	26	7.59
	12	50m	Thorny	6	7	0.69	0.78	6.5	0.74	17	19	5.04	5.46	18	5.26
	13	50m	Open/control	11	12	1.26	1.34	11.5	1.3	29	31	8.61	8.91	30	8.76
	14	100m	Open	15	18	1.71	2.02	16.5	1.86	11	12	3.26	3.44	11.5	3.36
	15	200m	Open	3	4	0.34	0.45	3.5	0.39	2	5	0.59	1.43	3.5	1.02
	16	300m	Open	0	0	0	0	0	0	0	0	0	0	0	0
Delbo Wogene	17	100m	Open	0	0	0	0	0	0	30	28	8.9	8.04	29	8.47
	18	200m	Open	0	0	0	0	0	0	9	12	2.67	3.44	10.5	3.07
	19	300m	Open	0	0	0	0	0	0	0	0	0	0	0	0
Damot Waja	20	100m	Open	0	0	0	0	0	0	40	42	11.9	12.1	41	11.97
	21	200m	Open	0	0	0	0	0	0	10	10	2.97	2.87	10	2.92
	22	300m	Open	0	0	0	0	0	0	0	0	0	0	0	0
Konasa Pulasa	23	100m	Open	0	0	0	0	0	0	117	119	34.7	34.19	118	34.45
	24	200m	Open	0	0	0	0	0	0	35	30	10.4	8.62	32.5	9.48
	25	300m	Open	0	0	0	0	0	0	0	0	0	0	0	0
Total				**875**	**893**	**100**	**100**	**884**	**100**	**337**	**348**	**100**	**100**	**342.5**	**100**

Table 4. Image data of olive baboon and grivet monkeys by camera traps of twenty five maize fields during 2020 and 2021

Study sites	**Camera ID**	**Distance to forest edge**	**Preventive and Non-preventive measures**	**Olive baboon**		**Grivet monkey**	
				CRE	**CFE**	**CRE**	**CFE**
Gurumu Woide	A1	50m	Wire mesh	4	0	0	0
	A2	50m	Human guard	10	0	0	0
	A3	50m	Scarecrow	12	3	0	0
	A4	50m	Thorny bushy	6	0	0	0
	A5	50m	Open/control	9	0	0	0
	A6	100m	Open	3	0	0	0
	A7	200m	Open	0	0	0	0
	A8	300m	Open	0	0	0	0
Kokate Marachare	B1	50m	Wire mesh	0	0	0	0
	B2	50m	Scarecrow	0	0	1	0
	B3	50m	Thorny bush	0	0	1	0
	B4	50m	Open/control	0	0	1	0
	B5	50m	Human guard	0	0	0	0
	B6	100m	Open	0	0	1	0
	B7	200m	Open	0	0	0	0
	B8	300m	Open	0	0	0	0
Delbo Wogene	C1	100m	Open	0	0	1	0
	C2	200m	Open	0	0	0	0
	C3	300m	Open	0	0	0	0
Damot Waja	D1	100m	Open	0	0	1	0
	D2	200m	Open	0	0	0	0
	D3	300m	Open	0	0	0	0
Konasa Pulasa	E1	100m	Open	0	0	11	2
	E2	200m	Open	0	0	2	0
	E3	300m	Open	0	0	0	0
Total				**44**	**3**	**19**	**2**

Table 5. A linear mixed model (LMM) was used to analyze maize damage by primates during crop raiding events (CREs) (n = 95).

	Estimate	**Std. Error**	**DF**	**t value**	**Pr(>|t|)**
(Intercept)	66.646	4.424	30.611	15.064	1.06e-15 ***
distance_farm100m	-1.848	2.004	256.286	-0.922	0.35731
distance_farm200m	-10.088	3.698	256.976	-2.728	0.00681 **
distance_farm300m	-6.388	4.196	257.913	-1.523	0.12910
duration of_raiding3.1-6 minute	-3.276	2.312	257.931	-1.417	0.15775
duration of_raiding6.1-9 minute	-6.466	3.244	182.907	-1.993	0.04774 *
duration of_raiding9.1-12 minute	-3.517	4.119	217.458	-0.854	0.39417
duration of_raiding12.1-15 minute	-7.025	5.300	147.578	-1.325	0.18710
duration of_raiding15.1-18 minute	-9.031	5.434	218.392	-1.662	0.09794.
duration of_raiding18.1-21 minute	-6.752	6.370	232.020	-1.060	0.29026
duration of_raiding21.1-24 minute	-8.664	6.813	248.224	-1.272	0.20470
duration of_raiding24.1-27 minute	-11.756	7.637	245.037	-1.539	0.12500
duration of_raiding27.1-30 minute	-11.639	8.685	228.281	-1.340	0.18153
duration of_raiding>30 minute	-8.555	10.282	227.031	-0.832	0.40627
crop_phenology_fruiting	-46.620	3.999	98.983	-11.656	< 2e-16 ***
crop_phenology_maturity	-55.256	4.084	176.050	-13.530	< 2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 6. The proportion of the total number of on-field primates during CREs (n = 367) that were adults, sub-adults, or infants.

	Total number of individuals on fields			
	Adults	Sub-adults	Infants	Total
Anubis baboon	151 (57.6%)	78 (29.8%)	33 (12.6%)	262
Grivet monkey	65 (61.9%)	40 (38.1%)	0 (0%)	105
Total	216	118	33	367

Table 7. Age-category composition of primate raiding groups during CREs (n = 95).

	Composition of crop-raiding group			
	Adults only	Adults and sub-adults	Adults and infants	Adults, sub-adults, infants
Species	% CREs	% CREs	% CREs	% CREs
Anubis baboon	36	45	4.4	14.6
Grivet monkey	68	32	0.0	0.0

S1 table 1. Camera traps recorded the Crop Raiding Events (CRE) and Crop Feeding Events (CFE) of olive baboons and grivet monkeys among twenty-five selected maize fields. Each field comprised study plots measuring 10x10 meters, observed during the maize cropping seasons of 2020 and 2021.

S2 file. The rate of maize damage by olive baboons in different crop phonological stages was analyzed in both protected and open/control fields using R code.

S3 file. The rate of maize damage by grivet monkeys in different crop phenological stages was analyzed in both protected and open/control fields using R code.

S4 table 2. A linear mixed model of the maize damage rate by primates, considering different spatio-temporal variables, was analyzed using R code.

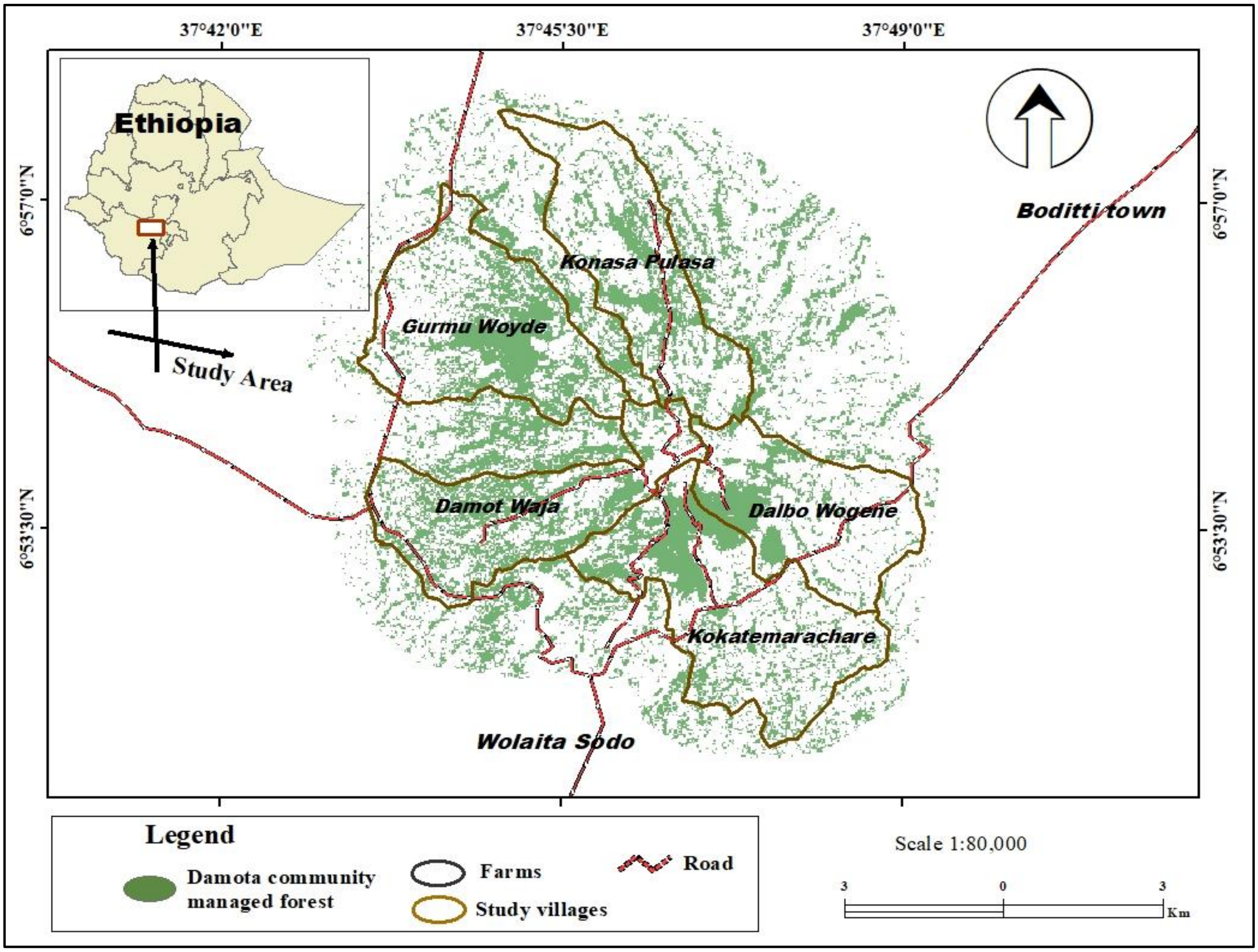

Fig 1. Location map of the study area (created with ESRI ArcGIS Desktop 10.8)

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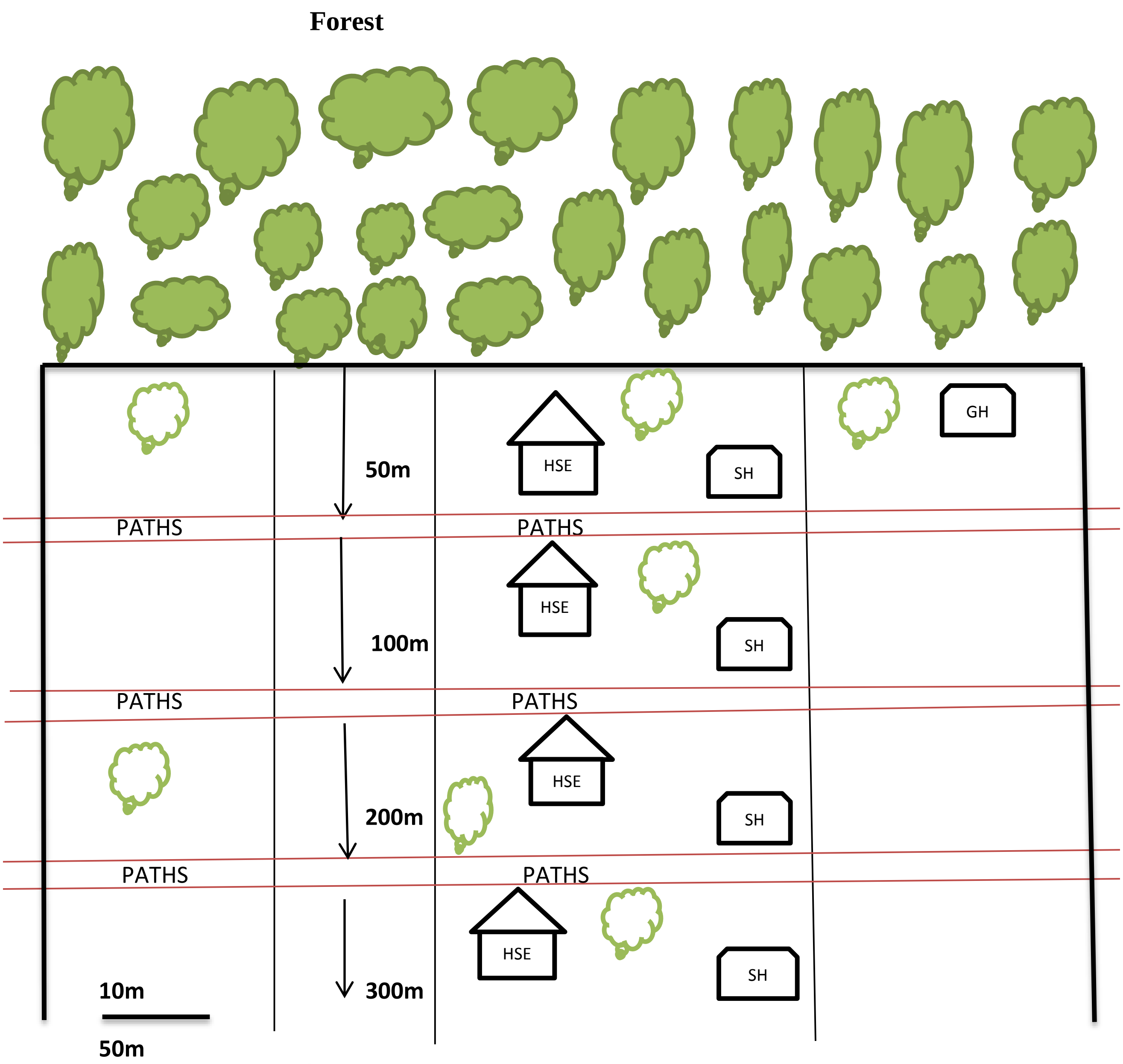


Figure 3. Diagrammatic example of a field map used by observers. HSE = house. GH = guard hut. SH = storage hut. Solid black lines = field boundary. Green objects = trees.

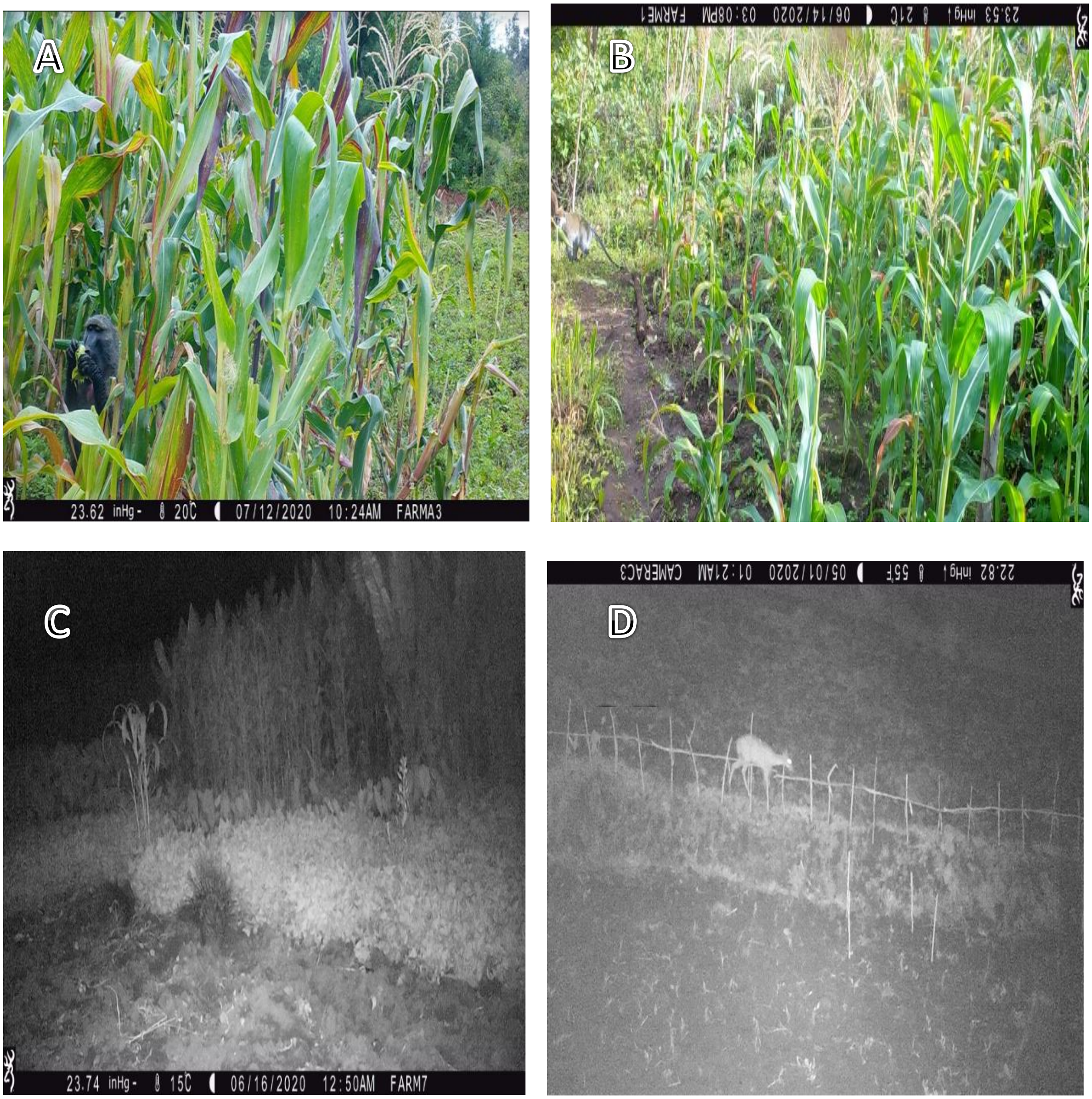


Fig 4. The images above depict camera trap captures of various wildlife species observed in maize field sites located in Damota Mountain, southern Ethiopia: (A) Anubis baboons (*Papio Anubis*), (B) Grivet monkeys (*Chlorocepus aethopis*), (C) Porcupine (*Hystrix cristata*), and (D) Common bushbuck (*Tragelaphus scriptus*)

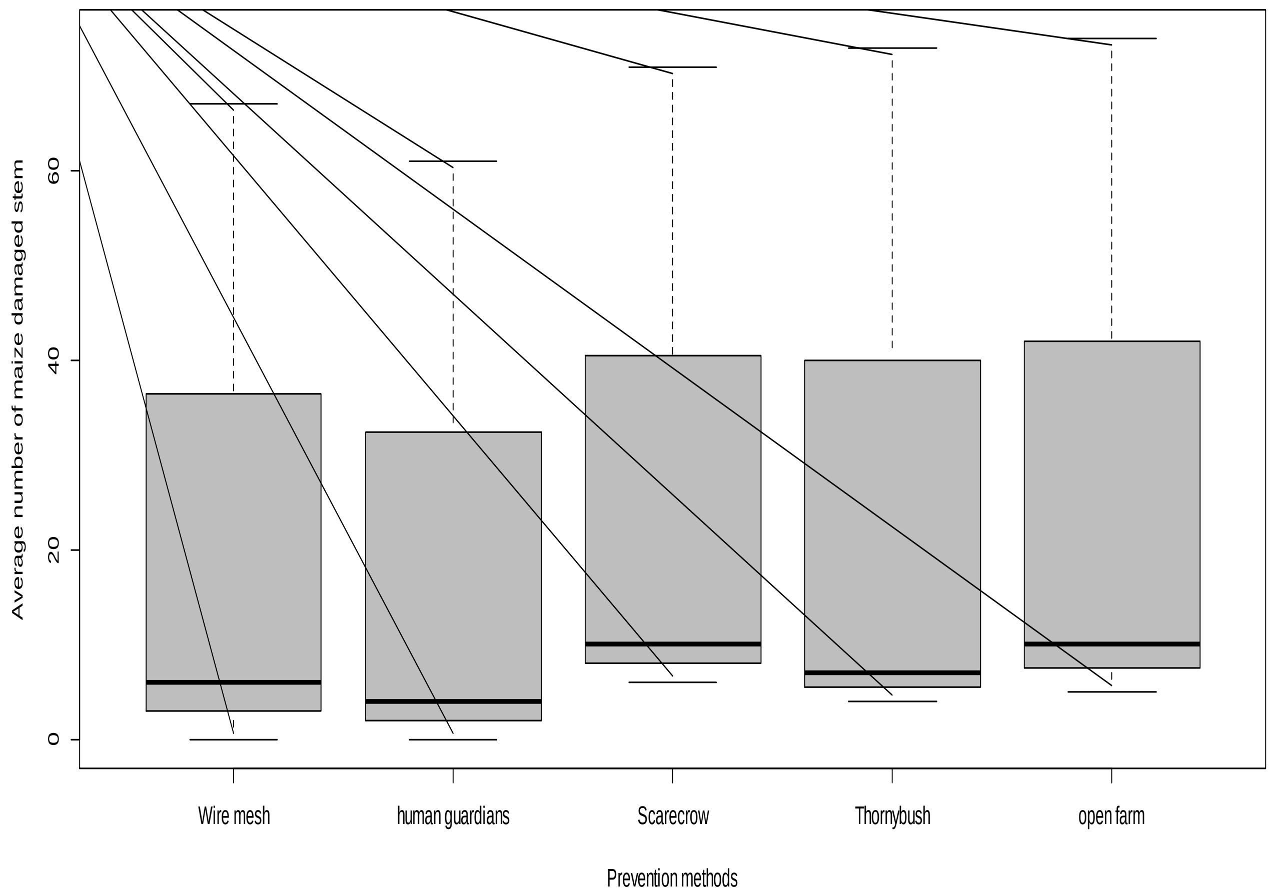
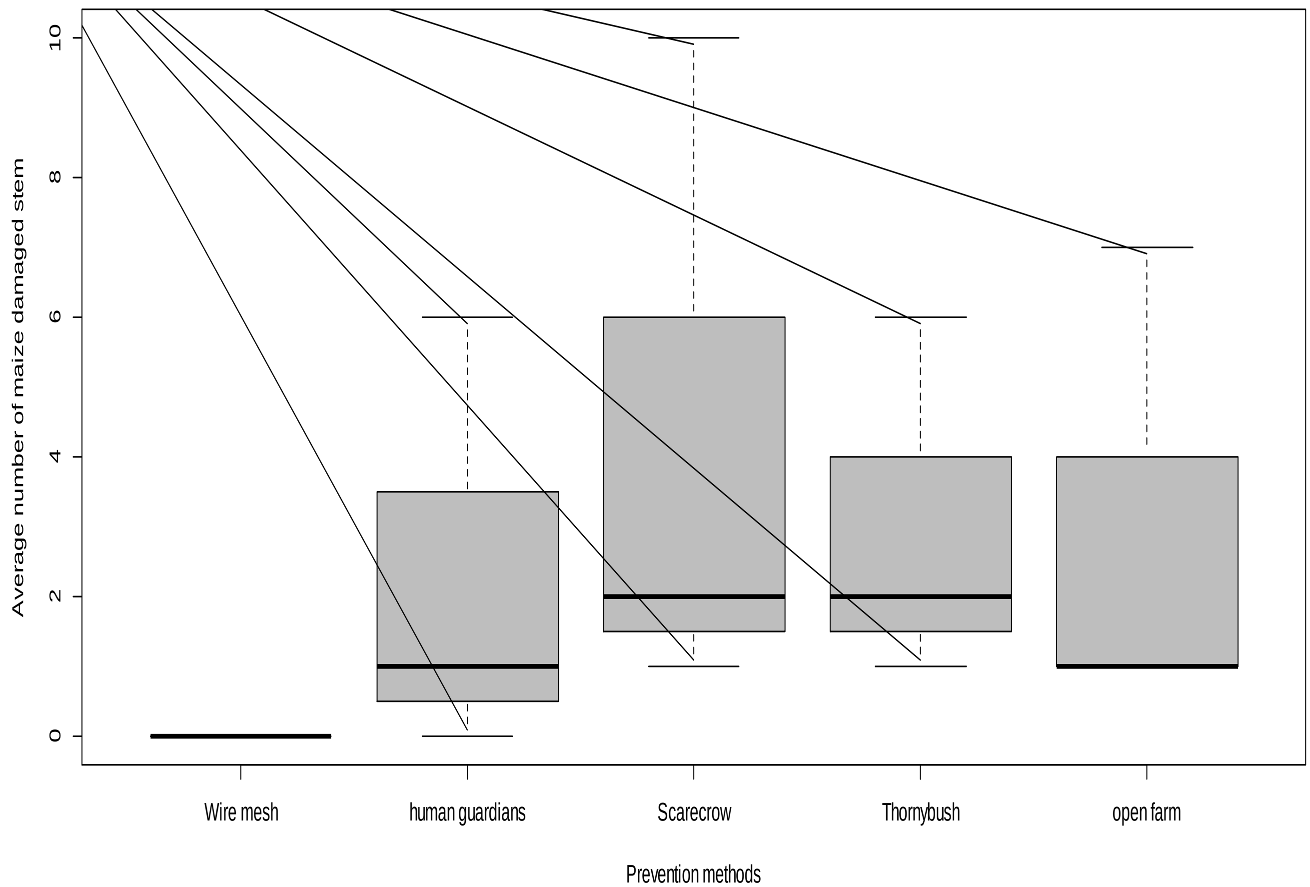


Fig 5. The average of maize stems (≈number of cobs) damaged within 10m x 10m study plots by Olive baboons was examined in relation to various prevention methods at a distance of 50 meters from the forest edge during the 2020 and 2021 maize cropping seasons and crop phenology in the Gurumu Woide and Kokate Marachare (GW) sub-district. The boxplot illustrates a significant difference in crop damage among different prevention methods ($p < .001$).



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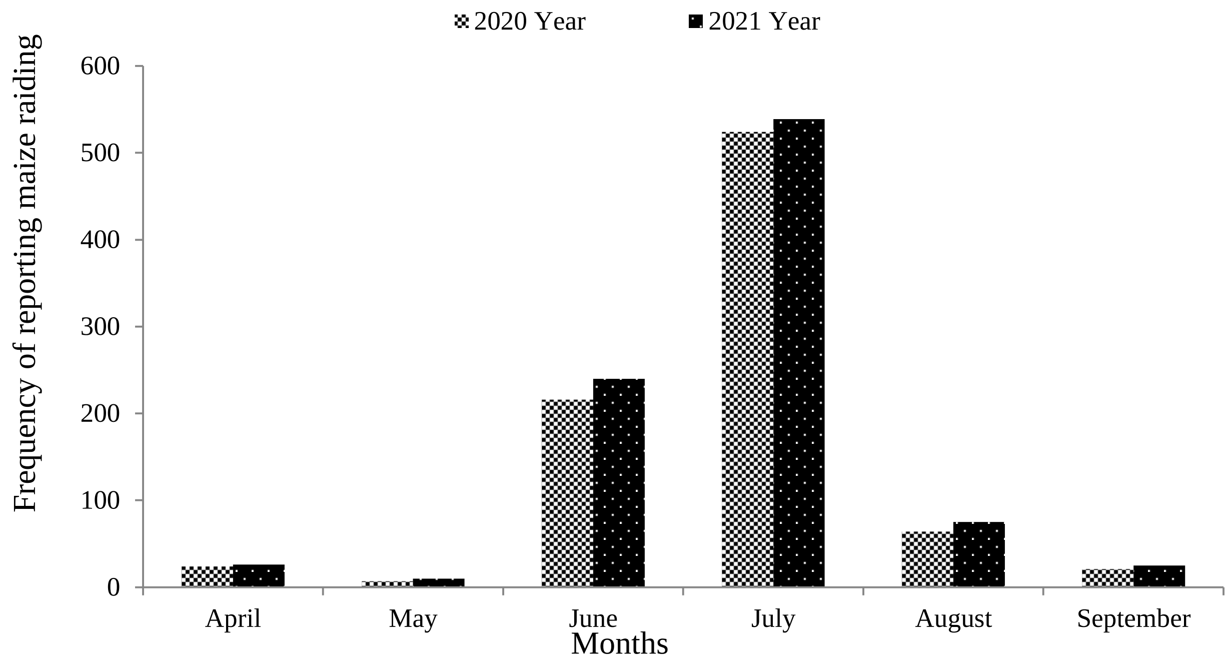


Fig 7. The frequency of primate maize crop raided during the 2020 and 2021 maize cropping seasons (n = 95)

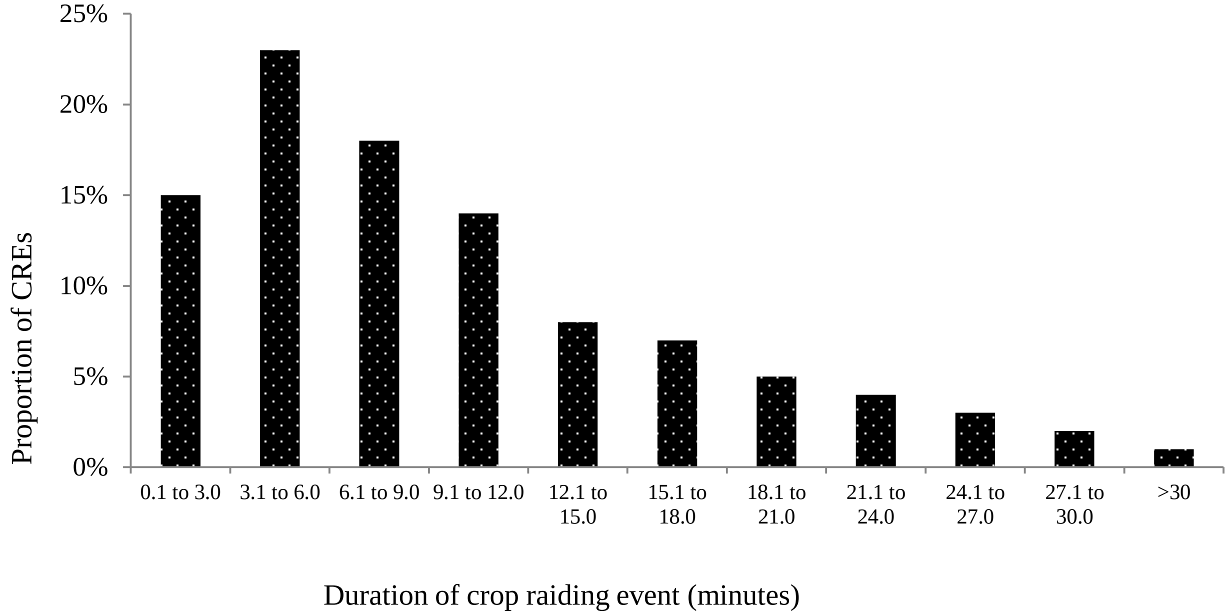


Fig 8. Relative frequency of raid durations by primate CREs (n = 95).

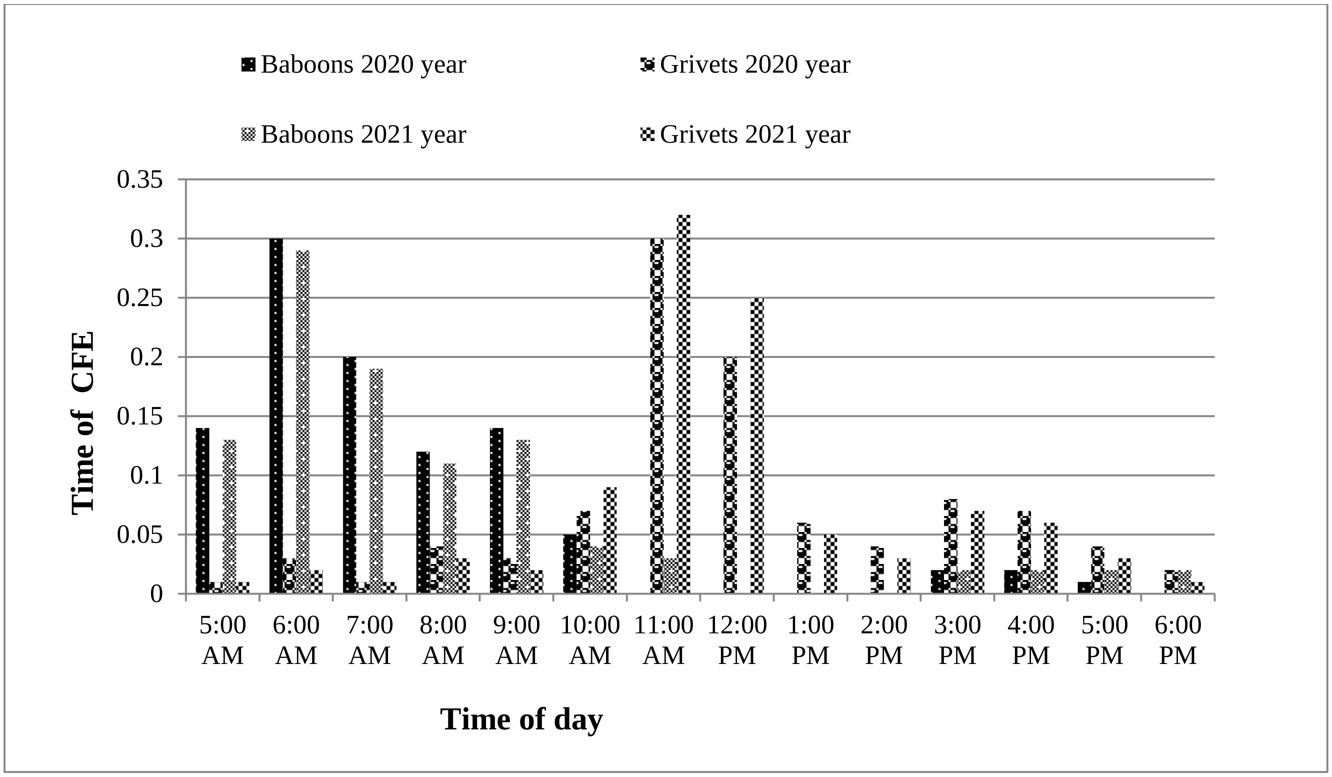
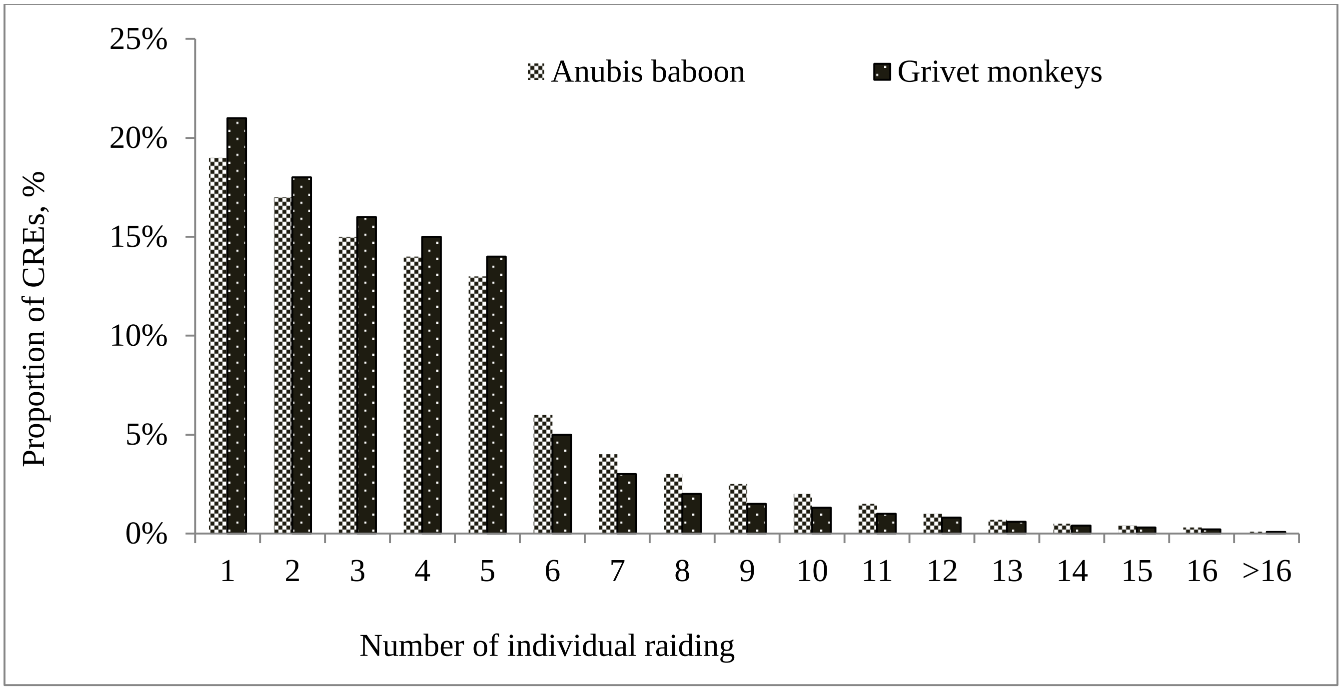


Fig 9. The frequency of baboon and grivet monkey CFEs by time of day (N = 95) between April to September 2020 and 2021 years.



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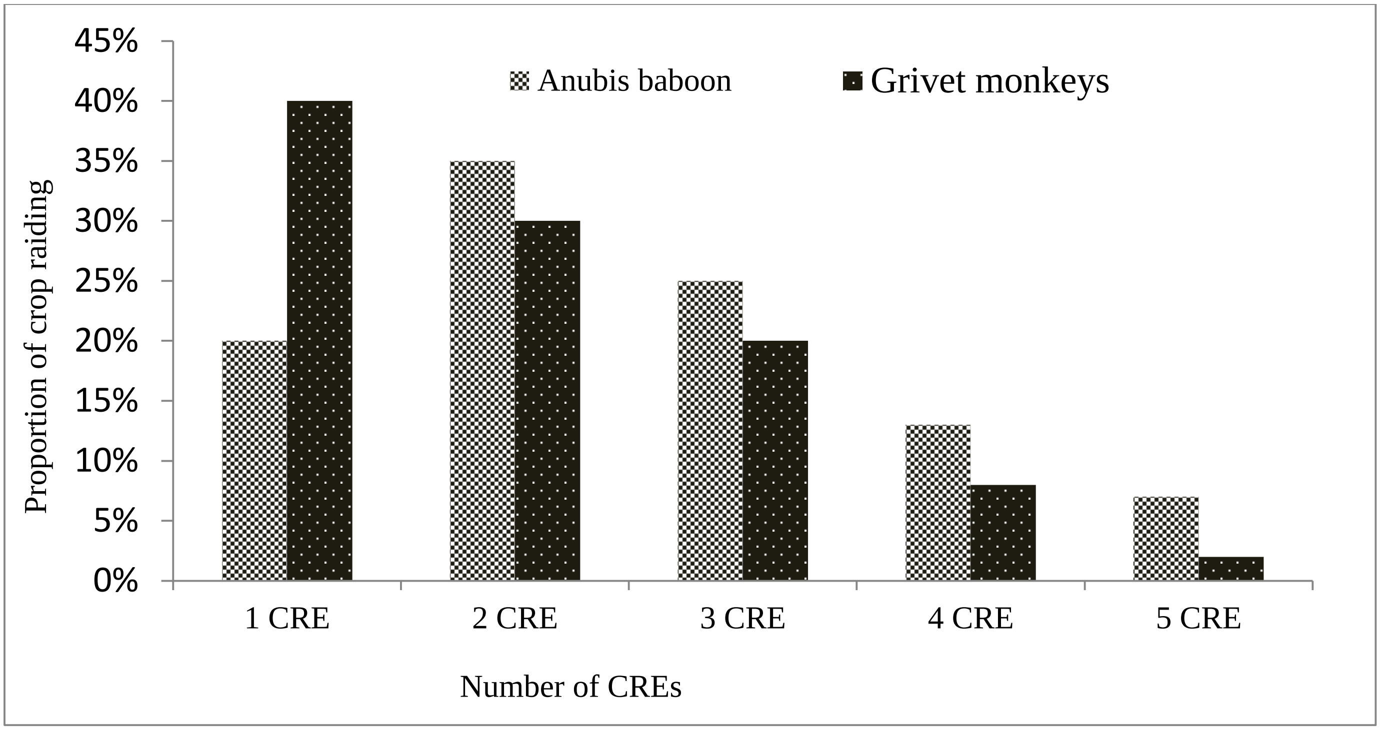

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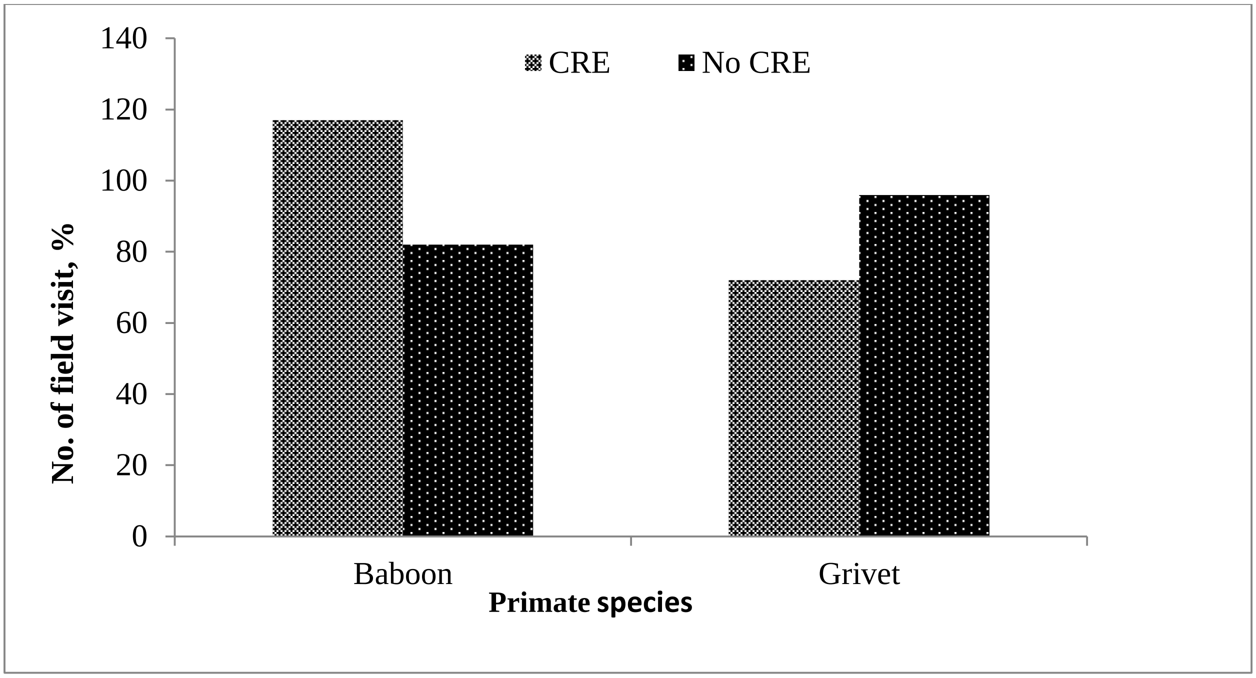

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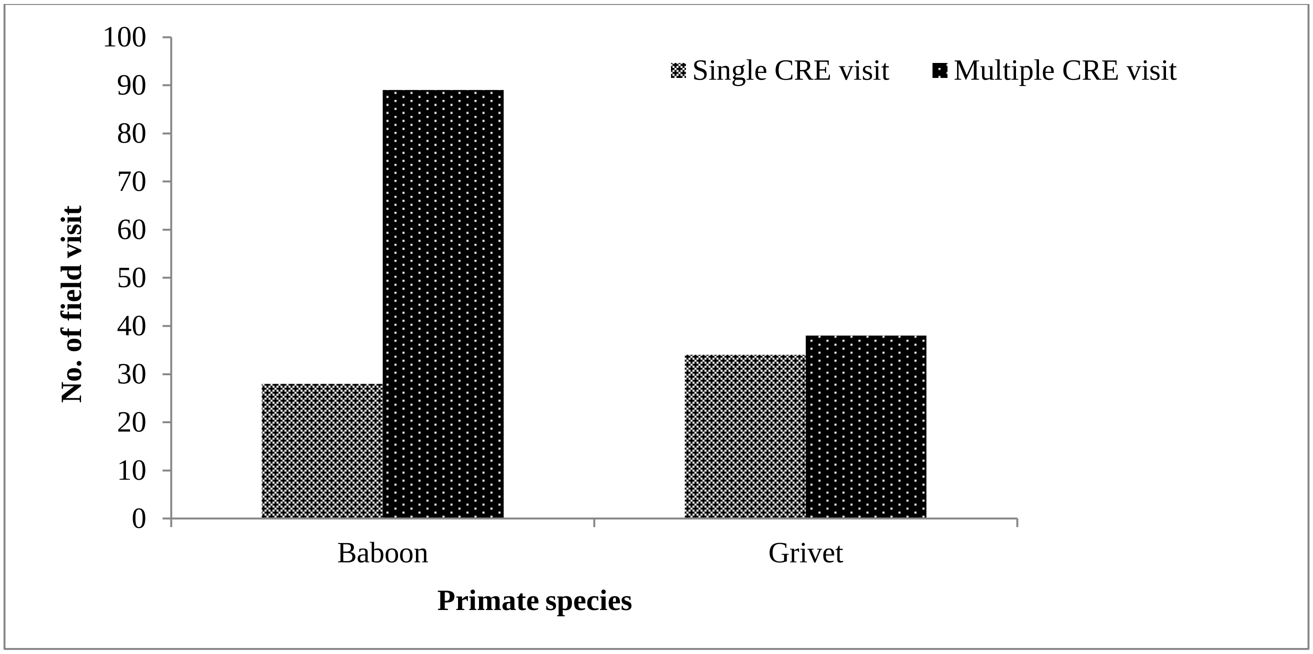

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Click here to access/download
Supporting Information
S3 file. grivet monkeys.docx

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Supporting Information
S4. table 4. LMM.docx

Patterns of Primates Crop Raiding and the impacts on incomes of Smallholders across Mosaic agricultural Landscape of Wolaita Zone, Southern Ethiopia

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Abstract

Crop damage caused by non-human primates poses a significant challenge to wildlife conservation efforts. This study aims to assess primates crop foraging /crop raiding events and the extent of maize damage in 25 small (10x10m) maize fields, including both protected and non-protected fields. Data were collected over a twelve-month period spanning 2020 and 2021 in the Sodo Zuriya and Damot Gale regions in the Southern Highlands of Ethiopia, utilizing field experts and camera traps. Farmers reported that olive baboons, porcupines, and grivet monkeys were the most notorious crop raiders. Baboons and grivet monkeys were found to attack maize more frequently in June, July, and August. Baboons primarily targeted maize in the morning, while grivet monkeys did so in the afternoon. Notably, primate raids were more common in maize fields located closer to the forest edge than in those situated farther away. The average maize yield losses due to nonhuman primate damage amounted to 43.14% and 31.4% in the protected and non-protected fields, respectively. Within this figure, 43.14% of the damage occurred in the protected fields situated 50 m from the forest edge. Conversely, non-protected fields experienced lower rates of damage: 14.42%, 13.18%, 3.7%, and 0.1% at distances of 50 m, 100 m, 200 m, and 300 m from the forest edge, respectively. Camera traps recorded 47 photos of baboons, 21 photos of grivet monkeys, and documented 8 primate crop foraging events. Consequently, our study concluded that maize fields positioned within 50 meters of the forest edge faced significant primate raids. Despite the utilization of wire mesh fencing, it displayed limited effectiveness in deterring olive baboons and grivet monkeys. Furthermore, while guarding is assumed to be an efficient protective strategy, our findings suggest its ineffectiveness when not implemented continuously.

Key words: Anubis baboon, Grivet monkeys, Human-Wildlife conflicts, Non-human primate, Maize damage, Prevention method

Introduction

Crop raiding occurs when wild animals leave their natural habitats to pilfer crops grown by farmers for their own and their families' consumption [1, 2]. This concern has persisted since humans and wild animals began sharing landscapes and resources. In protected areas, the human-wildlife conflict is severe and presents a growing challenge mainly due to mismatches between conservation interests and the improvement of local residents' livelihoods [3, 4]. The frequency of crop raiding and the resulting damage may vary along a distance gradient from natural habitats into human-modified landscapes [5, 6]. A commonly reported pattern is that wild animals move from non-cultivated habitats to raid crops [7, 8]. Crops grown near forest edges are therefore more susceptible to raids than those farther away from the forests [4, 10-13, 20]. Moreover, the intensity of crop raiding depends on the type of crop raider species, crop species grown, and the season [14].

Therefore, finding ways to resolve conflicts between people and wildlife is essential for coexistence outside protected areas. Identifying successful methods will significantly enhance conflict resolution and wildlife conservation in general [4]. Current threats to wildlife stemming from conflict require strategies to manage and contain conflict for populations to persist [15]. Conflict resolution is also crucial in reducing the vulnerability of people who come into conflict with wildlife by minimizing the magnitude of wildlife damage sustained [16]. The success or failure of any mitigation technique is likely to be site and species-specific; determining the appropriate action depends on factors such as the species, location, timing, and historical and socio-ecological context [5, 17]. For instance, species' activity patterns and ranging behavior, which influence daily and seasonal damage patterns as well as the types of crops targeted, can significantly impact mitigation effectiveness [17].

Currently, wild mammals such as baboons, monkeys, bush pigs, porcupines, chimpanzees, and elephants have been identified across different regions of Africa as the most destructive crop raiders [18-21], causing substantial damage to many species of cereals, root crops, and fruits [5, 9]. Primates that attack subsistence farmers' crops are particularly concerning as they endanger farmers' livelihoods [18-20]. Studies on human-primate conflict have been conducted in various African countries, including Guinea-Bissau [22, 23], Madagascar [24], Rwanda [25], South

Africa [26], Tanzania [27], and Uganda [28-30]. These studies have acknowledged human-primate conflict as a serious issue with drastic impacts on the livelihoods of rural households. Subsistence farmers heavily rely on their agricultural production, making crop raiding by wildlife, such as primates, a serious threat to local food security. Additionally, the livelihood of local communities around protected areas mainly depends on agriculture, which is highly vulnerable to crop raiders [30, 31].

Similarly, various wild animals, including insect pests, small and large mammals, and birds, have been reported to raid crops in Ethiopia [18]. In southwestern Ethiopia, several large mammals such as olive baboons, bush pigs, giant forest hogs, vervet monkeys, porcupines, warthogs, colobus, and blue monkeys have been identified as significant crop raiders in both field crops and home gardens [6, 32]. However, the frequency and extent of crop raiding incidents may vary along a distance gradient from natural habitats into human-modified landscapes [5, 6]. Despite this variation, little is understood regarding the pattern and socio-economic impacts of crop raiding by wild primates in the biodiversity hotspots of Southern Ethiopia, including the Wolaita Damota Community Managed Areas. Therefore, our aim was to understand the pattern and extent of crop damage caused by primate species at different distances from forest edges surrounding the Damota Community Managed Areas. We hypothesized that the frequency of crop raiding by large wild primates and the corresponding magnitude of crop damage decrease with the distance from the forest edges and vary depending on the type of protection method employed in the crop fields. To achieve this, we aimed to determine the socio-economic impacts of crop raiding primates on farms located at four different distances (50m, 100m, 200m, and 300m) from the forest edges of the Damota Community Managed Areas. Subsequently, we quantified crop damage by primates in fields safeguarded with wire mesh, human guardians, scarecrows, thorny bushy maize fields, and in non-protected (open) maize fields. We also evaluated the efficacy of these preventive methods against primate crop raiding in the forest-agricultural landscape mosaic in Wolaita Damota Areas, Southern Ethiopia.

Materials and methods

Study area

The study was conducted in the Sodo Zuriya and Damot Gale districts, located approximately at 6.54°N 37.45°E through 6.9°N 37.75°E in the Highlands of Southern Ethiopia. The study sites included the Gurumu Woyde, Kokate Marachere, Konasa Pulasa, Damot Waja, and Dalbo Wogene sub-districts (Fig 1). The study area covers 380 km² and is primarily situated atop Mt. Damota. The Damota Community Managed Forest was established in January 2006 through collaboration between the Sodo community and World Vision Ethiopia. The aim was to restore and protect the montane high-forest on the slopes of Mount Damota. The land is collectively owned by five Sodo Zuriya and Damot Gale Communities, who secured the site and obtained land user-rights certificates from the Ethiopian Government in 2006. Furthermore, the Ethiopian government has supported the community's ownership of carbon rights trading, allowing them to earn revenue from carbon offsets. Additionally, cooperatives were established to manage the protected areas. According to the institute's assessment, the area also plays a role in global climate regulation [33]. This region experiences a dry period from October to March and a wet season from April to September, receiving 1450 to 1800 mm of rainfall, respectively [33]. The maximum rainfall occurs between June and September, with shorter rains falling in March and April [33]. The temperature ranges from 16°C to 24°C between the wet and dry seasons.

The Damota Community Managed Forest is characterized by rugged topography and diverse agro-ecology, fauna, and flora. The vegetation is marked by various types, including evergreen needle-leaved, deciduous needle-leaved, evergreen broadleaved, and deciduous broadleaved forests, mixed with shrubland, herbaceous vegetation, herbaceous wetland, moss and lichen, sparse/bare vegetation, and cropland [33]. Dominant plant species in this area include *Syzygium guineense* (woodland waterberry), *Juniperus procera* (African juniper), *Croton macrostachyus* (Broad-Leaved Croton), *Erica arborea* (briar root), *Olea europaea* (common olive), and *Acacia hockii* (Shittim Wood) [33]. The region is home to various large and medium-sized mammals, such as olive baboons (*Papio anubis*), grivet monkeys (*Chlorocebus aethiops*), duikers (*Sylvicapra grimmia*), common bushbucks (*Tragelaphus scriptus*), Guenther's dikdik (*Madoqua guentheri*), and porcupines (*Hystrix cristata*). Predators include golden jackals (*Canis aureus*), black-backed jackals (*Canis mesomelas*), leopards (*Panthera pardus*), African civets (*Civettictis *civetta*), and spotted hyenas (*Crocuta crocuta*) [33]. The entire area sustains a population of 16,342 people [34].

In Mount Damota, farmers typically possess very small plots of land. The range of landholding sizes spans from 0.06 to 1.75 hectares, with an average size of 0.5 hectares [35]. The Wolaita zone, characterized by a highland perennial farming system, supports a diverse array of crops [36]. According to [36], primary food crops in this region include maize, teff, various vegetables, and root and tuber species such as cassava, yam, potato, sweet potato, and taro. Additionally, tropical and temperate fruit tree crops like banana, avocado, mango, and apple are cultivated in the Wolaita Areas [36]. Maize fields in these areas tend to be quite small, often measuring around 10 x10 meters, and are interspersed with fields growing different crops. For the purposes of this study, maize fields were selected to assess the extent of damage caused by non-human primates.

Experimental setup

We set up our study using 25 maize fields. Ten maize study plots were situated 50 meters from the forest edge and were used to compare protective measures in the villages of Gurumu Woide and Kokate Marachare. The protected study plots were safeguarded using wire mesh, human guardians, scarecrows, and thorny bushes, while the non-protected fields remained open/control (Fig 2). Furthermore, we set up a total of fifteen non-protected maize study plots (Table 1), including Gurumu Woide, Kokate Marachare, Delbo Wogene, Damot Waja, and Konasa Pulasa. The study plots were located at varying distances: 100 meters, 200 meters, and 300 meters from the forest edge. The distances of each study plot farthest away from the forest edge were measured using the Garmin 72H GPS device. Distances from field edges to reference features or structures (e.g. trees, paths, or huts) were recorded to aid in distance estimation (Fig 3).

Each study field, we designated a study plot measuring 10m x 10m (Table 1). Within these study plots; we planted the high-yielding maize variety BH-546, well-suited for the region's agro-ecology. Maize seeds were sown early in the rainy season, typically in April, reaching the milky stage in late July and ripening by mid-August, with harvesting in September. Prior to sowing, oxen-drawn plows were used to prepare the fields by creating rows. Initially, 580 seeds were sown in each study plots in both the 2020 and 2021 maize cropping seasons. However, in one field (Field no. 25) seeds were removed or added by the farmer resulting in 532 seeds (19 rows x 28 seeds) during the 2020 maize cropping season and 627 seeds (19 rows x 33 seeds) during the 2021 maize cropping season. Each hole received one seed, with a planting distance of 40 cm x 30 cm, while maintaining a distance of at least 50 meter between one maize study plot and the next.

All cultivation practices, including fertilizer application, cultivation, and weeding, were carried out as usual. However, non-uniform germination of the sown maize seeds resulted in varying maize harvests across different plots. In this study, we collected data using (1) Field experts (2) Camera traps

Field experts

The data collection for Crop Foraging or Raiding Events (CFE/CRE) in primates was conducted by six field experts trained by researchers to ensure a thorough understanding of the subject. Each field expert monitored and assessed CFE/CRE incidents in both baboons and grivet monkeys. They actively participated in the project during two maize harvest seasons (from April to August in both 2020 and 2021). Additionally, these experts collaborated with twenty five local farmers during field observations and reporting. The overall data collection process was supervised by four researchers.

Researchers defined the primate crop foraging or crop raid event (CFE/CRE) to potential aspiring field experts as follows: *CFE /CRE is defined as when one or more individuals of a species entered (i.e. crossed a field boundary) and make trampling the field and left the field (CRE), and interacted with one or more maize stem and eat the stem (CFE). The CFE/CRE episode begins when the first primate enters the field; eat the stem and ends when the last primate leaves the farm. The duration is measured in seconds using a digital stopwatch. Primate age categories are adult (full species-sex-specific size), sub-adult (not fully grown, beyond infant development, exhibits independent behaviour frequently), or infant (developmentally small and dependent, carried frequently, maintains close proximity to adults).*

Field experts responded to the following questions: (1) What is the extent of primate damage to maize on protected and non-protected fields? (2) When and during which months do primates raid maize crops? (3) How long do primates typically stay during their maize raids? (4)

How frequently and at what times do farmers report primate incursions? (5) Which crop-feeding species have farmers reported encountering? (6) What is the extent of primate maize damage on fields located at a distance? (7) How many individual primates raided maize and entered fields? (8) In what proportion do multiple and single primate raid events occur? (9) How many individual primates typically visit maize fields? (10) In which age categories are maize crop-raiding primates typically found?

Data were also collected regarding the presence or absence of humans on fields, the nature of on-field human activity, the extent of guarding behavior, and responses to crop-raiding primates. Crop damage was determined by counting stems damaged by primates. Trained field experts assessed and counted the damage caused by primates to maize daily at 18:00 hours.

Camera traps

To gather information on the timing, frequency, and location of feeding behavior by olive baboons and grivet monkeys within the 25 study plots, we utilized Bushnell camera detection equipment (Browning trail camera Model No BTC-6HDX).

These motion-trigger cameras were configured to capture and store data, including the date, time, location, and temperature for each photo. The cameras were set to take only one photo per trigger, with a 2-second interval between triggers [37]. Cameras were securely housed and locked in metal cases. A potential CFE/CRE was recorded when one or more individuals olive baboons and grivet monkeys were merely present in the field [37]. An actual CFE was documented if the photo or video indicated physical manipulation and/or consumption of crop items [37, 38]. An interval of more than an hour between captured images was considered as an independent CFE [37]. During the course of this project, different camera traps were installed and dismantled on different days, resulting in varying numbers of trap days for each unit.

Cameras were installed on each study plot. We used 30mm x 30mm stainless steel wire mesh with a wire diameter of 1.6 mm and a height of 2.5 meters. For data storage, we utilized 16GB and 32GB Class 4 SDHC memory cards for each camera. Farmers monitored the camera traps to prevent theft. Data from the camera traps were collected from April to September in both 2020 and 2021, with cameras installed in each of the 25 maize fields for four consecutive trapping nights. We installed the cameras for 192 trapping days. During camera installation, we collected the following information: camera ID, GPS position, date, and altitude. Subsequently, we downloaded the photos and videos from the camera traps onto a laptop. We checked each photo/video for the presence of wildlife and other relevant information. We also investigated the presence of humans and dogs, among other factors. Photos containing baboons and monkeys that could damage the crop were numbered and placed in a digital folder. We cataloged all the saved photos/videos and associated information in a spreadsheet.

Data Analysis

We utilized SPSS Version 16 for Windows (SPSS Inc., Chicago, USA) to analyze the data. Tests were two-tailed, and results were deemed statistically significant when $p \leq 0.05$. The images captured by camera traps were interpreted to determine the frequency and timing of Crop Foraging/CRE Events (CFE/CRE). Descriptive statistics were employed to analyze crop feeding data. A chi-square test was conducted to examine the variation in maize damage by primates across different variables, including primate species raiding duration, multiple versus single raid events, primate CFE timing, and age-category of raiding in single or group. Median values were used to describe central tendency. For continuous variables, we conducted the Mann-Whitney U test, Spearman's Rank Correlation Coefficient, t-test, and F-test. Specifically, the Mann-Whitney U test compared primate CREs of raiding durations and different age categories of primate species on CREs. The Spearman correlation coefficient assessed the relationship between the number of individuals entering a field and the number at the forest edge prior to raiding. The independent sample t-test compared estimates of maize damage among variables such as the number of individuals raiding, Primate CREs, farm distance, duration of raiding, and crop phenology. The F-test compared estimates of maize damage between preventive and non-preventive strategies in the cropping seasons, as well as between single and multiple raids. The extent of primate assaults on maize in preventive and non-preventive maize fields during different crop phenological stages was analyzed using R (bplot function in the Rlab package) [39]. Similarly, linear mixed models were employed to analyze the different spatial-temporal variables. These models included fixed factors (distance, duration, and phenology) and random factors (Primate CREs, number of individuals raiding). The response variable was the rate of maize damage, and the analysis was conducted using R [39]. Maize damage was reported in three aspects: the average number of maize stems/cobs affected, the estimated amount of maize damaged in kilograms, and the proportion of maize damage caused by primates in relation to the expected harvest. To calculate monetary loss, we converted market prices for maize crop per kilogram to US dollars using the prevailing exchange rate at the time of the survey. Additionally, we estimated that the maize seeds in one maize stalk weighed approximately 0.2 kg after harvest.

Ethical statement

The study was approved by the institutional ethics committee, adhering to the established ethical guidelines of Wolaita Sodo University, under Reference No. WSU15/12/915. Subsequently, permission was obtained from the Wolaita Zone Agriculture, Environment, Forest, and Climate Change Regulatory Office, as well as the respective district authorities. Verbal consent was obtained from each study participant. All social data of the study participants were kept confidential and anonymized before analysis.

Result

Farmers-reported crop feeding or raiding species

All farmers consistently reported that baboons, porcupines, and grivet monkeys were the primary culprits responsible for the most severe crop damage to maize, and these species exhibited a high frequency of Crop Foraging/CRE Events (CFE/CRE). Additionally, some farmers (N = 10) suggested that bushbuck might also be involved in crop feeding or raiding. However, the reported CFE/CRE frequency of bushbuck in crop fields was notably low, occurring only 24 times (Table 2).

Farmer-reported maize damage assessments

The average percentage of maize cobs lost by olive baboons in wire mesh, human guard, scarecrow, and thorny bush setups was 8.23% (equivalent to 72.8 maize stems/cobs), 7.38% (65.3 maize stems/cobs), 9.82% (86.8 maize stems/cobs), and 9.45% (83.5 maize stems/cobs), respectively. These fields were located 50 meters from the forest edge. In non-protected fields, the average percentage of maize cobs lost by olive baboons were 10.04% (88.8 maize stems/cobs), 1.53% (13.5 maize stems/cobs), 0.4% (3.6 maize stems/cobs), and 0.1% (0.9 maize stems/cobs) located at 50 meters, 100 meters, 200 meters, and 300 meters from the forest edge, respectively (Table 3).

The average percentage of maize cobs lost by grivet monkeys in wire mesh, human guard, scarecrow, and thorny bush setups were 0, 1.83% (6.3 maize stems/cobs), 3.8% (13 maize stems/cobs), and 2.63% (9 maize stems/cobs), respectively. These fields were located 50 meters from the forest edge. In non-protected fields, the average percentage of maize cobs lost by grivet monkeys were 4.38% (15 maize stems/cobs), 11.65% (39.9 maize stems/cobs), 3.3% (11.3 maize stems/cobs), and 0, located at 50 meters, 100 meters, 200 meters, and 300 meters from the forest edge, respectively (Table 3).

In total, the average percentage of maize cobs lost by these two primate species in the protected fields was 43.14% (equivalent to 336.7 maize stems), located at 50 meters from the forest edge. The average percentage of maize cobs lost by primates in the non-protected fields was 14.42% (103.8 maize stems), 13.18% (53.4 maize stems), 3.7% (14.9 maize stems), and

0.1% (0.9 maize stems) located at 50 meters, 100 meters, 200 meters, and 300 meters, respectively.

Camera trap results

Our cameras recorded 47 photographs of baboons and 21 photographs of grivet monkeys, as summarized in Table 3. Of the 47 photographs of baboons, only 3 were confirmed as actual (CFE), while the remaining 44 were potential (CRE). Similarly, out of the 21 photographs of grivet monkeys, only 2 were confirmed as actual (CFE), with the remaining 19 being potential (CRE). Notably, the longest CRE event, recorded by camera ID A3 and E1, occurred in scarecrow and open maize fields (Table 4, Fig 4).

Farmers-reported extent of primate crop damage on protected and open/control fields

The average percentage of maize damaged by Olive baboons in both Gurumu Woide and Kokate Marachare study sites, as reported by farmers, was 23.62% in wire mesh, 21.03% with a human guard, 28.15% with a scarecrow, and 27.2% in thorny bush fields, respectively (Fig 5). The results of a one-way ANOVA indicated that the amount of damage in maize fields was significantly higher in thorny bush fields compared to the levels of damage from wire mesh, a human guard, and a scarecrow ($F=292.5$, $df=11$, $p < .001$, Fig 5).

The average percentage of maize damaged by grivet monkeys in the Kokate Marachare study site, as reported by farmers, was 0% in wire mesh, 24.14% with a human guard, 44.83% with a scarecrow, and 31.03% in thorny bush fields, respectively (Fig 6).The results of a one-way ANOVA indicated that the amount of damage in maize fields was significantly higher in thorny bush fields compared to the levels of damage from wire mesh, human guards, and scarecrows ($F=5.4$, $df=11$, $p < .005$, Fig 6).

Time or months of maize raided

According to farmers' responses, a higher frequency of maize cobs being plucked was reported in July, with 524 ± 3.8 maize cobs in the year 2020 and 539 ± 4.6 maize cobs in the year 2021. Moderate frequencies of maize raiding were reported in June and August, with 216 ± 4.6 and 64 ± 2.1 maize cobs in 2020, and 240 ± 5.2 and 25 ± 1.6 maize cobs in 2021, respectively. The lowest frequencies of maize raiding occurred in April, May, and September for both 2020 and 2021 (Fig 7).

Duration of crop-raiding events

The average raid duration ranged from 15.1 to 18 minutes, with a standard deviation of 0.66. There was significant difference in raid duration between species, as indicated by the Kruskal-Wallis test ($\chi^2 = 58.62$, df = 10, $P < 0.05$). Raid durations were significantly shorter when carried out by single individuals (median 1 minute, SD = 0.42) compared to raids by two or more individuals (median 3 minutes, SD = 2.42), as confirmed by the Mann-Whitney U test (n (single) = n (two+) = 38, U = 34.0, $p < 0.001$). The majority of Crop Raiding Events (CREs), approximately 70%, lasted between 0.1 and 12 minutes (Fig 8)

Farmers-reported CFE frequency and timing

Farmers observed that baboons typically fed on crops early in the morning, while grivet monkeys fed on crops throughout the day. According to farmers, neither baboons nor grivet monkeys were seen eating on crops at night. Baboon Crop Foraging Events (CFEs) occurred throughout the day but not in a uniform distribution, as revealed by photographic data from five locations (Chi-square goodness of fit: $\chi^2 = 32.36$, df = 12, $p < 0.001$). Similarly, Grivet monkey CFEs occurred throughout the day, also with a non-uniform distribution, based on photographic data from five locations (Chi-square goodness of fit: $\chi^2 = 35.86$, df = 8, $p < 0.001$). Morning CFEs were more common in baboons (6:00–7:00 a.m.) than afternoon CFEs (2:00–3:30 p.m.). In contrast, CFEs were more common in the early afternoon (11:00 a.m.–12:00 p.m.) for grivet monkeys than in the morning (6:00–7:00 a.m.) during both 2020 and 2021 years. Farmers reported no baboon CFEs in all five locations between 11:00 a.m. and 6:00 p.m. during both 2020 and 2021 years (Fig 9).

Determinants of maize damage by primates

In this study, the spatial-temporal variables affecting the incidences of maize damage by primates were analyzed using a linear mixed model. The model indicated that farms located 200 meters from the forest edge experienced significantly fewer maize raiding incidences compared to farms located 50 meters from the forest edge ($t = -2.728$, DF = 256.9, $P < 0.006$). The duration of maize raiding incidences was significantly longer, lasting 6.1-9 minutes, compared to durations of 0.1-3 minutes ($t = -1.993$, $DF = 182.9$, $P < 0.04$). Similarly, maize raiding incidences were significantly higher at both the fruiting stage ($t = -11.656$, $DF = 98.9$, $P < 2e-16$) and the maturity stage ($t = -13.53$, $DF = 176.05$, $P < 2e-16$) compared to the seedling stage (Table 5).

Primate crop raiding events

A total of 367 primates were observed at the forest edges immediately before or during Crop Raiding Events (CREs). Out of these, 367 individuals, accounting for 75%, ventured into fields (Table 6). This included all 75 CREs by Anubis baboons (79%) and 20 CREs by grivet monkeys (21%). Notably, Anubis baboons were significantly more likely to be found near the forest edge than grivet monkeys, as indicated by the Kruskal-Wallis test ($\chi^2 = 263.1$, $df = 15$, $p < 0.001$). The number of individuals entering a field showed a positive correlation with the number at the forest edge prior to raiding, which was confirmed by the Spearman's Rank Correlation Coefficient ($rs = 0.434$, $n = 95$, $p = 0.006$). This correlation persisted even when humans were present on the field, with a Spearman's Rank Correlation Coefficient of $rs = 0.324$, $n = 59$, and $p = 0.04$. Regarding the composition of CREs, the majority (36.1%) involved three or fewer individuals, while 47.8% consisted of a single individual or a pair. Only 16.1% of CREs involved more than five individuals (Fig 10). It's worth noting that baboons raided in significantly larger groups than other species, as shown by the Kruskal-Wallis test ($\chi^2 = 41.57$, $df = 5$, $p < 0.001$); however, most baboon raiding groups were small, with 78% comprising fewer than five individuals. On the other hand, grivet monkeys were more likely to raid alone, according to the Kruskal-Wallis test ($\chi^2 = 88.01$, $df = 5$, $p < 0.001$).

Multiple versus Single raid events

A significantly greater proportion of raids (64%; n = 61) occurred in groups rather than as single raids, as confirmed by the Chi-square test ($\chi^2 = 15.9$, $df = 4$, $p = 0.003$). Among the group raids, 67% consisted of either 2-CRE or 3-CRE groupings, indicating a diverse pattern of multiple-CRE profiles for both grivet monkeys and baboons (Fig 11). On the other hand, single raids accounted for 36% (n = 34) and were more likely to involve a single raiding individual. It's worth noting that the extent of maize crop damage per CRE differed significantly between single raids and group raids, as evidenced by the F-test ($F = 22.17$, $df = 1$, $p < 0.001$).

Primate field visit and crop raiding events

Seventy-five percent of primate field visits (comprising 22.3% baboons and 26.1% grivets) did not involve crop raiding at all, as illustrated in Fig 13. Among the visits that did include crop raiding, it was observed that 76% more baboon visits involved multiple crop-raiding events rather than a single event. In the case of grivets, 53% more visits involved multiple events, as confirmed by the Chi-square test (baboon - $\chi^2_1 = 11.63$, $df = 1$, $p < 0.001$; Grivet - $\chi^2_1 = 16.00$, $df = 1$, $p < 0.001$; Fig 12 & Fig 13).

Age categories composition of crop-raiding primates

Significantly more adults were observed on study plots during CREs compared to sub-adults, and more sub-adults were observed than infants. These differences were statistically significant (Mann-Whitney U tests: n (sub-adult) = 118, n (adult) = 216, U = 1653.5, $p < 0.001$; n (infant) = 33, n (sub-adult) = 118, U = 952.0, $p = 0.510$). This age category distribution was consistent for each primate species, as confirmed by a Chi-square test ($\chi^2 = 71.4$, $df = 1$, $p < 0.001$) (Table 7). Nearly 58% (n = 55) of raiders were single adults, and the majority of adults were present in 42% of CREs involving multiple individuals (n = 40). Baboons exhibited mixed age-category raiding groups significantly more frequently than grivet monkeys (Kruskal-Wallis test, $\chi^2 = 58.05$, $df = 5$, $p < 0.001$), and baboon raiding groups were more diverse (Kruskal-Wallis test, $\chi^2 = 10.88$, $df = 4$, $p = 0.028$). At least one infant was observed during six baboon raids. Most baboon and grivet raiders were accompanied by an adult during their raids. Almost two-thirds of baboon raiding groups included one or more sub-adults. All on-field adult and sub-adult primates damaged at least one crop stem. While infants occasionally interacted with crops by pulling or biting stems, they often traveled or rested near an adult female or engaged in play behavior with other infants or sub-adults, suggesting they were not anxious during CREs. Female primates with infants were particularly vigilant on fields; they were usually the first to return to the forest while carrying their infants and the first to flee in response to human actions. The sex of raiding individuals was not reliably determined for analysis; however, counts of male (n = 38) and female (n = 14) adult baboons on-field during CREs did not significantly differ ($\chi^2 = 29.45$, $df = 1$, $p < 0.001$). While significantly more maize stems were damaged by mixed-age groups than by adults-only groups, the former groups also comprised more individuals, traveled further onto fields, and raided for longer durations. These findings were supported by Mann-Whitney U tests (n (adults) = 10.0, n (mixed) = 36: stems U = 2840.5, $p = 0.021$; individuals U = 20.5, $p = 0.367$; maximum distance U = 24.5, $p = 1.000$; median distance U = 429.0, $p = 1.000$; duration U = 528.5, $p < 0.001$).

Discussion

Numerous primate species have been involved in crop raids, as documented in various studies [30, 40-44]. In this study, the average maize yield losses attributed to nonhuman primate damage were estimated at 340.8 kg per hectare. A study by [3] noted an average maize yield loss of 264.1 kg per hectare due to pests (baboons and pigs), representing 34.2% of the anticipated total yield. In the Budungo Forest Reserves of Uganda, a study by [9] reported that farmers observed 73% of crop damage caused by primates. Similarly, in another study [31] conducted in the Taita Hills of Kenya, characterized by a forest-agricultural mosaic landscape, farmers reported that 87% of the maize crop was attacked by primates.

In this study, the linear mixed model provides a parameter estimate of maize crop loss during primate Conflict-Raiding Events (CREs), incorporating spatio-temporal patterns relevant to maize raided by primate species. This is supported by reference [58], indicating that the fitted linear model is a good predictor for estimating the total number of crop loss events by wildlife. Conversely, in the study referenced [30], multiple regression models yield an improved estimate of maize crop loss during primate CREs by focusing on crop prevalence; maize was most frequently raided by olive baboons and vervet monkeys. Similarly, as stated in reference [30], the maize model maintains broad applicability while capturing a significant proportion of local stem damage. Considering that primate raiding behavior is often context-dependent [10], it is unlikely that CRE parameters contribute equally to maize crop loss during a raid [30].

Our study demonstrates the value of strategically positioned camera traps in providing insights into various aspects, including recording primate species, their targeted crop types and growth phases, daily and seasonal patterns of crop-feeding activity, and whether crop-feeding occurs individually or in groups [37]. Our identifications were likely biased toward more conspicuous individuals, primarily adult males [37]. Additionally, while camera traps may capture evidence of primate groups' presence in fields, they may not consistently provide photographic evidence of actual crop manipulation and consumption, as supported by reference [37]. Therefore, many events identified as Crop Foraging Events (CFEs) through camera traps may not indeed are actual CFEs.

To assess the severity of crop damage caused by primate feeding, we supplemented our research with additional methods, including farmers' reports. These reports helped monitor baboon and grivet monkey behavior, estimate daily maize damage, and assess post-harvest damage, as supported by references [12, 47].

The behavior of primates in the study area was influenced by their habits and foraging, with baboons on rocky cliffs and caves and grivet monkeys in large trees within the forest. Based on our field observation, Gurumu Woide has high forest fruit availability and an abundance of steep cliffs and caves suitable for the existence of a baboon troop. In contrast, Kokate, Konasa, Delbo, and Waja have lower forest fruit availability and fewer steep cliffs and caves for baboon survival. This may explain the reduced maize damage by baboons in these study sites. In this study, the distance traveled by both baboons and grivet monkeys to inspect and raid crops did not vary, as both species traveled up to 300 meters. During our observations in the caves, we found that baboons were located at far distances, approximately 400 meters from the first farmer fields.

Baboons raided the crops that are available close to the forest edge. Primates predominantly raided crops within 10 meters of the farm-forest edges [42, 48, 49]. However, baboons still visited farms located 300 meters from the forest edge, even though maize crop feeding events were infrequent at this distance. In Uganda, grivet monkeys ventured up to 55 meters into crop fields, while baboons reached up to 110 meters [50]. The highest distance observed was over 700 meters, notably in the Ngangao Forest in the Taita Hills, Kenya [31]. This variation may be influenced by the distribution of households and the number of farms investigated at different distances [31].

In this study, maize raids by primates were reported during the maturation of maize cobs. Our findings suggest that scarecrows and thorn bushes were generally ineffective in deterring the return of baboons or grivet monkeys to the fields. Our wire mesh (wire diameter of 1.6 mm and a mesh size of 30 mm x 30 mm, and a height of 2.5 meters) protection method reduced maize damage, but it did not deter baboons from raiding the crop, and they quickly habituated. Kokate

Marachare is one of our experimental study sites; in this site, the wire mesh fence was effective in discouraging olive baboons and grivet monkeys from attacking maize crops in fields located 50 meters from the forest's edge, but it was not effective in discouraging olive baboons in Gurumu Woide. We hypothesize that the presence of multiple baboons in the Gurumu Woide study site made them highly vigilant and determined to raid maize crops despite the crop fenced with wire mesh fences. In contrast, in Kokate Marachare, where only a single baboon was involved, hence the wire mesh fence most likely deterred them from crop raiding. According to a paper by [46], the net wire fences exhibited limited effectiveness against primate raiding in Budongo Forest Reserve, Uganda. Indeed, field guards were often absent due to other (social) activities, school attendance, etc. However, a study conducted by [3] found that continuous guarding is a principal strategy for effectively mitigating crop damage by pests. The extended protection duration was particularly necessary in villages at higher altitudes where maize takes longer to mature [3].

Both baboons and grivet monkeys are frequently observed foraging for crops in human-dominated settings in the study area, with baboons causing more damage than grivet monkeys. The time of day had differing effects on the crop-foraging patterns of the two species, with baboons foraging more frequently in the morning and grivet monkeys in the afternoon. This variation in the time of activity might be related to the presence of baboons, which appeared to deter grivet crop-foraging behavior [45]. Similarly, the time activity pattern varied in different areas; reference [51] recorded a peak in baboon crop foraging in Zimbabwe between 8 and 10 am, potentially driven by the need to find food upon waking. In contrast, a reference [10] found that primates in Uganda foraged on crops more frequently between noon and sunset than between sunrise and noon.

To access crops, baboons were observed using a 'sit and wait' strategy near the edge of crop fields [52]. The more time baboons and grivet monkeys spent close to the fields, the more likely they were to forage within crops. Furthermore, when they entered crops during these visits, they were more likely to enter multiple times. Crop raiding wasn't a behavior practiced by all members of primate social groups, with baboon raiding parties averaging five individuals [42]. In our study, more adults were observed on maize fields during CREs compared to sub-adults. This varies in different areas; in some studies, adult primates were the main crop raiders, as referenced in [42-45], while in other studies, sub-adults were identified as the primary raiders, as cited in [53-56]. However, this behavior was rare and observed only in baboons. Additionally, perceptions of risk may impact the age composition of primate raiding groups, with adult females with infants raiding the least frequently, likely due to increased caution, as suggested by [44, 57]. However, the diverse raiding group compositions among baboons, the presence of infants on fields, and high rates of raiding by baboons suggested that they were generally more comfortable on fields than other primate species.

Conclusion

The current significant crop losses underscore the necessity for continuous vigilance in maize fields, from sowing to harvest, to deter wild primate pests. The parameters of CRE (Crop Raiding Events) can serve as quantifiable standards for assessing the behavioral impact of techniques aimed at deterring primate crop raiding. Wire mesh fencing was found to have limited effectiveness in deterring baboons and grivet monkeys. Although guarding is assumed to be an efficient protective strategy, our study revealed its ineffectiveness when implementation lacks continuity. Thus, there was no completely effective method for preventing primates from crop raiding during this study. The linear mixed model was a relevant choice for analyzing the extent of maize damage by primates across various spatio-temporal factors. In general, understanding the spatio-temporal patterns of wildlife-induced crop deprivation and evaluating the key parameters related to CRE are crucial steps in mitigating the socio-economic impacts of primate pests originating from forest edges.

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Fig 1. Location map of the study area (created with ESRI ArcGIS Desktop 10.8)

Fig 2. Various prevention strategies (Wire mesh (A), Human guardian tower (B), Scarecrow (C), Thorny bush (D)) were assessed in eight experimental maize field sites to evaluate their effectiveness in deterring crop raiders. The study was conducted in maize field sites located in Gurumu Woide and Kokate Marachare (Photo credit: Yigrem Deneke).

Fig 3. Diagrammatic example of a field map used by observers. HSE = house. GH = guard hut. SH = storage hut. Solid black lines = field boundary. Green objects = trees.

Fig 4. The images above depict camera trap captures of various wildlife species observed in maize field sites located in Damota Mountain, Southern Ethiopia: (A) Anubis baboons (*Papio anubis*) (B) Grivet monkeys (*Chlorocebus aethiops*), (C) Porcupine (*Hystrix cristata*), and (D) Bushbuck (*Tragelaphus scriptus*)

Fig 5. The average of maize stems (≈number of cobs) damaged within 10m x 10m study plots by Olive baboons was examined in relation to various preventive methods at a distance of 50 meters from the forest edge during the 2020 and 2021 maize cropping seasons and crop phenology in the Gurumu Woide and Kokate Marachare (GW) sub-district. The boxplot illustrates a significant difference in crop damage among different prevention methods ($p < .001$).

Fig 6. The average of maize stems (≈the number of cobs) damaged within 10m x 10m study plots by grivet monkeys illustrates the relationship with various prevention methods at a distance of 50 meters from the forest edge during the 2020 and 2021 maize cropping seasons and crop phenology in the Kokate Marachare (KM) sub-district. The boxplot shows a significant difference in crop damage with different prevention methods ($p < .005$).

Fig 7. The frequency of primate maize crop raided during the 2020 and 2021 maize cropping seasons ($n = 95$)

Fig 8. Relative frequency of raid durations by primate CREs ($n = 95$).

Fig 9. The frequency of baboon and grivet monkey CFEs by time of day ($N = 95$) between April to September 2020 and 2021 years.

Fig 10. Relative frequency of raiding by primate CREs ($n = 95$)

Fig 11. The frequency distribution of CREs that were single raids or within a series of multiple-CREs for each of these two primate species ($n = 95$)

Fig 12. The number of baboon and grivet monkey field visits that did and did not involve crop-raiding events (CRE) on maize fields in the Highlands of Damota Mountain, April to September 2020 and 2021 years ($n=367$)

Fig 13. The number of baboon and grivet monkey field visits that involved single- and multi-crop raiding events on maize fields in the Highlands of Damota Mountain, April to September 2020 and 2021 years ($n=189$).

Table 1. Maize field and study plot size on the protective and non-protective maize fields

Study sites	Field number	Maize field size in hectare	Study plot size (10x10m)	Distance to forest edge	Preventive and non-preventive measures
Gurumu Woide	1	0.01	0.01	50m	Wire mesh
	2	0.06	0.01	50m	Human guard
	3	0.1	0.01	50m	Scarecrow
	4	0.1	0.01	50m	Thorny bushy
	5	0.1	0.01	50m	Open/control
	6	0.2	0.01	100m	Open
	7	0.3	0.01	200m	Open
	8	0.3	0.01	300m	Open
Kokate Marachare	9	0.2	0.01	50m	Wire mesh
	10	0.2	0.01	50m	Scarecrow
	11	0.2	0.01	50m	Thorny bushy
	12	0.2	0.01	50m	Open/control
	13	0.2	0.01	50m	Human guard
	14	0.3	0.01	100m	Open
	15	0.3	0.01	200m	Open
	16	0.3	0.01	300m	Open
Delbo Wogene	17	0.2	0.01	100m	Open
	18	0.2	0.01	200m	Open
	19	0.3	0.01	300m	Open
Damot Waja	20	0.06	0.01	100m	Open
	21	0.3	0.01	200m	Open
	22	0.3	0.01	300m	Open
Konasa Pulasa	23	0.01	0.01	100m	Open
	24	0.3	0.01	200m	Open
	25	0.3	0.01	300m	Open

Table 2. The comparison of farmer response frequency and CFE/CRE frequency of crop feeding/raiding species from April to September 2020 and 2021 years

Pest species	Number of farmers reporting the species	Frequency of CFE/CRE
Baboon (*Papio anubis*)	22	80
Grivet monkey (*Chlorocebus aethiops)*	17	45
Porcupine (*Hystrix cristata*)	25	75
Common bushbuck (*Tragelaphus scriptus*)	10	24

Table 3. Farmer observation and reported of maize damage assessments (580 maize stem expected per plot except field no. 25 (see the text)

Study sites	Field number	Distance to forest	measures	Olive baboons						Grivet monkeys					
				Maize cobs loss		% damaged		Av. damaged	Av.%	Maize cobs loss		% damaged		Av. damaged	Av. %
				2020	**2021**	**2020**	**2021**	**2020/21**	**2020/21**	**2020**	**2021**	**2020**	**2021**	**2020/21**	**2020/21**
Gurumu Woide	1	50m	Wire mesh	145	146	16.57	16.35	145.5	16.46	0	0	0	0	0	0
	2	50m	guard	127	128	14.51	14.33	127.5	14.42	0	0	0	0	0	0
	3	50m	Scarecrow	165	167	18.86	18.7	166	18.78	0	0	0	0	0	0
	4	50m	Thorny	160	161	18.29	18.03	160.5	18.16	0	0	0	0	0	0
	5	50m	Open/control	164	168	18.74	18.81	166	18.78	0	0	0	0	0	0
	6	100m	Open	48	54	5.48	6.05	51	5.77	0	0	0	0	0	0
	7	200m	Open	16	13	1.83	1.46	14.5	1.64	0	0	0	0	0	0
	8	300m	Open	4	5	0.46	0.56	4.5	0.51	0	0	0	0	0	0
Kokate Marachare	9	50m	Wire mesh	0	0	0	0	0	0	0	0	0	0	0	0
	10	50m	guard	4	2	0.46	0.22	3	0.34	12	13	3.56	3.74	12.5	3.65
	11	50m	Scarecrow	7	8	0.8	0.9	7.5	0.85	25	27	7.42	7.76	26	7.59
	12	50m	Thorny	6	7	0.69	0.78	6.5	0.74	17	19	5.04	5.46	18	5.26
	13	50m	Open/control	11	12	1.26	1.34	11.5	1.3	29	31	8.61	8.91	30	8.76
	14	100m	Open	15	18	1.71	2.02	16.5	1.86	11	12	3.26	3.44	11.5	3.36
	15	200m	Open	3	4	0.34	0.45	3.5	0.39	2	5	0.59	1.43	3.5	1.02
	16	300m	Open	0	0	0	0	0	0	0	0	0	0	0	0
Delbo Wogene	17	100m	Open	0	0	0	0	0	0	30	28	8.9	8.04	29	8.47
	18	200m	Open	0	0	0	0	0	0	9	12	2.67	3.44	10.5	3.07
	19	300m	Open	0	0	0	0	0	0	0	0	0	0	0	0
Damot Waja	20	100m	Open	0	0	0	0	0	0	40	42	11.9	12.1	41	11.97
	21	200m	Open	0	0	0	0	0	0	10	10	2.97	2.87	10	2.92
	22	300m	Open	0	0	0	0	0	0	0	0	0	0	0	0
Konasa Pulasa	23	100m	Open	0	0	0	0	0	0	117	119	34.7	34.19	118	34.45
	24	200m	Open	0	0	0	0	0	0	35	30	10.4	8.62	32.5	9.48
	25	300m	Open	0	0	0	0	0	0	0	0	0	0	0	0
Total				**875**	**893**	**100**	**100**	**884**	**100**	**337**	**348**	**100**	**100**	**342.5**	**100**

Table 4. Image data of olive baboon and grivet monkeys by camera traps of twenty five maize fields during 2020 and 2021

Study sites	**Camera ID**	**Distance to forest edge**	**Preventive and Non-preventive measures**	**Olive baboon**		**Grivet monkey**	
				CRE	**CFE**	**CRE**	**CFE**
Gurumu Woide	A1	50m	Wire mesh	4	0	0	0
	A2	50m	Human guard	10	0	0	0
	A3	50m	Scarecrow	12	3	0	0
	A4	50m	Thorny bushy	6	0	0	0
	A5	50m	Open/control	9	0	0	0
	A6	100m	Open	3	0	0	0
	A7	200m	Open	0	0	0	0
	A8	300m	Open	0	0	0	0
Kokate Marachare	B1	50m	Wire mesh	0	0	0	0
	B2	50m	Scarecrow	0	0	1	0
	B3	50m	Thorny bush	0	0	1	0
	B4	50m	Open/control	0	0	1	0
	B5	50m	Human guard	0	0	0	0
	B6	100m	Open	0	0	1	0
	B7	200m	Open	0	0	0	0
	B8	300m	Open	0	0	0	0
Delbo Wogene	C1	100m	Open	0	0	1	0
	C2	200m	Open	0	0	0	0
	C3	300m	Open	0	0	0	0
Damot Waja	D1	100m	Open	0	0	1	0
	D2	200m	Open	0	0	0	0
	D3	300m	Open	0	0	0	0
Konasa Pulasa	E1	100m	Open	0	0	11	2
	E2	200m	Open	0	0	2	0
	E3	300m	Open	0	0	0	0
Total				**44**	**3**	**19**	**2**

Table 5. A linear mixed model (LMM) was used to analyze maize damage by primates during crop raiding events (CREs) (n = 95).

	Estimate	**Std. Error**	**DF**	**t value**	**Pr(>|t|)**
(Intercept)	66.646	4.424	30.611	15.064	1.06e-15 ***
distance_farm100m	-1.848	2.004	256.286	-0.922	0.35731
distance_farm200m	-10.088	3.698	256.976	-2.728	0.00681 **
distance_farm300m	-6.388	4.196	257.913	-1.523	0.12910
duration of_raiding3.1-6 minute	-3.276	2.312	257.931	-1.417	0.15775
duration of_raiding6.1-9 minute	-6.466	3.244	182.907	-1.993	0.04774 *
duration of_raiding9.1-12 minute	-3.517	4.119	217.458	-0.854	0.39417
duration of_raiding12.1-15 minute	-7.025	5.300	147.578	-1.325	0.18710
duration of_raiding15.1-18 minute	-9.031	5.434	218.392	-1.662	0.09794.
duration of_raiding18.1-21 minute	-6.752	6.370	232.020	-1.060	0.29026
duration of_raiding21.1-24 minute	-8.664	6.813	248.224	-1.272	0.20470
duration of_raiding24.1-27 minute	-11.756	7.637	245.037	-1.539	0.12500
duration of_raiding27.1-30 minute	-11.639	8.685	228.281	-1.340	0.18153
duration of_raiding>30 minute	-8.555	10.282	227.031	-0.832	0.40627
crop_phenology_fruiting	-46.620	3.999	98.983	-11.656	< 2e-16 ***
crop_phenology_maturity	-55.256	4.084	176.050	-13.530	< 2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 6. The proportion of the total number of on-field primates during CREs (n = 367) that were adults, sub-adults, or infants.

	Total number of individuals on fields			
	Adults	Sub-adults	Infants	Total
Anubis baboon	151 (57.6%)	78 (29.8%)	33 (12.6%)	262
Grivet monkey	65 (61.9%)	40 (38.1%)	0 (0%)	105
Total	216	118	33	367

Table 7. Age-category composition of primate raiding groups during CREs (n = 95).

	Composition of crop-raiding group			
	Adults only	Adults and sub-adults	Adults and infants	Adults, sub-adults, infants
Species	% CREs	% CREs	% CREs	% CREs
Anubis baboon	36	45	4.4	14.6
Grivet monkey	68	32	0.0	0.0

S1 table 1. Camera traps recorded the Crop Raiding Events (CRE) and Crop Feeding Events (CFE) of olive baboons and grivet monkeys among twenty-five selected maize fields. Each field comprised study plots measuring 10x10 meters, observed during the maize cropping seasons of 2020 and 2021.

S2 file. The rate of maize damage by olive baboons in different crop phonological stages was analyzed in both protected and open/control fields using R code.

S3 file. The rate of maize damage by grivet monkeys in different crop phenological stages was analyzed in both protected and open/control fields using R code.

S4 table 2. A linear mixed model of the maize damage rate by primates, considering different spatio-temporal variables, was analyzed using R code.

Title: Patterns of Primates Crop Raiding and the impacts on incomes of Smallholders across Mosaic agricultural Landscape of Wolaita Zone, Southern Ethiopia

Manuscript Number: PONE-D-23-43746-R3

Response to Reviewers

We are great full to the editors and reviewers for their insightful and valuable comments on our paper. We have carefully considered the comments and tried our best to address every one of them. We hope the manuscript after careful revisions meet your higher standard journal. The authors welcome further constructive comments if any. We provided the point by point responses. All modifications in the manuscript have been highlighted in yellow color.

Sincerely,

Yigrem Deneke

Journal Requirements:

Please review your reference list to ensure that it is complete and correct. If you have cited papers that have been retracted, please include the rationale for doing so in the manuscript text, or remove these references and replace them with relevant current references. Any changes to the reference list should be mentioned in the rebuttal letter that accompanies your revised manuscript. If you need to cite a retracted article, indicate the article's retracted status in the References list and also include a citation and full reference for the retraction notice.

Response

The following reference was removed from the manuscript in the first-round revision (R1):

- The linear regression model results are reported as R^2 values (proportion of variance accounted for), beta values (contribution to the model), t statistics (statistical significance of the contribution), and regression equations (the combination of variables best accounting for observed outcomes) (Sokal RR & Rohlf FJ, 1995). This was removed from the data analysis because the linear model only analyzes data with fixed factors. In contrast, the linear mixed model analyzes data with both fixed and random factors, along with the response variables.

The following nine references were added to the manuscript in the second-round revision (R2):

- Hill, CM, Webber, AD, 2010; Hockings, KJ, Sousa, C, 2013; Freed, BZ, 2012; McGuinness, S, Taylor, D, 2014; Findlay, LJ, 2016; Gillingham, S, Lee, PC, 2003; Aharikundira, M, Tweheyo, M, 2011; Ango, TG, Börjeson, L, Senbeta, F, Hylander, K, 2014; Fang L, Hong, Y, Zhou Z, Chen, W, 2021. This is added to the manuscript because it includes important additional background information for this study.

The following reference was removed from the manuscript in the second & third-round revision (R2 &R3):

- R core team. R, 2020. This reference was removed because the data were only analyzed using SPSS in the manuscript.

The following reference was added to the manuscript in the third round revision (R4):

- R core team. R, 2024. I used the latest version of the R program because it is robust for analyzing various datasets. This reference is now included to highlight the effectiveness and reliability of R in handling the spatio-temporal datasets.

- ❖ I have replaced Table 5 and text, Figure 5, and Figure 6, which were analyzed using SPSS, with new versions that can be analyzed using the R program.
- ❖ I have included the number of field experts and local farmers participated in this study
- ❖ I have included a relevant remarks in the conclusion section
- ❖ I have included the following supporting documents in the manuscript (R3):
  - ✓ S2 file. The rate of maize damage by olive baboons in different crop phonological stages was analyzed in both protected and open/control fields using R code.
  - ✓ S3 file. The rate of maize damage by grivet monkeys in different crop phenological stages was analyzed in both protected and open/control fields using R code.
  - ✓ S4 table 2. A linear mixed model of the maize damage rate by primates, considering different spatio-temporal variables, was analyzed using R code.

Response to Reviewer 1

Reviewer #1: Thank you once again for inviting me to review furthers this manuscript. It is clear that the study is interesting and has some novelty. However, I think the authors need strong support for the statistical analysis part. With my previous comments, I was trying to encourage them to analyze their data in a robust way using LMM with the inclusion of random factors using R program instead of SPSS. The authors are stating that they used SPSS to do so and they even took out the R now from their data analysis section with this version. Still how they used the different statistical tools for the analysis is crude and not explicitly described. If the authors are willing to improve their manuscript by including these comments, I think the manuscript may be accepted for the publication without further review process.

Response: Thank you very much for the comments. I included the analysis done with R, running the analysis using LMM to account for both fixed and random factors and response variables. This analysis is clearly indicated in the supporting documents. The different statistical tools used for the analysis are also explicitly described in the data analysis section.

Reviewer #2: You corrected all the comments and suggestions that I gave you in the second round. Hence, I suggest to the editor that it be published in the journal.
Good luck.

Response: Thank you very much.