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Human-elephant conflict in the African rainforest landscape: crop-raiding situations and damage mitigation strategies in rural Gabon

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While the conservation of forest elephants is a global concern, human-elephant conflict (HEC), especially crop-raiding by elephants, is a serious threat to both human livelihoods and conservation efforts. However, only a few studies have explored elephant crop-raiding and related damage mitigation strategies in Central Africa's forest landscapes, which are characterized by low human and high animal densities and shifting cultivation practices. This study investigates HEC in rural Gabon, where human activities are limited, and local livelihoods are severely threatened by crop-raiding elephants. Through long-term ethnographic research and an in-depth analysis of damage mitigation practices by local people, the study unveils serious crop-raiding by elephants, leading to a significant change in the local lifestyle. Most households spend the majority of days in the field protecting crops, resulting in the village becoming almost empty. In addition to the physical burden of staying in poor living conditions, there is a considerable psychological burden for local people. Establishing effective elephant conservation systems requires understanding each local situation and evaluating the various costs to local people. To sustain livelihoods and address the challenge of HEC, it is crucial for local communities and various stakeholders to act collectively.

KEYWORDS

human-elephant conflict, damage mitigation, social changes, forest landscape, Gabon, *Loxodonta cyclotis*

1 Introduction

Gabon, located on the Atlantic coast of central Africa, is one of the most important countries for the habitat of African forest elephant (*Loxodonta cyclotis*). It is estimated that Gabon is home to more than half of the world's remaining forest elephant population (Maisels et al., 2013; Thouless et al., 2016; Laguardia et al., 2021). A recent nationwide survey utilizing a DNA-based approach estimated the population of forest elephants in Gabon to be approximately 95,110, with a mean density of 0.38 individuals per km^2 (Laguardia et al., 2021). This notable abundance of forest elephants in Gabon can be attributed to its low human population density and limited human impact. Gabon has maintained a substantial amount of forest cover, accounting for 91% of the country's total land area (FAO, 2020). At present, the ratio of humans to forest elephants is one elephant per 20 people, and elephant density is high both within and outside protected areas (Laguardia et al., 2021).

While the conservation of forest elephants remains a global concern, human-elephant conflict (HEC), especially instances of crop-raiding by elephants, is a serious threat to human livelihoods and impedes conservation efforts (Lahm, 1996; Walker, 2010; Inogwabini et al., 2013; Nsonsi et al., 2017). In Gabon, crop damage by forest elephants has considerable negative impacts on the local economy and deteriorates local livelihoods (Lahm, 1996; Walker, 2010, 2012; Fairet, 2012; Fairet et al., 2014; Terada et al., 2021). The challenges associated with HEC are becoming increasingly severe, particularly in rural areas characterized by low human and high elephant densities. In addition to HEC, the lack of infrastructure, inadequate social services, and economic disadvantages contribute to rural exodus (Walker, 2010; Fairet, 2012; Fairet et al., 2014; Terada et al., 2021). Although the Gabonese Government has implemented electric fences at select locations, this measure is not a definitive solution to crop-raiding, nor is it feasible for all regions due to its high cost and enormous maintenance demands. Moreover, local communities receive little compensation from the government for HEC-related crop loss.

To mitigate similar instances of crop-raiding by savanna elephants in eastern and southern Africa, diverse strategies, including acoustic, visual, and olfactory deterrents, have been extensively studied (Hoare, 2015; Shaffer et al., 2019). More recently, innovative non-lethal approaches such as beehive fences, chili fences, and unmanned aerial vehicles have also emerged and been investigated (Chang'a et al., 2016; Hahn et al., 2017; King et al., 2017; Kiffner et al., 2021). However, research on crop-raiding situations and corresponding mitigation measures specific to forest elephants are considerably limited when compared to savanna elephants.

In Gabon, only a handful of studies have explored elephant crop-raiding and related damage mitigation strategies. For instance, in a survey conducted by Walker (2010) across 36 sites in Gabon, farmers were observed to use constructed fences made of rope and cans, sheets of zinc roofing, or logging cable to abate crop-raiding elephants. They also highlighted a strategy that involved sleeping in the field overnight to chase away raiding elephants, which had the lowest material costs but demanded expensive labor costs (Walker, 2010). Similarly, Fairet (2012) conducted an intensive study on crop-raiding mitigation in Loango of southwestern Gabon and observed that the local people employed both active and passive methods, that included making noise, setting up camps, placing barriers, using lamps, and creating fires, to repel elephants (Fairet, 2012). In addition, Terada et al. (2021) conducted a survey around Moukalaba-Doudou National Park in southwestern Gabon and identified similar methods to mitigate crop-raiding elephants as those found in previous studies, including the construction of fences made of lianas or metallic cables equipped with noisemakers, as well as the practice of staying in fields to scare elephants (Terada et al., 2021). Regarding novel protection measures, Ngama et al. (2016) experimentally assessed the effectiveness of beehive fences, while in another study, Ngama et al. (2018) analyzed the reaction of elephants to chili using camera traps.

Although empirical studies on HEC in Gabon are gradually accumulating, they are still insufficient for establishing effective and sustainable protection strategies. Moreover, it remains unclear whether the measures developed for savanna landscapes are equally effective in the Central African forest landscapes, which are characterized by low human and high animal densities and crop fields created through shifting cultivation (Fairet, 2012). In contrast to the HEC observed in eastern and southern Africa, where conflicts have escalated due to human activity expansion, HEC in rural Gabon is closely associated with limited human activities—as human activities have decreased, protection measures are weakened and crop-raiding by elephants has increased. Further studies are required to address specific situations in areas where local communities are highly vulnerable to crop-raiding by elephants, given the scarcity of human activities and the significant threat posed to local livelihoods.

The characteristics of shifting cultivation in the forest landscape should also be considered. For instance, constructing fences in an undulating forested area poses more significant challenges than in flat savanna terrain. In addition, these would need to be relocated along with the shifting cultivation cycle. Ngama et al. (2019) examined the correlation between topography and the occurrence of elephant raids in the Monts de Cristal National Park in Gabon and observed that fields on hillsides characterized by shallow and steep aspects experienced fewer raids than those on flat fields. Consequently, considering the topographical background and field locations is crucial for developing effective strategies to protect fields within the forest landscape against crop-raiding elephants.

This study aims to investigate the HEC in rural Gabon focusing on the crop-raiding situation and damage mitigation practices. The study is centered on a village adjacent to Moukalaba-Doudou National Park (MDNP) in southwestern Gabon, where human activities are limited, and local livelihoods are severely threatened by crop-raiding elephants. Through long-term ethnographic research conducted among local communities, this study first demonstrates shifting patterns of crop fields corresponding to elephant raiding and documents changes in local circumstances over a 12-year period from 2008–2019. Secondly, it describes the elephant crop-raiding situation in the study location and conducts an in-depth analysis of the associated damage mitigation practices by local people. Based on daily records provided by local

collaborators and insights gathered from interviews conducted in 2019 and 2020, this study illustrates the crop-guarding practices utilized by local people in the field in response to the crop-raiding patterns of elephants. Lastly, the study discusses the characteristics of HEC in rural Gabon, where human activities are scarce and shifting cultivation practices in the forest area are prevalent. It also proposes effective strategies for mitigating the elephant-related damages to the fields in the region.

2 Materials and methods

2.1 Research area

Field studies were conducted in Doussala Village, which is located near the Moukalaba River, the border of the MDNP in Nyanga Province in southwestern Gabon (Figure 1). There are several villages along the road on the eastern side of the MDNP, and Doussala is the last village on the road, approximately 70 km from the provincial capital, Tchibanga. The MDNP covers approximately 5,000 km^2 and exhibits a mosaic landscape consisting of forests and savannas. Its annual rainfall is 1,176–2,043 mm (Hongo et al., 2018), and it has a clear distinction between the dry season and the rainy season (Dry season: May–September, Rainy season: October–April, Takenoshita et al., 2008). The area is rich in biodiversity, which includes a large population of forest elephants (Nakashima, 2015; Johnson et al., 2019; Laguardia et al., 2021). The elephant density in the area is estimated at 0.387 individuals per km^2 (Laguardia et al., 2021). Elephants are distributed both within and outside the MDNP, with higher densities observed outside the National Park (Laguardia et al., 2021). While illegal hunting of elephants poses a serious problem in northern Gabon, with poachers often entering from neighboring countries like Cameroon (Maisels et al., 2013; Poulsen et al., 2017), poaching of elephants in the research area is relatively rare due to its low accessibility and strict control of illegal hunting (Terada et al., 2021).

The rich biodiversity in the study site can be attributed to the low impact of human activities. The human population density is significantly low in the area (0.8 persons per km^2, Thibault and Blaney, 2003), with no large-scale commercial activities to date. While this area experienced commercial logging between the 1960s and 1980s, the operation ended in 1989 and no subsequent commercial activities have been undertaken (Matsuura and Moussavou, 2015). During the logging era, this area housed a substantial population of logging laborers and their families, but after the closure of the logging base, the human population sharply declined, and the infrastructures deteriorated accordingly (Terada et al., 2021).

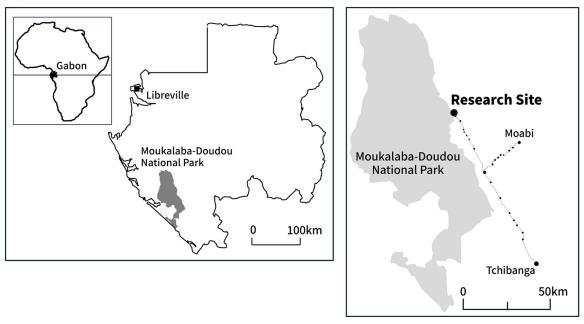

FIGURE 1
Research site.

Despite the limited commercial activities, research and conservation projects have been implemented in the study site since the 1990s (Terada et al., 2021). For instance, Japanese researchers initiated ecological studies on great apes within the area in 1999 and successfully habituated a group of gorillas. Subsequently, research and conservation projects expanded following the creation of MDNP in 2002. A large-scale research project called PROCOBHA, aimed at biodiversity conservation and local development, was funded by the Japanese Government and ran from 2009–2014. Almost all the inhabitants of villages adjacent to MDNP were involved in this project and benefitted directly from employment opportunities it provided. Additionally, a locally based non-governmental organization, PROGRAM, was established in 2004 to promote local development through ecotourism.

Since 2015, there has been an ecotourism development project supported by the Japanese Government. As part of this initiative, some gorilla research assistants and PROGRAM staff have been trained as ecotourism guides and a community center was established in Doussala. Alongside these activities, private tourism operators have also commenced operations, attracting tourists to the area. As a result, a few villagers now have the opportunity to generate income by serving as guides and providing various services to visitors. However, the development of ecotourism in the area is still in its early stages. Notably, the tourism industry has been significantly impacted by the COVID-19 pandemic, and it is far from being able to fully sustain local livelihoods.

2.2 Local community

The inhabitants of Doussala Village primarily belong to western Bantu language groups, with the majority being Punu (Bantu B43), Vungu (B40.3), and Varama (B40.2) (Guthrie, 1967; Perrois and Grand-Dufay, 2008). These groups are presumed to have migrated from Congo several hundred years ago and are currently distributed from central and southern Gabon to the south of the Republic of the Congo (Perrois and Grand-Dufay, 2008). Their society is characterized by high mobility and relatively relaxed hierarchical system (Gray, 2002; Mayer, 2002; Matsuura and Moussavou, 2015). As their society practices the matrilineal descent system and patrilocal residence rule, there is a lack of congruence between residence and lineage in their community. Moreover, clan alliances hold more significance than territoriality and ethnic categories are less important (Gray, 2002; Mayer, 2002; Matsuura and Moussavou, 2015).

A principal subsistence activity of these inhabitants is shifting cultivation, and the local people rely primarily on agricultural products for their livelihoods (Matsuura and Moussavou, 2015). They usually gather firewood in and around their crop fields, which are created in secondary forests. Cultivated crops include cassava, plantain banana, taro, yam, sugarcane, sweet potato, maize, peanuts,

and more (Matsuura and Moussavou, 2015). The farming cycle involves slashing and burning forests during the dry season (July–August), planting in September and October, and harvesting starting in February. New fields are cleared every year, and the harvest continues for about two years in the same field. Fishing and hunting supplement their subsistence activities (Matsuura and Moussavou, 2015; Van Gils et al., 2019). Due to the distance from urban areas, opportunities for generating cash income through the sale of crops and forest products are considerably limited.

The population of Doussala Village in 2020 was only 34 individuals, including children, spread across 10 households. From the 2000s to the early 2010s, including the period during which the PROCOBHA project operated, the population in Doussala was around 100–150 individuals. However, it declined drastically after the termination of the project (Terada et al., 2021). Many people, particularly those of working age and their families, subsequently migrated to nearby towns in search of employment opportunities and better access to public services such as schools and hospitals. Compared to the peak population in 2012, Doussala Village experienced an almost 80% decline by 2020 (Terada et al., 2021). Similar trends of significant population decline, and deterioration of public facilities have been observed in other villages around the MDNP as well (Terada et al., 2021).

In addition to the lack of labor opportunities, serious crop-raiding by wildlife is attributed to the decline of the human population in the area. Crop-raiding animals in the research area include forest elephants, greater cane rats (*Thryonomys swinderianus*), African brush-tailed porcupines (*Atherurus africanus*), western gorillas (*Gorilla gorilla*), common chimpanzees (*Pan troglodytes*), and monkeys such as red-capped mangabeys (*Cercocebus torquatus*). Among them, the elephants are the most destructive and cause enormous crop damage. Sex is a key driver of elephant movement behavior (Beirne et al., 2021), and both males and females, including infants, contribute to the destruction of the fields. According to a study on the visitation patterns of elephants in Northern Gabon using GPS tracking data, the female elephant was drawn toward the availability of crops, whereas the male showed a lower affinity for crops (Mbamy et al., 2023). In the research site, some elephants arrived from the National Park area, whereas others arrived from the forest area on the opposite side and the savanna. The elephants damage crops in almost all seasons, causing widespread destruction once they enter a field. This crop damage not only deprives people of food resources but also eliminates opportunities for cash income through crop sales.

In this area, there are no foolproof measures practiced to protect fields against raiding elephants in this area; only traditional and simple measures are employed (Terada et al., 2021). The most effective way is guarding the fields overnight and scaring elephants each time they attempt to enter. However, this method demands a significant workforce and effort, taking a toll on the physical and mental health of local people. In addition to HEC, the various challenges of rural life cause local people— especially the younger generation—to leave their villages and immigrate to towns. Due to this rural exodus, there is a lack of human labor to protect fields, and labor costs for the remaining people, mainly elders, increase severely. As a result, the local communities in the study area find themselves in a negative spiral.

2.3 Data collection

The authors have conducted ethnographic research data in Doussala Village since 2008. The first author made 13 visits from 2008 to 2020, totaling approximately one year of stay. Data on village demography and the patterns of their subsistence activities including agricultural practices were collected through participant observation and semi-structured interviews. The second author spent four months in Doussala from November 2019 to March 2020, primarily for an ecological study on elephants but also collected data on agricultural practices through observation and interviews.

Information regarding the location of crop fields belonging to each household in Doussala was collected during each research period. Whenever possible, the authors visited the field, measured their size using handheld GPS units (Garmin GPSMAP 62s and 64s), plotted the location of huts used for guarding, documented the crop types cultivated, and recorded their owners. Field measurements were conducted from 2008–2011 and then once more from 2016–2019. During the periods when field measurements were unable to be recorded due to the absence of the researchers (2011–2015), village informants were later interviewed to confirm the approximate field locations. The approximate boundaries were established using images of Google Earth Pro 7.3.6. As the fields recorded from 2011, 2012, and 2013 bordered each other and could not be measured on site, it was not possible to separate each field, so they are presented collectively.

To understand the actual local crop-raiding scenario by elephants, a focused investigation was conducted on a particular field over a 13-month period from February 2009 to February 2010. This field, cleared in October 2008, was collectively used by 17 households to reduce the burden of guarding. The authors counted all the bananas in the fields. For cassava stems, they conducted counts in two plots, each measuring 10 by 10 meters, and then evaluated the total number. A local collaborator recorded all crop-raiding events during the period. Another investigation on the crop-raiding situation and local practices for protection was carried out over an 11-month period from December 2019 to October 2020. Prior to this, the field was cleared in October 2019. This field was shared by all 10 existing households in Doussala. For this phase of the study, the authors requested daily records from the representatives of all 10 households, detailing which days and which household members stayed at the hut in the field overnight. When they were present in the hut, they also noted whether they heard any sounds or noises of elephants, specifying the time of the first observation and whether they were successful in deterring the elephants.

This study was conducted with approval from the Centre National de Recherche Scientifique et Technologique and the Agence Nationale des Parcs Nationaux. Prior to the interview, participants were fully informed about the study's purpose, and verbal consent was obtained.

3 Results

3.1 Transition of field locations

The locations of the fields shifted over a 12-year period between 2008 to 2019. During this period, the field locations underwent substantial changes as illustrated in Figure 2. Between 2008 and 2013, the fields were primarily situated about 2 km east of the village, across the savanna. The eastern area was characterized by steeper slopes and was relatively distant from the MDNP border. Farmers cited one of the reasons for choosing this location was their belief that it experienced fewer visits by elephants.

In 2008 and 2009, all households in Doussala (17 households in 2008 and 20 households in 2009) had their fields in the same eastern area. However, in 2010, three households relocated to the northern area along the Moukalaba River. These households originally belonged to the neighboring village, Mboungou, which had been merged into Doussala Village due to a substantial population decline and eventual abandonment in 2014. The area where these households established their fields was close to the former location of Mboungou Village and fell within the territory of the village.

Between 2014 and 2019, there was a noticeable shift in field locations, as farmers chose to establish fields closer to the village. This change was primarily triggered by the termination of a large-scale research project that had employed many local people, resulting in a significant decrease in the population of Doussala. Field sizes also underwent changes after 2014, with a notable reduction attributed to the population decline. The total field sizes measured were as follows: 11.1 ha in 2008, 13.7 ha in 2009, 13.7 ha in 2010, 6.2 ha in 2016, 5.1 ha in 2017, 5.6 ha in 2018, and 5.7 ha in 2019.

During this period, there had been two small farming groups. One group, consisting of four to five households, established their fields in the northern area near the village (100–200 m) along the Moukalaba River. Another group, comprising five to six households, initially created their fields southeast of the village near the Dibotsa River between 2014 and 2016. They chose this location due to their belief that it had fewer elephant visits due to its relative distance from the MDNP. However, despite this choice, several elephant incursions occurred during the last three months (April–June) of the field period in 2017. Consequently, when they cleared the field in August 2017, they decided to relocate it to a steeper slope in close proximity to the area where the field had previously been situated until 2013, with the aim of avoiding elephants. In addition to these topographical adjustments, they implemented additional elephant-deterring measures, including setting cables, some of which were double-layered, around the field. Despite these stringent measures, elephants entered the field and caused extensive crop damage within a single day in 2017. Furthermore, the fences fastened to trees around the field using nails were also destroyed, necessitating significant repair efforts.

As a result, in 2018, the group decided to relocate the field. They established a new field to the south of the village, adjacent to the

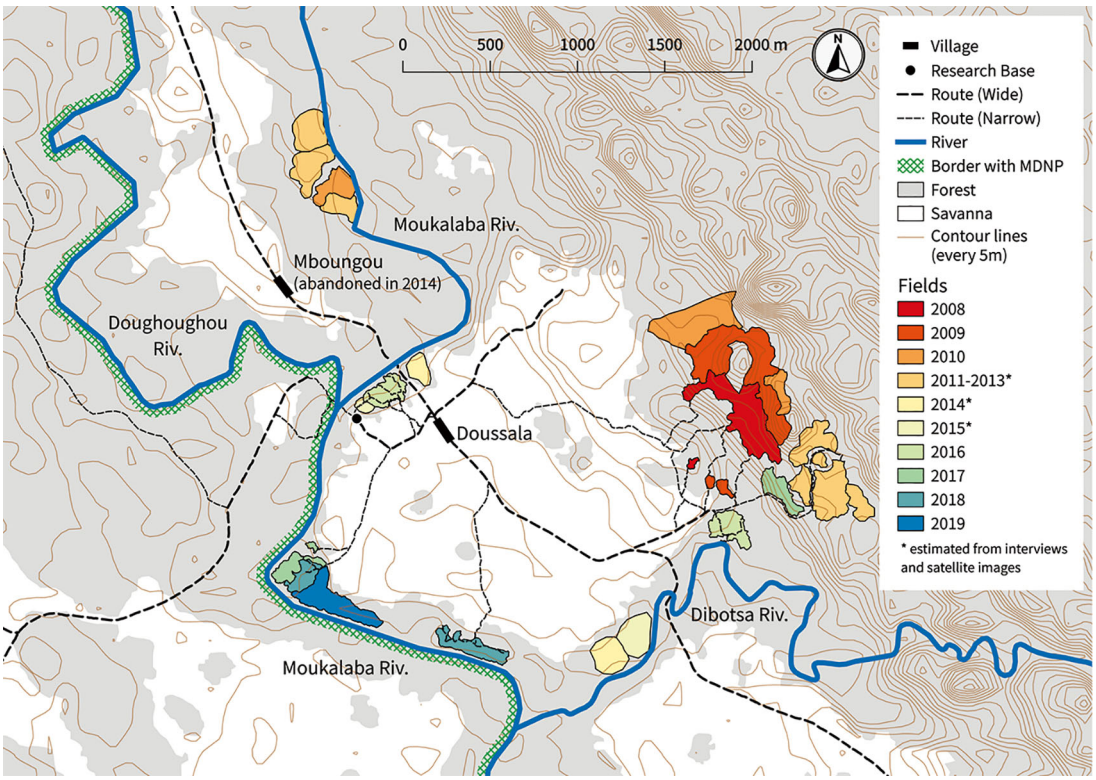

FIGURE 2
Changes in the location of fields during 2008–2019 in the research village.

Moukalaba River. This led to the coexistence of the two farming groups in close proximity during 2018–2019. In 2019, these two groups merged once again and collectively established a field in the same location next to previous fields. The field was divided among the households, with each household cultivating its own designated area. Despite the fact that this location made it relatively easy for elephants to access because of its proximity to the border of the MDNP across the river, the villagers accepted this disadvantage. They did so because it allowed them to easily travel from the village to the field for guarding. All 10 households constructed huts in the field and independently monitored and guarded their crops.

3.2 Crop-raiding by elephants and guarding behavior of local people

In the field cleared in 2008, there were 1,186 bananas and approximately 48,600 cassava stems. The number of crop-raiding events by elephants over a 13-month period from February 2009 to February 2010 was recorded in collaboration with a local assistant. All events noted during this period are shown in Table 1. Elephants raided the fields eight times during that period, and raided a total of 52 cassava stems, 54 bananas, and other crops. From the count and records of crop-raiding events, it was assessed that the elephants destroyed 4.6% of bananas and 0.1% of cassava. Although these percentages may seem low, it is crucial to note that farmers spend excessive time, physical effort, and even money to prevent crop raiding. Each household constructed a hut primarily used for daytime farming activities, and some households stayed overnight in them. If the farmers are in their huts when the elephants approach the fields, they scare them away by making noise through shouting or banging metal vessels, or with flashlights. Some households partially enclosed their fields with fences made of tin sheets. These measures were primarily aimed at deterring rodents, and cable snares were set at some points around the fence to capture them. However, the fences were not large enough to prevent elephant intrusion.

TABLE 1 Crop-raiding events by elephants from February 2009 to February 2010 in a field.

date	No. of crops damaged		
	cassava	banana	other crops
28 Feb 2009	3		
9 Mar 2009	3	4	
15 Mar 2009	6		
17 Mar 2009	20	30	
23 Oct 2009	10		10 sugarcanes
13 Jan 2010			10 peanuts
13 Feb 2010		10	10 taros, 10 maizes
26 Feb 2010	10	10	
total	52	54	

To offer additional insights into the crop-raiding situation and behavior of local people at this time, two noteworthy events observed outside of the data collection period are presented below.

Example 1.

In 2008, a female kiosk manager in Doussala had her field along the border of the Moukalaba River. To safeguard her field, she employed a guard at a monthly cost of 25,000 francs CFA (approximately 40 US dollars). The guard stayed in her field every night, and this arrangement effectively deterred elephant crop-raiding until December 2008. However, during the New Year's ceremony in the village, which took place from 31 December 2008 to 2 January 2009, the guard took a three-day leave, and this brief absence presented an opportunity for elephants to invade the field, resulting in substantial crop damage. Subsequently, in late January, the owner decided to discontinue hiring the guard. This decision led to further crop damage as elephants came to the field on three consecutive days in early February. The cumulative damage became so severe that the owner eventually had no choice but to abandon her field (interviewed and observed on 26 August 2009).

Example 2.

Some people had stayed in the field cleared in 2011 to protect crops continuously since April 2012. Based on interviews conducted with these farmers, they effectively deterred elephants from entering the field on multiple occasions, particularly in June and July 2012, by making noise and scaring the elephants away. The authors corroborated these accounts by observing decayed elephant feces near the boundary between the field and the forests. However, all villagers temporarily vacated the field in August to attend a funeral and the Independence Day ceremony. It was during this brief period, surrounding these events, that elephants visited the fields several times, resulting in significant damage (interviewed and observed on 28 August 2012).

In the field cleared in 2019, the authors requested daily records from the representatives of all 10 households regarding their protection practices because it was observed that farmers had been spending much longer time in the field since around 2017 (Figure 3). Table 2 presents the number and proportion of days that the 10 households stayed in the field from December 2019 to October 2020. It also includes information on the days when they heard any sounds or noises of elephants during their stay. While the authors requested recording as 'stayed' when at least one member of the household stayed in the hut, in reality, there was no rotation among members within the household; instead, all the members stayed together on nearly all 'stayed' days in all households. Occasionally, some relatives who did not reside in the village returned to the village from towns for vacations. In such cases, they also stayed in the field with their respective families.

From December 2019 to October 2020, almost all villagers stayed in the field almost every day (3301 household*day, accounting for 98.5% of the period). There were no significant differences by month or among households, as all 10 households were present in the field on most days. There was no rotation between households, but all 10 households constructed huts and guarded their field independently. Consequently, the village remained consistently vacant, regardless of the time of day or season. We observed villagers bringing many household items

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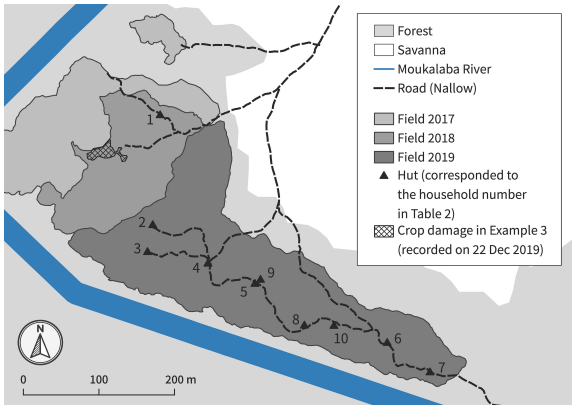

FIGURE 3
The field created in 2019 and location of huts for each household.

and livestock such as goats and chickens into the field huts (Figure 4). As a result of the village's regular emptiness, trucks transporting beverages from town no longer made stops at the village. Instead, they went directly to the field to serve the villagers. The only exception occurred on 27 December 2019 due to two special events in the village late at night: a funeral and a dance performance for tourists. On that particular night, only six households stayed in the field. However, it is important to note that over half of the households still chose to stay in the field even during such special events, underscoring the threat posed by elephants and the strong influence of this threat on the villagers' way of life.

This phenomenon underscores the significantly high likelihood of elephant raiding and the severity of the threat it poses. It is evident that people reported hearing elephant sounds on a certain percentage of days during their stay in all months (8.7%–46.2%). The proportion of days when they heard the sounds was notably

TABLE 2 The number of days stayed in the field and heard elephant sounds for each household (from December 2019 to October 2020).

Household	Dec 2019–Apr 2020		May–Sep 2020		Oct 2020		Total	
	(151 days*)		(153 days)		(31 days)		(335 days)	
	S	H	S	H	S	H	S	H
No.1	150	71	153	42	31	0	334	113
	99.3%	47.3%	100.0%	27.5%	100.0%	0.0%	99.7%	33.8%
No.2	151	67	153	25	31	5	335	97
	100.0%	44.4%	100.0%	16.3%	100.0%	16.1%	100.0%	29.0%
No.3	150	70	153	27	31	6	334	103
	99.3%	46.7%	100.0%	17.6%	100.0%	19.4%	99.7%	30.8%
No.4	150	14	153	9	31	0	334	23
	99.3%	9.3%	100.0%	5.9%	100.0%	0.0%	99.7%	6.9%
No.5	150	5	153	6	31	0	334	11
	99.3%	3.3%	100.0%	3.9%	96.8%	0.0%	99.7%	3.3%
No.6	143	17	151	35	31	4	325	56
	94.7%	11.9%	98.7%	23.2%	100.0%	12.9%	97.0%	17.2%
No.7	151	49	153	63	31	9	335	121
	100.0%	32.5%	100.0%	41.2%	100.0%	29.0%	100.0%	36.1%
No.8	151	19	151	1	30	0	332	20
	100.0%	12.6%	98.7%	0.7%	100.0%	0.0%	99.1%	6.0%
No.9	142	7	153	4	31	0	326	11
	94.0%	4.9%	100.0%	2.6%	100.0%	0.0%	97.3%	3.4%
No.10	151	56	153	57	31	12	335	125
	100.0%	37.1%	100.0%	37.3%	100.0%	38.7%	100.0%	37.3%
avg.	148.9	37.5	152.6	26.9	30.9	3.6	332.4	68
	98.6%	25.2%	99.7%	17.6%	99.7%	11.7%	99.2%	20.5%

Periods are divided according to season. Dec–Apr: Rainy season, May–Sep: Dry season, Oct: Rainy season.
*data collected 30 days in Dec 2019 (from 2nd to 31st).
S (stayed): the number of days stayed at the hut in the field overnight (percentage of stayed days out of the total number of days in the month).
H (heard): the number of days heard any sounds or noises of elephants (percentage of days they heard the sounds out of the number of stayed days).

FIGURE 4
Lifestyle in a hut in the field. Photo credit: Mayuko Nomoto.

high during the early rainy season (from December–February), with the peak occurring in February. Elephant sounds were reported more frequently during the night compared to the daytime. The most common time for people to first notice these sounds was between 11:00 p.m. and 0:00 a.m., although this varied from 5:30 p.m. to the following morning.

On 77.9% of the days (261 out of 335 days), at least one household reported hearing elephant sounds, and 2.0 households (SD = 1.8) reported hearing elephant sounds on average. On the other hand, there were only 16 days (4.8%) when more than half of the households heard the sounds, and just one day (0.3%) when all households reported hearing them. There was no synchronization in the days when each household heard the sounds. The frequency of hearing varied depending on the location of the hut, with households near the field's border reporting hearing them more frequently than those in the middle of the field.

Despite the persistent threat by elephants, there was minimal damage reported in the field cleared in 2019. This was primarily because nearly all villagers consistently stayed in the fields almost every day and drove away elephants when they approached, effectively deterring elephant incursions. However, instances of crop-raiding were observed in the field cleared in 2018, despite the presence of farmers in the adjacent field during the research period. If the fields are adjacent to each other, they can be protected simultaneously; however, the old field may still attract elephants. Based on our interviews, there were two types of scenarios that led to crop damage. In the first scenario, the villagers failed to perceive the sound due to three reasons: (1) the metallic and liana cables with empty cans to make noise surrounding the field were detached, (2) the field was too large for the sound to be heard, or (3) people were in deep sleep. The second scenario involved villagers chasing elephants away once, only to have the elephants return later to raid crops. Several villagers claimed that even if they succeeded in driving elephants away, the elephants would sometimes return shortly afterward. An example of such damage is as follows.

Example 3.

Between December 16 and 21, 2019, elephants raided 92 bananas, 17 cassava, and 1 taro from the field cleared in 2018. Some bananas were overturned and trampled, while others, despite not being overturned, had all their leaves plucked out. According to the owner of the field, elephants visited the field almost every day during that week. He mentioned that the older field was far from his hut, making it difficult to notice the sound of elephants. Even if he did notice the elephants and attempted to chase them away, they were less frightened due to the distance between them (recorded on 22 December 2019).

4 Discussion

4.1 Human elephant conflict in the study site

This study has unveiled a severe HEC situation in rural Gabon, where the human population is low, and the elephant population is high. The extent of this conflict has compelled local people to make significant changes to their lifestyles and residential patterns. In contrast to previous studies that suggested a decrease in elephant presence near villages and roads (Laurance et al., 2006; Granados and Weladji, 2012; Vanthomme et al., 2013; Beirne et al., 2021), elephants in our study area frequented human spaces, likely due to the limited human presence.

On the other hand, several studies have highlighted that elephants are drawn to human activity areas, attracted by human food resources such as crops and fruit trees (Von Gerhardt et al., 2014; Ngama et al., 2018; Fai et al., 2022; Hahn et al., 2022). This behavioral pattern is observed in Asian elephants as well, which exhibit a preference for areas with regrowth and new plantations, utilizing ridgelines for traveling through agriculture landscapes (Evans et al., 2020; de la Torre et al., 2022). This tendency is prominently evident in our study site, where elephants visit crop fields at irrespective of the time of day or season. Elephants are also attracted to fruit trees such as mangoes and oil palms planted around the village. During the logging era, the human population was much larger with an activity area much wider than it is today. However, the human population declined after the closure of the logging base in the 1980s and the mango and oil palm trees remained, in the areas far from the present human residence. Elephants come to visit these fruit trees much more freely despite this elephant-ranging area being overlapped with humans.

At present, people encounter elephants around the village frequently. Elephants are even observed to use some paths created by people and vice versa (Remis and Jost Robinson, 2020). When logging companies existed in the research area, there were many vehicles, and roads were maintained. These man-made roads are important paths for elephants today. In contrast, villagers use elephant trails to travel through the forest for hunting and gathering. Villagers also use elephant trails daily to access their crop fields. As people and elephants live in closer proximity together, many accidents including fatalities have been reported within elephant-ranging areas (Dunham et al., 2010; Shaffer et al., 2019). In addition, the elephants cause damage to properties (e.g., houses and stores), which results in a higher economic loss than crop damage (Gross et al., 2021).

There are also indirect impacts of living close to elephants, such as the potential fear of attack (Gross et al., 2021; Sampson et al., 2021). The feeling of fear is expected to be greater around the village because of the possibility of direct damage to bodies and properties. At least during the study period, there have been no injury cases in the study site. However, it is certain that villagers, especially women and children, are at high risk of being attacked by elephants. They are very careful when going out at dusk and night. They live in a precarious situation where incidents could occur at any time.

In previous studies, humans and elephants are indicated to exist in close proximity due to the increase in human activities and expansion of human areas, resulting in an increase in HEC (Hill, 2004; Graham et al., 2010; Shaffer et al., 2019). However, the present study demonstrates that both the proximity and conflict increases despite the decline of human activities and the expansion of the elephant range. As such, the conflict in this area is considered to be more serious because of the lack of manpower required to deter it, compared to more densely human-populated areas.

4.2 Social changes due to elephant crop-raiding

Due to serious crop-raiding by elephants, local people have made significant changes to their way of life. The field location has been shifted multiple times between 2008 to 2019. Until 2013, the fields were located far from the village and the border of the MDNP, where elephants from the national park could not access easily because of the distance from the park and the slope of the terrain. Previous studies demonstrated that elephants tend to avoid mountainous terrain and that the elephant density is low on steep slopes (Wall et al., 2006; Wall et al., 2021; Laguardia et al., 2021). According to a study of the buffer zone of Monts de Cristal National Park of Gabon, crop fields on hillsides experienced fewer raids and there was no crop-raiding in fields with slopes greater than 25% (Ngama et al., 2019). In our study site, villagers were also aware that elephants do not like slopes based on their experiences, and consequently chose hillside locations.

However, crop-raiding by elephants still occurs on the slopes. In fact, there has been damage in almost all fields between 2008 to 2013. Due to the damage, villagers were eventually forced to move their fields to the area closer to the village and the national park in 2014. Although the area has associated risks because of the frequent elephant visits, the site was selected because it was more easily accessible to the village. Thus, they switched the strategy of selection of the crop field location. Before, the area where elephants were less likely to visit was preferred. However, elephant visits were still not completely avoidable and raiding elephants caused enormous damage from just one visit. Therefore, the villagers accepted that elephants were encroaching their fields, and instead selected a new area easily accessible to the village and intensified guarding practices by spending much of their time in the field.

Therefore, most households stayed in the fields for the majority of days in 2019–2020 regardless of whether it was crop harvest season. Household goods and livestock were brought to the field, and the base of their livelihood moved to the field, resulting in the village becoming almost empty. The severe crop-raiding by elephants ceased the functioning of the village and transferred the human settlement to the fields. However, the living conditions in the fields are not sufficiently secure and comfortable. The field huts are small and simple and are not completely protected from rain. In addition, elephants tend to appear late at night, and people must wake to scare them. However, elephant visits are not restricted to a specific time; thus, people are always in a stressful condition caused by restless sleep. In addition to the physical burden of staying in poor living conditions, there is a considerable psychological burden of not knowing when elephants may appear.

The villagers bear a substantial labor cost in protecting their fields (Fairet, 2012; Walker, 2012). Considering the health impacts of this labor and the associated opportunity costs is crucial, as it results in the loss of alternative work opportunities and restricts their mobility (Barua et al., 2013; Mayberry et al., 2017; Manoa et al., 2021). The challenges related to diminishing psychosocial well-being are also significant. Once the fields are left unattended, elephants immediately enter and raid crops. In other words, crop-raiding is prevented at the point of entry, and farmers are always forced to fear the crop-raiding risk. In order to evaluate the severity of animal damage, it is important to consider not only visible impacts of crop-raiding, but also "hidden impacts" (Barua et al., 2013; Mayberry et al., 2017; Manoa et al., 2021). Fairly evaluating the various types of costs incurred by local people, including physical and mental, direct and indirect costs, is crucial. Establishing a system to sustain local livelihoods with effective measures to mitigate crop damage by elephants, along with appropriate compensation for the costs, is imperative.

5 Conclusions

When tangible crop loss is small, the HEC is considered superficially small. However, this situation is based on the considerable labor costs and physical and emotional burden of local communities. To establish effective elephant conservation systems, it is necessary to understand each local situation and evaluate the various costs to local people (Fairet, 2012; Walker, 2012; Barua et al., 2013; Mayberry et al., 2017; Terada et al., 2021). Considering the local context, here we discuss the effective and sustainable measures of damage mitigation and wildlife management at our study site.

It is clear that there are no established and foolproof measures to protect crops from elephants and keep them away from the field. Limited financial resources and manpower pose significant challenges. Constructing large-scale electric fences is challenging even in savanna areas, but it becomes even more difficult in forested landscapes with slopes and thick trees (Kioko et al., 2008; Ngama et al., 2019). In addition to the challenges in construction, there is a significant cost involved in maintaining fences in the forest. Furthermore, the fact that fields shift annually necessitates the relocation of the fences. Recently, novel mobile electric fences adapted to the tropical forest environment and shifting cultivation system, are being introduced in Gabon by elephant conservation organizations (Prentice and Van Der Perre, 2022; Gabonews, 2023). They are characterized by their low cost and low specifications,

featuring a single wire powered by solar panels and batteries. However, it is worth noting that this method also requires regular and intensive maintenance; if not well maintained, these fences can easily be broken down by elephants (Gross et al., 2022).

Beehive fences were introduced with external support in 2018. In the first year, bees nested, and a small amount of honey was obtained, but the initiative was eventually abandoned owing to maintenance difficulties. Although non-palatable crops have yet not been experimented with in the research site, questions about their sustainability have been raised by the local community comprising of 30–40 inhabitants, predominantly elders. There is also an issue of ownership. Among local people, there is a strong belief that wild animals, including elephants, are owned by the government. There is a prevailing sentiment that it is the responsibility of the government and international organizations to address crop-raiding issues. Consequently, whatever method is introduced, it will require sufficient and continuous support from outside and efforts of sensibilization efforts for local people to enable them to sustain themselves.

In such conditions, guarding in the field proved to be a highly effective measure. However, it comes significant labor costs and burdens. Thus, improving the guarding method by alleviating these burdens would be impactful. One option is to organize farmers and regulate the guarding area and working days through the implementation of rotations. Gross et al. (2021) claimed that the non-strategic and small-scale guarding practices were ineffective and emphasized the need for preventive and collaborative community-led approaches, such as the aggregation of cultivated areas protected by a well-developed strategic communal guarding system.

For this, the local social context should be considered. The local community in the research site is characterized by high mobility and less territoriality due to the matrilineal and patrilocal social system (Gray, 2002; Mayer, 2002; Matsuura and Moussavou, 2015). In the matrilineal and patrilocal system, women maintain strong ties with their relatives even after marriage, and family members visit women's homes frequently. In this system, inheritance of land and property occurs through the maternal line, and husbands have less connection with their land. In this way, the local community is highly mobile and fluid. Additionally, local people have diverse backgrounds because of the historical process. The area had been a logging base initially, before being converted an area that hosted several research and conservation projects after the closure of the logging base. Thus, the local community is not monolithic, and solidarity among local people is lacking.

In fact, the authors' attempts to create 'a community plantation' as a local development aid in 2012 and 2013 failed due to a lack of cooperation among villagers. Despite several discussions with the farmers, the project was abandoned because they were displeased that a local association had been selected to lead the project. Their mistrust resulted in boycott of work, and the project was halted when the field was cleared and about to be set on fire. This social context does not allow for the collective management of the field; each household is responsible for its own field and hut (Figure 3). Therefore, to establish a local association for the rotation of guarding, careful discussion and consensus-building among all villagers with the active involvement of external actors is necessary.

In terms of possible external aid, providing materials to construct huts and improving comfort and security would be beneficial. It would also be effective to support personnel to assist with guarding. Developing hybrid measures by combining high-tech and traditional methods and utilizing both material and human resources is necessary (Sitati et al., 2005; Gross et al., 2019). Not only should local people be able to maintain their livelihoods and overcome the problem of HEC, but various stakeholders including the government, international NGOs, and scientists, should take up the responsibility of providing sustainable local development and implementing elephant conservation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Centre National de Recherche Scientifique et Technologique (Gabon). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

NM: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. MN: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Resources, Writing – original draft, Writing – review & editing. ST: Writing – review & editing. MC: Writing – review & editing. HM: Writing – review & editing. G-MM: Investigation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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