

Balancing boundaries: elephant movements in the changing landscape around Murchison Falls National Park, Uganda

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Abstract

We examine elephant movement and human–elephant conflict around Murchison Falls National Park (MFNP) in northern Uganda, a landscape shaped by rapid agricultural expansion, displacement, and ongoing land conflict. Elephant movements beyond the Park’s boundaries are still poorly understood. Between 2019 and 2022, we collected data through GPS collaring ($n = 5$), ground observations, and crop-raiding surveys. Collared elephants favoured areas near water, tree cover and lower elevations, with use of human-occupied areas ranging from 0–24%. Outside MFNP, they sheltered near refuge sites during the day and raided farms at night. Raiding typically targeted mid-growth crops with a median of 30% damage per affected farm. Calves were present in approximately 20% of raids, and some groups exceeded 30 individuals. Only 9% of farmers used deterrents beyond reactive chasing. Snaring injuries were recorded in 32% of the observed elephants, indicating persistent poaching pressure. Unresolved land tenure, community distrust, and evictions further complicate elephant management outside the Park. We recommend prioritizing elephant protection inside MFNP by strengthening anti-snaring operations. Outside the Park, boundary communities require training for coordinated night-guarding and locally suitable low-cost deterrents. A feasibility study, in consultation with affected farmers, should assess limited fencing on community lands while retaining a central corridor linking MFNP to areas further north.

Résumé

Nous étudions dans cet article les mouvements des éléphants ainsi que les conflits humains-éléphants se produisant autour de la zone de conservation de Murchison Falls, dans le nord de l’Ouganda – un paysage façonné par l’expansion de l’agriculture, les déplacements de populations et les conflits liés au foncier. Les mouvements des éléphants au-delà des limites du parc national de Murchison Falls sont encore mal compris. Entre 2019 et 2022, nous avons recueilli des données grâce à des colliers GPS installés sur les animaux ($n = 5$), des observations de terrain et des enquêtes relatives aux dégâts infligés aux cultures. Les éléphants équipés privilégiaient les espaces proches de l’eau, sous un couvert forestier et situés à basse altitude, avec une utilisation des zones occupées par l’homme allant de 0 à 24 %. En dehors du parc, ils s’abritaient près des habitats refuges pendant la journée et pillaient les fermes la nuit. Ces pillages ciblaient généralement des cultures en cours de croissance, avec un taux moyen de 30 % de dommages répertoriés par ferme. Les éléphanteaux étaient présents dans environ 20 % des pillages et certains groupes dépassaient les 30 individus. Seuls 9 % des agriculteurs utilisaient des moyens de dissuasion autres que la poursuite en réaction

au pillage. Des blessures causées par des pièges ont été relevées sur 32 % des éléphants observés, ce qui indique que la pression du braconnage est toujours très présente. Les conflits relatifs au foncier, la méfiance des communautés et les expulsions forcées des habitants compliquent d'autant plus la gestion des éléphants en dehors des limites du parc. Compte tenu de ces dynamiques et de l'accélération de la conversion des terres, il paraît peu envisageable d'entreprendre une restauration des corridors. Nous identifions ici les obstacles majeurs qui entravent la gestion des éléphants hors du parc de Murchison Falls, et nous fournissons des données de référence pour soutenir les futures interventions. En outre, nous recommandons de prioriser la protection dans l'enceinte du parc et de renforcer l'engagement communautaire par des initiatives axées sur la transparence et l'établissement de relations de confiance. S'appuyer sur le suivi des éléphants et sur l'usage, par les populations locales situées en première ligne, de moyens de dissuasion adaptés au contexte et peu onéreux, peut contribuer à réduire les conflits et à encourager l'implication des communautés.

Introduction

Mapping elephant movements is a key tool for mitigating human–wildlife conflict, identifying crop-raiding hotspots and guiding interventions such as fences or corridors (Douglas-Hamilton et al. 2005; Tiller et al. 2021). Yet implementing such measures is severely constrained in contexts of contested land tenure, where ongoing disputes and evictions can undermine conservation planning, limit community participation and exacerbate marginalization (Kobusingye et al. 2017).

We examine the intersecting challenges of elephant conservation and land conflict around Murchison Falls National Park (MFNP) in northwest Uganda. MFNP, Uganda's largest protected area, is a key biodiversity stronghold supporting over 76 mammal species and 450 bird species (Plumptre et al. 2015a). It also plays a central role in Uganda's tourism sector, which generated USD 1.28 billion in 2025 (MTWA 2025). Park entry fees support wildlife conservation and fund sustainable development initiatives in surrounding communities. These contributions are crucial in a country recovering from decades of civil conflict during the 20th century (Parker 2019), during which elephants and local communities were displaced, and habitats and settlements damaged or destroyed. As human and elephant populations recover and reoccupy areas around the Park, their interactions are increasingly marked by conflict. Crop raiding has become a major concern for communities, driven by population growth and agricultural expansion along the Park's unfenced boundary (Oniba and Robertson 2019). Open boundaries allow elephants easy access to farmland, and in areas with limited economic alternatives, even

partial crop losses can be devastating (Alfred 2004; Mackenzie et al. 2012;). These pressures occur amid unresolved land tenure, conflict over land titles, and forced evictions (Mabikke 2011; Kobusingye 2017). For some, the daily threat of crop loss and displacement echoes the trauma of wartime displacement (van der Zeijden 2024). The management of biodiversity, and especially of elephants, around MFNP must account for this history while balancing conservation and community needs.

In this context, acquiring elephant movement data to guide management is urgent. Yet few studies have examined elephant movements across MFNP and surrounding areas. To address this gap, we conducted a field study (2019–2022) in regions of intense human–elephant conflict (HEC) to the northwest of the Park. Our objectives were to document 1) elephant movements within and beyond the Park; and 2) crop-raiding incidents in affected farming communities. The following section describes the socio-ecological context that shaped our study design, followed by the methods, results and discussion. The conclusion reflects on the challenges of balancing elephant conservation with the needs of neighbouring communities.

Socio-ecological context of the Murchison Falls landscape

In 1894, when Uganda became a British Protectorate, elephants ranged across 70% of the country. When a trypanosomiasis (sleeping sickness) outbreak along the Victoria Nile forced the evacuation of local communities, the depopulated land was designated a game reserve, and subsequently, in 1952, gazetted as Murchison Falls National Park (Parker 2019). To the north, Aswa-Lolim (70 km²) and Kilak (1,800 km²) were established as game reserves for colonial

trophy hunters. These areas supported dense wildlife populations and linked the Murchison ecosystem to East Madi Wildlife Reserve and South Sudan, forming part of a broader elephant migration network (Andama et al. 2024). As human populations and agriculture expanded, elephants were compressed into national parks and, by 1959, the elephant range had contracted to 17% of Uganda's land area (Brooks and Buss 1962). Confined to shrinking habitats, MFNP's elephant population grew rapidly, leading to exhaustion of food supplies and widespread woodland degradation (Buechner and Dawkins 1961). Between 1965 and 1967, some 3,000 elephants were culled to halt further ecological damage (Laws et al. 1970).

In the following decades, political instability, armed insurgencies and weak enforcement caused the collapse of protected area management, while poaching decimated wildlife populations, especially of elephants (Parker 2019) and rhinos (Wheater and Parker 2019). Elephant numbers fell from 14,000 in the 1960s to fewer than 300 by the 1990s (Rwetsiba and Nuwamanya 2010). In the 1970s, President Idi Amin degazetted controlled hunting areas north of the Park to promote private ranching and agriculture, but the ensuing conflict prevented these developments (Olanya et al. 2022). From 1986 onwards, fighting by the Lord's Resistance Army further destabilised northern Uganda, including areas north of Murchison. Nearly two million people were forcibly relocated to camps for internally displaced persons (IDPs), suffering violence and the loss of land and livelihoods (Mabikke 2011). During this prolonged human displacement, elephants and other wildlife progressively recolonized abandoned lands surrounding the Park. Conservation efforts by the Uganda Wildlife Authority (UWA) and partners have since supported elephant recovery, with recent estimates ranging between 1,150 and 2,700 individuals (Grogan et al. 2019; R. Lamprey, pers. comm., 1 May 2025). Building on these gains, studies have explored re-establishing historical migration corridors between MFNP and East Madi Wildlife Reserve (Fig. 1b) (Lamprey et al. 2003; Andama et al. 2024). However, the feasibility of corridor restoration remains uncertain given rapid resettlement, population growth and overlapping land claims around the Park. Elephants also face

renewed threats from poaching, habitat loss caused by agricultural expansion, and oil extraction activities within MFNP (Plumptre et al. 2015b; Grogan et al. 2019).

Recognising these pressures, UWA continues to prioritize elephant conservation by combating poaching, maintaining habitat connectivity and reducing crop raiding. These efforts aim to ensure that elephant populations support socio-economic development through tourism at both national and local levels (UWA 2016). At the same time, these conservation priorities pose challenges for post-conflict recovery of local communities. After hostilities ceased in 2006, IDPs began returning to their former lands, only to encounter widespread land disputes and evictions (Mabikke 2011; Kobusingye et al. 2017). The liberalization of Uganda's land market and the discovery of oil in MFNP have intensified competition for titled land (Dowhaniuk et al. 2018). With formal titling processes remaining inaccessible to rural households, land insecurity has become ubiquitous. Tensions between UWA and communities have deepened following evictions to establish private hunting concessions (Kobusingye et al. 2017).

The absence of coordinated land-use planning has also enabled agricultural expansion up to the unfenced park boundary, creating a stark transition between farmland and protected habitat that is visible in satellite imagery (approx. 2°12'38" N, 31° 32' 13" E)¹. This proximity enables elephants to raid crops, sometimes destroying entire harvests of smallholder farmers (MacKenzie and Ahabyona 2012; Alfred 2014). Additional impacts include property damage, human injury and fatalities, and occasional traffic collisions involving elephants. Some communities believe oil infrastructure within MFNP has disrupted migration routes, contributing to increased incursions (Dowhaniuk et al. 2018; Grogan et al. 2019). In response, local leaders have at times called for retaliatory killings of elephants (Monitor 2016).

These pressures are likely to intensify as Uganda's population is projected to increase from 48.7 million in 2023 to 85.4 million by 2050 (WHO 2025), placing greater pressure on land in and around the Park and increasing competition with wildlife. Addressing this complex landscape will require management

¹<https://www.protectedplanet.net/956?utm>

approaches that carefully balance ecological and socio-economic priorities, enabling both elephants and local communities to recover and thrive without undermining each other's long-term prospects.

Methodology

Study Area

Murchison Falls National Park (3,898 km²) is located in northwest Uganda. It forms a part of the wider Murchison Falls Conservation Area (MFCA) including Karuma Wildlife Reserve (678 km²), Bugungu Wildlife Reserve (474 km²) and Budongo Forest Reserve (817 km²) (Plumptre et al. 2015b). The MFCA is bisected by the Victoria Nile that flows east to west through the MFNP from Karuma Falls to its confluence with Lake Albert (Fig. 1a). The area features expansive grasslands, acacia woodlands, and dense stands of *Borassus aethiopum* palms, whose seasonal fruits are consumed and dispersed by elephants. Elevation rises from approximately 650 m a.s.l. along the Albert Nile in the west to 1290 m on the eastern boundary. Rainfall is bimodal, with peaks from mid-March to May and mid-August to November (Grogan et al. 2019), and mean annual temperatures average 31°C, with peaks exceeding 40°C in February.

The landscape has changed substantially in recent years following the discovery of oil within and around the Park. There are now over 400 oil wells within MFNP and surrounding areas (Climate Rights International 2024), alongside new infrastructure including a bridge across the Victoria Nile and an upgraded 12 m-wide tarmac road running 85 km from Kichumbanyobo Gate in the south to Tangi Gate in the north. Speed bumps and cameras have been installed to reduce wildlife–vehicle collisions (S. Goss, pers. comm., 12 August 2025).

The study area comprised community lands along MFNP's north-western boundary (2.4512°–2.6331°N; 31.4469°–31.7709°E), bounded by the Park to the south and the Aswa River to the north, an area that was formerly part of the Aswa-Lolim Game Reserve linking MFNP to East Madi Wildlife Reserve (Fig.

1b), and now forms part of Got Apwoyo Subcounty, Nwoya District, with a population of approximately 10,000 (<https://statistics.ubos.org>). Kita and Latoro are small towns near the Park boundary that experience crop raiding (Oniba and Robertson 2019). Most households rely on cultivation as their primary livelihood, typically farming plots of 0.5–1.5 ha that produce cassava, *simsim* (sesame), beans, groundnuts, and maize (Alfred 2024). In the east, commercial farms grow rice and soybeans. The bimodal rainfall pattern supports two agricultural growing seasons, in March–July and August–December. However, the widespread cultivation of long-maturing crops such as cassava and sweet potato prolongs productivity beyond these periods, so fields remain under cultivation for most of the year. Most fields are bare only in February–March, after dry-season burning and before planting.

To supplement farming income, some households engage in illegal activities including poaching, charcoal production, timber harvesting, and firewood collection. Charcoal production drives extensive deforestation around MFNP, particularly in private and community forests, reducing woodland forage and cover for elephants (Forest Trends 2024; S. Goss, pers. comm., 4 July 2025). Forest clearance is linked to increased elephant crop raiding in farms near forest edges, creating a feedback loop that intensifies HEC (Puyravaud et al. 2019).

To address crop raiding, community wildlife scouts monitor elephant movements, respond to incursions, and report illegal activity. Deterrents such as “smelly repellents” have been successfully piloted (Oniba and Robertson 2019), but beehive fences installed near the Latoro ranger post were later abandoned due to lack of maintenance. Four ranger posts were operational until 2022, when one was dismantled in 2022 following community evictions in Kita village (Fig. 3). Since then, a 44 km electric fence has been built along the Park's northern boundary (Fig. 1a), with 101 km planned in total (UWA 2023). The area is an increasingly popular tourism destination, supporting about 20 lodges, mainly in the southwest, and offers trophy hunting safaris run by a private concession.

Data collection

GPS collaring was conducted between 2020–2022 in the northern section of MFNP, above the Victoria Nile. Ground-based elephant observations (2019–

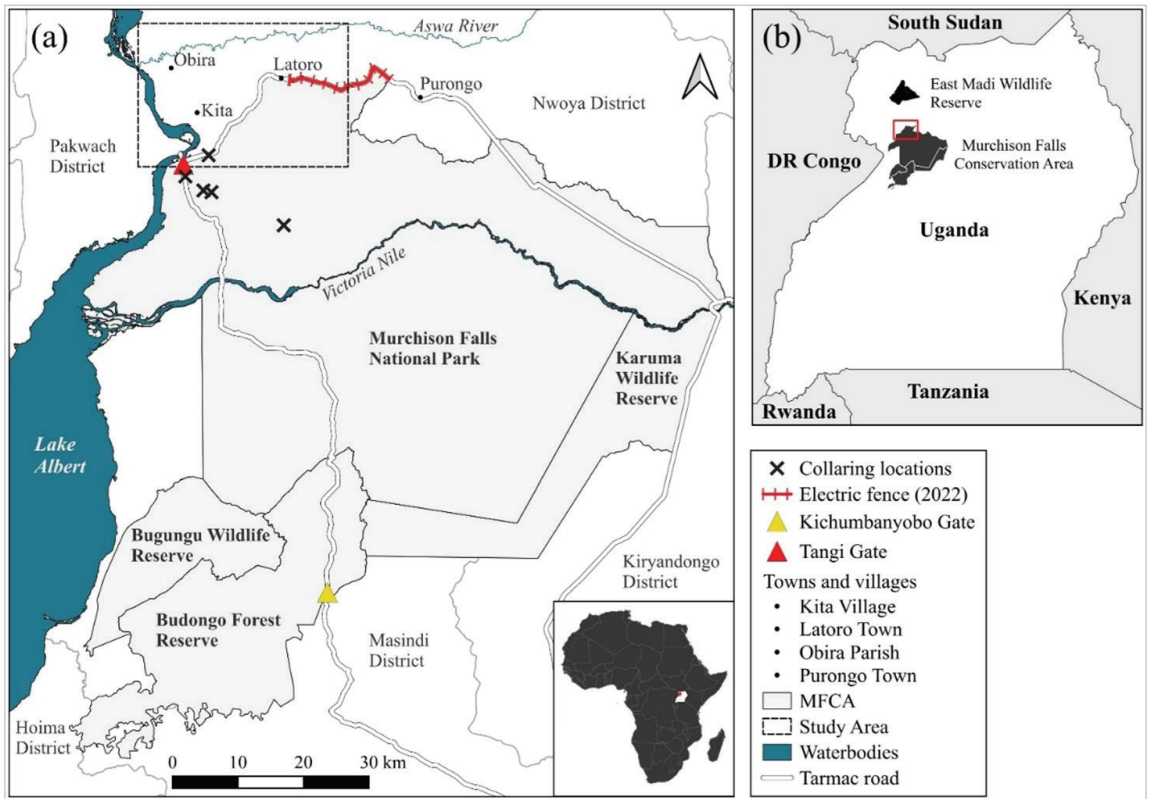


Figure 1. Murchison Falls Conservation Area. The rectangles (left panel: dashed line; right panel: red line) indicate the location of the study area to the northwest of Murchison Falls National Park.

2020) and crop-raiding surveys (2020–2021) were conducted in community areas along the Park's northwestern boundary (Fig 1b). We combined data from these sources to investigate elephant movement patterns. The study area was remote, with limited road access and several safety concerns, including dangerous wildlife in tall grass, poaching activity, active evictions (notably in Obira Parish), and proximity to military and private installations. Due to these constraints, we adopted a convenience sampling strategy that prioritized safe and accessible areas, resulting in under-sampling in the north-west. To expand coverage, we established a community volunteer network in 2019 around Kita Village (west) and Latoro Town (east), identified during early meetings with local leaders and farmers as sites of frequent elephant activity. Some residents expressed concerns that the study was related to land acquisition, and field teams were occasionally stopped for clarification. In response, we distributed informational booklets

in the local languages (Alur and Acoli) explaining the project's aims and encouraging residents to report elephant sightings and crop-raiding incidents.

We conducted ground-based observations three to five times per week using a 4×4 vehicle or motorcycle, primarily along the Gulu–Arua highway and other accessible public roads. Each session lasted approximately three hours and occurred at various times of day. When elephants were observed, we recorded group size, number of individuals, sex, behaviour (feeding, walking, resting), and GPS location. Where possible, we took high-resolution photographs and documented indirect signs of elephant presence such as dung and footprints. As the study progressed, we noticed visible snare injuries to some elephants' trunks and legs (Fig. 2). Although snares are typically set for smaller game, elephants can become entangled while foraging, indicating ongoing poaching-related harm. As these injuries were not always easily detected in the field, we used high-resolution photographs to create an individual identification database and improve snare injury detection. Identification followed Elephant

Table 1. Summary of five collared elephants inside Murchison Falls Protected Area on 2–3 December 2020. Ages were estimated from photographs for four individuals: the age of one elephant was unknown.

Elephant ID	Group composition at collaring	Approx. age	Snare injuries
Male-3477	Adult male	35–49	Left front leg minor snare scar
Male-3478	Adult male	35–49	None
Female-3479	3 female adults, 1 juvenile	–	Trunk tip missing
Female-3480	3 female adults, 1 juvenile, 1 calf	20–25	Trunk tip missing
Male-3481	Adult male	Late 20s	Trunk tip missing

Voices protocols² using features such as ear notches, body markings, tusk shape and length, and tail morphology. The database continues to expand as part of ongoing monitoring.

To document crop raiding, we trained two local field assistants to conduct regular bicycle patrols in and around the same two focal areas—Kita and Latoro—between January 2020 and November 2021. Patrols occurred three to five days per week, depending on the assistants' household and farming commitments. Given the large area and variable community engagement, we adopted an opportunistic sampling approach: when assistants encountered farmers during patrols, they conducted brief interviews about recent elephant sightings or crop damage. Farmers also contacted the assistants directly to report incidents, and the team responded when possible. Where fields were accessible, we obtained permission to collect data. We used standardized forms to record crop type, estimated damage by percentage (visual), crop stage (seedling, intermediate, mature), crop quality (poor, medium, good), and protective measures (Hoare 1999). Reports also included date, time, location, estimated number of elephants, and presence of calves (as a proxy for family groups). Farmers could add other relevant observations under “other comments”. Separate forms were used for fields with different crops; raids on intercropped plots were recorded as single incidents due to the overlap in damage. GPS-tagged photographs were taken during

visits, and assistants recorded sightings and indirect signs such as dung and footprints.

In December 2020, we fitted five elephants with Savannah Tracking GPS collars. Collaring was conducted by UWA veterinary teams over two days using four vehicles, prioritizing individuals near the northern boundary of MFNP where elephants regularly approach farmland (inside the Park 0.15–15.24 km from the main road; Fig. 1). Three adult males and two adult females from small family groups were collared (Table 1). Four of the elephants showed signs of snare injuries. Collars were programmed to transmit hourly locations from December 2020 to November 2022, balancing spatial resolution with battery life.

Data analysis

We undertook a preliminary descriptive analysis to identify spatial and temporal patterns in elephant movements and crop-raiding incidents. The aim was to provide a foundation for future work that will undertake a more detailed examination. All summary statistics were generated in RStudio (version 2024.04.2). From the ground observation data, we calculated the proportions of male and female elephants recorded outside MFNP, the median group size and the proportion of sightings with visible snare injuries. Estimates of snare injuries were also derived from the photographic identification database.

GPS collar data were mapped and visually examined in QGIS (version 3.34.15–Prizren) to provide an overview of movement patterns. Elephant movement is shaped by environmental features such as water availability, vegetation, topography and tree cover (Mlambo et al. 2024). To investigate these relationships, we compiled relevant environmental

²<https://www.elephantvoices.org/>

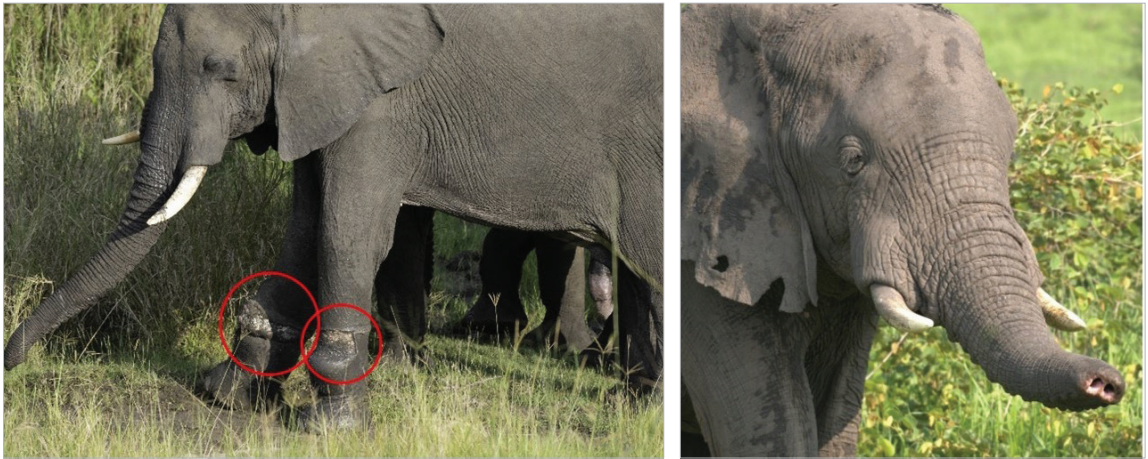


Figure 2. Common snare injuries observed during ground surveys. Left: foreleg wounds (treated by UWA veterinarians, November 2020). Right: partial trunk loss (June 2019). Similar injuries were seen on four of the collared elephants.

shapefiles from open-access sources, including protected areas (National Forest Authority 2007; via DataBasin.org), roads (datashare.ed.ac.uk), 30 m SRTM elevation data, tree cover (via Digital Earth Africa), and waterbodies (global-surface-water.appspot.com). Further details are available from the authors on request.

Minimum convex polygons (MCPs) were generated to delineate the outer boundaries of individual elephant ranges, and kernel density estimation (KDE) was applied to identify core activity areas. For each collared elephant, we calculated the distance from every GPS location to the nearest tree cover, water source, Park boundary (the Gulu–Arua highway), crop-raiding GPS point (used as a proxy for farmland), and the MFNP boundary (with locations inside communities coded as 0) using the Distance to Nearest Hub tool. Elevation values were extracted directly from the elevation raster. To examine seasonal differences, we compared median distances between wet (April–May; August–November) and dry (December–March; June–July) seasons in 2021, the only year with complete data for four elephants. We also compared elephant movements and the frequency of crop raiding with rainfall patterns and local farming calendars. Seasonal MCPs were also generated to assess variation in overall range use.

Outside MFNP, we analysed distances of collar locations to trees, water, and crops. Crop distance calculations were based on recorded

raiding sites collected during field surveys, rather than a comprehensive farmland layer, and therefore underrepresent the true extent of cultivated land. Therefore, we restricted the analysis to GPS points located within identified crop-raiding zones, where farmland presence was confirmed. For this component, we used the full collaring dataset ($n = 1,608$) rather than 2021 alone ($n = 507$) to increase sample size. We further limited the analysis to the two elephants (Female-3480 and Male-3481) that contributed most GPS locations outside the Park.

To examine crop-raiding patterns, we calculated monthly incidents in the Kita and Latoro zones, the proportions of incidents by crop type, crop stage, and crop quality, and the median number of elephants (including calves) involved. The total area of crops damaged was derived from reported land size and percentage damage. We also estimated the proportion of farmers who reported using protective measures such as lighting fires and constructing fences).

Results

Crop raiding

We collected 733 crop-raiding forms between January 2020 and November 2021 (Fig. 3) These reported 885 instances of crop raiding including 117 cases involving multiple crops, with damage to 988 ha (23% of the cultivated area). The number of incidents declined from 507 in 2021 to 207 in 2020. Thirty types of crops were raided, with most

incidents affecting intermediate-stage crops and some regional variation in damage extent (Table 2; Fig. 3). Damage ranged from <1% to total crop loss, with a median of 30%. The distribution was right-skewed: 42% of farms lost <21%, while 25% lost >50%. Farmers reported a median of four elephants per raiding group, with the largest group comprising up to 30 individuals, and calves were present in approximately 20% of events. Most crop-raiding incidents (98%) occurred at night with a pronounced peak ($n = 353$; 48%) between 21:00 and 23:00. Raiding events peaked in June–July

and October–November in both 2020 and 2021 and were rare during the planting season (March–April) (Fig. 4). Although most crops are dormant during the January–February dry season, long-maturing crops remain vulnerable, with 51 raids on cassava and sweet potatoes recorded during this period in 2021. Correspondingly, 19% of collaring points in January–February 2021 fell within community areas (mostly for Male-3481) (Fig. 6 below). Only 68 informants (9%) reported taking preventive measures to deter elephants before an incursion occurred. These included lighting fires (30 records), using dogs to raise the alarm (13), constructing

Table 2. Summary information from the crop raiding forms.

Summary information		Western region		Eastern region		Total	
		No.	%	No.	%	No.	%
Crop raiding forms submitted	Forms submitted	332	45	401	55%	733	100
	Records ^a	414	47	471	53	885	100
	Intercropping records ^a	83	20	57	12%	140	100
Top crops damaged ^b	Maize	129	26	82	15	211	20
	Cassava	170	34	19	3	189	18
	Rice	7	1	135	25	142	14
	Groundnuts	33	7	71	13	104	10
	Sweet potato	27	5	69	13	96	9
	<i>Simsim</i>	43	9	21	4	64	6
	Cotton	39	8	-	-	39	4
Crop age ^c	Mature	135	41	167	41	302	41
	Intermediate	175	53	218	53	393	53
	Seedling	20	6	24	6	44	6
Crop quality ^c	Good	187	57	148	36	335	46
	Medium	119	36	251	62	370	50
	Poor	23	7	9	2	32	4
Land size (ha)	Median	2.5	-	2.5	-	2.5	-
	Maximum	14.8	-	247.1	-	247.1	-
Area damaged (ha)	Total	356.7	-	641.1	-	997.8	-
	Median	0.74	-	0.49	-	0.61	-
No. of elephants per raid	Median	5	-	4	-	4	-
	Maximum	30	-	20	-	30	-
Forms reporting calves present	Total	21	6	127	32	148	20

^aWhen raids on multiple crops were reported on a single form these were recorded as separate instances if they occurred in distinct plots. Otherwise, they were recorded as a single “intercropping” raid.

^bCounts of the number of crops were drawn from all records, since a single form could include more than one crop type.

^cData on crop age and quality calculations exclude intercropping records, as well as records with missing or unknown responses.

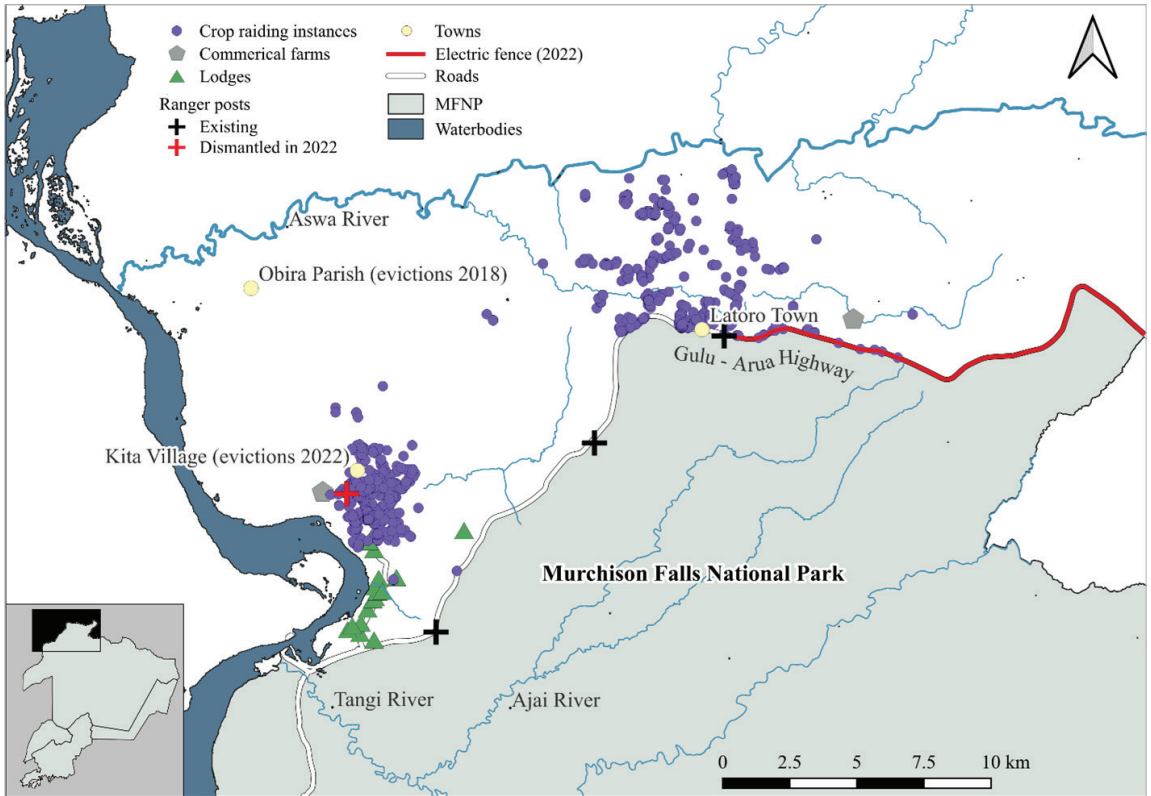


Figure 3. Instances of crop-raiding within reported in the study area between January 2020 and November 2021.

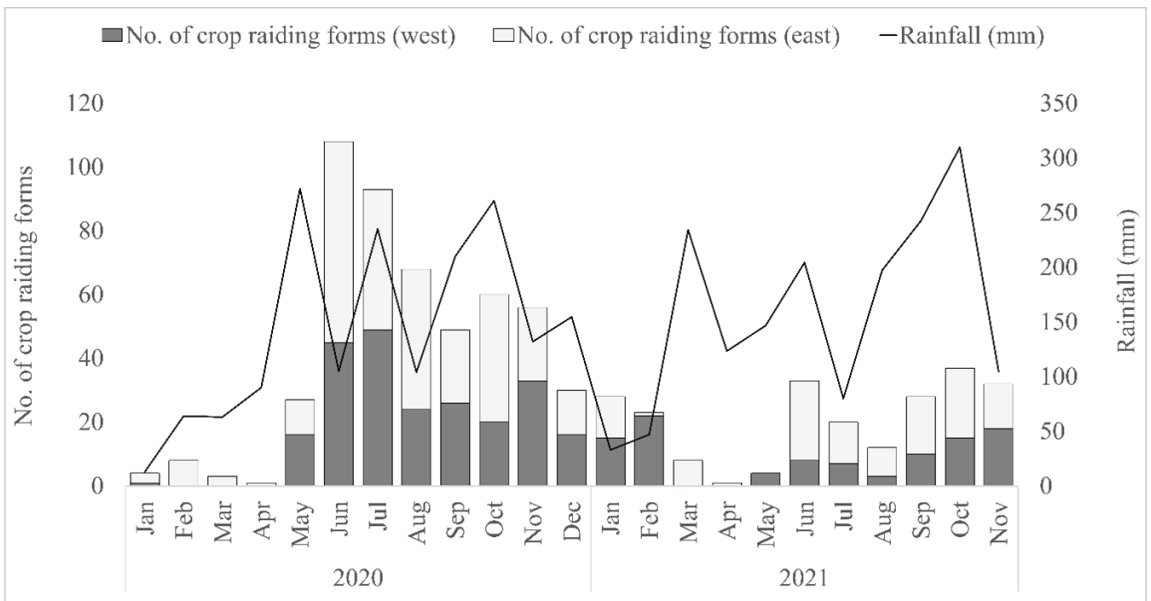


Figure 4. Monthly numbers of crop-raiding reports from communities adjacent to MFNP in the western (Kita Village) and eastern (Latoro Town) regions, 2020 to 2021. Rainfall data were obtained from Agriserve Ltd.

fences (8), burning dung or tyres (7), sleeping or guarding in fields (5), using smelly repellents (3), torches (1), and scarecrows (1). However, most households, (96%), households relied on reactive responses once elephants were already present, typically chasing them away, flashing torches, throwing stones, or, occasionally, scare shooting by UWA rangers. During the peak raiding periods, vuvuzelas were frequently heard throughout the night around Kita Village. Farmers who did not chase elephants cited reasons such as being unaware of their presence (asleep, not heard due to rain, or away from home), fear, or “lack of effort”.

Elephant ground surveys and collaring

Of the 1,131 ground-based elephant observations recorded either within community areas (50%) or just inside the Park near the Gulu–Arua highway boundary (median distance 100 m, maximum 1 km), 90% involved males. The number of elephants sighted ranged from 1–24 (mean = 5) individuals. Snare-related injuries were observed in 132 cases (12%), and photographic identification of 38 elephants showed that 12 (32%) had visible trunk injuries, likely caused by wire snares.

Transmission durations of collared elephants varied among individuals, with the shortest lasting 129 days (Male-3477, ending April 2021) and the longest continuing until November 2022 (Male-3477 and Female-3480; Table 3). The home ranges of the five collared elephants (Fig. 5a) ranged from 309–883.5 km², with total movement distances of 2,165–3,528 km and 0–24% of GPS points outside the Park (Table 3). Collar tracks from five elephants revealed concentrated activity around the Tangi River in the northwest, the Nile Delta in the southwest,

and along the shorelines of the Nile (Fig. 5a; 5b). Field and satellite observations confirmed that the Tangi hotspot is characterized by availability of water sources, wetlands, low terrain, and extensive *Borassus* and acacia woodland (Fig. 5b). Evidence of elephants’ seasonal use of *Borassus* palm fruits (January–April) was provided by photos from the field showing dung containing palm seeds, supporting the hypothesis that the presence of these palms attracts elephants to the Tangi River area. Multiple movement paths linked the Delta to the Tangi River, suggesting goal-directed movement and possible corridor use, although Male 3481 and Female 3480 stayed mainly within the Tangi area. Elephants generally remained within the north-western section of the Park, with few excursions into the central sector, which may be linked to the rise in elevation from the west near Lake Albert toward the Park interior (600–1,000 m).

Elephants displayed different median distances to water, tree cover and the MFNP boundary, as well as elevation. Distances to trees and water were strongly right-skewed, with annual median and maximum distances, respectively, of 91.2 and 2,729.5 m to trees, and 184.0 m and 952.1 m to water, but seasonal variation was minimal, with median values differing by less than 45 m between wet and dry seasons. Elevations ranged from 619–891 m (median 648 m), with no difference between wet and dry seasons (Table 4).

For elephant movements outside the Park, most data were derived from two individuals—Male-3481 and Female-3480—who together accounted for 92% of all GPS locations recorded beyond MFNP. Their movement patterns contrasted sharply in both seasonality and extent (Fig. 6). Female-3480 had the largest home range (884 km²; Table 4) and travelled furthest from MFNP (21.1 km straight-line distance), crossing the Aswa River twice in 2021 (26 May–1 June; 17 November–1 December), with a third attempted

Table 3. Home ranges and movements of collared elephants

Elephant ID	Days collared	Points outside MFNP	Home range in 2021 (km ²)	Distance travelled in 2021 (km)
Male-3477	129	228 (8%)	-	-
Male-3478	725	150 (1%)	673	2,938
Female-3479	674	16 (0%)	309	2,165
Female-3480	725	3,393 (24%)	884	3,528
Male-3481	637	1,248 (9%)	388	2,883

crossing in August 2022 (Fig. 5a). She spent more time outside the Park during the wet season (26.1%) than the dry season (2.2%), and during peak crop-raiding months (19.2%) compared to non-raiding months (9.1%). In contrast, Male-3481 had a smaller home range (388 km²) and spent more time outside the Park in the dry season (15.6%) than in the wet season (2.7%). He also used farmland differently, with slightly more time outside in non-raiding months (10.1%) than in crop-raiding months (8.2%). At the diel scale, collared elephants spent similar times in community areas during the day (48%) and night (52%). However, for the two elephants that ranged furthest into community land, distances to environmental features showed a clear day–night shift (Fig. 7). Male-3481 remained close to trees

(57 m) and water (75 m) while avoiding crops (505 m) during the day, but after 19:00 moved sharply towards cropland, with distances to crops dropping to ~61 m around midnight as distances to trees and water rose to >250 m. Female-3480 showed the same pattern but less markedly: daytime distances to crops averaged 408 m but declined steadily after dusk to 144–178 m between 22:00 and 04:00, while distances to trees and water increased during the night.

Discussion

Key findings on elephant movements

Movements recorded from GPS-collared elephants varied considerably among individuals, as is typical in studies with small sample sizes. Nevertheless,

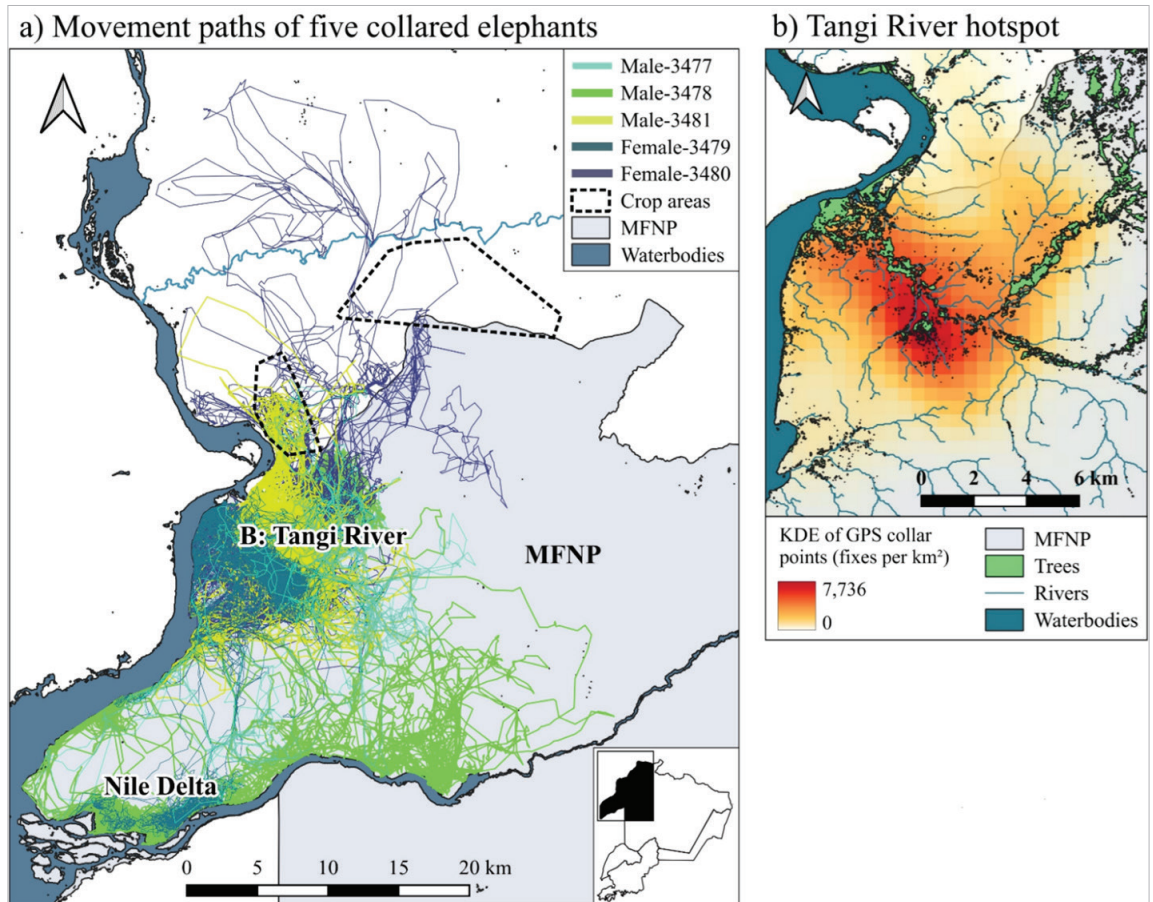


Figure 5. GPS location data for five elephants collared in December 2020. (a) Movement paths in and around MFNP and crop-raiding areas. (b) Kernel density estimation (KDE) analysis (0.5-pixel, 2-kernel radius) of a hotspot of elephant activity near the Tangi River.

Table 4. Summary of elephant GPS data comparing wet and dry season movements within and around MFNP in 2021.

Elephant ID	Median distances			Movement range (km ²)	Median elevation (m)	Points outside MFPA	
	Trees (m)	Water (m)	MFNP boundary (km)			No.	%
<i>Wet season</i>							
Male-3478	48	173	20	567	636	31	0.7
Male-3481	112	200	4	209	650	119	2.7
Female-3479	118	192	20	298	638	6	0.1
Female-3480	101	203	3	842	666	1,132	26.1
Total	94	191	7	1,375	647	1,288	7.3
<i>Dry season</i>							
Male-3478	41	173	19	667	654	0	0.0
Male-3481	75	156	3	247	647	673	15.6
Female-3479	140	200	5	217	646	0	0.0
Female-3480	105	177	5	620	649	93	2.2
Total	88	176	5	1,391	648	766	4.4

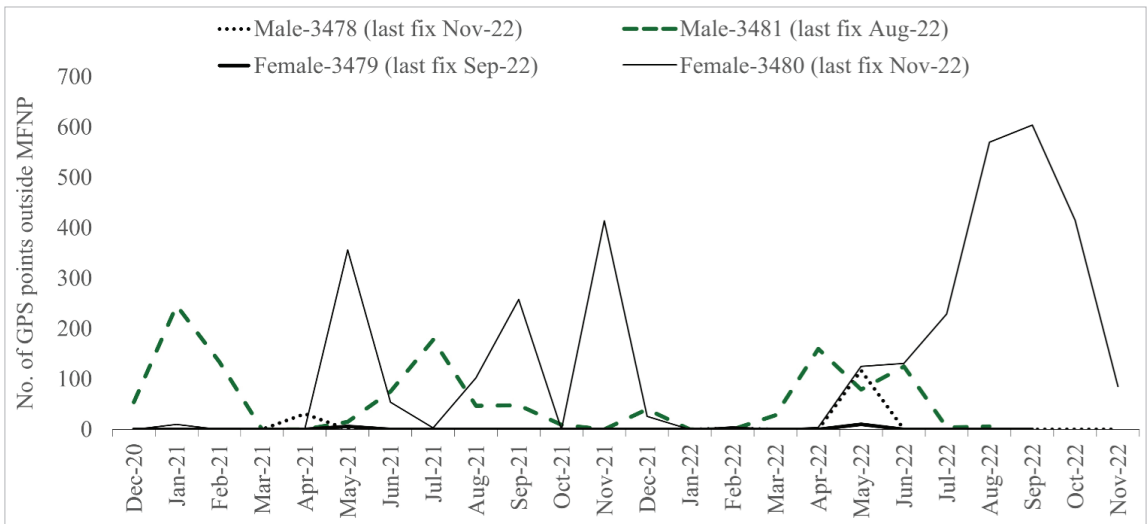


Figure 6. Monthly GPS-collared elephant locations within the community areas.

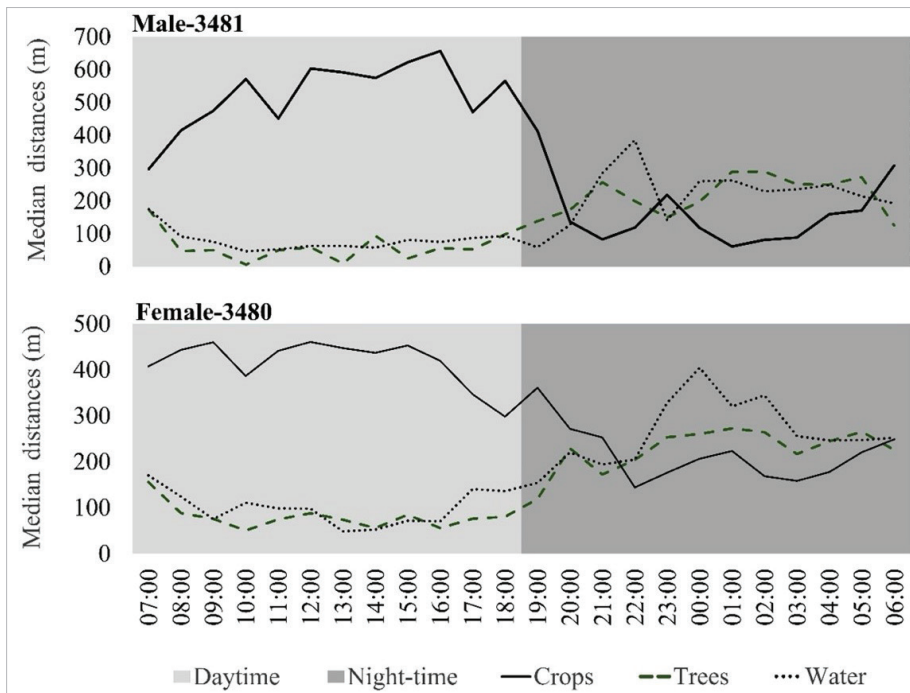


Figure 7. Median hourly distances to trees, water, and crops for two collared elephants within crop-raiding zones outside MFNP ($n = 1,608$).

movement patterns broadly matched earlier findings for MFNP and other studies of crop-raiding elephants (Graham et al. 2010; Wilkie and Douglas-Hamilton 2018; Grogan et al. 2019). Elephants remained closer to water and tree cover by day and shifted towards croplands at night, with minimal seasonal change, which is consistent with year-round water availability. Limited use of the central and eastern sectors of MFNP likely reflects rising elevation and topographic constraints on movement (Wall et al. 2006). Female-3480 had the largest home range, contrary to expectations of wider male ranging (Duffy et al. 2011). This may reflect the small sample size, but is compatible with mixed evidence reporting either larger male ranges or no sex-based difference (Grogan et al. 2019; Shannon et al. 2006). At the diel scale, collar data indicated that elephants spent comparable time outside the Park by day and night, and ground observations confirmed frequent daytime incursions by males. These results suggest that use of community lands is not solely driven by raiding but also by foraging on non-crop resources (such as the *Borassus* palms and

other riverine woodland outside the Park). Future work will develop more detailed spatial models of elephant movements, incorporating additional covariates such as *Borassus* palms, whose fruits are dispersed by elephants. We noted many mature and newly established palms but few mid-aged trees, perhaps reflecting reduced seed dispersal during the elephant population collapse of the 1970s–1990s. *Borassus* also appears to be expanding in parts of the Park, which may be linked to elephants now being more spatially constrained compared to the past. A more detailed ecological study is needed to confirm these patterns.

Key findings on crop raiding

Crop raiding in our study was predominantly nocturnal and peaked in June–July and October–November, aligning with the main farming seasons and interview-based accounts (Alfred 2014). These months coincide with peak crop value, both nutritionally and economically. The two growing seasons and presence of long-maturing staples such as cassava and sweet potatoes expose communities to sustained pressure from raiding across much of the year. Although other studies report a preference for mature crops (Adjewodah

et al. 2005; Chiyo et al. 2005), elephants in our study also targeted crops at intermediate growth stages. One explanation is that guarding effort by farmers may be lower at these stages (Tiller et al. 2021). Another is that elephants, which we observed outside the Park during the day, may monitor crop availability and raid as soon as crops become edible. Our surveys also showed that raids involved both males and family groups. This contrasts with expectations that males raid more as part of risk-taking behaviour to maximize reproductive success (Chiyo and Cochrane 2005), whereas females avoid community areas because of risks to themselves and their calves (Sukumar and Gadgil 1988). Crop raiding by mixed groups has, however, been reported elsewhere (Tiller et al. 2021). Further collars and camera traps are needed to clarify group composition in this landscape.

Farmer responses were largely reactive, involving noise, lights, and chasing, consistent with other studies (Mackenzie and Ahabyona 2012). Preventative deterrents were rarely used (e.g. fences, smelly repellents), likely due to cost or lack of knowledge. Reactive tactics rarely stopped damage; instead, they often pushed elephants back and forth between farms, creating a kind of ‘elephant pinball’ that increased stress for both farmers and elephants. Consequently, most farms still suffered losses, with the majority experiencing less than 20% damage, consistent with similar studies (Adjewodah et al. 2005). However, the impacts of even such modest losses can be severe for small farmers relying on cash crops to earn a living. Finally, the lower number of reports in 2021 most likely reflects research fatigue rather than reduced raiding. Several respondents stated that people would cease volunteering without tangible support, citing previous NGO activities that provided little benefit to communities. This underscores the need to pair monitoring with practical support, which we now discuss.

Implications for management in a changing landscape

Two cropping seasons expose communities near MFNP to crop raiding for much of the year. Mitigation must therefore deliver year-round deterrence while remaining financially viable and preserving habitat connectivity. Preliminary evaluation of the 44 km Latoro Town fence

indicates a reduction in crop raiding (Luwaga 2025). However, extending fencing along the entire boundary would be costly, restrict wildlife movements, and risk both stranding elephants outside the Park and increasing densities inside to unsustainable levels, requiring renewed culling (Laws et al. 1970). Alternatively, UWA could deploy targeted electric fencing and trenches in community lands in the western and eastern farming zones, while maintaining a central corridor to retain historic movements from the Park northwards. Re-establishing a corridor to East Madi Wildlife Reserve (c. 70 km) is unlikely in the near term, but a shorter corridor to the Aswa River (c. 12 km) offers a pragmatic starting point.

Funding could draw on corporate social responsibility partnerships with oil companies (notably Total Energies and the China National Offshore Oil Corporation), tourism revenues, and NGO support, with resources ring-fenced for maintenance, monitoring, and community engagement. Community-led arrangements could further strengthen implementation. UMOJA is a grassroots initiative that works with private landowners to integrate conservation and livelihoods³. In a facilitation role, UMOJA could support inclusive consultations, design benefit-sharing frameworks, and develop lodge partnerships for tourism, while building local support for conservation through education (Gessa et al. 2024). However, re-establishing a corridor raises ethical concerns, as restricting land access in a region marked by displacement risks reinforcing past injustices. A detailed feasibility and ethical assessment would therefore be essential before implementation. The assessment should be undertaken swiftly before further land conversion forecloses the corridor option.

While broader debates over fencing and corridors continue, immediate support for communities adjacent to MFNP is essential. Our data show that most households lacked preventive measures and relied on reactive tactics such as chasing or shouting, which were ineffective and dangerous. Farmers often acted individually rather than collectively, driving elephants between fields and increasing risks at night. We recommend providing training and equipment for collective guarding, alongside expanded community scout programmes under UWA’s leadership. Options include lookout towers, alarms, and low-cost tools such

³<https://umojaconservancies.com/>

as vuvuzelas and bangers, which can be effective when used cooperatively (Guerbois et al. 2012). Existing tools, such as the *Human–Elephant Coexistence Toolbox*⁴ could be presented directly to communities, enabling them to select measures they are willing and able to adopt (Montgomery et al. 2022). This is crucial in a region marked by long years of exclusion from participation in management and the legacy of displacement. In March 2022, for example, all residents of Kita Village were evicted for a foreign-owned soybean plantation, and the dismantling of the ranger post has left neighbouring communities even more exposed to crop raiding. With partial protection now provided by electric fencing in Latoro Town, attention should shift to remaining communities in the Kita area and further north, focusing on the adoption of preventive strategies before elephants expand further.

Conclusion

This study examined elephant movements in and around northern MFNP and assessed the extent of crop raiding in neighbouring communities. The findings align with patterns reported elsewhere: elephants concentrated near water and tree cover, and at low elevations, shifting towards farms at night. Raiding began as soon as crops became edible, facilitated by the regular presence of elephants in community lands, which allowed them to monitor availability. Movements outside the Park were not confined to crop raiding; elephants also entered farmland during non-peak seasons and in daylight, suggesting they were seeking non-crop resources such as trees and browse. These resources are being increasingly reduced by deforestation, which may further intensify crop raiding. With crops maturing across much of the year, households are under sustained risk from crop raiding with limited deterrents. Such pressures may drive households toward coping strategies such as charcoal production or poaching, reinforcing cycles of poverty, deforestation, and conflict.

Balancing elephant conservation with community needs and an increasing population

remains a central challenge. We make three recommendations. First, reduce wire-snare poaching, which causes serious injuries to elephants and other wildlife. Detection could be improved by using machine learning to map high-risk areas, guiding patrols more effectively, and deploying practical aids like snare-detecting dogs. Ground-penetrating radar may help, though cost and field conditions are major constraints (Feldmeier et al. 2025).

Secondly, investment is needed to support frontline communities in the west, especially near Kita Village, where recent evictions leave both the remaining residents and neighbouring communities to the north more exposed to elephants. Training in elephant deterrence and crop protection, together with scout programmes and equipment, could strengthen collective capacity to reduce damage and risks. Thirdly, a feasibility study should evaluate whether land between the western and eastern raiding zones could be retained as a managed corridor or wildlife tourism area. This assessment should focus initially on maintaining connectivity up to the Aswa River. It would need to address resident populations, land tenure, and the practicality of fencing or trenches, alongside financial, ethical, and ecological considerations. Adopting electric fencing as the sole strategy could cause permanent loss of elephant habitat outside the Park. The resulting concentration of elephants within MFNP could accelerate woodland degradation compel UWA to reconsider measures such as culling.

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⁴<https://ste-coexistence-toolbox.info/en/>

former Chief Warden of MFNP and Kibale NP; Dr Ronald Clarke, Rutgers University; and Tito Dal Lago, Doctors with Africa CUAMM. Their support and insights are still deeply valued.

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