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SHORT COMMUNICATION

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# Are elephants attracted by deforested areas in miombo woodlands?

Paola C. Amaya[1] | Marie Nourtier[1] | Frédérique Montfort[1,2,3] | Alessandro Fusari[4] | Telina Randrianary[5] | Emmanuelle Richard[4] | Thomas Prin[4] | Hugo Valls-Fox[6,7]

[1]Nitidæ, Montpellier, France
[2]Forêts et Sociétés, CIRAD, Montpellier, France
[3]Forêts et Sociétés, Univ Montpellier, CIRAD, Montpellier, France
[4]François Sommer Foundation, Paris, France
[5]Nitidæ, Antananarivo, Madagascar
[6]UMR SELMET, CIRAD, Montpellier, France
[7]SELMET, INRAE, CIRAD, Univ Montpellier, Institut Agro, Montpellier, France

**Correspondence**: Marie Nourtier, Maison de la télédétection, 34 000 Montpellier, France.
Email: m.nourtier@nitidae.org

Hugo Valls-Fox, Route du Front de Terre, Dakar, Sénégal.
Email: hugo.valls-fox@cirad.fr

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Nitidæ

## 1 | INTRODUCTION

Protected areas (PAs) are often the part of larger ecosystems and their establishment can leave areas of ecological importance beyond their limits (DeFries et al., 2007). Human pressure and land-use change are well-established causes of wildlife decline (Ripple et al., 2015), mainly resulting from habitat loss and fragmentation.

Interactions between wildlife and people living around PAs are influenced by social and ecological factors such as access rights to land by PAs and local communities, and the impact of human activities on habitats and wildlife behaviour (Laudati, 2010). For instance, in Southeast Asia, camera trap surveys revealed deforestation for agriculture inside a PA had confined large mammals to small patches of remaining forest (Kinnaird et al., 2003) whereas in a selectively logged forest on Borneo, some large mammals, including elephants, were only found in areas where forests had been logged (Brodie et al., 2015). Regenerating forest patches have been identified as key habitats for Asian elephants (Sitompul et al., 2013) and possibly African forest elephants (Barnes et al., 1991).

In Africa, small-scale subsistence agriculture remains an important driver of deforestation (Curtis et al., 2018; Hosonuma et al., 2012) and can be a main cause of habitat loss for wildlife. However, the livelihoods of people living around PAs can also be affected by wildlife damaging their crops (Peterson et al., 2010). In Mozambique, crop-raiding by elephants is widespread (Dunham et al., 2010) and perceived as a major concern by local communities (De Boer & Baquete, 1998). The drivers of crop-raiding are complex to disentangle, elephants usually avoid populated areas and farmland (Galanti et al., 2006), so isolated fields within a savannah or forest matrix are more susceptible to crop-raiding (Pittiglio et al., 2014).

In Gilé National Park (GNAP), a population of around 50 African elephants (*Loxodonta africana*) (Macandza et al., 2017) has remained since the population was decimated by hunting in the early 1970s (Ntumi et al., 2012). Yet, crop destruction by elephants affects part of the communities that settled around the park after the civil war ended in the 1990s and where small-scale agriculture is currently the main activity for 89% of the population (Etc Terra, 2017). Indeed, some farmers of a small village in the periphery of the park were recently affected by crop-raiding by elephants and moved their fields to the other side of the road (Etc Terra, 2017).

Nourtier and Valls-Fox should be considered as senior authors

  

Fields are harvested at the end of the rainy season or beginning of the dry season and farmers use slash and burn agriculture with a cycle of 3 years of cultivation followed by 3–10 years of fallow during which the miombo woodland regenerates until a new slash and burn, cultivation cycle (Etc Terra, 2017). As a result, yearly fires are frequent in the miombo woodland, mostly caused by the uncontrolled preparation of land for agriculture or hunting (Frost, 1996). In GNAP, the entire park burns every year effectively removing understory vegetation, mostly at the middle or end of the dry season when slash and burn are practised. To reduce the intensity of fires later in the dry season, 'cold' fires are ignited at the beginning of the dry season as they are not as destructive for trees and seldom affect the canopy (Etc Terra, 2017; Ryan & Williams, 2011).

The slash and burn practices have generated patchworks of forest, cultivated clearings and regenerating woodland at different stages of regrowth along the buffer zone of GNAP (Montfort et al., 2021). In 2019, nearly half of deforested patches were no longer cultivated and were covered by dense regenerating miombo vegetation (F. Montfort pers. obs.) suggesting natural vegetation rather than agricultural fields may have been attracting elephants outside GNAP.

The aim of this study was to identify potential mechanisms explaining the excursions of elephants outside GNAP. We hypothesised elephants were attracted by deforested patches around the boundary of GNAP. Our analyses distinguished recently deforested patches (assumed to be fields) and older deforested patches (assumed to be regenerating woodland). Indeed, although crop-raiding by wildlife and the impact of deforestation on wildlife have been extensively studied, the role of regenerating vegetation on resource selection has received much less attention. The use of small, scattered, deforested patches or fields (crop-raiding) needs to be analysed at the scale of the animal's behaviour (Manly et al., 2004). For example, crop-raiding elephants spend very little time in fields (in our case it was ~3% of their time) so fields will not appear clearly in home range metrics such as utilisation distributions (Benhamou, 2011). To estimate the selection of deforested patches, we followed an approach similar to the one used by Valls-Fox et al. (2018) to assess the importance of waterholes in large herbivore movement patterns: We used Step Selection Functions (SSF) (Fortin et al., 2005) that calculate selection strength at the spatiotemporal scale of a foraging bout.

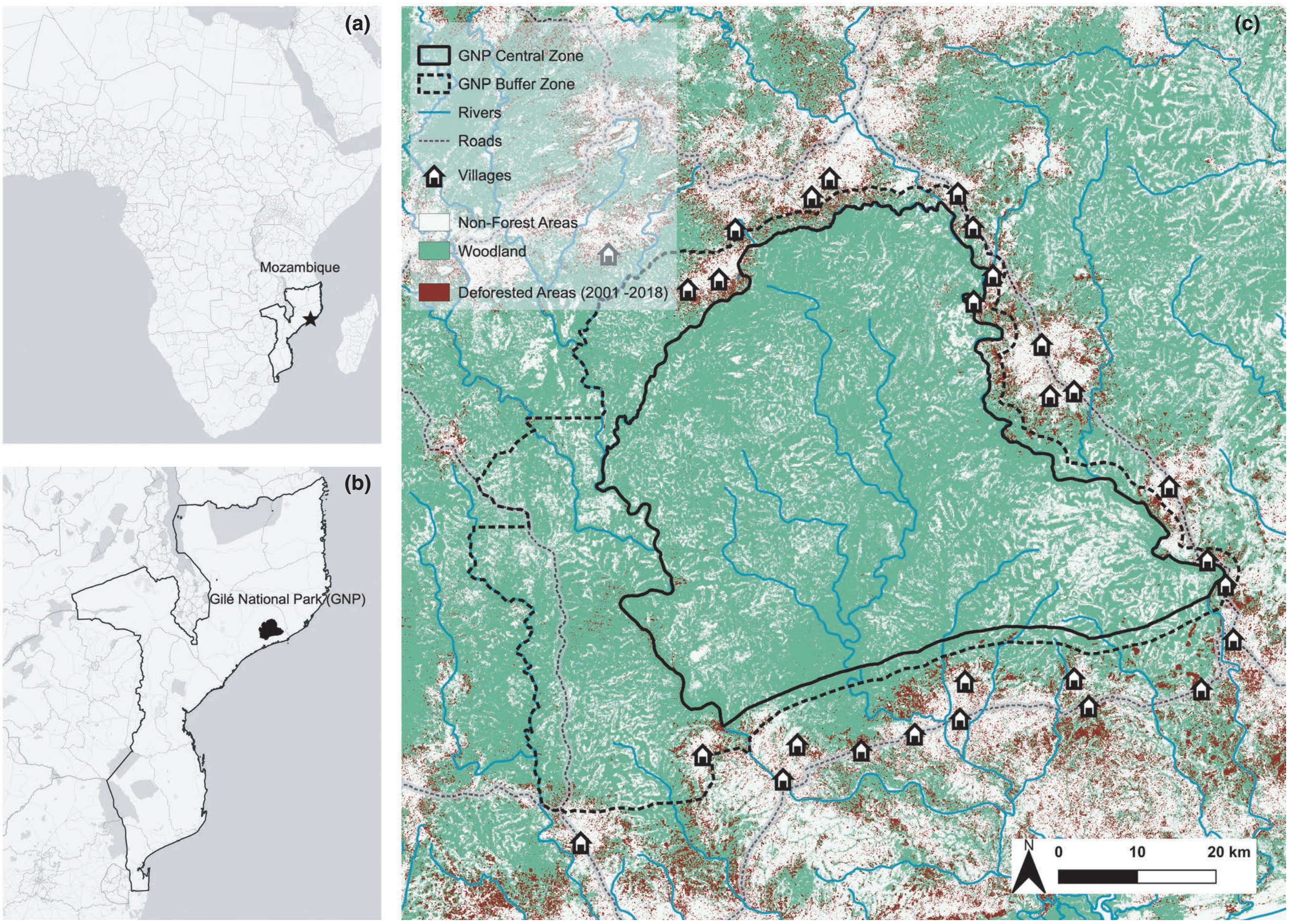


FIGURE 1 Map of Gilé National Park in Mozambique (Hansen et al., 2013; Mercier et al., 2016). (a) Mozambique is in Southeast Africa (b) Gilé National Park in Mozambique (c) Gilé National Park and surrounding areas

## 2 | METHODS

### 2.1 | Study site

The study was conducted in Gilé National Park, Mozambique. GNAP has a total area of 4,532 km$^2$, divided between fully protected core area (2,861 km$^2$) and a buffer zone (1,671 km$^2$) (Figure 1). A total of 32,000 inhabitants live around GNAP. Between 2005 and 2016, about 3,900 ha of forest were cleared each year for agriculture in the buffer zone (Etc Terra, 2017).

The tropical climate comprises a well-defined wet period between November and April and a dry period from May to October (Frost, 1996). Annual average rainfall is around 800–1,000 mm. The landscape of GNAP consists of a miombo woodland (67%) with continuous 10–20 m high tree cover (Montfort et al., 2021; White, 1983) and low nutrient quality for both woody-plant and grass leaves (Frost, 1996) (Figure 2). Within this forest matrix, 30% of the land cover is composed of edaphic grasslands that are often flooded during the rainy season (Chidumayo, 1997). Miombo woodland understory vegetation is scarce, it can be found along the few perennial rivers (3% riparian forests) and in post-cultivation regenerating woodland (0.3%) (Montfort et al., 2021). Around the park, vegetation is a mosaic of small fields (<1 ha each), patches of regenerating woodland and open wooded savannahs that have lost their capacity to regenerate miombo woodlands (Figure 2).

### 2.2 | Elephant monitoring and data collection

Three GPS collars (Africa Wildlife Tracking, South Africa) were initially deployed in 2014 and three new collars were deployed to replace them in 2016. In October 2014, two adult females (F1 and F2) and one adult male (M1) were collared. In July 2016, only one female was recollared (F1) and another female (F3) and one male (M2) were collared for the first time because F2 and M1 were not found. Collars were set to record one location every 4 h (Table 1).

Statistical analyses were conducted separately: from October 2014 to September 2016 for F1, F2 and M1 and from September 2016 to February 2019 for F3. F1 was not included in the second period, she was illegally killed in the south-east of the park on the 11th of September 2016. M2 was removed from the analysis due to the short duration of the data set (<8 months), which did not allow us to study seasonal patterns. In total, 14,250 GPS fixes were used in this study.

### 2.3 | Data analysis

#### 2.3.1 | Habitat selection

Home ranges were estimated by 95% utilisation distributions using the biased random bridge method (Benhamou, 2011) with *adehabitatHR* R package (version 0.4.15 in R 3.5.3). Resource selection (Manly et al., 2004) was estimated by SSF (Fortin et al., 2005). For each observed step, 10 control steps were generated with the same starting point but different length and angle using the *rdSteps* function from the *hab* R package (version 1.20.4 in R 3.5.3). The maximum length of control steps was set at 6,078 m (95% quantile). Random steps were sampled within a buffer of 2 km from the 100% Minimum Convex Polygon using *adehabitatHR* R package.

### 2.4 | Landscape predictor variables

Deforested patches were identified with the Global Forest Change map, based on Landsat data with a spatial resolution of 30 m, which

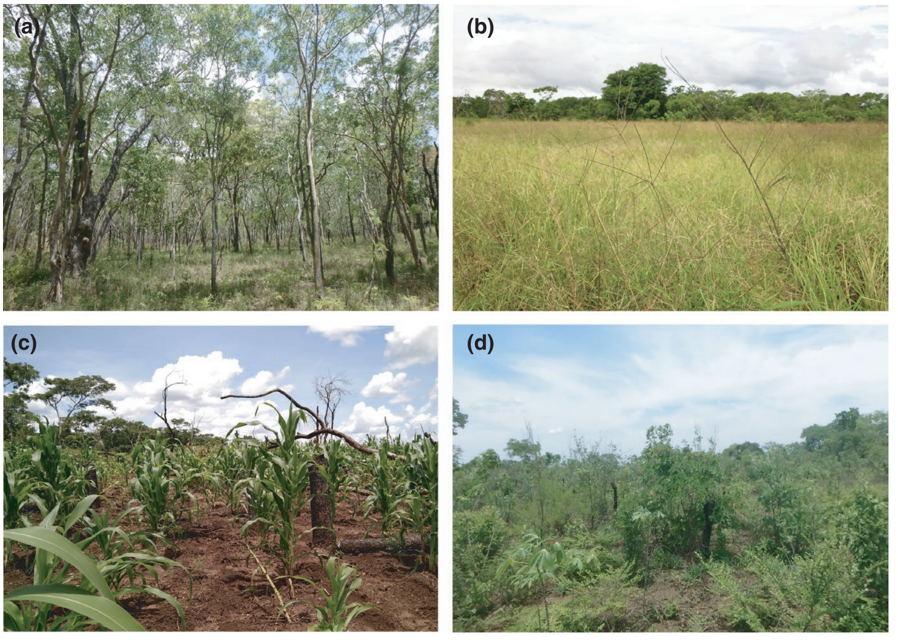


FIGURE 2 Vegetation types in Gilé National Park and its periphery (Montfort, 2016). (a) miombo woodland inside Gilé National Park (GNAP), (b) non-forest areas in GNAP and its periphery, (c) recently deforested patch (field) around GNAP and (d) older deforested patch (regenerating woodland) after slash and burn agricultural practices around GNAP. Photographs M. Nourtier ©

**TABLE 1** Details on the elephants collared and used in the study

| Id | Sex | Age | Data collection Start | Data collection End | Number of months | Number of points | Success rate (%) |
|---|---|---|---|---|---|---|---|
| F1 | Female | Adult | 3/10/14 | 11/09/16 | 24 | 3,413 | 80 |
| F2 | Female | Adult | 5/10/14 | 4/06/16 | 20 | 1,996 | 55 |
| F3 | Female | Adult | 9/07/16 | 11/02/19 | 32 | 5,154 | 90 |
| M1 | Male | Adult | 4/10/14 | 12/02/16 | 17 | 2,210 | 74 |
| M2[a] | Male | Adult | 7/07/16 | 16/03/17 | 8 | 1,477 | 97 |

*Note:* Success rate corresponds to the number of GPS locations that were successfully reported every 4 h divided by the expected number of GPS locations. Further individual characteristics such as specific age for each elephant were not known.

[a]M2 was removed from the data set because we needed at least a full year of data to model seasonal variation.

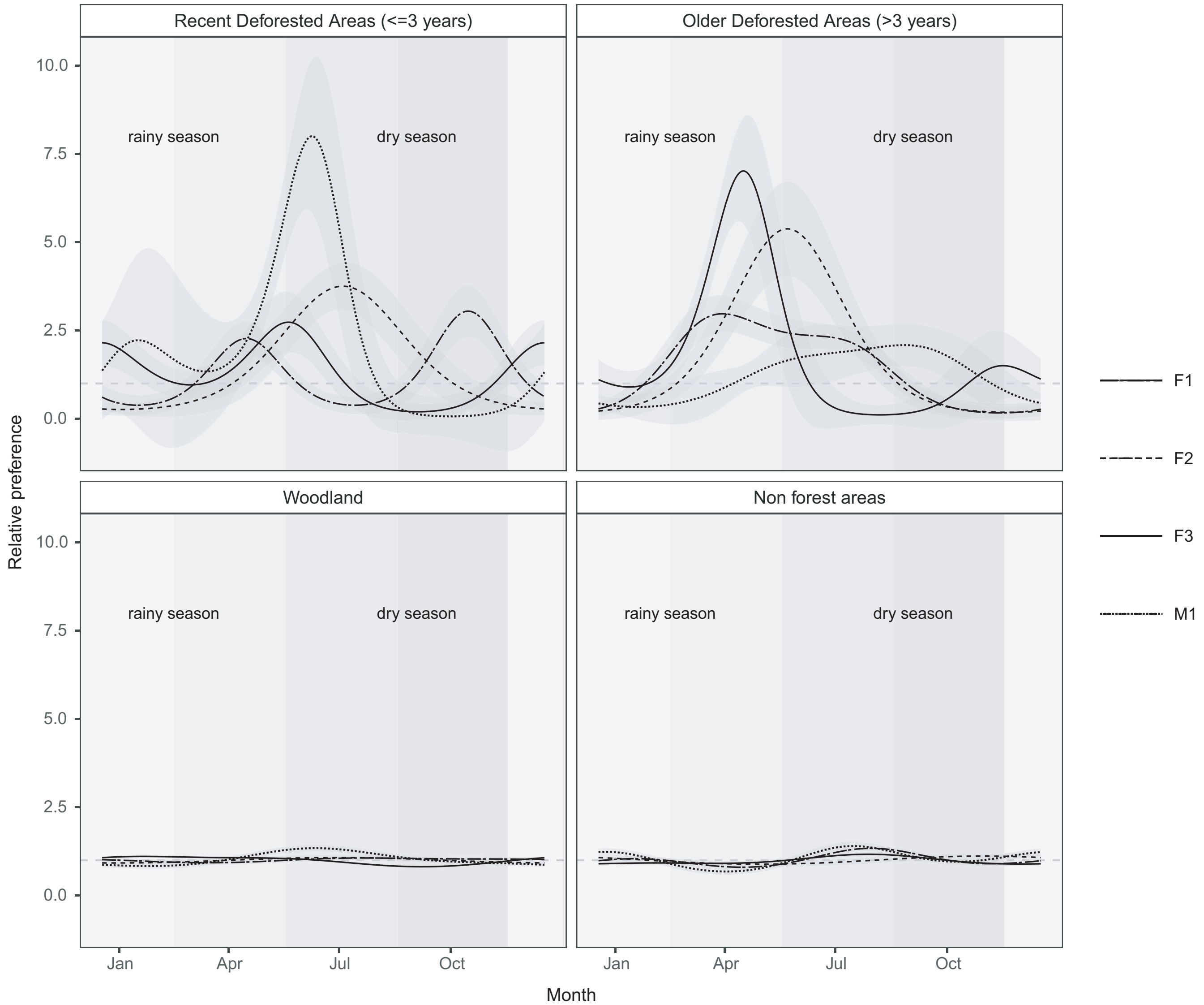


**FIGURE 3** Seasonal variation of selection strength in four habitats by four collared elephants. Continuous and dashed lines represent individual females (F1, F2, F3) and the dotted line corresponds to a male (M1). Grey areas represent standard errors for each prediction. A selection strength higher than one in the *x*-axis corresponds to a preference for a certain type of habitat, a selection strength close or equal to one shows no preference

indicates tree cover loss between 2001 and 2018 on a yearly basis (Hansen et al., 2013). We inferred a given pixel was a recently deforested area (field) if it had been cleared <3 years before or an older deforested area (fallow) if it had been cleared 3–7 years before. In the study area, fields are cultivated for a maximum of 3 years after slash and burn and after this cultivation period, fields are left as abandoned fallow to regenerate and recover their fertility (Montfort et al., 2021). Patches cleared more than 7 years before were excluded from the analysis since they could either be fields or regenerating woodland.

Since Global Forest Change maps only provide percentage tree cover, other pixels were classified either as woodland (tree cover >50%) or non-forest areas (tree cover <50%). Land cover was obtained from the 2016 map of GNAP produced from Landsat satellite images at 30 m resolution (Mercier et al., 2016). Other variables used in the models were proximity to rivers, to roads and proximity to dense forest patches (tree cover >75%). Correlation between variables was tested using the Pearson correlation coefficient, with no significant correlation ($p$-value >0.05).

To analyse how seasonal patterns influenced the selection of environmental variables, we used time-dependent $\beta_i$ parameters (Forester et al., 2009). Movement models were constructed separately for each individual using the *survival* package in R (Coulon et al., 2008; Ziolkowska et al., 2016). A total of 67 models were built and we selected the model with the lowest Akaike Information Criterion.

## 3 | RESULTS

During the study period, the proportion of each elephant's home range outside the geographic boundaries of GNAP ranged from 45% (F2) to 56% (M1). On average, miombo woodland covered 60% of their home range and 37% corresponded to non-forest areas, both of which were used proportionately to their availability in the landscape (Figure 3). Conversely, the SSF showed that elephants strongly select deforested patches (Figure 3). These areas only cover 3% of their home range.

Selection patterns of deforested patches varied according to season and individuals (Figure 3). Seasonal preference for recently deforested patches (fields) was clearest for M1 with a single significant peak in June when crops are harvested. The pattern was similar for F2 with a lower and delayed preference (August). Seasonal patterns are less clear for F1 and F3 with two peaks each during the rainy and the dry season.

All three females preferred older deforested patches (regenerating woodland) during the late rainy season. The level of preference and duration differed between individuals: it was longest but lower for F1 (March–July) suggesting repeated visits to these patches whereas it was greater but briefer for F3 (April–May), suggesting more time spent in these patches during a brief period. The pattern for F2 was in between F1 and F3 with a broader peak from May to July. Finally, selection patterns for M1 contrasted with the females, with a delayed and lower preference for regenerating woodland during the dry season.

## 4 | DISCUSSION

Although miombo woodland is the predominant habitat inside GNAP and deforested patches account for a small percentage compared to this habitat, the SSF revealed a marked selection by elephants of deforested patches at some periods of the year. This preference may explain why elephants spent about half of their time outside GNAP. Differences between individuals (Figure 3) may also reflect environmental variation, indeed F1, F2 and M1 were monitored from 2014 to 2016 whereas F3's dataset covers the 2016–2019 period (Table 1). The drought triggered by the 2016 El Niño event may explain why F3 selected regenerating woodland only during the late rainy season whereas, in previous years, F1 and F2 also did so during the early dry season (Figure 3).

Our results are consistent with previous studies of crop-raiding behaviour by elephants (La Grange, 2016) and reports of crop-raiding by local communities (F. Montfort pers. comm.). Indeed, fields are more likely to be visited at the end of the growing season when the quality of crops supersedes natural vegetation (Osborn, 2004). Elephant bulls have a greater tendency to raid crops than females (Branco et al., 2019; Vogel et al., 2020; Von Gerhardt et al., 2014) as shown by M1's clear preference for recently deforested patches (Figure 3). There is a notable individual variability related to crop-raiding, whereas M1 and F2 selection patterns are compatible with crop-raiding, F1 and F3 patterns are less clear as they do appear to select these patches but no clear seasonal pattern can be discerned (Figure 3).

However, crop-raiding does not explain why older deforested patches, which are no longer cultivated, remain attractive for elephants (Figure 3). There is a broad consensus that agricultural expansion and intensification is detrimental to wildlife due to net habitat loss as well as the direct (e.g. hunting) and indirect effects (e.g. disturbance) of human activities (Ripple et al., 2015). Yet, closed-canopy tropical forests, or mature miombo woodlands with little or no undergrowth, provide few foraging opportunities for large herbivores. Understory vegetation is important for elephants throughout their range. In Laikipia, Kenya, 70% of plants found in the elephant diet correspond to understory vegetation (Coverdale et al., 2016) and low-structure forests are important habitats for elephants in Borneo (Evans et al., 2018).

Studies on the regeneration of miombo in GNAP show that species composition and woody vegetation structure (density, tree height) differ between regenerating and mature miombo patches (Montfort et al., 2021). Unfortunately, we lack data on elephant diet in GNAP to evaluate the suitability of GNAP for elephants from a foraging perspective. Patches of regenerating woodland are nevertheless likely to be key habitats where elephants can maximise their energy intake from foraging (Bischof et al., 2012) and take cover in the dense vegetation (Barnes et al., 1991; White, 1994).

Several factors such as fire frequency and low herbivore density may explain the lack of attractiveness of GNAP. The uncontrolled yearly fires that sweep through GNAP negatively impact the understory (Etc Terra, 2017; Fusari et al., 2010), and may reduce the availability of palatable grasses and shrubs. Understory vegetation is the main source of food for elephants, it can be positively affected by elephant browsing (Coverdale et al., 2016). The extirpation of many herbivore species and the low densities of remaining species due to colonial and post-colonial hunting may have increased tree cover and the proportion of miombo woodland in the landscape as in Gorongoza National Park (Daskin et al., 2016).

Our analysis suggests that recently and older deforested patches may be one of the factors attracting elephants outside GNAP in human-dominated landscapes. However, the limited quality of GPS data available for this study and small size of deforested patches make it difficult to ascertain to what extent fields or regenerating woodlands were the main cause of elephant excursions outside of the PA. Our study highlights the potential importance of regenerating woodland patches as resources for large herbivores. Yet, the miombo woodland belt to which GNAP belongs in coastal Mozambique still constitutes the main habitat for elephants and other species in the area. Uncontrolled and illegal deforestation remains a major threat to its conservation. Adaptive management, such as selective logging of small-designated areas associated with firebreaks, could be considered to create clearings and stimulate the regeneration of young forest tree species. Carefully planned and monitored interventions may increase plant diversity and improve coexistence with neighbouring subsistence farmers by attracting elephants back inside GNAP away from their fields.

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## CONFLICT OF INTEREST

The authors state that they have no conflicts of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from François Sommer Foundation. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the authors with the permission of the François Sommer Foundation.

## ORCID

*Hugo Valls-Fox* https://orcid.org/0000-0001-7482-1205

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