High-resolution tracking technology reveals distinct patterns in nocturnal crop raiding behaviour of an African elephant (*Loxodonta africana*) in Amboseli, Kenya

Ryan D Wilkie[1]* *and Iain Douglas-Hamilton*[2]

[1,2] Save The Elephants, PO Box 54667, Nairobi 00200, Kenya
*corresponding author: ryan.wilkie94@gmail.com

Abstract

Conflict between humans and elephants is a notoriously complex problem requiring a detailed understanding of the underlying patterns and processes in order to develop effective solutions. Advances in radio tracking technologies have enabled researchers to examine in detail the ways in which tracked animals interact with their environments. We analysed the movement patterns of an habitual crop raiding African elephant (*Loxodonta Africana*) in the Amboseli ecosystem in southern Kenya. We identified three distinct patterns of movement associated with instances of crop raiding; these were (1) opportunistic raiding, (2) purposeful raiding, and (3) incidental raiding. The distinct characteristics of each of these movements serve to demonstrate the differing circumstances under which elephants are brought into contact with agricultural areas in their daily negotiations of the network of human land-use and protected areas. These findings highlight the need to understand patterns of elephant movement and interactions with farmland in order to craft management strategies that are effective in reducing levels of human-elephant conflict and promote tolerance of elephants in rural communities.

Résumé

Le conflit entre les hommes et les éléphants est un problème notoirement complexe qui nécessite une compréhension détaillée des types et des processus sous-jacents afin de développer des solutions efficaces. Les progrès des technologies de repérage radio ont permis aux chercheurs d'examiner en détail la manière dont les animaux suivis interagissent avec leur environnement. Nous avons analysé les schémas de mouvement d'un éléphant d'Afrique (*Loxodonta Africana*) normalement habitué à la maraude des cultures dans l'écosystème d'Amboseli au sud du Kenya. Nous avons identifié trois types de mouvements distincts associés à des cas de maraude; il s'agissait (1) des maraudes opportunistes, (2) des maraudes ciblées et (3) des maraudes fortuites. Les caractéristiques distinctes de chacun de ces mouvements servent à démontrer les différentes circonstances dans lesquelles les éléphants entrent en contact avec les zones agricoles dans leurs négociations quotidiennes du réseau de zones utilisées par des humains et protégées. Ces résultats soulignent la nécessité de comprendre les schémas de déplacement des éléphants et les interactions avec les terres agricoles afin d'élaborer des stratégies de gestion efficaces dans le but de réduire les conflits hommes-éléphants et promouvoir la tolérance des éléphants dans les communautés rurales.

Introduction

Human-elephant conflict (HEC) is becoming more frequent as human development advances across African landscapes (Woodroffe et al. 2005). It is a notoriously complex problem and mitigating its effects requires a detailed understanding of the underlying patterns and processes involved (Sitati et al. 2003). Investigations of HEC in Africa have primarily focused on elephant crop raiding activities identifying seasonal patterns in crop raiding behaviour (Osborn 2004; Chiyo et al. 2005), social drivers and dynamics of crop raiding elephant groups (Chyio et al. 2011; 2012), and spatial aspects of HEC (Sitati et al. 2003), as well as more human dimensions of the conflicts (Naughton et al. 2000) and potential mitigation strategies (Hoare 1995; Davies et al.

2011; King et al. 2009). However, few of these studies have examined the actual movements of elephants in relation to areas under cultivation.

In Kenya, elephants are largely able to move freely and disperse from protected areas owing to the absence of fences around national parks. However, this dispersal from protected areas into increasingly human-dominated landscapes brings elephants into contact with human livelihoods and sparks competition over shared resources. These conflicts can be a major cause of elephant mortality as farmers attempt to secure their crops from depredation by injuring or killing elephants identified as culprits of crop damage or potential threats (Hoare 2000). With the human population of Kenya set to double by 2050 (World Bank 2010) and the proliferation of agriculture in the proximity of protected areas making inroads into elephant habitat and increasingly constraining elephant movements, interactions between humans and elephants, and levels of HEC, are likely to increase.

Global positioning system (GPS) technology has been a popular tool in elephant movement studies since the mid-1990s (Douglas-Hamilton 1998). GPS collars have been widely used in mapping elephant movement patterns around human settlements (Cook et al. 2015), identifying established (historical) migration corridors between Protected Areas (PAs) (Douglas-Hamilton et al. 2005), and investigating elephant movements in changing landscapes (Graham et al. 2009; Bohrer et al. 2014). These studies have typically employed relatively coarse-scale tracking data, recording the location of individuals at one- to eight-hour intervals, to analyse patterns of elephant movement over longer timescales of months and years. Here we use comparatively fine resolution tracking data to understand how and under what circumstances elephants are brought into contact with agricultural areas in their day-to-day negotiation of the Amboseli National Park and surrounding areas in southern Kenya.

Materials and Methods

Study area

Amboseli National Park (ANP) protects an area of 392km^2 in southern Kenya and is situated at the base of Mount Kilimanjaro. Amboseli was first established as a game reserve in 1948 before being gazetted as a national park in 1974 and declared as a UNESCO

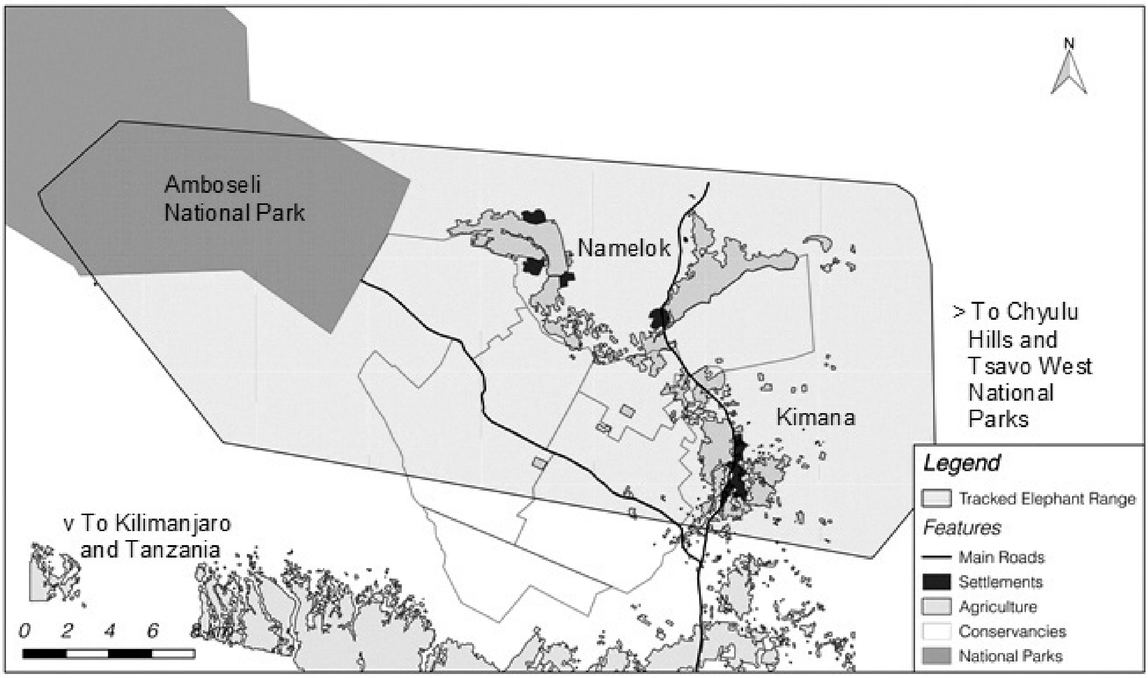

Figure 1. Amboseli National Park and eastern dispersal area, showing minimum convex polygon of elephant's range throughout the Kimana Corridor conservancies and surrounding human land-use.

Table 1. Total land area under conservation and total area used for agriculture in the Greater Amboseli Ecosystem from 1987 to 2014 (Source: Big Life Foundation and Space for Giants 2015).

Year	Area (km^2) Agriculture	Conservation
1987	136	545
2000	153	568
2006	258	602
2010	252	871
2014	498	924

Man and the Biosphere Reserve in 1991. The study area is centred around the ANP and the system of cultivated wetlands to the east of the park at Namelok and Kimana that form the eastern dispersal area for the Amboseli elephant population (see Fig. 1). This population has been the subject of intense study by the Amboseli Elephant Research Project (AERP) since 1972. The core of the area outside the perennial swamps is divided into a series of community conservancies, which together comprise the Kimana Corridor linking Amboseli National Park to the Chyulu Hills and Tsavo West National Parks to the east. Other areas around Kimana and the lower slopes of Kilimanjaro to the south are dominated by rain-fed agriculture.

The Amboseli elephant population comprises c. 1,700 individuals (AERP pers. comm. April 2018), which seasonally use the national park and surrounding dispersal areas. This population is contiguous with elephants from Tsavo West and Chyulu Hills National Parks, with ranges overlapping in the Kimana Sanctuary—the eastern-most conservancy shown in Fig. 1 (Moss 2001).

Land use patterns in the Amboseli ecoystem are changing at an unprecedented rate due to the increased sedenterization of pastoralists and the expansion of rainfed and irrigated agriculture by the local Maasai population and migrant communities, (see Table 1). These changes have not only resulted in the loss of rangeland through conversion to agriculture but the interactions between pastoralists, farmers and wildlife have also been fundamentally altered over the past few decades (Campbell et al. 2003).

Data Collection

A GPS collar was fitted to a single bull elephant, aged 47, who had been previously identified by AERP as an habitual crop-raider. Due to the size of the individual the collar had to be specially designed to fit around the neck. The collaring operation was carried out by the Kenya Wildlife Service (KWS) in September 2016 and the elephant's movements were monitored until October 2017. GPS data continue to be collected as part of on-going research by Save the Elephants and partners in the ecosystem.

The satellite collar was manufactured by Savannah Tracking and configured to record and transmit multiple locations every hour. Initially the collar recorded locations at half-hour intervals but was later remotely reconfigured to record locations every 15 minutes. Tracking data were accessible from a bespoke mobile app and stored in a centralised database.

Unlike adult female elephants who live with their kin in family groups, bulls become independent around 14 years of age developing complex association patterns with other males and family groups (Lee and Moss 1999). As male associations vary significantly over time, GPS tracking results from this collar can only be held to be representative of a single individual. However, the collared elephant was most frequently found in the company of other adult bulls suggesting that the recorded movements are likely indicative of patterns of behaviour of other elephants in the ecosystem.

Data Analysis

We monitored the daily movements of the tracked elephant using Save the Elephants' Real-time Monitoring (RTM) system (Wall pers. comm. April 2018) noting each instance of the elephant crossing (or attempting to cross) into agricultural areas. Once distinct raiding tracks were identified, 24-hour sections of the tracking data were isolated and retrieved from the centralised database covering the period from 12:00pm the day before the event to 12:00pm the following day. Each of these tracks were then individually mapped in *QGIS* (QGIS Development Team 2018).

Displacement rates or movement speeds (km/h) were calculated from locational data by first using the spherical law of cosines to determine the distance travelled between consecutive GPS fixes according to the following formula:

$$d = acos(sin\ \varphi 1 \bullet sin\ \varphi 2 + cos\ \varphi 1 \bullet cos\ \varphi 2 \bullet cos\ \Delta\lambda) \bullet R$$

where φ is latitude, λ is longitude, R is earth's radius (mean radius = 6,371km), before dividing by the time interval between consecutive fixes. Displacement rates were usually calculated for movements over 15-minute intervals; however, there were occasions when data were lost (140 of 13,296 total fixes or 1.05%) resulting in displacement rates being calculated over longer periods up to one hour.

The analyses of movement characteristics focused on the elephant's nocturnal movements between the hours of 18:00 and 06:00, as elephant raids on cultivated fields invariably occur under cover of darkness, in order to minimise the risk of detection (Chiyo et al. 2011; Graham et al. 2009; Zepplzauer and Stoeger 2015). In examining the variability in raiding movement types we calculated the total distance travelled, mean velocity, net displacement and an index of linearity (calculated as the net displacement between the first and last points divided by the total distance travelled) for each raiding track. By combining these movement characteristics derived from the tracking data with the individual raid maps, we were able to identify and classify distinct patterns in raiding movements, highlighting the time the elephant spent in cultivated fields.

Results

A total of 178 raiding events were recorded between October 2016 and October 2017, all occurring during the hours of darkness between 19:00 and 05:00. We used a combination of the elephant's plotted trajectory and movement characteristics to classify each of these raiding events into three broad categories of raiding behaviour explained below (see Table 1). Of the 178 recorded raiding events, 107 (60.1%) were classified as 'opportunistic' raids (Fig. 2a, b). A further 42 events (23.6%) were classified as 'purposeful' raids (Fig. 2c, d), while the remaining 29 raiding events (16.3%) were classified as 'incidental raids' (Fig. 2e, f).

Movement characteristics differed significantly between raiding types (see Table 1). During opportunistic raids the elephant's movements were mostly confined to a small area with short, sporadic spikes in movement speeds. Purposeful raids were characterised by sustained and directed high-speed movements between diurnal refuges to agricultural areas interspaced with short periods of slow movement, which indicated the elephant was foraging on crops. The looping trajectory between diurnal refuges and agricultural areas resulted in the elephant covering relatively long distances with a comparatively low overall displacement between the hours of 18:00 and 06:00. Incidental raids were associated with short migratory movements involving high rates of displacement as the elephant traversed intervening areas of farmland between distinct diurnal refuges. While the mean velocity and total distance travelled are comparable to purposeful raids, the result is a much more linear trajectory with only small deviations from the optimal route between the point of origin and the target refuge during which the elephant might engage in crop foraging.

Opportunistic raids displayed the greatest degree of variation (with highest CV values) across all movement characteristics, with purposeful raids also showing a considerable amount of variability. Some of this variation may be attributed to the interventions of rapid response units (provided by Big Life Foundation) chasing the elephant out of farmland as part of the on-going conflict management strategies in the study area.

A number of these raiding events were likely to have been cut short by the interventions of these ranger units, while others may have been extended due to prolonged and/or repeated chases around cultivated areas. These interventions did not appear to affect incidental raids to the same degree given the comparatively low levels of variation in movement characteristics.

The vast majority of opportunistic raids (98.1%) were recorded in the Kimana area, while purposeful raiding behaviour was mostly observed in the Namelok area (with incidental raids occurring during movements between these two core areas of the elephant's range).

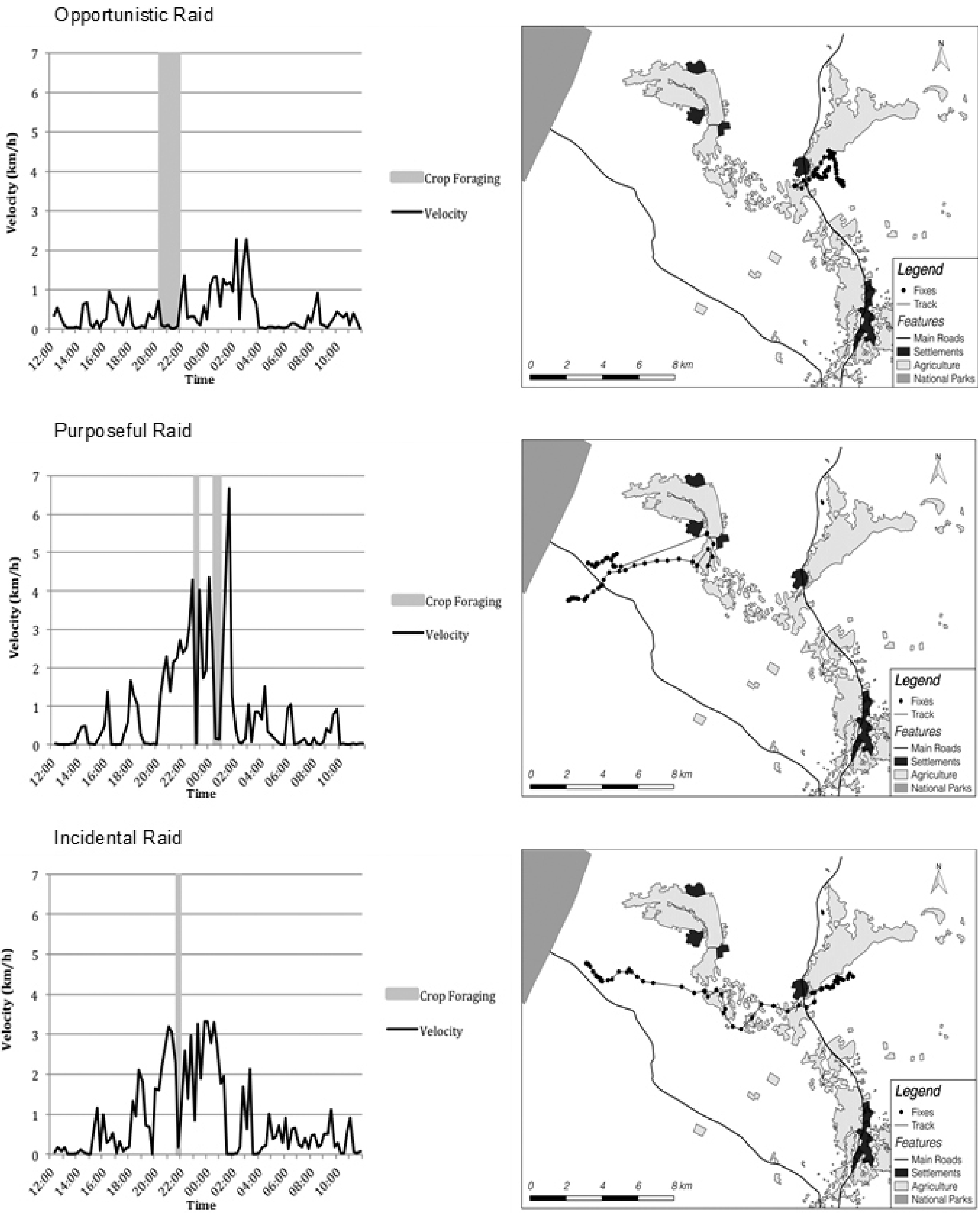

Figure 2. Three different patterns of elephant movement associated with raiding behaviour (a) movement profile of an opportunistic raid, (b) plotted trajectory of the elephant. (c) movement profile of a purposeful raid, (d) plotted trajectory of the elephant. (e) movement profile of an incidental raid (f) plotted trajectory of the elephant.

Table 2. Mean movement characteristics ±SE and coefficient of variation (CV, in parentheses) by raiding movement type.

Movement Characteristic	Opportunistic Raids (n=107)	Purposeful Raids (n=42)	Incidental Raids (n=29)
Total distance travelled (km)	7.31 ±0.30 (42.54)	13.07 ±0.68 (33.96)	15.35 ±0.81 (28.29)
Mean velocity (km/h)	0.60 ±0.02 (42.67)	1.07 ±0.06 (34.31)	1.26 ±0.07 (28.00)
Net displacement (km)	1.76 ±0.12 (72.98)	2.79 ±0.20 (47.35)	9.83 ±0.65 (35.70)
Index of Linearity	0.26 ±0.02 (62.37)	0.23 ±0.02 (48.29)	0.63 ±0.02 (18.42)

Discussion

It has been well documented that elephants use the cover of darkness to manage risk when negotiating human-dominated landscapes (Hoare 1995; Sitati et al. 2003; Graham et al. 2009). However, this is the first time, to our knowledge, that tracking data has been used to distinguish between different types of elephant movements in relation to human land-use. There is a clear distinction in this study between those movements associated with temporary incursions into farmland for the purposes of raiding cultivated crops (opportunistic and purposeful raiding) and those associated with migrations between elephant refuges through the intervening human-dominated landscape (incidental raiding). Farmers, however, are unlikely to appreciate the behavioural nuances that distinguish a purposeful raid from an incidental one when attempting to secure their crops from elephant incursions. The spatial patterning of raiding behaviours indicates that the differences between these movement patterns, and the elephant's behaviour, are likely influenced by the underlying geography of this area. In particular, the relative distribution of agricultural areas to high-quality elephant habitat, and patterns in the elephant's use of different refuges have been considered.

The finding that elephants are brought into contact with farmland under different geographical and ecological circumstances is broadly consistent with ideas presented by Sukumar (2003) in his study of the proximate causes of crop raiding by Asian elephants (*Elephas maximus*). He suggested that some crop raiding by elephants could be explained by the expansion of agriculture into areas previously occupied by elephants causing their continued utilisation of these areas to lead to crop raiding. While other instances of crop raiding were likely to be the result of cultivated fields being established between areas of natural habitat or water sources, obstructing the free movement of elephants, often over historical elephant routes.

The opportunistic pattern of raiding described in this study would appear to fit the former narrative with the elephant moving onto smallholder agricultural land that directly abuts high-quality elephant habitat. This pattern may also be common in more fragmented landscapes where forest fragments in the vicinity of cultivated fields provide convenient daytime refuges for raiding elephants (Sukumar 1990). The incidental raiding movement pattern appears to fit the latter narrative with the elephant maintaining high rates of displacement over an extended period of time thereby minimising the time spent in high-risk areas. This behaviour is consistent with other studies of elephant movements and speeds outside PAs (Douglas-Hamilton et al. 2005; Graham et al. 2009; Cook et al. 2015).

However, neither of these narratives appears sufficient to explain the purposeful pattern of raiding observed in this study—in which the elephant moves at high speed across an intervening 'buffer zone' to exploit foraging opportunities in relatively distant farms. This behaviour requires a different narrative in which crop raiding is considered a matter of ecological strategy and elephants have developed a pattern of movement geared toward actively seeking and raiding cultivated plants as a means of optimizing their daily foraging intake. By targeting cultivated fields, which provide a concentrated source of highly palatable and nutritious foodstuffs, elephants can meet their entire daily energy requirements in a matter of hours (Chiyo and Cochrane 2005; Sukumar 2003). This foraging strategy involves higher levels of risk than feeding in the wild but may also confer greater rewards (Chiyo et al. 2011).

The distinction between these different raiding patterns and behaviours could have important implications for differentiating between habitual crop raiders, whose movement strategies are primarily geared toward raiding (the purposeful pattern), and more occasional crop raiding elephants whose incursions into farmland may be attributable to more systemic issues around changing land-use patterns and habitat loss (the opportunistic and incidental patterns).

Each site has specific characteristics, such as the relative availability and distribution of cultivation zones and elephant refuges, which can influence the conflict situation and the success of deterrent methods (Osborn and Parker 2003). Understanding the distinct features of each conflict site is central to developing management strategies that are effective in reducing conflict and promoting tolerance between humans and elephants (Graham et al. 2010) for each situation. Knowledge of elephant movements and patterns of behaviour can provide information vital to understanding how pressures can be reduced. Where conflicts can be traced to the actions of a handful of habitual crop raiders, showing purposeful raiding movements, aversive conditioning techniques targeted at select individuals may be effective in reducing the spread of raiding behaviours through social learning. However, where patterns of elephant crop raiding that are opportunistic or incidental point to fundamental incompatibilities between wildlife movements and human land-use such short-term and reactive measures are unlikely to resolve the issue. In such situations, a more comprehensive and preventative approach to resolving incompatibilities in land use by people and elephants is necessary. This approach could include maintenance of movement corridors and a suite of deterrence measures appropriate at the site level, aimed at reducing farm incursions and HEC, in a framework of land use planning and zoning.

The current study focused on the behaviour of a single male elephant, living in a particular range area with specific local characteristics. The distinct types of, and motivations for raiding behaviour that were identified in this study should now be confirmed through replication of the described methodology in other localities. Ideally, these follow-up studies should be carried out not only within the Amboseli ecosystem, but also other areas of Kenya and African elephant range states, to confirm the robustness and broader relevance of the concept.

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