African Journal of Ecology

The influence of lunar cycles on crop-raiding elephants; evidence for risk avoidance

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Abstract

Long-term solutions to crop raiding by elephants (*Loxodonta africana)* should be based on an understanding of their behaviour and ecology. The real and perceived risks from humans have been shown to affect elephant behaviour. This is evidenced by elephants predominantly raiding crops at night, avoiding the height of human activity. If such human avoidance behaviours are apparent, it might also be expected that elephants avoid risks associated with higher visibility and increased human activity as may occur during the full moon. However, elephant nocturnal crop-raiding behaviour in relation to lunar cycles has largely been a neglected factor in studies of human–elephant interactions. In this study around Mikumi National Park, Tanzania, we apply circular statistics in this context for the first time to show a significant decrease in crop raiding during the full moon and apply this method retrospectively to data from another site in West Africa with similar results. Additionally, a greater proportion of farms raided was guarded during the full moon than any other moon phase. Our results indicate that variations in crop raiding with lunar phase could be a general feature of elephant behaviour and thus could be used to design and time mitigation efforts.

Key words: behavioural ecology, crop raiding, elephants, human-elephant conflict, lunar cycle, moon phase

Résumé

À long terme, les solutions aux dégâts causés aux récoltes par les éléphants (*Loxodonta africana*) devraient être basées sur une bonne compréhension de leur comportement et de leur écologie. Il a été montré que les risques réels et ressentis vis-à-vis des hommes affectent le comportement des éléphants. Preuve en est le fait que les éléphants s'attaquent aux cultures principalement la nuit, évitant ainsi le pic d'activité des hommes. Si de tels comportements d'évitement sont bien visibles, on pourrait aussi s'attendre à ce que les éléphants évitent les risques liés à une plus grande visibilité et à une activité humaine accrue, comme cela peut être le cas pendant la pleine lune. Pourtant, le lien entre le comportement nuisible des éléphants dans les cultures et le cycle lunaire est un facteur qui a toujours été largement ignoré dans les études des interactions hommes-éléphants. Dans cette étude réalisée dans le Parc National de Mikumi, en Tanzanie, nous appliquons pour la première fois des statistiques circulaires à ce contexte pour montrer une diminution significative des dommages pendant la pleine lune, et nous appliquons cette méthode, rétrospectivement, aux données venant d'un autre site d'Afrique de l'Ouest, avec des résultats similaires. De plus, une plus grande proportion d'exploitations agricoles attaquées ont été gardées pendant la pleine lune que pendant toute autre phase lunaire. Nos résultats montrent que des variations des dommages causés aux cultures selon la phase de la lune pourraient bien être une caractéristique générale du comportement des éléphants et pourraient donc servir à concevoir et à programmer les efforts de mitigation.

Introduction

Human-elephant interactions are increasing as a result of a complex array of factors associated with human population growth and development. Urbanization, intensive

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agriculture, encroachment and the rising rate of poaching for meat and ivory are some of the factors contributing to the increasing rate of human–elephant interactions (Douglas-Hamilton, 1987; Tchamba, 1996; Naughton, Rose & Treves, 1999; Nyhus & Sumianto, 2000; Blanc *et al.*, 2003; Linkie *et al.*, 2007). Strategies to successfully conserve elephant (*Loxodonta africana*) populations must address crop-raiding prevention and mitigation while considering the causes and patterns of crop raiding within human communities adjacent to elephant populations. Long-term solutions should be based on an understanding of the behaviour and ecology of elephants and how this leads to conflict with human communities (Barnes, 2002). This study will consider one such aspect of elephant behaviour, the effect of moon phase on crop raiding.

Patterns of activity in animals throughout the daily 24 h cycle are commonly related to season (Hill *et al.*, 2003), food availability and access (Donati *et al.*, 2007), and predation risk (Lang *et al.*, 2006). Less understood are animal activities related to ambient light conditions resulting from either seasonal variation, lunar phase or atmospheric condition (Beltran & Delibes, 1994; Barnes *et al.*, 2006; Dixon *et al.*, 2006; Lang *et al.*, 2006; Sabato *et al.*, 2006; Grant, Chadwick & Halliday, 2009; Grant, Halliday & Chadwick, 2013). The only published study on elephant behaviour in relation to lunar cycles is that of Barnes *et al.* (2006) in the Kakum Conservation Area (KCA) in Southern Ghana, West Africa. They found that raiding was lowest around the full moon and hypothesized that this pattern was due to risk avoidance behaviour either in response to nocturnal predators' activity and/or human guarding effectiveness during periods of greater nocturnal visibility.

As the largest terrestrial mammal, the elephant has few predators. The lion (*Panthera leo)* and hyaena (*Crocuta crocuta)* are identified as preying on young animals (Power & Compion, 2009). The principal predatory pressure on adult elephants comes from human hunting and poaching (Blanc *et al.*, 2003). Cozzi *et al.* (2012) found that the nocturnal activity patterns of lions and hyaenas are unaffected by moonlight and remain constant over the lunar cycle. Consequently, one would predict that elephant behaviour to avoid lion/hyaena predation should be unrelated to variations in nocturnal visibility.

The real and perceived risks from humans have, however, been shown to affect elephant behaviour. Poaching pressures, human settlements and activity within elephant ranges alter ranging and activity patterns and cause human avoidance behaviours in elephant (Hillman-Smith *et al.*, 1995; Naughton-Treves, 1998; Hoare, 1999b; de Boer *et al.*, 2000; Hill *et al.*, 2003; Graham *et al.*, 2009). Given that elephants are active during both day and night (that is they are cathemeral, Shoshani *et al.*, 2004) and that they universally raid crops almost exclusively at night (Hillman-Smith *et al.*, 1995; Sitati *et al.*, 2003; Graham *et al.*, 2009; Gunn, 2009) suggests that they are avoiding risks associated with diurnal human activity (Gunn, 2009). Humans are less active and can see less well at night; therefore, elephants have a lower risk of encountering and being detected by humans if they raid crops at night.

Barnes *et al.* (2006) provided further evidence of human risk avoidance behaviour by demonstrating that nocturnal crop raiding decreased on bright, moonlit nights. They hypothesized that this avoidance behaviour is due to the long-term effects of increased guarding effort (time and strategies used by farmers or others to defend their farms, food or water stores from elephants or other crop-raiding animals) during the full moon, which has created a higher perception of risk during this moon phase. Variations in human guarding behaviour with moonlight could therefore underlie lunar cycles of elephant crop raiding in addition to the higher risk of being detected on moonlit nights because of the visual advantage gained by humans.

We address the hypothesis of Barnes *et al.* (2006) that elephants crop raid less during the full moon and that this is due to elephants avoiding risks associated with higher visibility and greater human guarding activity using data from a population of elephants in south-east Tanzania. We apply circular statistics (Batschelet, 1981) in this context for the first time, to show that variations in the lunar cycle correlate with variations in crop raiding and also with human guarding behaviour.

Materials and methods

Study area

This study was conducted within and around Mikumi National Park (MINAPA) in Tanzania. MINAPA is approximately 300 km west of Dar es Salaam (7.00′ to 7.45′S, 37.00′ to 37.30′E) and covers an area of 3230 km^2 adjacent to the north of the Selous Game Reserve (over 50,000 km^2). MINAPA and the Selous Game Reserve are part of the Mikumi-Selous ecosystem (>150,000 km^2

including both protected and unprotected areas) which is a mosaic of protected areas of differing size and status, surrounded by patches of human settlements of varying size and type. The Mikumi-Selous ecosystem holds one of the largest populations of wild elephant remaining in Africa (Mduma *et al.*, 2011).

This study was conducted around the Wami River catchment in the north of MINAPA (Fig. 1). The Wami catchment is one of three river systems arising within MINAPA and contains the Mkata floodplain bordered by a mixed woodland mosaic. The Mkata floodplain is an almost treeless tall grass seasonal floodplain. The Mkata riverine system contains approximately one-third of the park's area. The land rises from the floodplain into the hills, forming a catena where bushland and woodland increase with elevation. These hills form a horseshoe around the floodplain. Although the rainfall patterns are highly variable, a single wet season generally starts in December and ends in May. The average annual rainfall is 860 mm (Norton, 1994).

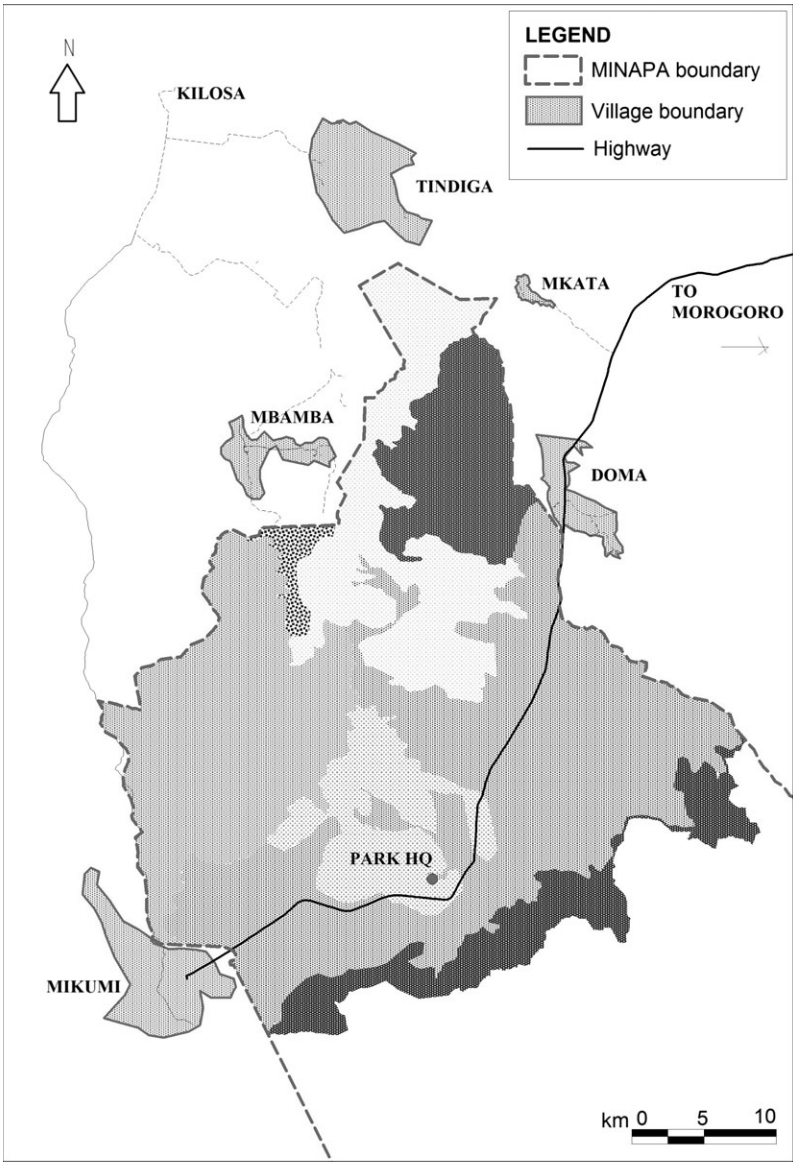

Fig 1 Study area: the wami catchment in MINAPA including study villages

The five villages selected for this study (Table 1) are a subset of the eighteen villages that border the park in the north, with varying spatial gaps between cultivation edge and the park boundary. These villages were selected based on their proximity to the Wami catchment which, topographically, is a clear distinct unit and more easily studied than the other catchments in the park. We also considered the villages' proximity to the park boundary, their latitudinal and longitudinal difference and their willingness to participate in the project. Because of the large distances between the villages surveyed (minimum of 10 km), we assumed them to be independent of one another, for example, crop raiding that occurred in one village was independent of crop raiding that occurred in another village. Table 1 shows the demographic and landscape attributes of the five study villages.

Data collection

We implemented a protocol for the quantitative assessment of human–elephant conflict based on the recommendations of IUCN African Elephant Specialist Group's Human–Elephant Conflict taskforce (Hoare, 1999a,c). We adapted these recommendations to include all wildlife species for broader research objectives and for the purposes of collecting independent data on farming activities and guarding in relation to the lunar cycle that was independent of elephant raiding behaviour (Gunn, 2009). In this study, we considered 'wildlife' as animals that are native to Tanzania and occurring within MINAPA. We translated all data forms and instructions into Kiswahili.

Village representatives from each village were selected by their peers to collect and collate data on human–wildlife conflict. Representatives were responsible for recording all human–wildlife conflict in their village for a period of 1 year (August 2004–July 2005 inclusive) on standard datasheets and collating this information once per month. Information recorded for each event at each farm included the type of event, the date and time, the wildlife species involved and area of crops damaged. For each event, the representative also recorded whether or not the farmer was guarding during the time of the event, and if guarding was carried out, who was guarding at the time of the event and the techniques used to scare animals away.

Data analysis

As we could not assume independence of raiding events occurring during the same night in the same village, we used 'raid day' (a 24-hour period starting at 6 am), in which all records within a village caused by the same animal species were combined. To assess guarding effort, we used records from all events involving nocturnally active animals (elephants, buffalo and bushpig) to establish the ratio of the number of farms guarded versus not guarded against nocturnal raids. For these data, we considered farms to be independent, as each farmer was independent in his choice to guard or not guard. This assumes that there is little or no cooperative guarding which is supported by the lack of any reports of this during the study, although no formal assessment was made. In addition to assessing frequency of crop raiding, as measured by raid day, we looked at extent of damage measured by summing the total area damaged during each moon phase by month.

We measured the lunar cycle in two ways: days since full moon (DFM) (Grant, Chadwick & Halliday, 2009) and moon phase. We assigned DFM values to each date during the study period using data available through NASA's phases of the moon for this study year (Espenak, 2007).

Table 1 Demographic and landscape attributes of the five study villages

Village details	Doma	Mikumi	Mbamba	Mkata	Tindiga
Human population	>3000	>14,000	>2200	>350	>8000
Area of settlement (km^2)	>25	>50	>20	>3	>70
Human density (people/km^2)	150.0	311.1	146.7	175.0	177.8
Distance from village centre to park boundary (km)	1.7	2.2	5.5	2.0	9.0
Nearest distance from cultivation edge to park boundary (km)	0.3	0.3	1.2	1.5	1.7
Furthest distance from cultivation edge to park boundary (km)	6.0	8.0	10.0	4.0	10.0
Distance from cultivation edge to permanent water (km)	10.0	12.0	22.5	9.0	26.0
Park boundary length parallel to village (km)	11.5	19.5	15.5	4.7	8.2

When using moon phase, we defined four phases of the lunar cycle described by Espenak (2007): full, waning, new and waxing. The full moon phase was defined as the night of the full moon, three nights before and three nights after. Similarly, the new moon phase was the night of the new moon, three nights before and three nights after. The waning moon phase was the nights between the full and the new moon phases. The waxing moon phase was the nights between the new and full moon phases.

We analysed lunar patterns of number of raid days using the circular statistics software ORIANA 2.0 (http://www.kovcomp.co.uk/oriana/oribroc.html, Kovach Computing Services, Anglesey, U.K.). First, we converted DFM values to angles (°) by dividing by 30 (the length, in days, of the lunar cycle) and then multiplying this by 360°. We used the Rayleigh test for uniformity around the circular space (Batschelet, 1981) to assess whether raid days occurred uniformly with respect to the lunar cycle. The circular histograms that we present in conjunction with these analyses show the frequencies of raiding events, and therefore, the scales vary depending on the value of the sample size in each case (n = 177 in Fig. 2a and n = 294 for Fig. 2b).

We used a Friedman's test to assess the null hypothesis that area damaged does not differ between moon phase, relating data for the same lunar month. We analysed patterns of guarding using a likelihood ratio two-way chi-square goodness-of-fit test to determine whether guarding frequency differed significantly by moon phase.

Barnes *et al.* (2006) observation of reduced crop raiding by elephants around KCA was based on alternative statistical techniques. For direct comparison with the MINAPA data, we reanalysed these KCA data using the Rayleigh test.

Results

The number of elephant raid days around MINAPA during 2004–2005 varied significantly through the lunar cycle (Rayleigh test: n = 177; Z = 3.8; $P = 0.02$) with fewer raid incidents occurring around the full moon (Fig. 2a). The number of elephant crop-raiding incidences around KCA during 2000–2002 also varied significantly though the lunar cycle (Rayleigh test: n = 294; Z = 7.4; $P < 0.001$) and similarly showed the lowest incident of raiding around the full moon (Fig. 2b). Unlike the MINAPA data, the KCA data from Barnes *et al.* (2006) also show apparent peaks of crop-raiding activity around the waxing and waning moon phases; specifically days 9 and 23 of the lunar cycle.

In MINAPA, the area damaged per month differed significantly by moon phase (Friedman's Test: $\chi^2_3 = 10.2$, n = 12, $P = 0.017$), with the full moon having the lowest median area of damage of each of the moon phases. The total area damaged during the full moon was half that during waxing and waning, suggesting potential peaks during these phases (Fig. 3).

Farms were reported as being guarded when raiding occurred (involving all nocturnally raiding animals, not just elephants) for less than a quarter of the overall MINAPA records, but this proportion varied significantly between moon phases (two-way likelihood ratio chi-square: $\chi^2_3 = 9.060$, n = 721, $P = 0.028$), with the highest proportion guarded found during the full moon (Fig. 4).

Discussion

Our analyses are consistent with the results of Barnes *et al.* (2006) that there is significant variation in crop-raiding frequency with moon phase around both MINAPA and KCA. Crop raiding occurs less frequently during the full moon phase, and the extent of crop damage during the full moon phase is half the damage occurring in any of the other phases. Our results indicate that variations in crop raiding with lunar phase could be a regular feature of elephant crop-raiding behaviour and not an isolated outcome related to site-specific factors. This supports the hypothesis that elephants alter their behaviour to reduce the risks of encountering humans by being most active in human dominated areas when they are hard to detect and when humans are less active. Importantly, this pattern is a potentially important source of variation to control for when designing studies to investigate patterns of crop raiding and the effectiveness of mitigation efforts. If these lunar patterns are consistent across populations, then these patterns can be used to design and time mitigation efforts.

Barnes *et al.* (2006) hypothesized that reduced crop raiding during the full moon could be a risk avoidance behaviour either in response to the activity of nocturnal predators and/or human guarding behaviour. We have reviewed in the introduction why predation is less likely to cause risk avoidance behaviours due to variations in the lunar cycle and why human guarding activity is more

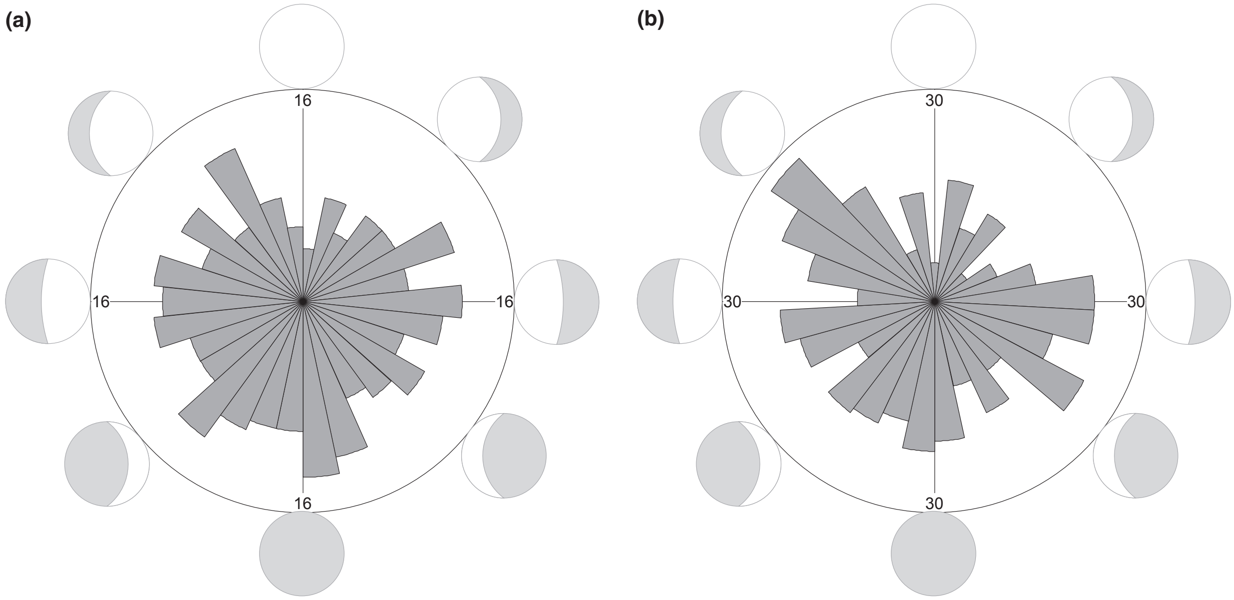

Fig 2 Relative frequency of raid days during the lunar cycle by elephants around (a) MINAPA (Tanzania, East Africa) 2004–2005; (b) Kakum Conservation Area (Ghana, West Africa) 2002–2003 (data from Barnes *et al.*, 2006). The number of elephant raid days varied significantly through the lunar cycle for both (a) Rayleigh test: n = 177; Z = 3.8; $P = 0.02$ and (b) Rayleigh test: n = 294; Z = 7.4; $P < 0.001$. The radius of the circle is the axis representing frequency, the concentric rings marking off four, nine and sixteen from the centre point (0) in Fig. 2a and 2, 5, 10, 15, 20, 25 and 30 from the centre (0) in Fig. 2b. The grey segments show the frequency of raiding events on days 0–29 following the start of the full moon. The angle of the grey segments from the vertical indicates the stage of the lunar cycle to which they correspond with the vertical line at 0° being the first day of the full moon. The symbols around the outside indicate the eight phases of the moon corresponding to the angles at their position on the circumference (full, waning gibbous, 3rd quarter, waning crescent, new moon, waxing crescent, first quarter, waxing gibbous: For further details, see Table 1 in Grant, Chadwick & Halliday, 2009)

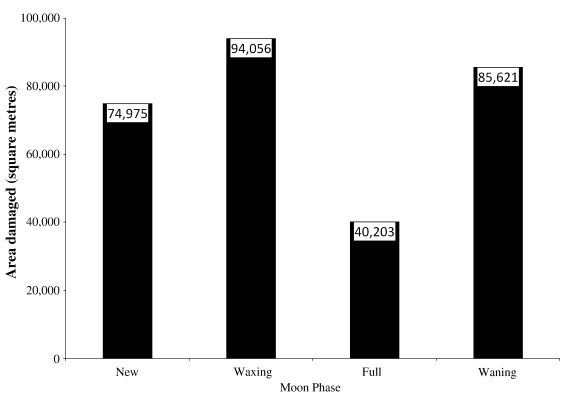

Fig 3 Total area of crops damaged during the different moon phases (each lasting 7–8 days) by elephants in five villages around MINAPA (Tanzania, East Africa) 2004–2005. The area damaged differed significantly by moon phase (Friedman's Test: $\chi^2_3 = 10.2$, n = 12, $P = 0.017$)

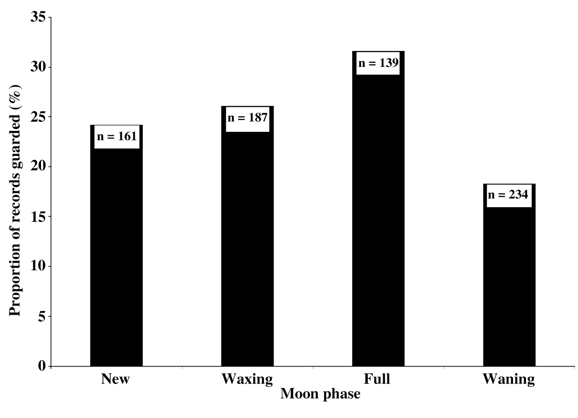

Fig 4 Distribution of guarding by moon phase. Proportion of records of guarding using data from all nocturnally active animals differed significantly between moon phases (two-way likelihood ratio chi-square: $\chi^2_3 = 9.060$, n = 721, $P = 0.028$)

likely as a causative factor. Our results on patterns of crop raiding and human guarding frequency by moon phase and the patterns of guarding frequency described by Barnes *et al.* (2006) provide further support for this.

As in the KCA, farmers around MINAPA predominantly reported using simple, cheap, immediate forms of protection against wildlife. These included making noise by banging metal or using a whip, using a fire, dog or torch as deterrents. In many cases, farmers reported that they were defenceless against elephants and felt that game guards should be responsible for scaring elephants away either with their vehicles, or with gunshots. While no data were collected on the patterns of guarding overnight around MINAPA, the study in the KCA reported that noise and activity were at their maximum in the early evening and as dawn approached. Human activity was minimal in the KCA between 11 pm and 3 am.

The predominantly nocturnal raiding behaviour shown by elephants (Hillman-Smith *et al.*, 1995; Sitati *et al.*, 2003; Graham *et al.*, 2009; Gunn, 2009) is consistent with avoidance of the risks associated with humans, but may also be associated with foraging needs and thermoregulation. The extent to which a reduction in crop raiding by elephants during the full moon phase is a behavioural response to a perceived increased threat from humans merits further examination. We hope this study will stimulate both the retrospective interrogation of data to confirm, or otherwise, the pattern found in MINAPA and KCA, and future research designed specifically to assess risk avoidance and other potential explanations.

With appropriate planning, this future research could employ a modelling approach. For example, the generalized linear mixed model (GLMM) could be used to investigate the effect of lunar cycle, guarding intensity and other potential explanatory variables on a response variable measuring crop raiding (Gunn, 2009). It is important to note that to apply any type of linear model, circular variables like DFM need to be transformed to avoid violation of model assumptions. This can be achieved by converting the number of days since the last full moon to an angular measurement (Φ) by the formula $\Phi = 2\pi$ (t/T), where t is the days of the lunar cycle and T is the period (which in this case is the length of the lunar cycle and using sin Φ and cos Φ in linear regression . (de Bruyn & Meeuwig, 2001).

While crop-raiding frequency and area damaged are lowest during the full moon, our results also indicate that the damage caused to farms during crop raiding is the greatest during the waxing and waning moon phases around MINAPA, and likewise, there were peaks of crop raiding during the waxing and waning moon phases in KCA. These results suggest that elephants spend more time foraging on crops during the waxing (and possibly waning) moon phase(s) than any other lunar phase. We suggest that elephants may balance the cost of high visibility and increased human guarding against the benefits of improved foraging when moonlight allows them to use visual senses to supplement olfaction and audition. Future research should consider the possibility that there is a trade-off between foraging efficiency and risk.

The effects we observed were strong and consistent between the two study sites: it is evident that elephants raid crops less around the full moon. Our results support the hypothesis that this pattern is a result of elephants responding to the risk of entering human dominated areas when they are more likely to encounter and be detected by humans. Our results highlight the need to better understand the role of lunar cycles as an explanatory factor in elephant crop-raiding behaviour when planning and interpreting studies. As we have discussed previously, future research should consider other factors including, for example, season, cloud-cover, temperature, rainfall and luminosity and a modelling approach would be informative. Historical and current elephant poaching activities, small-scale hunting around the boundaries, weather patterns, predator hunting behaviour and raiding elephant group size and structure may all influence the patterns of crop raiding in relation to the moon phase described in this study. Such research is necessary because of the implications for the management and mitigation of crop raiding. If levels of moonlight affect elephant and/or human behaviour with regard to crop raiding and guarding, this knowledge could, for example, be used to develop innovative technologies that utilize solar power and artificial illumination of farms or guide simple temporal variations in farmers' guarding behaviour.

Acknowledgements

We are grateful for the permission granted by Tanzania National Parks (TANAPA), Tanzania Wildlife Research Institute (TAWIRI) and The Tanzania Commission for Science and Technology (COSTECH) to conduct this research in Tanzania. Hilary Conlan, Phyllis Lee and Toby Carter provided useful help and advice. Funding was provided by the Darwin Initiative for the Survival of

Species, and the Animal and Environmental Research Group, Anglia Ruskin University.

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(*Manuscript accepted 16 May 2013*)

doi: 10.1111/aje.12091