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by Kerry John-Davis

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Understanding Human-Elephant Conflict: Analyses of activity patterns and the effect of the lunar cycle on movements of male social groups and breeding herds of the African Savannah Elephant *(Loxodonta africana)*

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Declaration

I declare that the work in this report was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Taught Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, this work is my own work. Work done in collaboration with, or with the assistance of others, is indicated as such. I have identified all material in this report which is not my own work through appropriate referencing and acknowledgement. Where I have quoted from the work of others, I have included the source in the references/bibliography. Any views expressed in the dissertation, other than referenced material, are those of the author.

SIGNED: (Kerry John-Davis) DATE: 11th September 2022

Abstract (286 words)

The continuing decline of the African savannah elephant (*Loxodonta* africana) across Africa (Gobush et al., 2021) is mainly due to poaching, habitat loss and human population expansion leading to an increase in human-elephant conflict throughout Africa (Shaffer, Khadka, Van Den Hoek, & Naithani, 2019). Botswana holds a population of approximately 130,000 of Africa's elephants (Thouless et al., 2016). This study analyses camera trap data collected by Elephants for Africa (EfA) over a three-year period in the Makgadikgadi Pans National Park (MPNP) in Botswana, which has recently seen higher numbers of elephants, due to the resurgence of the Boteti river (Evans, 2019). High elephant density in the MPNP, particularly of male elephants (Evans, 2019; Stevens, 2018) has caused an increase in human-elephant conflict (HEC) as local communities and elephants compete for resources (Evans, 2019; Mayberry, Hovorka, & Evans, 2017; Thouless et al., 2016). This study contributes to EfA's aim to mitigate HEC in the area, informing local communities and farmers who have historically had little exposure to elephants (Evans, 2019). By studying the movement of elephants along elephant highways, particularly the lesser-studied males, this study builds upon research conducted at EfA, to further aid our understanding of elephant social dynamics (Agell, 2021; Allen, Brent, Motsentwa, Weiss, & Croft, 2020; Stevens, 2018).
Results of this study show that both male and female elephants are more likely to travel in smaller groups at night compared to the day. Male elephants are over 4 times more likely to be alone at night than during the day, with male adults the most likely age group to be seen at night. There are significantly less sightings of all elephants during the full moon with higher rainfall having a positive effect on sightings.

Keywords: African savannah elephant, human-elephant conflict, elephant sociality, Loxodonta africana, male elephants, matriarchal herds, elephant highways, Botswana, Makgadikgadi Pans, Camera trapping

Table of Contents

Introduction

The IUCN reports that the African Savannah Elephant *(Loxodonta africana)* is suffering from continent-wide decline due to habitat loss and fragmentation, poaching, human-elephant conflict (HEC), and more recently, climate-change (Gobush et al., 2021) as humans and elephants increasingly compete for resources (Graham, Douglas-Hamilton, Adams, & Lee, 2009; Mpakairi, Ndaimani, Tagwireyi, Zvidzai, & Madiri, 2019; Thouless et al., 2016). There has been an increase of human settlements alongside the Makgadikgadi Pans National Park (MPNP) in Botswana since elephants historically occupied the region, exacerbating HEC along the Boteti river and increasing the socio-economic impact to local communities bordering the park (Evans, 2019). Male elephants tend to be responsible for crop-raiding (Jackson, Mosojane, Ferreira, & van Aarde, 2008) meaning that the influx of 'colonising' male elephants into MPNP after 2009 is thought to have contributed to the region becoming a hotspot for HEC, with the age of male elephants (predominantly older) increasing their propensity to crop-raid (Stevens, 2018). There is an ongoing need to understand elephant behaviour, demographics and spatio-temporal movements across the region in particular the use of 'elephant highways' which allow the elephants to navigate through the park. Areas with high elephant density, in close contact with people, are usually accompanied by behaviours such as crop raiding and reciprocal loss of life (Hoare, 1999, 2015). Addressing the issue of crop raiding is particularly important to subsistence farmers as it jeopardizes human livelihoods (Raphela & Pillay, 2021). Crop raiding and other forms of HEC also undermine local community perceptions of elephants and their willingness to adopt HEC mitigation tactics as a part of conservation efforts (Kiffner et al., 2021; Terada, Yobo, Moussavou, & Matsuura, 2021). There is evidence of an increasing poaching problem in Botswana outside of the MPNP, despite its stable elephant population (Schlossberg, Chase, & Sutcliffe, 2019), an important factor to consider given the known associations between increased HEC and elephant poaching (Compaore et al., 2020), although this is not yet the case in the MPNP. Effective human-elephant co-existence in the MPNP will greatly depend upon the analyses of field data on sociality, ecological needs, movements and demographics of its elephant population, particularly given the lack of local cultural knowledge on how to live alongside the elephants following their relatively recent population expansion (Evans, 2019; Thouless et al., 2016).

Elephants live in complex multi-tiered fission-fusion (Couzin, 2006) family or bond groups, with the mother-calf relationship central to the matriarchal herd (McComb, Moss, Durant, Baker, & Sayialel, 2001). There has been much less study of male sociality than of matriarchal herds, but it is understood that the degree of sociality of males alters as they progress through different life stages (Evans & Harris, 2008). Males leave the matriarchal herd between the age of 10 to 15 years, alternating between solitary all-male groups and occasionally, 2-3 months a year, they join female groups when they are in musth (Allen et al., 2020; P. I. Chiyo et al., 2011). Older males support cohesion and reduce aggression in younger male groups and act as a knowledge repository in a similar way to the matriarch and the breeding herd (Allen, Croft, & Brent, 2021; McComb et al., 2001). A male elephant's proximity to other male elephants who crop raid increases its probability of crop raiding, as these adult males are knowledge repositories for younger males (P. I. Chiyo, Moss, & Alberts, 2012; Hoare, 1999). As older males are more desirable for their tusks, poaching removes their positive influence from male society and may lead to higher incidences of HEC (Compaore et al., 2020). Elephants are known to prefer crop raiding at night (Graham et al., 2009; Gunn et al., 2014; Hoare, 1999), and tend to be more active at night in areas with high poaching pressure (F. W. Ihwagi et al., 2018), increasing nocturnal activity when in close proximity to nomadic pastoralist communities (Duporge et al., 2022; Gaynor et al., 2018). Previous studies have shown a decrease in elephant crop raiding incidents during the full moon phase (brightest) of the lunar cycle (Barnes et al., 2006; Gunn et al., 2014), behaviour which was consistent with the avoidance of humans, but which could also be due to thermoregulation requirements or foraging needs (Gunn et al., 2014). Another factor which influences elephant movements is rainfall, as this influences food availability with an increase in elephant home range size being observed during the wet season (Leggett, 2006). Understanding elephant's spatial use of their environment is important for planning to reduce HEC, particularly where human settlements and protected areas are in close proximity to one another. Elephant highways are a network of routes used by elephants to navigate their environment, which are also utilised by other wildlife (Haynes, 2012), so by placing camera traps along these highways in the MPNP it provides a useful way to analyse elephant spatio-temporal movements within the park for HEC mitigation whilst also gaining an understanding of their important role as ecosystem engineers (Gaynor et al., 2018; Haynes, 2012).

Methodology

Study Area and Data collection

Eight Reconyx HC600 Hyperfire camera traps were placed in trees upon elephant highways in the MPNP (Figure 1) which have a detection range of approximately 60ft. The camera traps were in operation from 2014 to 2017 with a period in April, May and June 2016 when the camera traps were not deployed. As the analyses conducted in this study were primarily comparing day/night sightings, the lunar period and group sizes, this is thought to be least affected by the downtime, although camera trap effort adjustments were made to hourly sightings to account for the different day/night lengths on each date.

Camera Trap Citizen Science Study: identification of individuals and groups sighted

All images were identified using a citizen science project (Appendix 1): Zooniverse (https://www.zooniverse.org/) by SnapShotSafari.

Identification of Males, Females and Age categories

The identification of males and females and their respective ages was carried out using criteria provided by EfA (Appendix 2), and subcategorised by ages as follows: Juveniles (0-9 years), Subadults (10-20) and Adults (21-36+). Data was included in the study if the citizen science identification co-efficient (confidence in identification) was ≥ 0.8. Male groups were identified as groups which did not have juveniles present, and breeding herds had juveniles present. All statistical analyses were non-parametric and conducted in R version 4.2.1 (R Core Team, 2022) after data distributions were checked for normality (Appendix 3, Appendix 4, Appendix 5).

Summarising of group sizes and hourly capture rates

The median group size identified per camera capture, represents the median average of the number of elephants per sighting as identified by each Zooniverse participant. The number of elephants in a group were aggregated from all sightings over each five-minute period to allow for a passing herd. A mean hourly capture rate was calculated for day/night comparisons to account for each particular day or night length, thus adjusting for camera trap effort. Day and night groups were calculated according to the sunrise and sunset times of each day.

The lunar cycle

The effect of the lunar cycle on sightings was investigated by compiling a total of sum of elephants (from the median group size) for every sighting on each date, for every day in the period from 01/06/2014 to 13/04/2017. Eight phases of the moon were identified from the corresponding part of the moon which is visible from the Earth at each phase (Dunford & NASA, 2014). The appropriate moon phase was assigned to each date from the following: New Moon, First Quarter, Full Moon, Last Quarter, Waning Crescent, Waning Gibbous, Waxing Crescent and Waxing Gibbous (Dunford & NASA, 2014). Each of the other moon phases were compared against the new moon as this is the darkest period (the full moon being the brightest).

Rainfall

Preliminary analyses indicated there may be a correlation with rainfall and elephant camera capture sightings (Appendix 6). For statistical analyses, average monthly rainfall figures were collected from Elephants for Africa over the period 01/01/2014 to 01/05/2017. The total elephant count is the sum of all individual elephants captured for each sighting from the median group size identified per camera capture, per month, which is analysed alongside corresponding monthly average rainfall figures.

Hypotheses

Hypothesis 1 (H1) analysed the differences between male elephant hourly camera capture rates during the day and at night as preliminary observations had indicated a difference in males' preference for certain times of the day/night (Figure 2, Figure 3, Figure 4). For hypothesis H1b (H1b), the median group size of males per sighting was compared in the day and night. Both hypotheses were analysed with a generalised linear model with a log link (Poisson regression) (Nelder & Wedderburn, 1972). To further ascertain whether male elephants more likely to be alone in the day/night, sightings were categorised into groups of alone or not alone (group size >1 or 1) for hypothesis H1c (H1c), analysed with a generalised linear model with a logit link (Binomial).

To further understand the demographics of male night sightings, hypothesis H2 (H2) analysed the difference in the hourly capture rate of male elephants of different age categories sighted on the elephant highways at night (Figure 3). Male age groups were compared to adult groups when assessing hourly capture rates. Hypothesis H2b (H2b) compared hourly capture rates of only sub-adult males in the day/night, which were analysed with a generalised linear model with a log link (Poisson regression). There were a total of 527 camera observations of sub-adult males identified for this (H2b) analysis. A total of 2185 observations from 2014 – 2017 were analysed with a fitted regression model using an Ordinary Least Squares linear regression $\boldsymbol{y = mx + c}$ (*where y is the dependent variable, m is the gradient, x is the independent variable, and c is the intercept*) (Galton, 1886).

Hypothesis H3 (H3) analysed the hourly day/night camera capture rates of total of 1847 observations of breeding herds using a generalised linear model with a log link (Poisson regression). Initial analyses of female observations indicated that there was a preference for female groups to certain periods of the day/night (Appendix 7). Group sizes of breeding herds were compared in the day/night for hypothesis H3b (H3b) using a generalised linear model with a log link (Poisson regression).

For hypothesis H4 (H4) The total number of observations for both male and breeding herds at each moon phase (Figure 3) were compared for a significance against the total number of new moon sightings using a generalised linear model with a log link (Poisson regression). For hypothesis H4b (H4b) an analysis of the effect of rainfall on the total sum of all elephants sighted (Appendix 6) was conducted using a generalised linear model with a log link (Poisson regression). Finally, the combined effect of the full moon sightings and rainfall upon the total number of all elephant sightings was conducted for hypothesis H4c (H4c) using a generalised linear model with a log link (Poisson regression).

Results

Male elephant behaviours in the day/night

Hourly camera capture rates of male groups in the day/night (H1)

The dataset for all males consisted of 22543 camera captures from 24/06/2014 to 10/04/2017. Mean hourly camera capture rates for all males were 0.082 (SD± 0.007) in the day and 0.084 (SD± 0.007) at night. The coefficient of day or night(night) indicated no significant effect of day/night on male camera capture rates (p-value = 0.59, Z-value: 0.94, Est. coeff: 0.04), (see Table 1, H1, Appendix 8).

Male group sizes and likelihood of being alone during the day/night (H1b, H1c)

From the male dataset, mean group sizes were 2.7 (SD± 3.85) in the day and 1.8 (SD± 1.67) at night (Figure 3). Analysis of distribution of group size data revealed a non-normal (poisson) distribution (Appendix 3). Analyses indicated that night-time had a significant negative effect on male group size compared to day-time (p-value = < 0.00, Z-value = -30.10, Est. coeff: -.038), (Table 1, H1b) and that males were significantly more likely to be alone at night compared to being alone in the day, with an odds ratio of over 4:1 (95% CI), (Table 1, H1c, Appendix 8).

Difference in male age category sightings during the day/night (H2)

Sub-adult males were not significantly less likely than adults to be sighted at night than during the day (p-value = 0.09, t value = -1.661, df: 2180), however, juveniles were significantly less likely than adults to be sighted at night than during the day (p-value = <0.000). The effect of day/night on the number of unidentified 'unknown' age sightings was not statistically significant (Table 1, H2, Appendix 8).

Number of subadult male sightings during the day/night (H2b)

Of the 527 sub-adult male observations there was a mean hourly sighting rate of 0.078; SD± 0.005 (day) and 0.087; SD± 0.007 (night). The total range of hourly capture rates in both day and night was 0.073 to 0.096. Subadult males were significantly more likely to be seen at night than in the day (p-value = <0.00, T-val: 14.41, d.f: 526, Est. Coeff: 0.01), (Table 1, H2b).

Female and breeding herd behaviours in the day/night

Difference in hourly capture rate of breeding herds sighted during the day/night (H3) and difference in female group size during the day/night (H3b)

Of the 1426 female breeding herd observations, there was no significant effect of day or night on hourly capture rates (Table 1, H3). Mean group sizes were 2.8 (SD± 3.05) in the day and 2.13 (SD± 2.42) at night. Breeding herd group size analyses for day and night sightings (Table 1, H3b, Appendix 8) showed that night-time had a highly significant negative affect on group size compared to day-time (p-value <0.00, Z-value: -7.70, Est. Coeff: -0.28).

Effects of the lunar cycle and rainfall on elephant sightings

The effect of certain times of the lunar cycle on the number of elephant sightings (H4)

A total of 1193 observations (of total elephants per night) were used for the analysis of the effect of lunar cycle on sightings (Table 1, H4) showing a highly significant (p-value: <0.00, Z-value: -4.27, Est. coeff: -0.20) negative effect of the full moon on elephant sightings when compared to the new moon (Appendix 8).

(H4b): The effect of rainfall and (H4c) : rainfall and the full moon on the number of sightings

Rainfall alone had a highly significant positive effect on all elephant sightings (Table 1, H4b); (p-value: <0.00, z-value:12.37, d.f: 1192), and the combined effect of rainfall and the full moon had a highly significant effect on sightings (Table 1, H4c, Appendix 8).

Discussion

Whilst overall male or female hourly capture rates in the day/night were not significantly different, the analysis of day/night sightings when broken down into male age subcategories indicated that male adults were significantly more likely to be seen than other age groups at night, and overall, males were much more likely to be alone at night. Previous studies have shown that crop-raiding incidents are usually by independent males (P. Chiyo & Cochrane, 2005; Smit, Pozo, Cusack, Nowak, & Jones, 2019), although it cannot be verified for certain that this is why the largely solitary males in this study were using the elephant highways at night. If the reason for night movement was due to thermoregulation needs, then it would be expected that both male and female elephants would show similar day/night sightings, which is not evident in this study. All elephants were significantly less likely to be seen during the full moon phase which suggests, as stated in previous studies, that this is an example of risk avoidance behaviour (Barnes et al., 2006; Gunn et al., 2014). Females and males moved along the highways in smaller groups at night (highly significant), although this could be due to the cameras being less able to detect all members of a herd at night. Although younger sub-adult males were less likely to be seen at night, this is not necessarily due to them not being detected by the camera traps as they are of similar size to adult females, so it is likely that they have an equal chance of detection.

Conclusion

Understanding how and when is useful to alert farmers and local communities as to when there is a higher risk of HEC, so knowledge of the lunar cycle and rainfall effects upon the elephant sightings are important to conservation efforts. Understanding why adult and lone males are more likely to use the elephant highways is key area to be explored. By collecting data of HEC times and places it may be possible to ascertain the reasons for night-time use of the highways, including their relation to the lunar cycle. Avoiding activity due to the full moon may be due to a perception of being seen by farmers and may be a learned behaviour so it would be useful to gather information of the activities of local farmers and settlements during the lunar cycle. Evidence of risk avoidance behaviours such as avoiding the full moon and moving in smaller groups at night suggest that this population of elephants may be experiencing fear due to anthropogenic disturbances or due to their recent population expansion in the area. Knowledge of how and when elephants move throughout the MPNP region is vital for sustainable HEC management and human-elephant co-existence. Further study to analyse other aspects of elephant movement such as day/night speed ratio or tortuosity as an indication of poaching pressure or a perception of risk (F. Ihwagi, 2018; F. W. Ihwagi et al., 2018) using satellite collars could prove useful for HEC mitigation in the communities next to the MPNP, particularly if individual crop-raiding elephants can be identified and patterns of behaviour established. The use of trip alarms for detecting HEC incidents could also prove effective if the satellite collar method were adopted, together with a more thorough understanding of the elephant's home ranges and reasons for using the elephant highways (Robertson, Holland, & Minot, 2008; Valeria, Guido, Rossella, & Foley, 2000). By identifying crops favoured by elephants in the area, it may also be possible to mitigate HEC by planting those less favoured varieties (Matsika et al., 2020).

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Tables

Statistical Table of Results

Table 1: Summary of statistical results conducted in R studio (RStudio Team, 2022)

Hypothesis	Independent variable	Dependent Variable	n	Generalised Linear Model Family	Link function	Estimate	95% CI	Z value/t value	P value	Decision
H1: Difference in male hourly capture rates in the day/night (all ages)	Day/Night	Hourly camera capture rates (male only)	11296	Poisson	log	0.035	0.163	0.535	0.593	Not significant
H1b: Difference in male group size in the day/night	Day/Night	Male individual count (group size)	11296	Poisson	log	-0.381	-0.357	-30.097	0.000	Significant
H1c: Difference in likelihood of males being alone in the day/night	Day/Night	Alone/Not alone (group size >1 or 1)	22518	Binomial	logit	(Exp) 4.582	(Exp) 5.098	27.989	0.000	Significant
H2: Difference in male age category hourly capture rate during the day/night	Day/Night	Hourly capture rate (males)	2185	Ordinary Least Squares (OLS)		Adults: 0.010 Juveniles: -0.004 Sub-adults: -0.001	Adults: 0.010 Juveniles: -0.002 Sub-adults: 0.000		Adults: 0.000 Juveniles: 0.000 Sub-adults: 0.105	Adults: Significant Juveniles: Significant Subadults: Not significant
H2b: Difference in the hourly capture rate of subadult males in the day/night	Day/Night	Hourly camera capture rate (subadult males only)	527	Ordinary Least Squares (OLS)		0.009	0.010	15.412	0.000	Significant

H3: Difference in hourly capture rate of female breeding groups during the day/night	Day/Night	Hourly camera capture rate (female breeding herds only)	1426	Poisson	log	0.041	0.415	0.217	0.828	Not significant
H3b: Difference in female group size in day/night	Day/Night	Group size (count of individuals per group)	1426	Poisson	log	-0.277	-0.206	-7.699	0.000	Highly significant
H4: Difference in nightly total number of elephants sighted at different stages of the lunar cycle	Stage of lunar cycle	Total elephant sightings (sum of total elephants sighted per night)	1193	Poisson	log	-0.191	-0.103	-4.268	0.000	Highly significant (Full moon compared to New moon)
H4b: Effect of rainfall measured upon total number of sightings	Monthly average rainfall (mm)	Total elephant sightings (sum of total elephants sighted)	1193	Poisson	log	0.001	0.001	12.464	0.000	Highly significant
H4c: Effect of rainfall and lunar cycle upon total number of sightings	Monthly average rainfall (mm) and Full moon	Total elephant sightings (sum of total elephants sighted)	1193	Poisson	log	Fullmoon: -0.184 Rainfall: 0.001	Fullmoon: -0.115 Rainfall: 0.001	Fullmoon: -5.210 Rainfall: 12.374	Fullmoon: 0.000 Rainfall: 0.000	Highly significant

Figures

Figure 1: Map of the camera trap locations within the MPNP along the elephant highways which lead to and from the Boteti River. Also highlighted are the local communities and villages along the Boteti river. Image adapted from (Agell, 2021)

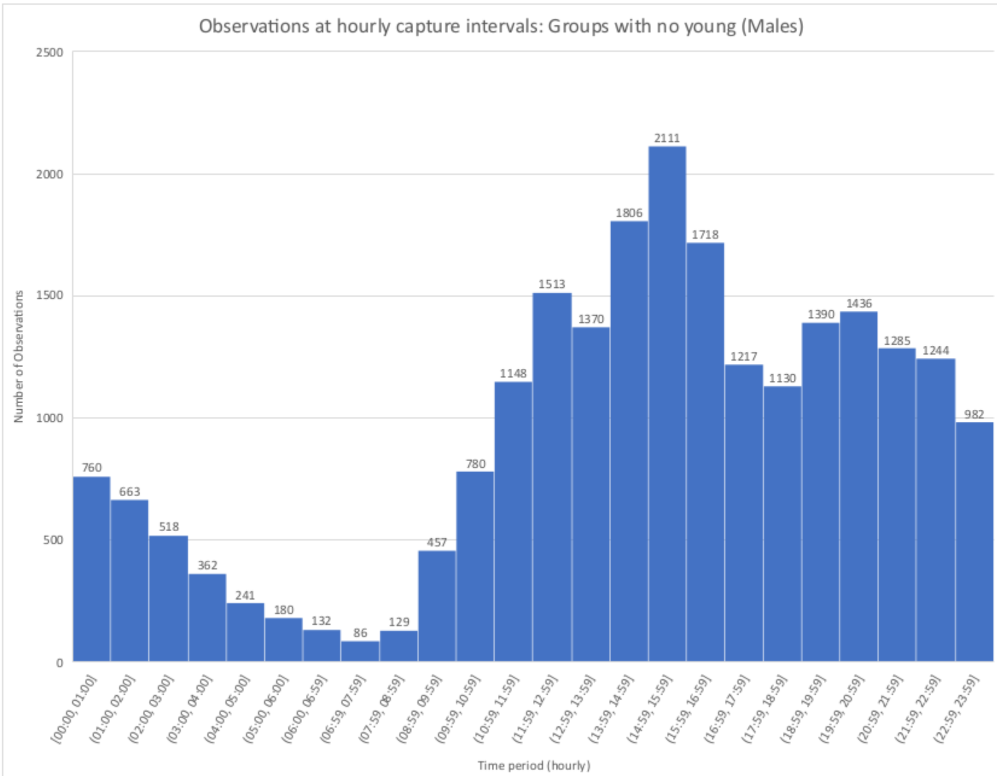


Figure 2: Total count of male elephant sightings for all camera traps over hourly intervals (24 hours) from data collected: 2014-2017.

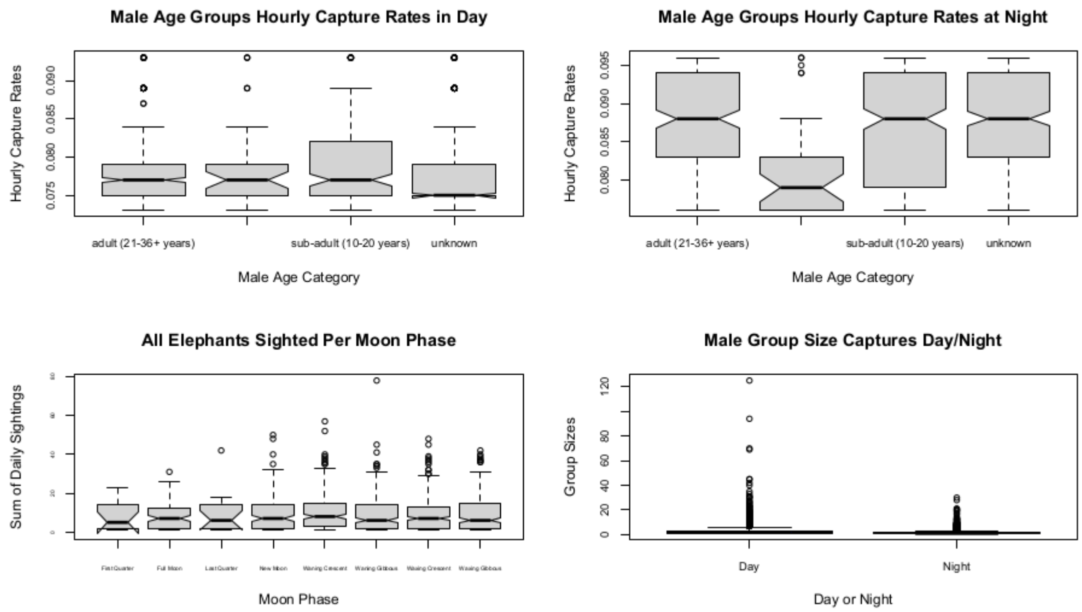


Figure 3: Boxplots of hourly capture rates of different male age categories during the day (top left) and at night (top right). Mean hourly rates were: Subadults: 0.078 (SD±0.005) day, 0.087 (SD±0.007) night, Adults: (0.078 SD±0.004) day and 0.088 (SD±0.005) night. Bottom left: Sum of all adult daily sightings per Moon Phase. Bottom right: Boxplot of male group sizes: mean size 2.7 (SD± 3.85) in the day and 1.8 (SD± 1.67) at night.

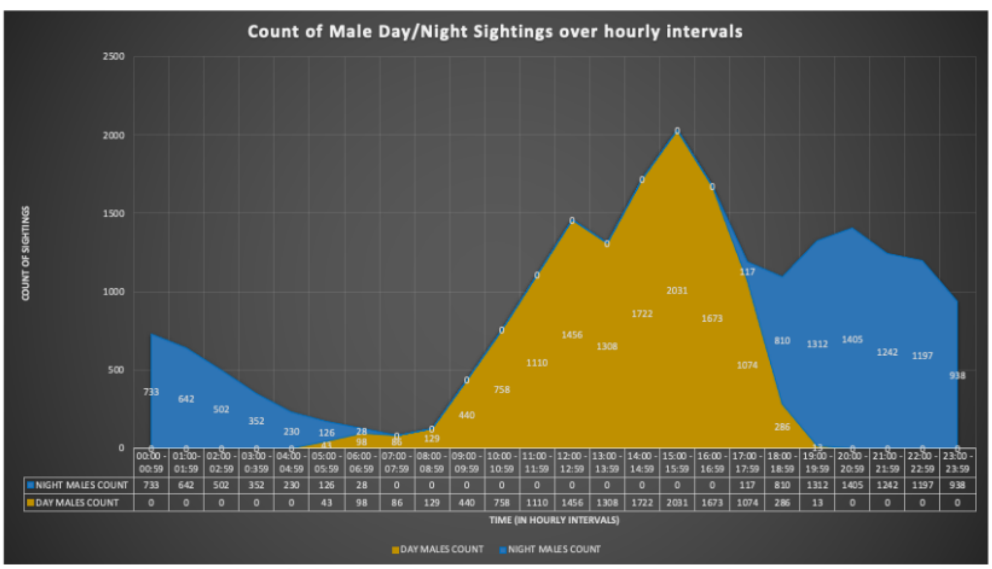


Figure 4: Graph of overall male day/night sightings (2014-2017), divided into hourly intervals with Day (yellow) defined as the period before sunset and after sunrise and night as the period after sunset and before sunrise for each date. Day and night-time hourly sightings overlap occasionally as sunset and sunrise times alter throughout the year.

Appendices

Appendix 1: Example of camera trap image used for identification in the citizen science Zooniverse identification process used by EfA.(https://panoptes-uploads.zooniverse.org/production/project_attached_image/702f2111-766d-4f7c-adf4-2e2d9b06d4c1.png)

A Guide to Ageing Elephants from Camera Trap Images
Our long-term monitoring of the elephant bulls of the Makgadikgadi Pans National Park involves assigning individuals to age classes in order to analyse the demographics of the elephant groups, preferred associations of different aged elephants, and the relative importance of age mates and mentors to different age classes. During our field observations we use the following seven age classes:

Years of age
Juvenile: 0-4, 5-9
Subadult: 10-15, 16-20
Adult: 21-25, 26-35, 36+

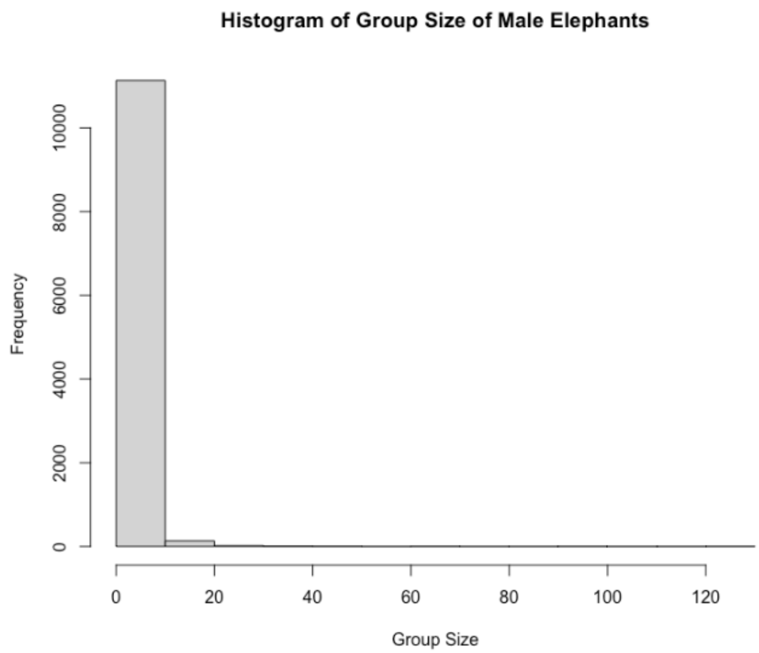
However, ageing elephants from camera trap images is a little tricky, and we cannot reliably assign elephants to such specific age categories. Therefore, we simply class elephants as "Juvenile", "Subadult" or "Adult".

Juvenile elephants
Juveniles can be identified by their small size. They may lack tusks, or if tusks are present they are extremely short, straight and thin. Juveniles will usually be part of a herd, consisting of adult females and sub-adult elephants, although older juveniles are occasionally sighted in all male groups. To the untrained eye, elephants can be quite difficult to sex (adult females and subadult males can look remarkably similar). Therefore, if an elephant is classed as a juvenile, the photo will be examined by experts from Elephants for Africa to determine the classification and if the group is a herd or an all-male group.

Subadult elephants
Subadult male elephants are larger than juveniles, usually 2.0 to 2.4m in height, thus are the same size as adult female elephants but smaller than adult male elephants. They have narrow, square-shaped foreheads. Their tusks are more developed than juveniles', but are still fairly thin, and straight. In older subadult males, the tusk start to curve forward, but the square-shaped forehead is still clearly visible. If an elephant is classed as subadult and not in a group with adult males, then the photo will be examined by experts from Elephants for Africa to confirm classification.

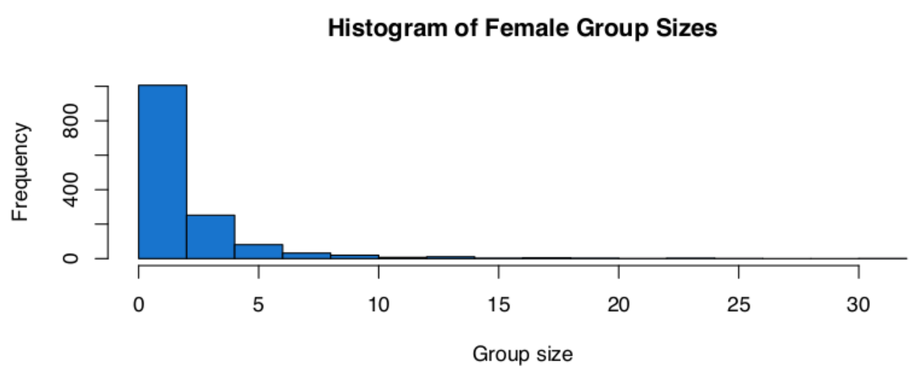
Adult male elephants
Adult male elephants are more than 2.4m in height. In male adults, their tusks are much thicker at the base (where they emerge from the face) than subadults and female elephants' (we use tusk thickness rather than tusk length as a measure of age because elephants regularly break their tusks) and become more splayed as an elephant gets older. An adult male elephant's forehead is more rounded and broader than a subadults', and the trunk is often thicker between the tusks. The head is also much larger relative to the body size and, when seen face on, the head develops a distinctive hourglass shape.

Appendix 2: A guide to identification of elephant age as provided to citizen science participants by Elephants for Africa.

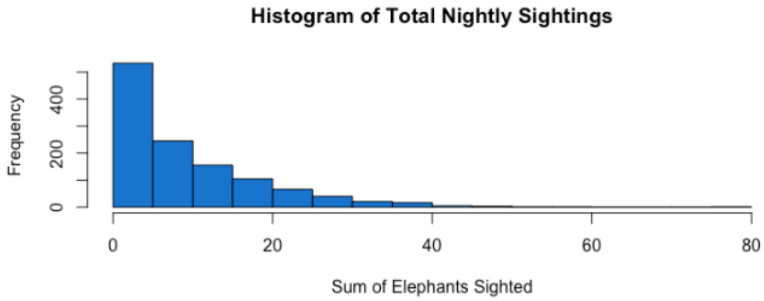


Appendix 3: Histogram of male group sizes showing non-normal poisson distribution

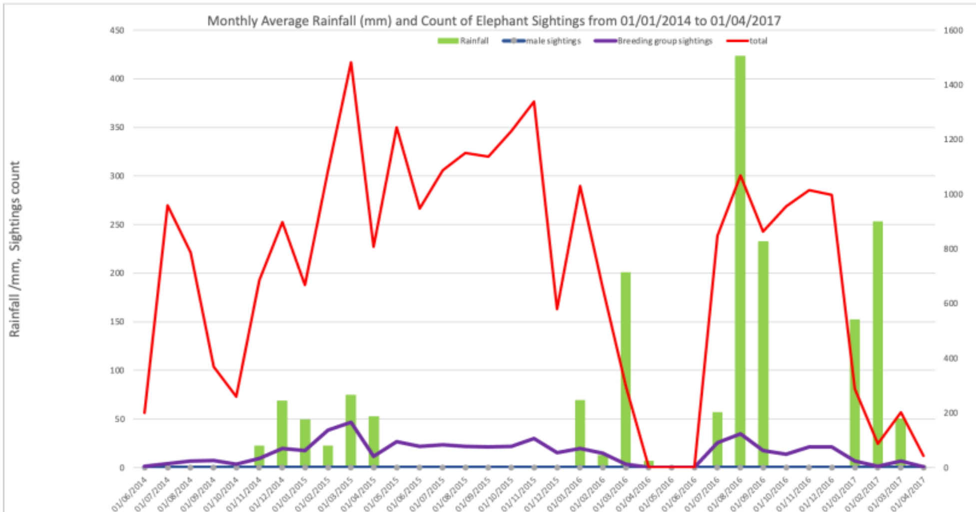
.



Appendix 4: Histogram of female group sizes showing non-normal poisson distribution



Appendix 5: Histogram of sum of total nightly sightings for males and females. (As used for hypothesis 4) indicating non-normal distribution (Poisson).

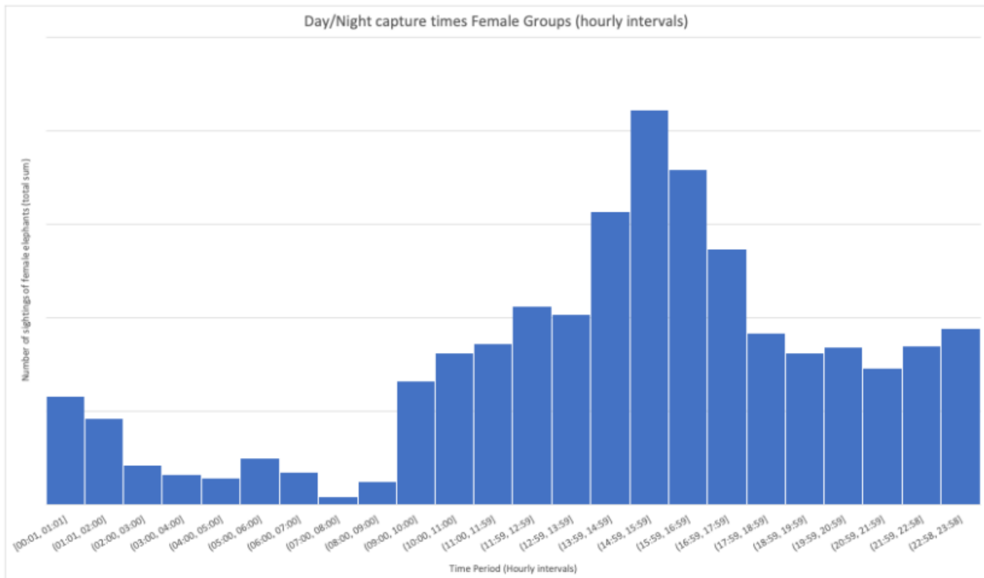


	01/06/2014	01/07/2014	01/08/2014	01/09/2014	01/10/2014	01/11/2014	01/12/2014	01/01/2015	01/02/2015	01/03/2015	01/04/2015	01/05/2015
Rainfall	0	0	0	0	0	22.1	68.2	48.9	22	74.5	52	0
male sightings	0	0	0	0	0	0	0	0	0	0	0	0
Breeding group sightings	4	15	24	25	13	33	69	62	136	166	41	95
total	201	959	787	368	259	685	897	668	1085	1483	807	1244

	01/06/2015	01/07/2015	01/08/2015	01/09/2015	01/10/2015	01/11/2015	01/12/2015	01/01/2016	01/02/2016	01/03/2016	01/04/2016	01/05/2016
Rainfall	0	0	0	0	0	1.4	0	68.9	12.5	200.6	6.5	0
male sightings	0	0	0	0	0	0	0	0	0	0	0	0
Breeding group sightings	78	84	77	75	78	106	55	69	52	13	0	0
total	947	1087	1151	1137	1232	1338	580	1030	658	299	0	0

	01/06/2016	01/07/2016	01/08/2016	01/09/2016	01/10/2016	01/11/2016	01/12/2016	01/01/2017	01/02/2017	01/03/2017	01/04/2017
Rainfall	0	56.5	422.8	232.5	0	0	0	152.2	252.5	50	0
male sightings	0	0	0	0	0	0	0	0	0	0	0
Breeding group sightings	0	90	124	63	49	75	76	23	5	23	2
total	0	847	1068	863	955	1015	998	288	88	202	44

Appendix 6: Graph of male and female elephant camera captures and monthly average rainfall for the period from 2014/2017.



Appendix 7: Graph of total female elephant captures taken from a total of 1847 observations of breeding herds which were collected between 2014 and 2017 for all camera traps, divided into hourly intervals.

Hypothesis	Description/variables	Results	Decision
*H1: Difference in **male hourly capture rates in the day/night (all ages)***	**Independent variable**: day/night **Dependent variable**: male group hourly camera capture rates.	MODEL INFO: *Observations:* 11296 *Dependent Variable:* Hourlycaprate *Type:* Generalized linear model *Family:* poisson *Link function:* log MODEL FIT: $\chi^2(1) = 0.286$, $p = 0.593$ *Pseudo-R² (Cragg-Uhler)* = NaN *Pseudo-R² (McFadden)* = NaN *AIC* = Inf, *BIC* = Inf *Standard errors:* Robust, *type* = HC1 Est. / 2.5% / 97.5% / z val. / p (Intercept) -2.508 / -2.599 / -2.417 / -53.982 / 0.000 daynightNight 0.035 / -0.093 / 0.163 / 0.535 / 0.593	**Not significant: (no difference in hourly capture rates in the day/night for <u>all</u> male age categories)**

*H1b: Difference in **male group size in the day/night***	**Independent variable**: day/night **Dependent variable**: individual count (group size)	MODEL INFO: *Observations:* 11296 *Dependent Variable:* count *Type:* Generalized linear model *Family:* poisson *Link function:* log MODEL FIT: $\chi^2(1)$ = 923.232, *p* = 0.000 *Pseudo-R^2 (Cragg-Uhler)* = 0.080 *Pseudo-R^2 (McFadden)* = 0.019 *AIC* = 46730.871, *BIC* = 46745.535 *Standard errors:* Robust, *type* = HC1 Est. / 2.5% / 97.5% / z val. / p (Intercept) 1.001 0.985 1.016 124.485 0.000 daynightNight -0.381 -0.406 -0.357 -30.097 0.000	**Significant: (smaller male group size at night)**
*H1c: Difference in likelihood of **males being alone in the day/night***	**Independent variable**: day/night **Dependent variable**: alone/not alone (group size >1 or 1)	MODEL INFO: *Observations:* 22518 *Dependent Variable:* count_bin *Type:* Generalized linear model *Family:* binomial *Link function:* logit MODEL FIT: $\chi^2(1)$ = 1002.439, *p* = 0.000 *Pseudo-R^2 (Cragg-Uhler)* = 0.085 *Pseudo-R^2 (McFadden)* = 0.062 *AIC* = 15183.967, *BIC* = 15200.011 *Standard errors:* Robust, *type* = HC1 exp(Est.) / 2.5% / 97.5% / z val. / p (Intercept) 4.766 4.551 4.991 66.318 0.000 day or night`Night 4.582 4.119 5.098 27.989 0.000  Odds ratio of being alone at night compared to day is over 4:1 (95% CI)  OR / 2.5 % / 97.5 % (Intercept) 4.766269 4.552348 4.992562 `day or night`Night 4.582489 4.123530 5.103747	**Significant: (Males more likely to be alone at night)**
*H2: Difference in **male age category hourly capture rate during the day/night***	**Independent variables:** day/night, male age category **Dependent variable:** Hourly capture rate	MODEL INFO: *Observations:* 2185 *Dependent Variable:* Hourlycaprate *Type:* OLS linear regression MODEL FIT: *F*(4,2180) = 357.505, *p* = 0.000 R^2 = 0.396 *Adj.* R^2 = 0.395 *Standard errors:* Robust, *type* = HC1 Est. / 2.5% / 97.5% / t val. / p (Intercept) 0.078 0.078 0.079 414.454 0.000 Day / Night`Night 0.010 0.009 0.010 36.144 0.000 question__speciesjuvenile (0-9 years) -0.004 -0.005 -0.002 -3.805 0.000 question__speciessub-adult (10-20 years) -0.001 -0.001 0.000 -1.623 0.105 question__speciesunknown -0.000 -0.001 0.000 -0.523 0.601	**Subadults: Not significant** **Male adults (Intercept): Significant: (more likely than other age groups to be seen at night)** **Juveniles: Significant: (less likely than male adults to be seen at night)**

H2b: Difference in the hourly ***capture rate of subadult males in the day/night***	**Independent variables:** day/night **Dependent variable:** hourly camera capture rate	MODEL INFO: *Observations:* 527 *Dependent Variable:* Hourlycaprate *Type:* OLS linear regression MODEL FIT: $F(1,525) = 207.789$, $p = 0.000$ $R^2 = 0.284$ Adj. $R^2 = 0.282$ *Standard errors:* Robust, *type* = HC1 Est. / 2.5% / 97.5% / t val. / p (Intercept): 0.078 / 0.078 / 0.079 / 207.929 / 0.000 Day / Night`Night: 0.009 / 0.007 / 0.010 / 15.412 / 0.000	**Significant: (subadult males more likely to be seen at night)**
H3: Difference in hourly ***capture rate of female breeding groups*** *during the day/night*	**Independent variables:** day/night **Dependent variable:** hourly camera capture rate	MODEL INFO: *Observations:* 1426 *Dependent Variable:* Hourlycaprate *Type:* Generalized linear model *Family:* poisson *Link function:* log MODEL FIT: $\chi^2(1) = 0.047$, $p = 0.828$ *Pseudo-R^2 (Cragg-Uhler)* = NaN *Pseudo-R^2 (McFadden)* = NaN *AIC* = Inf, *BIC* = Inf *Standard errors:* Robust, *type* = HC1 Est. / 2.5% / 97.5% / z val. / p (Intercept): -2.511 / -2.740 / -2.282 / -21.512 / 0.000 daynightNight: 0.041 / -0.332 / 0.415 / 0.217 / 0.828	**Not significant: (no difference in capture rates of female groups in day/night)**
H3b: Difference in ***female group size in day/night***	**Independent variable**: day/night **Dependent variable**: Group size (count of individuals per group)	MODEL INFO: *Observations:* 1426 *Dependent Variable:* count *Type:* Generalized linear model *Family:* poisson *Link function:* log MODEL FIT: $\chi^2(1) = 61.299$, $p = 0.000$ *Pseudo-R^2 (Cragg-Uhler)* = 0.043 *Pseudo-R^2 (McFadden)* = 0.010 *AIC* = 6322.221, *BIC* = 6332.746 *Standard errors:* Robust, *type* = HC1 Est. / 2.5% / 97.5% / z val. / p (Intercept): 1.033 / 0.994 / 1.072 / 52.066 / 0.000 daynightNight: -0.277 / -0.347 / -0.206 / -7.699 / 0.000	**Highly significant: (smaller female group size at night)**

<table>
<tr>
<td>H4: Difference in nightly total number of elephants sighted at different stages of the lunar cycle</td>
<td>Independent variable: stage of lunar cycle
Dependent variable: total elephant sightings (sum of total elephants sighted per night)</td>
<td>MODEL INFO:
Observations: 1193
Dependent Variable: total_sightings
Type: Generalized linear model
  Family: poisson
  Link function: log

MODEL FIT:
$\chi^2(7) = 44.491$, $p = 0.000$
Pseudo-R² (Cragg-Uhler) = 0.037
Pseudo-R² (McFadden) = 0.003
AIC = 13905.571, BIC = 13946.245

Standard errors: Robust, type = HC1
<table>
<tr><th></th><th>Est.</th><th>2.5%</th><th>97.5%</th><th>z val.</th><th>p</th></tr>
<tr><td>(Intercept)</td><td>2.286</td><td>2.228</td><td>2.343</td><td>78.181</td><td>0.000</td></tr>
<tr><td>relevel(as.factor(Moon_phase), ref = "New Moon")First Quarter</td><td>-0.196</td><td>-0.403</td><td>0.011</td><td>-1.853</td><td>0.064</td></tr>
<tr><td>relevel(as.factor(Moon_phase), ref = "New Moon")Full Moon</td><td>-0.191</td><td>-0.279</td><td>-0.103</td><td>-4.268</td><td>0.000</td></tr>
<tr><td>relevel(as.factor(Moon_phase), ref = "New Moon")Last Quarter</td><td>-0.031</td><td>-0.204</td><td>0.143</td><td>-0.348</td><td>0.728</td></tr>
<tr><td>relevel(as.factor(Moon_phase), ref = "New Moon")Waning Crescent</td><td>0.055</td><td>-0.015</td><td>0.125</td><td>1.539</td><td>0.124</td></tr>
<tr><td>relevel(as.factor(Moon_phase), ref = "New Moon")Waning Gibbous</td><td>-0.006</td><td>-0.076</td><td>0.065</td><td>-0.153</td><td>0.879</td></tr>
<tr><td>relevel(as.factor(Moon_phase), ref = "New Moon")Waxing Crescent</td><td>-0.031</td><td>-0.101</td><td>0.039</td><td>-0.872</td><td>0.383</td></tr>
<tr><td>relevel(as.factor(Moon_phase), ref = "New Moon")Waxing Gibbous</td><td>-0.012</td><td>-0.083</td><td>0.059</td><td>-0.334</td><td>0.739</td></tr>
</table>
</td>
<td>Highly significant: (Less sightings during the full moon compared to the new moon)</td>
</tr>
<tr>
<td>H4b: Effect of rainfall measured upon total number of sightings</td>
<td>Independent variable: Monthly average rainfall (mm)
Dependent variable: total elephant sightings (sum of total elephants sighted)</td>
<td>MODEL INFO:
Observations: 1193
Dependent Variable: total_sightings
Type: Generalized linear model
  Family: poisson
  Link function: log

MODEL FIT:
$\chi^2(1) = 143.351$, $p = 0.000$
Pseudo-R² (Cragg-Uhler) = 0.113
Pseudo-R² (McFadden) = 0.010
AIC = 13794.712, BIC = 13804.880

Standard errors: Robust, type = HC1
<table>
<tr><th></th><th>Est.</th><th>2.5%</th><th>97.5%</th><th>z val.</th><th>p</th></tr>
<tr><td>(Intercept)</td><td>2.207</td><td>2.186</td><td>2.228</td><td>204.259</td><td>0.000</td></tr>
<tr><td>Rainfall</td><td>0.001</td><td>0.001</td><td>0.001</td><td>12.464</td><td>0.000</td></tr>
</table>
</td>
<td>Highly significant: Rainfall has positive effect on the overall number of elephant sightings.</td>
</tr>
</table>

<table>
<tr>
<td>H4c: Effect of rainfall and lunar cycle upon total number of sightings</td>
<td>Independent variables: Monthly average rainfall (mm) and Lunar cycle
Dependent variable: total elephant sightings (sum of total elephants sighted)</td>
<td><pre>
MODEL INFO:
Observations: 1193
Dependent Variable: total_sightings
Type: Generalized linear model
  Family: poisson
  Link function: log

MODEL FIT:
χ²(2) = 171.954, p = 0.000
Pseudo-R² (Cragg-Uhler) = 0.134
Pseudo-R² (McFadden) = 0.012
AIC = 13768.109, BIC = 13783.361

Standard errors: Robust, type = HC1

                      Est.   2.5%   97.5%   z val.   p
----------------- -------- -------- -------- --------- -------
(Intercept)   2.222   2.200   2.244   199.369 0.000
Fullmoon   -0.184   -0.253   -0.115   -5.210 0.000
Rainfall   0.001   0.001   0.001   12.374 0.000

</pre></td>
<td>Significant:
Both full moon and rainfall variables had a significant effect upon total number of sightings. (Rainfall: positive effect and Full moon: negative effect)</td>
</tr>
</table>

Appendix 8: Statistical results conducted in R studio (RStudio Team, 2022), with variable descriptions, test type, test output, and outcome (decision) for each hypothesis.

Research Project 2185577

GRADEMARK REPORT

FINAL GRADE

67 /100

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

GRADING FORM: GWHC FEEDBACK AND MARKS

KERRY JOHN-DAVIS	0

TO COMMEND

Results are presented clearly, easy to follow, and statistical results presented well in main text. Really interesting and useful results showing that elephant behaviour varies by day and night, sex, age, and moon phase. Demonstrates depth of knowledge on the subject of elephant behaviour and human elephant conflict, and familiarity with relevant literature.

TO CONSIDER

The introduction skips over the story of elephants returning to the area/population expansion and seems to assume the reader knows about it. Lots of useful information and different relevant points in introduction but feels more like a list of points; would prefer to see a cohesive introduction to the study and its motivations/aims drawing on the relevant background. Discussion feels cut short – there is potential to put these interesting results into context of the wider literature and policy recommendations. Although the importance of the results is stated, it feels skimmed over and results are not fully explored in discussion.

GENERAL COMMENTS

The hypotheses are presented based on what was seen in preliminary data analysis, rather than a priori. I know the questions were narrowed based on preliminary analysis, but from our discussions these were also questions you were interested in prior to starting. It feels odd to present this as hypothesis-driven research, yet not have the theoretical justification for the hypotheses and to imply that these were all based on exploration of the data. Some figures were added in the appendix that if they were crucial to the results should have been included in the main paper. You worked very hard to get the statistical analyses right which was great, however perhaps the focus on getting the numbers out led to a lack of synthesis and contextualising of the results (which I know you are capable of). The results are really exciting and interesting, but I feel like you could have shown that more fully in the intro & discussion.