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First guidelines and suggested best protocol for surveying African elephants (*Loxodonta africana*) using a drone

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Unmanned aerial vehicles, commonly known as drones, are increasingly used in ecological management, conservation and research. Numerous reviews on drones tout almost unlimited potential within the wildlife sciences as they open up inaccessible habitats to observation. However, the influence of drones on the animals themselves is far less understood, and impact studies to construct protocols for best practices are urgently needed to minimise the potential for stress on target species. The impact of a quadcopter drone's approach speed, angle of approach and initial starting altitude was tested on the behavioural responses of African elephants (*Loxodonta africana*), along with sustained speed and flight pattern. Seventy-nine approach flights and 70 presence flights were conducted. The speed and angle of approach significantly impacted the success of a flight, but neither speed nor flight pattern had any measurable impact on elephants' behaviour during sustained flights. It is recommended that drones be launched at a distance of 100 m from an elephant or a herd of elephants, ascending to a height of 50 m by using an approach speed of 2m/s and an approach angle of 45 ° or less to successfully contact elephant targets.

Conservation implications: This study aimed to provide a significant step towards the ethical use of drones in wildlife research. Further research is required to investigate the impacts of drones on other taxa. Physiological responses to drones, for example, would determine if physiological stress responses unlinked to behavioural indicators are of concern in elephants.

Keywords: African elephant; aerial monitoring; drones; ethology; elephant behaviour; technology; unmanned aerial vehicles.

Introduction

Wildlife science usually focusses on the study, monitoring and management of animals and their habitats (Chabot & Bird 2015). Although these goals may be relatively simple, achieving them can be extremely challenging, particularly as resources are often limited and target species can be elusive, wide-ranging, sensitive to anthropogenic disturbances and/or dangerous to approach (Chabot & Bird 2015). Additionally, many target animals occupy habitats that are extensive, remote and often impossible to access at ground-level. New technologies have greatly aided accessing these difficult subjects in their challenging habitats. Examples include motion-triggered camera traps (O'Connell, Nichols & Karanth 2011), aircraft (Fleming & Tracey 2008), remote sensing satellites (Kerr & Ostrovsky 2003), radar (Larkin 2005), thermal cameras (O'Neil et al. 2005), projectile-based animal-capturing devices and chemical immobilisation agents (Roffe, Sweeney & Aune 2005; Schemnitz 2005) and a vast array of electronic tracking devices and accompanying software (Thomas, Holland & Minot 2011). One technology that is rapidly gaining popularity are the aerial units known variously as unmanned aircraft systems (UAS), unmanned aerial vehicles (UAV), remotely piloted aircraft systems or (mostly popularly) drones. The popularity of drones amongst wildlife biologists, ecologists and conservationists is clear from the many review articles investigating the applications and proliferation of drone use in remote sensing, natural resource sciences and ecology (Allan et al. 2015; Anderson & Gaston 2013; Christie et al. 2016; Colomina & Molina 2014; Jones, Pearlstine & Percival 2006; Koh & Wich 2012; Pajares 2015; Shahbazi, Theau & Menard 2014; Watts, Ambrosia & Hinkley 2012; Whitehead & Hugenholtz 2014; Whitehead et al. 2014). Chabot and Bird (2015) conducted an extensive review of drone use in wildlife management in which they highlighted optical surveying and observation of animals, uses of drones in autonomous wildlife telemetry tracking, habitat research and monitoring and a review of the broader potential for UAVs. Although the capabilities and potential practical uses of drones in the field of wildlife and conservation biology has been investigated thoroughly, their effects on the animals themselves have not been widely addressed (Leslie 2018).

This study assessed the possible effects of drones on African elephants (*Loxodonta africana*). Previous drone research on elephants has investigated the use of drones in mitigating human–elephant conflict (Hahn et al. 2016) and for population surveys (Vermeulen et al. 2013), but no work has examined the impact of drones on elephants or suggested any ethical recommendations for drone use. Because elephants exhibit high sensitivity to anthropogenic impacts and fit into many criteria for which drones might be considered as suitable monitoring tools (wide-ranging, sometimes in inaccessible habitats or perhaps dangerous to approach), there is a clear need to examine the potential impact of drones on elephants. The protocols developed in this study can be used to minimise the stress when utilising drones for elephant research.

Our specific objectives were to determine the following:

- What are the ideal approach speed and angles for drones to observe elephants without disturbance?
- What is the ideal sustained flight protocol for drones to observe elephants without disturbance?
- Do different types or sizes of elephant groups (breeding herds, lone bulls or bachelor herds) respond differently to the presence of a drone?
- Do elephant populations with greater exposure to previous, potentially negative drone or other aircraft encounters differ in their response to drone presence?

We hypothesised the following points: (1) slower speeds and a less steep angle of approach would minimise the disturbance to elephants as these patterns were successful with other taxa (Vas et al. 2015); (2) slower speeds and steady altitude would result in greater success rates for the sustained flight, that is keeping the drone with in close proximity to the elephants and collecting data; (3) herds containing dependent offspring would be more sensitive to the approach and presence of a drone; and (4) because of the higher levels of poaching, and subsequent helicopter and drone activity experienced by Liwonde National Park (LNP), we hypothesise that the elephants in the LNP would be more sensitive to the approach and presence of a drone (i.e. the approach or presence of a drone will be more likely to elicit higher response levels [see Table 2]).

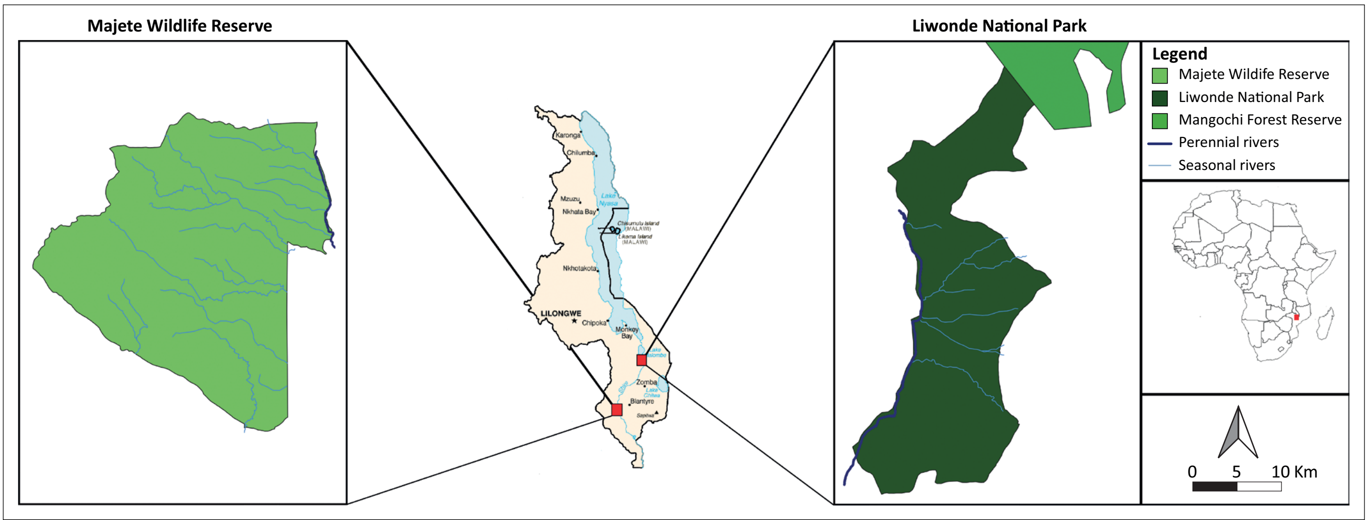
Methods

Study Area

Majete Wildlife Reserve

Majete Wildlife Reserve (MWR) is located at the southern tip of the Great Rift Valley in the lower Shire Valley region of southern Malawi (15.9364 °S, 34.6414 °E) (Figure 1). The reserve is 700 km^2 in size with two perennial rivers, the Mkulumadzi and the Shire. The altitude within the reserve varies greatly, with the western region containing steeply undulating hills disrupted by river valleys with the terrain flattening towards the Shire River in the east. Two well-defined seasons occur in Majete: the wet season (December to May) and the dry season (June to November). Annual precipitation varies according to topography from 680 to 1000 mm annually (Wienand 2013). Whilst surface water availability is dependent on seasonal rainfall, there are 10 artificial borehole-fed waterholes, as well as several naturally occurring perennial springs. MWR is not only dominated by multi-altitude woodlands, but also contains open savanna grassland areas (Forrer 2017).

In 1955, MWR was gazetted as a protected area, but poaching and poor management led to most of its large game being decimated by 2003 (Forrer 2017). As a result, a Public Private Partnership (PPP) agreement was made between African Parks, Majete (Pty) Ltd. and the Malawian Department of



Source: Created by Wian Nieman, PhD candidate and fellow member of the MWR research group.

FIGURE 1: Africa is shown with Malawi's location highlighted. A map of Malawi is also displayed in the centre, in which the locations of Majete Wildlife Reserve and Liwonde National Park can be seen. On the left, Majete Wildlife Reserve is displayed with perennial and seasonal rivers indicated, and on the right Liwonde National Park is shown with its perennial and seasonal rivers.

National Parks and Wildlife (DNPW) to initiate one of Africa's greatest reintroduction programmes. Over 2550 individual animals, comprising 14 different species, were reintroduced into MWR. Elephant, black rhino (*Diceros bicornis*), buffalo (*Syncerus caffer*), sable (*Hippotragus niger*), hartebeest (*Alcelaphus buselaphus*), several other antelope species and many predators were all included in the reintroduction programme. The reintroduction was considered successful as all wildlife populations are continuously increasing, including the elephant population which was steadily impacting the vegetation in MWR. The combination of increased rates of vegetation damage, because of the rapidly expanding elephant population within MWR, and the desire to reintroduce elephants to Nkhotakota Wildlife Reserve led to a decision to conduct a major translocation operation. During the months of June and July of 2017, 154 elephants were translocated out of MWR.

Liwonde National Park

Liwonde National Park is located in the Upper Shire Valley, which forms part of the Great East African Rift Valley in southern Malawi (14.8441 °S, 35.3466 °E) (Figure 1). The park is 548 km^2 in size and is generally flat except for three separate groups of hills. The dominant vegetation type in the park is *Colophospermum mopane* woodland, which occupies approximately 70% of the total area of the park (Morris 2006). Liwonde's dry season lasts from April to October and the rainy season from November to March. Annual rainfall ranges from 700 mm to 1400 mm. There are four artificial water points, which provide perennial water, located throughout the park (Morris 2006).

Historically a sport hunting ground for European planters and administrators from 1920 to 1969 (Morris 2006; Taylor 2002), LNP went through several status evolutions before being gazetted as a National Park in 1973, and formally opened to the public for wildlife viewing in 1978 (Morris 2006). In partnership with Malawi's DNPW, the African Parks Network assumed management of LNP in 2015. The new partnership saw significant investment in law enforcement and the construction of a new perimeter fence (Sievert, Reid & Botha 2018) reduced elephant and rhino poaching. Additionally, 1329 animals were translocated for restocking of other Malawian reserves, and the new partnership and protection resulted in the return of five, vulture species, the supplementation of the remnant black rhino population and the reintroduction of lion (*Panthera leo*) and cheetah (*Acinonyx jubatus)* (Sievert & Reid 2018; Sievert et al. 2018).

Unmanned aerial vehicle (drone)

This study used a UAV quadcopter, the Mavic Pro Platinum (DJI, Shenzhen, China). This specific model was chosen for its compact design, ability to launch and land in most places and noise reduction blades (4 dB quieter than the traditional DJI Mavic Pro), which at the time of the study, September 2018, made it the quietest commercial drone available. The drone is equipped with a GPS and internal measurement unit, which both aid in determining the position and height of the drone. The drone is remote controlled with a maximum flight range of 7 km. More information regarding the drone's specifications can be found in Appendix 1, Table 1-A1.

Data collection

Data collection in MWR occurred between September 2018 and April 2019, and in LNP between April and May 2019. The same methodology was applied within both reserves. As elephants range widely and unpredictably, the sampling scheme was opportunistic in nature. When an elephant or herd was encountered, primarily by vehicle, the elephant or herd was given time to 'settle' (i.e. display no outward signs of agitation or aggression) before the drone was launched and flown towards them. If the elephant or herd did not settle within 60 min, the drone was not launched. The DJI flight software displays the appropriate metadata (altitude, distance, speed, etc.) and was captured by screen-recording the playback device (Apple iPhone 7+, Apple Inc., USA). The location of launch and landing, the ambient temperature, the wind strength and the wind direction (towards launch point, away from launch point, across launch point) were all recorded. Wind strength was determined by using the Beaufort Scale (Appendix 1, Table 2-A1). Flights were not conducted if the wind speed was greater than a 'Strong breeze' (Beaufort number 6, 10.8–13.8 m/s) as this exceeds the drone's wind tolerance capabilities. The drone was launched at a minimum distance of 100 m from the elephants to ensure a safe distance should the launch induce an aggressive response.

Drone approach

The approach methodology largely followed that conducted by Vas et al. (2015). From the launch site, the drone ascended vertically to either a height of 35 m, 50 m or 100 m and then approached the elephants. Each flight had a pre-determined approach pattern, selected at random from 18 possible combinations that varied speed and angle of approach (Table 1). During each approach, the live on-screen video was recorded and analysed post-flight for elephant responses, which were scored by using a standardised scoring system

TABLE 1: The variables used throughout the *approach* and *presence* portions of data collection with the corresponding 'shortcuts' and abbreviations.

Portion of data collected	Type	Value	Shortcut	Abbreviation
Approach	Speed (m/s)	2	Slow	S
		4	Medium	M
		6	Fast	F
	Angle of approach (°)	45	Angle	A
		90	No angle	N
	Initial height (m)	35	Low	L
		50	Medium	M
		100	High	H
Presence	Speed (m/s)	2	Slow	S
		4	Medium	M
		6	Fast	F
	Flight pattern	Fixed height	Fixed	F
		Varied height	Varied	V

adapted from Langbauer et al. (1991), Poole (1999), O'Connell-Rodwell et al. (2006) and Soltis et al. (2014), with a five-point scale: No Response; Vigilance; Agitated; Flight; or Aggressive (Table 2). For each approach, the drone height, distance from the elephants and elephants' responses were recorded at 1-min intervals.

Approaches were classed as successful if the drone was able to reach a distance of 30 m or closer to the elephants without inducing a type 3, 4 or 5 response from at least one adult individual. Thirty metres was determined to be close enough to enable high-resolution observations with this drone model. Flights were terminated if the elephants displayed either a Flight (4) or an Aggressive (5) response at any point during the flight.

Drone presence

If an approach did not elicit a type 4 or 5 response, the drone was kept in contact with the elephants and a sustained flight was initiated, varying drone height and speed (Table 1) according to a randomly selected flight pattern. Drone height and distance and elephant response were scored at 1-min intervals up to a maximum flight duration of 25 min (because of the battery life of the drone). Flights were terminated if the elephants displayed either a Flight (4) or an Aggressive (5) response at any point during the flight (approach or presence).

TABLE 2: The various possible elephant responses recorded during both the *approach* and *presence* data collection.

Elephant response type	Code	Description
No response	1	No visible sign of disturbance. Elephants continue with what they were doing prior to the drone approaching or persisting.
Vigilance response	2	Elephants stop what they were doing. Head is turned towards the direction of the drone with ears slightly ajar and fixed. Trunk possibly extended towards the direction of the drone (attempting to smell the source of the noise i.e. the drone). Aware of the drone's presence, but no visible signs of disturbance.
Agitated response	3	Clearly aware of the drone's presence. Defensive behaviour: shielding of young ones, ears held completely out, slight vocalisations (small trumpets) and headshakes.
Aggressive response	4	Loud vocalisations (trumpeting); ears held completely out; headshakes; often stands on ground and faces the direction of the drone. Charging towards the drone, a possibility.
Flight response	5	Elephants actively fleeing in the opposite direction to the drone. Loud vocalisations possible (loud trumpeting).

Statistical analysis

Data were captured by using MS Excel and analysed by using STATISTICA 13 (*TIBCO Software Inc. (2017); http://statistica.io.,* Dell). Relationships between continuous variables and a nominal predictor variable were examined by using one-way ANOVA or non-parametrically by using Mann–Whitney or Kruskal–Wallis tests. Nominal variable relationships were investigated with contingency tables and likelihood ratio or Pearson's chi-square tests. Generalised linear models (GLZ) were used to investigate the influence of Environmental and Flight Variables (Appendix 1, Table 3-A1) on the success of flight approach or presence. Model fits were reported via multiple measures.

Ethical considerations

This study was cleared ethically by the University of Stellenbosch's Research Ethics Committee: Animal Care and Use (Protocol number: ACU-2019-7822).

Results

Contrary to expectations, there was no population level effect on drone flight success (χ^2, [$df = 1$] = 0.53, $p = 0.46555$) and the subsequent analyses dropped population as a variable. Instead, response as a function of previous drone experience was examined within the study as a shorter-term measure of potential disturbance.

Drone approach

Seventy-nine approach flights were conducted, and lone males were the most frequently contacted group type (Table 3). Group type did not affect the likelihood of an approach being successful (GLZ, Estimate = 0.44879, $p = 0.324$), but slower approach speeds increased the likelihood of a successful flight (GLZ [Akaike Information Criterion {AICc} = 64.98, BIC = 83.70, Nagelkerke $R^2 = 0.75$], Estimate = 0.9085, $p = 0.004$; Figure 2). Approach angles of 45° also increased approach success (GLZ [AICc = 64.98, BIC = 83.70, Nagelkerke $R^2 = 0.75$], Estimate = 0.0472, $p = 0.01456$; Figure 2). Starting altitude had no significant effect on the success of an approach (GLZ [AICc = 64.98, BIC = 83.70, Nagelkerke $R^2 = 0.75$], Estimate = 0.0055, $p = 0.718$), nor did environmental factors (GLZ [AICc = 64.98, BIC = 83.70, Nagelkerke $R^2 = 0.75$], Temperature: Estimate = -0.06374,

TABLE 3: The breakdown in the effort for Approach flights across Majete Wildlife Reserve and Liwonde National Park.

Elephant type	Majete Wildlife Reserve			Liwonde National Park			Total		
	Absolute number droned	Droned (%)	Success (%)	Absolute number droned	Droned (%)	Success (%)	Absolute number droned	Droned (%)	Success (%)
Bachelor herd	14	22	43	4	25	75	18	23	50
Breeding herd	12	19	50	3	19	33	15	19	47
Lone bull	25	40	56	6	38	67	31	39	58
Mixed herd	12	19	58	3	19	67	15	19	60
Total	**63**	**100**	**52†**	**16**	**100**	**60†**	**79**	**100**	**54†**

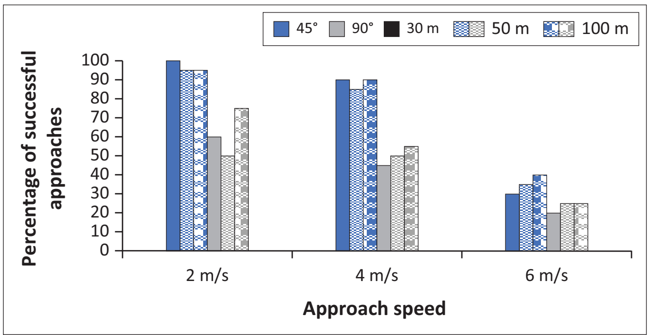
†, average.

Note: A total of 79 approaches were conducted across both locations with an average success rate of 54%. Sixty-three approaches were conducted in MWR with an average success rate of 52%. Sixteen approaches were conducted in Liwonde National Park with an average success rate of 60%.

p = 0.638; Season: Estimate = 0.40891, p = 0.310; Weather: Estimate = -0.35869, p = 0.622; Wind: Estimate = 1.4039460, p = 0.536).

Seventy presence flights were conducted with a 60% average success rate (Table 4). The average presence flight length was 15 min; however, the flight length of presence flights with a preceding successful approach differed significantly from those with unsuccessful preceding approach flights (Kruskal–Wallis chi-squared = 42.369, $p < 0.0001$, Figure 3). Successful approaches allowed a presence flight to be around the target elephants for an average of seven and a half minutes more than presence flights with an unsuccessful approach.

Once again, group type did not affect the likelihood of a presence flight being successful (GLZ [AICc = 52.20, BIC = 67.83, Nagelkerke R^2 = 0.79], Estimate = 0.68829, p = 0.422). Although some trends could be seen when broken down into flight variables (Figure 4), no presence flight variable (speed and flight pattern [fixed vs varied]) was found to significantly influence the success of a sustained presence flight (GLZ [AICc = 49.84, BIC = 66.63, Nagelkerke R^2 = 0.78], Speed: Estimate = -0.01996, p = 0.956; Flight Pattern: Estimate = 0.54753, p = 0.259). Likewise, no environmental factors were found to influence a sustained presence flight's success significantly (GLZ [AICc = 49.84, BIC = 66.63, Nagelkerke R^2 = 0.78], Temperature: Estimate = -0.07591, p = 0.658; Season: Estimate = -0.34112, p = 0.136; Weather: Estimate = 0.16054, p = 0.212; Wind: Estimate = 0.46393, p = 0.290). Notably, only the success of the preceding approach was found to influence the success of the following presence flight (GLZ [AICc = 52.20, BIC = 67.83, Nagelkerke R^2 = 0.79], Estimate = 2.39497, $p < 0.0001$).



Sustained Drone Presence.

FIGURE 2: The percentage of successful approaches, regardless of elephant category, when broken down by Approach Speed (2 m/s, 4 m/s or 6 m/s), Angle of Approach (45 ° or 90 °) and Starting Altitude (30 m, 50 m or 100 m).

Discussion

The timely and repeatable manner in which drones deliver high-definition (HD) picture and video footage of animals in often hard-to-reach places is a tool that every conservationist undoubtedly desires. A limited number of previous studies have indicated the usefulness of drones for collecting observational data (Ivoševi et al. 2015), and have quantified responses, for example with seals (Pomeroy & Connor 2015), birds (Vas et al. 2015) and bears (Ditmer et al. 2015). In this study, we quantified how elephants responded to various drone approach patterns and sustained drone flights. Although only a 54% and 60% success rate were achieved for the approach and presence flights, respectively, key insights into which factors influence elephants' behavioural responses were obtained.

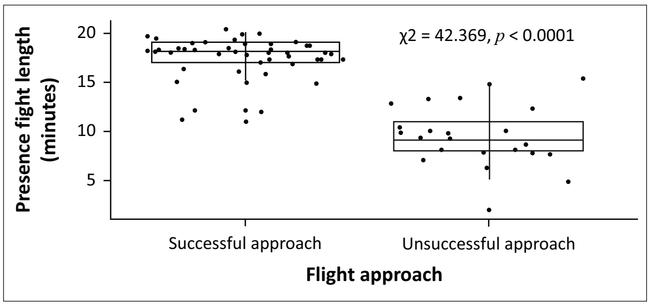


FIGURE 3: A significant difference was detected between the two groups (whether an elephant or group had a successful or unsuccessful approach flight) with significance levels measured at $p < 0.05$.

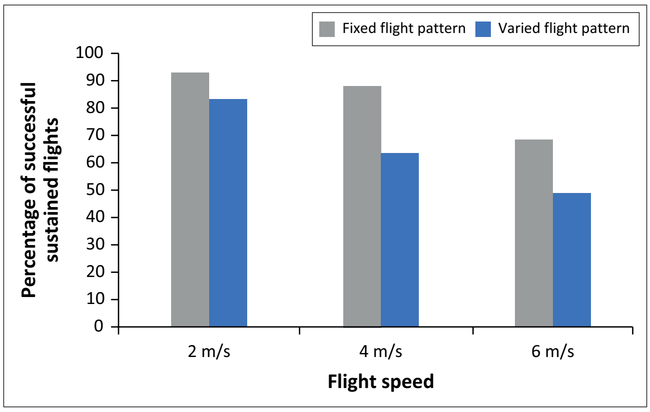


FIGURE 4: The percentage of successful presence flights, regardless of elephant category, when broken down by Flight Speed (2, 4 or 6 m/s) and Flight Pattern (Fixed or Varied).

TABLE 4: The breakdown in effort for presence flights.

Elephant type	Majete Wildlife Reserve			Liwonde National Park			Total		
	Absolute number droned	Droned (%)	Success (%)	Absolute number droned	Droned (%)	Success (%)	Absolute number droned	Droned (%)	Success (%)
Bachelor herd	12	21	58	3	21	100	15	21	67
Breeding herd	11	20	45	3	21	67	14	20	50
Lone bull	22	39	55	5	36	80	27	39	59
Mixed herd	11	20	64	3	21	67	14	20	64
Total	**56**	**100**	**55†**	**14**	**100**	**70†**	**70**	**100**	**60†**

†, average.

Note: A total of 70 presence flights were conducted across both locations with an average success rate of 60%. Fifty-six presence flights were conducted in Majete Wildlife Reserve with an average success rate of 55%. Fourteen presence flights were conducted in Liwonde National Park with an average success rate of 70%.

Environmental variables such as ambient temperature, weather, wind speed and season did not influence success rates of approach flights. It is likely that lone males were the most frequently contacted group type because the 2016–2017 translocation removed only female breeding groups, skewing the population structure towards males, and possibly resulting in female herds to be more cautious around vehicles. However, contrary to predictions, the category of elephant group targeted for a flight also had no effect on approach flight success, so females with calves and infants were not more sensitive to the approach of a drone, nor did starting altitude affect approach success, even though it would allow more time for elephants to assess whether the drone was a threat or not. Perhaps most surprisingly, there was no difference between populations, even though LNP elephants had high exposure to drones and helicopters and would be expected to show lower responses in general. This result might be interpreted with caution because of the low sample size in LNP.

Approach speed and angle significantly affected the success of an approach flight. The speed aspect makes logical sense, as the drone is quieter at slower speeds and may allow elephants additional time to identify (or attempt to determine) whether the drone is a threat or not. The reason a 45 ° angle of approach was preferable to a 90 ° of approach may very well follow a similar logic. In the field, when elephants elicited an agitated response, they were often observed to turn towards the direction in which the drone was approaching. With a 45 ° angle of approach, elephants were observed to tilt their heads upwards and appeared to be looking directly at the drone, once again, determining whether it was a 'real' threat or not. However, with a 90 ° angle of approach, elephants were unable to look directly above them and thus the noise from an unknown source descending upon them intuitively seems to explain their discomfort with this approach angle.

As for flight variables, very surprisingly neither pattern (a fixed or varied flight height) nor speed had a significant effect on success rates. It was assumed that slower speeds would yield greater rates of success as would a fixed flight height. A fixed flight height was assumed to be preferable to elephants as the pitch of the drone does not change much if kept at a constant height. This is shown in Figure 4, as across the three speeds, a fixed flight pattern consistently yielded a higher percentage of successful sustained flight. Likewise, slower speeds resulted in higher percentages of successful sustained presence flights. However, for both variables there was no statistical difference.

The only variable that was found to have a significant effect on the success of a sustained presence flight was whether the preceding approach flight had been successful or not. It was found that if an approach was successful, a sustained presence would almost always be too. It is therefore recommended that the approach protocols are always strictly adhered to, so as to prevent the initial disturbance and subsequent sustained disturbance of the elephants being droned. If the elephants are disturbed upon approach, it is unlikely they will return to an undisturbed state throughout the rest of the droning session. Should this occur, it is recommended that the droning session be cancelled for those elephants and only attempted again at a later stage.

As only just over a week was spent in LNP, a limited amount of data was collected. Not all approach or presence flight patterns were conducted, and thus a full pair-wise comparison was not possible with all the factors in one model. However, from the data collected, no clear trends were apparent in either the approach flights or presence flights. This indicates that there appears to be a critical amount or number of flights required for patterns to emerge. Somewhere between the number of flights conducted within MWR (63 approaches and 56 presences), where clear trends and significant differences were observed, and LNP (16 approaches and 14 presences) is the minimum amount or number of flights required for statistical validity.

Unlike in previous studies, where the animals were easy to locate and almost always readily accessible (e.g. Vas et al. 2015), droning sessions took place opportunistically when elephants were found in the field. Despite a lengthy field data collection period, a relatively low number of observational flights (both approaches and presences) were conducted. Additionally, not all patterns were flown the same number of times, with some never flown at all (the case for the LNP population). This may account for some of the variables not being significant in influencing elephant behavioural responses to the drone.

This study has clearly demonstrated that the speed and angle at which elephants are approached by a drone play a critical role in the elephants' ability to tolerate drones. Because presence flights depended only on the approach success, early exposure to drones determines the ability to stay with target subjects. Drone pilots, regardless of purpose (i.e. scientific or cinematic), need to be made aware of this and understand that speed and angle of approach will affect elephant responses, but once the approaches are unsuccessful, mitigating the effects in order to remain with target elephants becomes difficult. Drone pilots should always approach elephants with extreme care as reckless flying and repeated negative experiences are likely to limit drone success for elephants and may contribute to population stress. Furthermore, because drones are more likely to be used on stressed populations, pilots need to exert caution.

Further highlighting the importance of carefully approaching elephants aerially is the difference between the average length of time of sustained flights, for flights that had a successful versus unsuccessful approach, as seen in the time differences in the results. Aggressive or reckless approaches not only create negative associations between the target elephant population and drones, but they also ultimately inhibit long periods of observations and compromise the data and/or footage captured.

A major assumption of this study, as well as two previous studies (Pomeroy & Connor 2015; Vas et al. 2015), is the use of observable behaviour as a proxy for the animals' response to drones. Whilst this may serve as an acceptable model for the time being, greater efforts should be made to additionally measure the physiological response of the animals. Ditmer et al. (2015) found that although bears showed little to no outward behavioural response to drones, their heart rates increased significantly during drone flights. For elephants, the use of faecal samples to measure cortisol levels, to measure stress levels of elephants (Foley, Papageorge & Wasser 2002; Ganswindt et al. 2010; Viljoen et al. 2008), would provide information as to whether the outward behavioural response elicited by a drone is a good indicator of its physiological response as well.

This study is expected to act as a platform from which future research can be built upon. It aimed to outline a methodology of how to quantify an animal's response to the approach and presence of a drone. Although the sfocus of this study was elephants, the methodology employed can be easily manipulated to a wide variety of other wildlife species. If we wish to utilise new technology to aid in the efforts of conservation, at the very least we should understand how these technologies affect those species that we are trying to conserve.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

W.L.H. conceived the original idea, carried out the experiment and wrote the manuscript with support from A.L. and V.F. A.L. supervised the project.

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Data availability

The data that support the findings of this study are available from the corresponding author, W.L.H., upon reasonable request.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

References

Allan, B.M., Ierodiaconou, D., Nimmo, D.G., Herbert, M. & Ritchie, E.G., 2015, 'Free as a drone: Ecologists can add UAVs to their toolbox', *Frontiers in Ecology and the Environment* 13(7), 354–355. https://doi.org/10.1890/15.WB.015

Anderson, K. & Gaston, K.J., 2013, 'Lightweight unmanned aerial vehicles will revolutionize spatial ecology', *Frontiers in Ecology and the Environment* 11(3), 138–146. https://doi.org/10.1890/120150

Chabot, D. & Bird, D., 2015, 'Wildlife research and management methods in the 21st century: Where do unmanned aircraft fit in?', *Journal of Unmanned Vehicle Systems* 3(4), 137–155. https://doi.org/10.1139/juvs-2015-0021

Christie, K.S., Gilbert, S.L., Brown, C.L., Hatfield, M. & Hanson, L., 2016, 'Unmanned aircraft systems in wildlife research: Current and future applications of a transformative technology', *Frontiers in Ecology and the Environment* 14(5), 241–251. https://doi.org/10.1002/fee.1281

Colomina, I. & Molina, P., 2014, 'Unmanned aerial systems for photogrammetry and remote sensing: A review', *ISPRS Journal of Photogrammetry and Remote Sensing* 92, 79–97. https://doi.org/10.1016/j.isprsjprs.2014.02.013

Ditmer, M.A., Vincent, J.B., Werden, L.K., Tanner, J.C., Laske, T.G., Iaizzo, P.A. et al., 2015, 'Bears show a physiological but limited behavioral response to unmanned aerial vehicles', *Current Biology* 25(17), 2278–2283. https://doi.org/10.1016/j.cub.2015.07.024

Fleming, P.J.S. & Tracey, J.P., 2008, 'Aerial surveys of wildlife: Theory and applications', *Wildlife Research* 35(4), 258–267. https://doi.org/10.1071/WR07081

Foley, C.A.H., Papageorge, S. & Wasser, S.K., 2002, 'Non-invasive stress and reproductive measures of social and ecological pressures in free-ranging African elephants', *Conservation Biology* 15(4), 1134–1142. https://doi.org/10.1046/j.1523-1739.2001.0150041134.x

Forrer, F.A., 2017, 'The population status, habitat use and seasonal diet of African elephant (*Loxodonta africana*) in Majete Wildlife Reserve, Malawi', Master's thesis, Stellenbosch University, Stellenbosch.

Ganswindt, A., Munscher, S., Henley, M., Palme, R., Thompson, P. & Bertschinger, H., 2010, 'Concentrations of faecal glucocorticoid metabolites in physically injured free-ranging African elephants Loxodonta africana', *Wildlife Biology* 16(3), 323–332. https://doi.org/10.2981/09-081

Hahn, N., Mwakatobe, A., Konuche, J., De Souza, N., Keyyu, J., Goss, M. et al., 2016, 'Unmanned aerial vehicles mitigate human-elephant conflict on the boarders of Tanzanian Parks: A case study', *Oryx* 51(3), 513–516. https://doi.org/10.1017/S0030605316000946

Ivoševi, B., Han, Y., Cho, Y. & Kwon, O., 2015, 'The use of conservation drones in ecology and wildlife research', *Journal of Ecology and Environment* 38(1), 113–118. https://doi.org/10.5141/ecoenv.2015.012

Jones, G.P., Pearlstine, L.G. & Percival, H.F., 2006, 'An assessment of small unmanned aerial vehicles for wildlife research', *Wildlife Society Bulletin* 34(3), 750–758. https://doi.org/10.2193/0091-7648(2006)34[750:AAOSUA]2.0.CO;2

Kerr, J.T. & Ostrovsky, M., 2003, 'From space to species: Ecological applications for remote sensing', *Trends in Ecology and Evolution* 18(6), 299–305. https://doi.org/10.1016/S0169-5347(03)00071-5

Koh, L.P. & Wich, S.A., 2012, 'Dawn of drone ecology: Low-cost autonomous aerial vehicles for conservation', *Tropical Conservation Science* 5(2), 121–132. https://doi.org/10.1177/194008291200500202

Langbauer, J.R., Payne, W.R., Charif, R.A., Rapaport, L. & Osborn, F., 1991, 'African elephants respond to distant playbacks of low-frequency conspecific calls', *Journal of Experimental Biology* 157(1), 35–46. https://doi.org/10.1242/jeb.157.1.35

Larkin, R.P., 2005, 'Radar techniques for wildlife biology', in C.E. Braun (eds.), *Techniques for wildlife investigations and management*, 6th edn., pp. 448–464, The Wildlife Society, Bethesda, MD.

Leslie A.J., 2018, 'Earthwatch annual field report', Animals of Malawi [unpublished].

Morris, B., 2006, *The history and conservation of mammals in Malawi*, Monograph No. 21, Malawi Publishers Zomba, Kachere Series, 2006.

O'Connell, A.F., Nichols, J.D. & Karanth, K.U., 2011, *Camera traps in animal ecology*, Springer, New York, NY.

O'Connell-Rodwell, C.E., Wood, J.D., Rodwell, T.C., Puria, S., Partan, S.R. & Keefe, R., 2006, 'Wild elephant (*Loxodonta africana*) breeding herds respond to artificially transmitted seismic stimuli', *Behavioural Ecology and Sociobiology* 59, 842–850. https://doi.org/10.1007/s00265-005-0136-2

O'Neil, T.A., Bettinger, P., Marcot, B.G., Luscombe, B.W., Koeln, G.T., Bruner, H.J. et al., 2005, 'Application of spatial technologies in wildlife biology', in C.E. Braun (eds.), *Techniques for wildlife investigations and management*, 6th edn., pp. 418–447, The Wildlife Society, Bethesda, MD.

Pajares, G., 2015, 'Overview and current status of remote sensing applications based on unmanned aerial vehicles (UAVs)', *Photogrammetric Engineering and Remote Sensing* 81(4), 281–329. https://doi.org/10.14358/PERS.81.4.281

Pomeroy, P. & Connor, L.O., 2015, 'Assessing use of and reaction to unmanned aerial systems in gray and harbor seals during breeding and molt in the UK', *Journal of Unmanned Vehicle Systems* 3(3), 102–113. https://doi.org/10.1139/juvs-2015-0013

Poole, J.H., 1999, 'Signals and assessment in African elephants: Evidence from playback experiments', *Animal Behaviour* 58, 185–193. https://doi.org/10.1006/anbe.1999.1117

Roffe, T.J., Sweeney, S.J. & Aune, K.E., 2005, 'Chemical immobilization of North American mammals', in C.E. Braun (ed.), *Techniques for wildlife investigations and management*, 6th edn., pp. 286–302, The Wildlife Society, Bethesda, MD.

Schemnitz, S.D., 2005, 'Capturing and handling wild animals', in C.E. Braun (ed.), *Techniques for wildlife investigations and management*, 6th edn., pp. 239–285, The Wildlife Society, Bethesda, MD.

Sievert, O. & Reid, C., 2018, 'Liwonde National Park Aerial Survey', African Parks, Liwonde.

Sievert, O., Reid, C. & Botha, A.J., 2018, 'The re-emergence of African white-backed vultures (*Gyps Africanus*), White-headed vultures (*Trigonoceps occipitalis*) and Lappet-faced vultures (*Torgos tracheliotos*) in Liwonde National Park, Malawi', *Vulture News* 74(1), 12–19. https://doi.org/10.4314/vulnew.v74i1.2

Shahbazi, M., Theau, J. & Menard, P., 2014, 'Recent applications of unmanned aerial imagery in natural resource management', *GIScience & Remote Sensing* 51(4), 339–365. https://doi.org/10.1080/15481603.2014.926650

Soltis, J., King, L.E., Douglas-Hamilton, I., Vollrath, F. & Savage, A., 2014, 'African elephant alarm calls distinguish between threats from humans and bees', *PLoS One* 9(2), e89403. https://doi.org/10.1371/journal.pone.0089403

Taylor, P., 2002, 'Good news for Liwonde National Park, Malawi', *Oryx* 36(4), 323–324.

Thomas, B., Holland, J.D. & Minot, E.O., 2011, 'Wildlife tracking technology options and cost considerations', *Wildlife Research* 38(8), 653–663. https://doi.org/10.1071/WR10211

Vas, E., Lescroël, A., Duriez, O., Boguszewski, G. & Gremillet, D., 2015, 'Approaching birds with drones: First experiments and ethical guidelines', *Biology Letters* 11(2), 20140754. https://doi.org/10.1098/rsbl.2014.0754

Vermeulen, C., Lejeune, P., Lisein, J., Sawadogo, P. & Bouche, P., 2013, 'Unmanned aerial survey of elephants', *PLoS One* 8(2), e54700. https://doi.org/10.1371/journal.pone.0054700

Viljoen, J.J., Ganswindt, A., Palme, R., Reynecke, H.C., Du Toit, J.T. & Langbauer, Jr, W.R., 2008, 'Measurement of concentrations of faecal glucocorticoid metabolites in free-ranging African elephants within the Kruger National Park', *Koedoe* 50(1), 18–21. https://doi.org/10.4102/koedoe.v50i1.129

Watts, A.C, Ambrosia, V.G. & Hinkley, E.A., 2012, 'Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use', *Remote Sensing* 4(6), 1671–1692. https://doi.org/10.3390/rs4061671

Whitehead, K. & Hugenholtz, C.H., 2014, 'Remote sensing of the environment with small unmanned aircraft systems (UASs), Part 1: A review of progress and challenges', *Journal of Unmanned Vehicles and Systems* 2(3), 69–85. https://doi.org/10.1139/juvs-2014-0006

Whitehead, K., Hugenholtz, C.H., Myshak, S., Brown, O., LeClair, A., Tamminga, A. et al., 2014, 'Remote sensing of the environment with small unmanned aircraft systems (UASs), Part 2: Scientific and commercial applications', *Journal of Unmanned Vehicle Systems* 2(3), 86–102. https://doi.org/10.1139/juvs-2014-0007

Wienand, J.J., 2013, 'Woody vegetation change and elephant water point use in Majete Wildlife Reserve: Implications for water management strategies', Master's thesis, Stellenbosch University, Stellenbosch.

Appendices starts on the next page →

Appendix 1

TABLE 1-A1: Aircraft Specifications taken from the website of DJI (2018).

Variable	Component	Specifications
Aircraft	Supported battery	LiPo 3S (3830 mAh, 11.4V)
	Weight (battery & propellers included)	734 g
	Hover accuracy (ready to fly)	Vertical: ±0.1 m, horizontal: 0.3 m
	Max ascent/descent speed	5 m/s ascent, 3 m/s descent
	Max flight speed	65 km/h
	Max range from remote	7 km
	Max flight time (single battery)	27 min
	Diagonal motor-motor distance	335 mm
Camera	Sensor	1/2.3" (CMOS), effective pixels: 12.35 M (total pixels: 12.71 M)
	Lens	FOV 78.8 ° 26 mm (35 mm format equivalent) f/2.2 Distortion < 1.5% Focus from 0.5 m to ∞
	Image size	4000 × 3000
	Max video bitrate	60 Mb/s

TABLE 2-A1: The Beaufort Scale was used to determine the strength of the wind (wind speed) during drone flights.

Wind level	Description	Speed (m/s)
0	Calm – Smoke rises vertically	< 0.3
1	Light air – Smoke drifts	0.3–1.5
2	Light breeze – Wind felt on face	1.6–3.3
3	Gentle breeze – leaves and twigs in constant motion	3.4–5.5
4	Moderate breeze – Raises dust	5.6–7.9
5	Fresh breeze – Small trees begin to sway	8–10.7

TABLE 3-A1: Input variables used to investigate possible factors influencing drone approach and presence flights around elephants.

Variable	Environmental	Flight
Ambient temperature	X	-
Wind speed (Beaufort Scale)	X	-
Season (wet or dry)	X	-
Weather (overcast, cloudy or sunny)	X	-
Population (MWR or LNP)	X	-
Dependent offspring present?	X	-
Total number of individuals	X	-
Flight speed	-	X
Angle of approach	-	X
Starting altitude	-	X
Flight pattern	-	X

LNP, Liwonde National Park; MWR, Majete Wildlife Reserve.