RESEARCH ARTICLE

And Then There Was One: a camera trap survey of the declining population of African Elephants in Knysna, South Africa

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Conservation agencies rely on accurate wildlife population estimates to inform management practices. The importance of accuracy increases with smaller, threatened populations, but so too does the challenge in achieving it, especially for evasive species in low-visibility terrain. Non-invasive survey techniques have been successfully applied in such conditions; however, each technique bears a unique set of limitations and often deliver different results. The shy Knysna elephants (*Loxodonta africana*) occur at extremely low numbers in difficult terrain, and the past few decades have seen debates raging about their numbers, fuelled in part by differing survey outcomes, although a decline has been apparent over the last 150 years. We surveyed the known range of the Knysna elephant population for 15 months (July 2016 – October 2017), using camera traps, and identified one adult female elephant. The reliability of using camera trapping for surveying animal populations in conditions such as the Knysna elephant is compared with the previous faecal DNA genotyping survey. We conclude that this population has declined to a single individual and discuss the implications for local conservation authorities. Additionally, we highlight the importance of designing rigorous survey approaches where only a few individual animals are present.

Keywords: camera trap, elephant (*Loxodonta africana*), evasive behaviour, faecal DNA genotyping, small populations.

INTRODUCTION

With expanding human populations and their commensurate pressure on wildlife populations (Pollock, Nichols, Simons, Farnsworth, Bailey & Sauer, 2002), monitoring animal numbers is increasingly important (Trolliet, Huynen, Vermeulen & Hambuckers, 2014). Abundance is the most commonly used parameter in animal species' biology and conservation studies, and provides vital information for effective wildlife management and conservation (Blanc, Marboutin, Gatti, Zimmermann & Gimenez, 2014). Without it, preventative actions for local extinction and welfare risks are unlikely to be undertaken. Clearly there is a need for reliable estimates of the numbers remaining of species of concern.

Obtaining reliable field data for robust population estimates demands considerable time and resources and these challenges are compounded when sampling evasive species that occur at low densities and in habitats of low visibility (Karanth & Nichols, 1998). Under such conditions misinformed management decisions, based on crude population size estimations, educated guesses (Blake & Hedges, 2004) and misleading estimations from failed survey methodologies (Karanth & Nichols, 1998), can constrain effective conservation. Several non-invasive survey techniques have been developed to try to overcome these challenges. These include genetic sampling and camera trapping, which have become increasingly popular (McKelvey & Schwartz, 2004; Kühl,

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Maisels, Ancrenaz & Williamson, 2008; Rovero, Zimmermann, Berzi, & Meek, 2013).

The Knysna elephant population (*Loxodonta africana*), located in the southern Cape, South Africa, epitomizes this conservation challenge. It is both a relic population and Africa's southernmost group of elephants, existing at an extremely low density (Eggert, Patterson & Maldonado, 2007) in the mountainous landscapes and dense vegetation of the southern Cape forest and surrounding fynbos. These elephants are highly evasive and there is an aura of mystique around them in local culture, fuelled by popular writings (*e.g.* Watson, 2003). Their persistence may reflect their taking refuge in the forest, possibly due a historical persecution by humans in the 1700s and 1800s which ultimately led to their confinement to the forests (Seydack, Vermeulen & Huisamen, 2000; Kerley, Kowalczyk & Cromsigt, 2012). Since confinement, the population has declined considerably over the last 150 years (Table 1), making reliable counts particularly important. Although the drivers of decline are poorly understood, it was suggested that the forest is sub-optimal and therefore the primary driver (Koen, Hall-Martin & Erasmus, 1988; Seydack, Vermeulen & Huisamen, 2000), alternatively that the elephants were illegally killed (Carter, 1970).

The difficulty in counting these evasive elephants in the thick vegetation and steep terrain has delivered disparate findings (Eggert, Patterson & Maldonado, 2007). While a debate about the number of Knysna elephants persists, attempts for rigorous follow-up counts have been neglected, with the last scientific survey taking place more than a decade ago (Eggert, Patterson & Maldonado, 2007).

Although both DNA genotyping and camera trapping methods can be successfully applied using mark–recapture models through genetic tagging (McKelvey & Schwartz, 2004) and individual recognition, respectively (Karanth & Nichols, 1998), limitations still exist, especially for species occurring at extremely low densities (Brassine & Parker, 2015). In such cases, existing survey technologies may have to be applied intensively and in novel sampling designs (Brassine & Parker, 2015) and multiple techniques compared (MacSwiney, Clarke & Racey, 2008).

Faecal DNA genotyping (Eggert, Patterson & Maldonado, 2007), for example, provides estimates of population size, but does not provide information on the behaviour and ages of individuals. An added limitation is that dung freshness affects the reliability of DNA genotyping results (Fernando, Vidya, Rajapakse, Dangolla & Melnick, 2003; Piggott, 2004; Vynne, Baker, Breuer & Wasser, 2011). Considering the rough terrain and the evasiveness of the Knysna elephants, collection of sufficient good-quality dung samples is a challenge. Faecal DNA genotyping, therefore, needs to be checked against other sources of information to confirm its reliability.

Recent technological improvements in camera trap technology makes it a widely used, reliable application in ecological studies of evasive wildlife (Rovero, Zimmermann, Berzi & Meek, 2013). Camera-trapping, combined with a capture–recapture approach, has been successful in determining population sizes of evasive, individually identifiable species, such as tigers, *Panthera tigris* (Karanth & Nichols, 1998). Similarly, elephants' unique individual physical features such as ear notch patterns and tusk shapes and sizes, make

Table 1. Knysna elephant population decline since pre-colonial times, based on a variety of estimates.

Date	No. of elephants	Nature of estimate	Source
Pre-1652	1000s	Part of a continuous population in the southern Cape	Boshoff *et al.* 2002, 2016
1876	400–500	Conservators of Forests' official reports	Phillips 1925
1902	30–50	Forestry Department records	Dommisse 1951
1920	7–13	Forestry Department record less 5 killed by Major Pretorius	Dommisse 1951
1957	7	Cape Department of Nature Conservation Expedition (Fraser Expedition)	Woods 1958
1970	11	Wildlife Society Survey	Carter 1970
1981	3	Forestry Department records	Koen 1984
2007	5	Faecal DNA genotyping survey	Eggert *et al.* 2007

them individually identifiable (Moss, 1996). Camera trapping has, thereby, been successfully applied to investigate population sizes, demography and behaviour of evasive elephants in low-visibility habitats (Head *et al.*, 2013; Poole & Granli 2017, 2018).

Here we use camera-trapping, combined with capture–recapture methods, to determine how many free-roaming elephants are left in the Knysna region. In addition, we compare the outcomes of the applied camera-trapping to previously used techniques.

STUDY AREA

The study area represented the Knysna elephant range (33.80°S 22.85°E – 33.90°S 23.20°E), which was roughly 185 km^2 in size and situated in the Garden Route, southern Cape, South Africa. The range was identified by spatial elephant activity data, recorded annually for 30 years (SANParks, unpubl. data). The landscape has steep gradients with ravines cutting through the rugged, mountainous landscape in a north south direction (Baard & Kraaij, 2014), including those of the Homtini and Knysna rivers (Marker, 2003).

The elephant range included areas of the Garden Route National Park (GRNP), privately-owned commercial timber plantations and privately-owned forested land. The area was under various land use and is infiltrated by an extensive road network. Human activities included logging, ecotourism and alien invasive plant clearing activities, to name a few (Pauw, 2009). Roads and trails traversing the study area included hiking trails, forestry roads, logging slip-paths, public roads and a national highway.

The elephant range was composed of forest, classified as Southern Cape Afro-temperate Forest (Mucina & Rutherford, 2006), fynbos and commercial pine plantations. The Afro-temperate forest occurs mostly on the footslopes of the Outeniqua mountain range.

Indigenous medium to large mammal species, other than elephants, in the study area included bushpig (*Potamochoerus larvatus*), leopard (*Panthera pardus*), Chacma baboon (*Papio ursinus*), vervet monkey (*Chlorocebus pygerythrus*), caracal (*Caracal caracal*), small spotted genet (*Genetta genetta*), bushbuck (*Tragelaphus scriptus*), blue duiker (*Philantomba monticola*), Cape grysbok (*Raphicerus melanotis*), African clawless otter (*Aonyx capensis*), Cape porcupine (*Hystrix africaeaustralis*), honey badger (*Mellivora capensis*) and Cape grey mongoose (*Galerella pulverulenta*). Domestic animals encountered in the study area included dogs, cats, cattle, pigs and chickens.

The region's mean annual rainfall ranged between 800 and 1100 mm (Baard & Kraaij, 2014). Rain occurred throughout the year with peaks in spring (September–November) and autumn (March–May). The main rivers and their major tributaries throughout the area are perennial (Marker, 2003).

METHODS

Camera trap survey design

The sampling area covered the entire Knysna elephant range. The elephants have a predictable, seasonal movement pattern, moving from east to west and back east, annually. Although the elephant range is not fenced off, neighbouring farmland and natural features such as steep ravines confine elephant movement to within this range. The overall sampling area, therefore, covered the entire area where elephant or elephant signs had been recorded during the past three decades. The study area also adhered to the recommendation that the sampling area be large enough to capture the full extent of individual movements for such a population survey (Rovero, Zimmermann, Berzi & Meek, 2013).

Elephants tend to move directionally and in a non-random manner along clearly-defined elephant pathways between feeding patches and drinking places (Von Gerhardt, Van Niekerk, Kidd, Samways & Hanks, 2014). Our camera trap placement configuration therefore used a combination of this predictable, seasonal movement and a targeted camera placement approach (Brassine & Parker, 2015) by using well-used elephant paths as explained below. This configuration covered the elephant range evenly, with spaces between camera traps no larger than the smallest range recorded for our target species (Karanth & Nichols, 1998), elephant, which is roughly 10 km^2 (Douglas-Hamilton, Krink & Vollrath, 2005). In other words, considering elephant movement ecology, an elephant would not reside in a gap area, between camera trap stations, for the duration of the study. Trap locations were *a priori* identified using the 30-year elephant spatial database. Using ArcView 9.2 (ESRI, Redlands, California, U.S.A.), camera trap stations were placed across the Knysna elephant range, on known, well-used elephant trails (SANParks, unpubl. data), with no spaces between stations larger than about 10 km^2. This exercise, therefore, identified the number and distribution of camera trap stations required for the study.

Seventy-two passive infrared-triggered cameras (Bushnell Trophy Cam HD Aggressor No Glow) were deployed at 38 locations within the elephant range (Fig. 1) for the duration of the survey. The specific camera trap locations were chosen using a map of the *a priori* identified sites described above and confirmation from field rangers, experienced in elephant tracking in the area, that the sites had regular past as well as recent elephant activity.

An additional seven temporarily-positioned camera trap stations, using passive infrared-triggered cameras (Bushnell Trophy Cam HD Aggressor No Glow), were opportunistically deployed in the eastern side of the elephant range (Fig. 1) when elephant activity was reported in this area by conservation rangers, foresters, timber harvesters and hikers. The purpose was to gather data on elephant behaviour around infrastructure such as gates, and in high human disturbance zones, situated in areas where cameras could not be deployed permanently due to the high risk of theft. These areas were small enough to adhere to the assumption, made previously, that an elephant would not reside in it for the duration of the study. Although this paper does not deal with elephant behaviour, the data from these temporary traps were analysed for individual identification and are reported here.

Camera trap set-up and data collection

The sampling period spanned 14 July 2016 – 25 October 2017, when 37 of the 38 permanent camera stations were active simultaneously. One camera station was active from 14 July 2016 – 25 August 2017 as it had to be removed prematurely due to logging activities. Cameras were fastened to trees within 1 m of elephant-used roads and paths, at 1–1.5 m height (Meek, Ballard, Claridge, Kays, Moseby *et al.*, 2014). At 33 stations, two opposing cameras, housed in steel protective camouflaged casings, were angled with their infrared beams pointing towards the road so as to optimize capturing images of both sides for ear-notch pattern identification. The remaining five stations consisted of only one camera, as they lacked opposing trees.

The cameras were active 24 h per day and were set to take high-quality images (8 MP), with a 1-second interval between sequential photographs, and a 2-second delay between video clips. When elephant activity was reported close to cameras, settings were changed to record 15–30 second video clips, for behavioural data (not reported here) and footage for clearer identification. The sensor sensitivity level was set on 'normal' as elephants are homeotherms and do not require a high camera sensor sensitivity level (Meek, Ballard, Claridge, Kays, Moseby *et al.*, 2014). The flash intensity was set on 'high' when taking still images and on 'normal' when taking videos.

The cameras were serviced every 4–8 weeks to change batteries and SD cards. Camera malfunctioning, battery power failure, changes made to the settings of cameras and other relevant information were recorded at each inspection.

Elephant identification

All video clips and photographs of each capture event were visually inspected and analysed independently by two people (following Brassine & Parker, 2015). A capture event is defined as a single occasion in a location on which an elephant was present and recorded (Meek, Ballard, Claridge, Kays, Moseby *et al.*, 2014). Individuals were identified using combinations of physical features including appearance of 1) the left tusk, 2) right tusk and ear notch patterns of the 3) left and 4) right ears (Moss, 1996). For capture events where entire tusks or ear serrations were not clearly visible, other physical characters used were forehead wrinkle pattern, body shape and size, head shape and size, tail length and tail hair shape and temporal gland swelling (ElephantVoices, 2018). Sex identification was based on the reproductive organs (Moss, 1996).

Data analysis

For each camera station, the number of active camera days was calculated. Days on which both cameras at a station had simultaneously malfunctioned or were not active due to for example battery failure, were excluded (Brassine & Parker, 2015). The number of active trapping days per station were therefore the number of days that both cameras and/or one of the cameras were active. The total sampling effort of the survey, or total active camera trap days was the sum of active days of the 38 camera trap stations.

The capture frequency was calculated as the sampling period (days) divided by the number of capture events of an identified elephant.

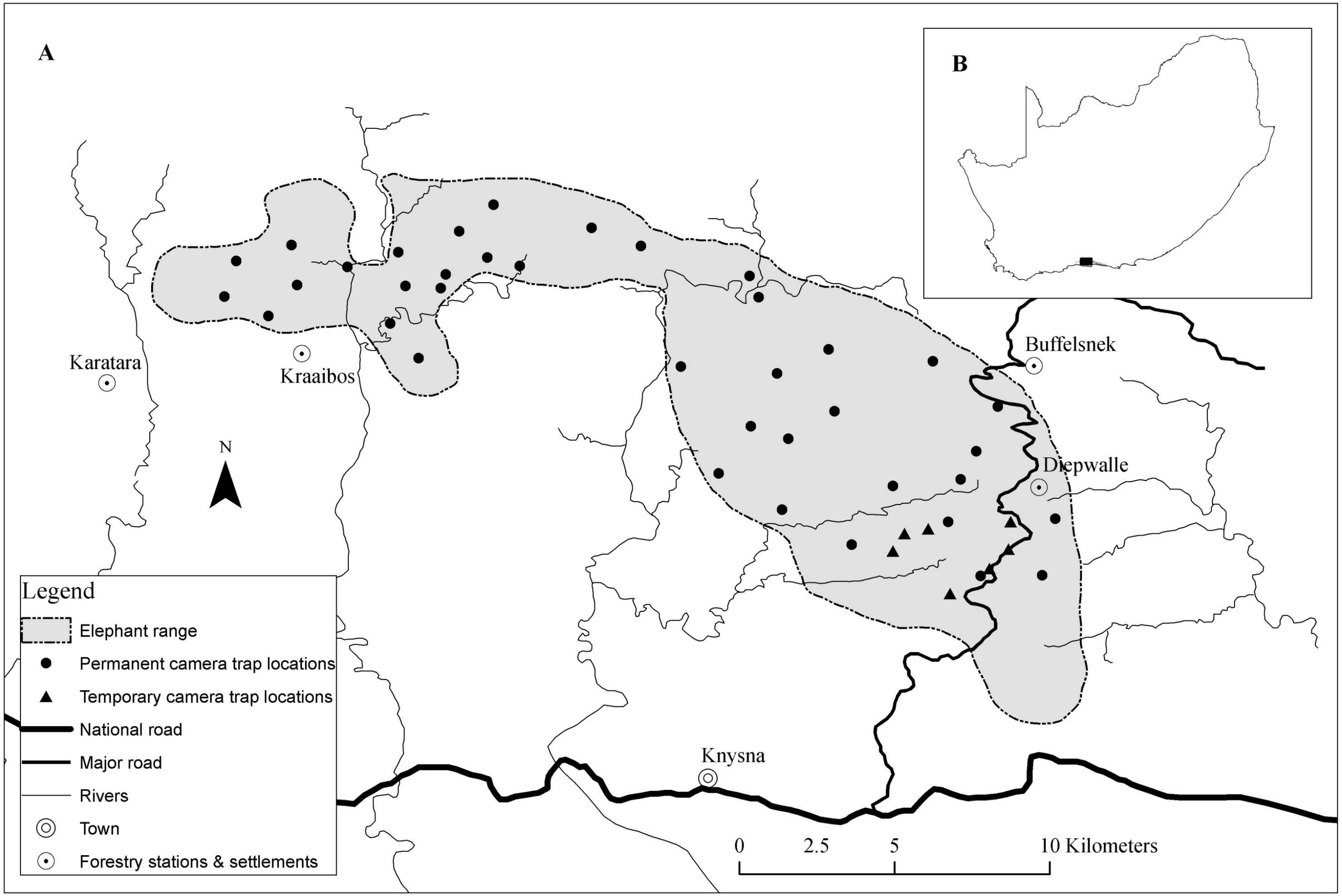

Fig. 1. Camera trap locations of the permanently-active stations ($n = 38$) and temporarily-active stations ($n = 7$), within the area to which the Knysna population has confined itself for the last 30 years (**A**). Inset (**B**) indicates the location of the Knysna elephant range in South Africa. Specific reference points are excluded to protect the elephant.

For each capture event, the number of unique physical features visible were recorded and whether the sex could be identified. Based on this, each capture event was categorized into a physical feature combination category (left tusk, right tusk, left ear, right ear and genitals) in order to illustrate the overall confidence in the identification process. Identification had a high confidence when two or more physical features were clearly visible. Even though identification could still be made with one physical feature visible, the confidence is lower in such cases. Capture events where an elephant was visible but none of the unique physical features were clearly enough visible for a confident identification, are also reported.

RESULTS

During the survey period, no reports of elephant activity were received in the area beyond the known elephant range.

The permanently-active stations had a total of 17 306 active camera trapping days during which a total of 5195 elephant photographs or video clips (15–30 seconds each) were captured, in 144 capture events (Table 2). All of these comprised only one detectable elephant at each event. Of these capture events, four captured a single elephant that was not sufficiently visible for identification purposes due the elephant being too far away or the images being too dark. Of the 144 capture events, 140 captures were identified to represent one recognizable individual adult female elephant. This individual was captured at 21 (55%) of 38 camera stations. The capture frequency shows that this elephant was captured on average every 3.2 days during the 447-day long survey. Detailed information of each elephant capture event, including dates, time, identification and temporal streaming, is available in the online supplement (Table S1).

The temporarily active stations, had a total of 434 active camera trapping days during which a total of 92 elephant video clips (15–20 seconds each) were captured, in five capture events (Table 2). In all of the capture events, only one individual adult female elephant was clearly identified (the same individual as identified using the data from the permanently-active stations). This elephant was captured at four (57%) of the seven camera stations. Detailed information of each elephant capture event, including dates, time, identification and temporal streaming, is available in the online supplement (Table S1).

A summary of the Knysna elephant unique physical features visible in capture events are provided in Table 3. The adult female elephant that was repeatedly identified, had unique ‘serrated’ ear notch patterns on both her left and right ears and relatively wide-spaced asymmetrical unbroken tusks, the left tusk higher than the right tusk (Figs 2–4). In addition, the left tusk had a chip on its tip presumably from a previous break, grown back but not smoothed yet (Fig. 5). In 99% of capture events showing the temporal area (n = 127), temporal streaming could be seen. Unusually for a female, her temporal glands were swollen (Figs 2A & 3A). Although the female could be identified successfully from her tusk conformation and ear serration patterns alone, she furthermore had a highly wrinkled forehead that formed a unique, easily identifiable pattern (Fig. 3A). She was a heavy, round-bodied female with an unusually rounded and wide forehead for a female (Fig. 3A). Her tail was short (reaching only to the level of her genitals) and the tail hairs were of uneven length – some long and some clearly shorter (Fig. 4). A

Table 2. Summary of the Knysna elephant camera trapping survey effort and data.

	Permanent stations	Temporary stations
Sampling period (days)	447	62 (mean)
No. of camera trap stations	38	7
No. of active camera trap days	17 306	434
No. of elephant photo/video captures	5 195	92
No. of elephant capture events	144	5
No. of capture events where identification possible	140	5
No. of individual elephant identified	1	1
No. of stations that captured elephant	21	4
Capture frequency per individual	3.2	12.4

Table 3. Summary of the Knysna elephant unique physical features visible in capture events, including the permanently active station capture events (n = 141) and temporarily active station capture events (n = 5).

Combination of unique physical features visible	No. of unique physical features visible (excl. sex)	Sex: male (M), female (F) or unknown (U)	No. of capture events
Features not visible	0	U	4
Left tusk	1	F	1
Right tusk	1	F	2
Left tusk & sex	1	F	2
Right tusk & sex	1	F	2
Left ear notches & sex	1	F	1
Both tusks	2	F	5
Right ear notches & right tusk	2	F	1
Both tusks & sex	2	F	22
Left ear notches, left tusk & sex	2	F	4
Right ear notches, left tusk & sex	2	F	1
Right ear notches, right tusk & sex	2	F	4
Left ear notches & both tusks	3	F	3
Right ear notches & both tusks	3	F	2
Left ear notches, both tusks & sex	3	F	27
Right ear notches, both tusks & sex	3	F	30
Both ear notches, both tusks & sex	4	F	38

further unusual and identifiable characteristic of note is that, although she was a fully mature adult female, she lacked developed breasts, because she was neither pregnant nor lactating (Figs 2A–C, 3A–C & 5A).

DISCUSSION

Our study confirms that there is only one elephant cow left in the Knysna forest and surrounding fynbos. It additionally shows that in some cases, camera trapping is a more reliable approach than DNA genotyping for surveying evasive, individually identifiable mammals occurring at extremely low numbers. These points are expanded upon below.

Apart from the consistent recording of only one individual elephant, for 15 months, across the entire elephant range, her sex together with her solitary status provides support that only one elephant remains. Female elephants spend their lives in family units of related adult females and their calves (Moss & Poole, 1983; Archie, Moss & Alberts, 2006), and lone cows are an extremely rare and unusual occurrence in the wild (Mubalama, 2000). One would, therefore, expect that if there were other elephants in the forest, the Knysna elephant cow would have been recorded together with them, at least on occasion.

The female elephant's shrivelled mammary glands suggest that she has not had a calf in a long

Fig. 2. Elephant identification relied on the shape of the tusks (**A**) and ear notch pattern of the right (**B**) and left (**C**) ears. Illustrated here is an example of the same event in which both tusks and both ears' notch patterns are visible. Note, too, the undeveloped or shrivelled mammary glands (**A**–**C**) and the swollen and secreting temporal glands (**A**).

Fig. 3. The same individual elephant can appear different in day-time (**A**) and night-time (**B** and **C**) exposures, but upon careful examination of the unique physical features, identification is possible. Illustrated here is an example of the Knysna elephant cow captured from the same angle at different times and in different light conditions. The tusks' shape and right ear notch pattern are clearly visible (**A**–**C**). In the daytime image (**A**), the wrinkle pattern on the forehead is clearly visible as are the swollen temporal glands.

Fig. 4. Sex served as an extra feature for individual identification. However, it was not used on its own for identification and other identifying features had to be clearly visible in the sequence. Visible in this photograph is the reproductive organ of the elephant female. In addition her relatively short tail can be seen.

time, if ever. Furthermore, swollen temporal glands and the excessive temporal streaming, seen in almost all of the capture events, is likely an additional indicator of her solitary status. Excessive temporal streaming has been reported in elephants that have been disturbed (Laws, 1970) and may therefore be an indication of stress. This suggests that the Knysna elephant may be experiencing stress, potentially as a result of her having no company.

In addition to determining the status of the Knysna elephant population, the camera trap survey has provided behavioural information on the remaining elephant (not reported here) as well as physical features that allow inferences on her age, physiological state (temporal gland swelling and streaming, which may indicate stress) and reproductive status (shrivelled mammary glands). The latter have identified a welfare challenge, which would not have been possible had the elephant not been continuously and non-invasively visually documented. Camera trapping, therefore, records conservation-relevant information beyond mere animal numbers, such as aberrant behaviours, and signs of non-reproductive status, and of stress in the species being surveyed (Caravaggi, Banks, Burton, Finlay, Haswell *et al.*, 2017).

The last survey of the Knysna elephant was undertaken between November 2002 and December 2003, using DNA genotyping, in which five individual elephant cows were reported (Eggert, Patterson & Maldonado, 2007). This study also

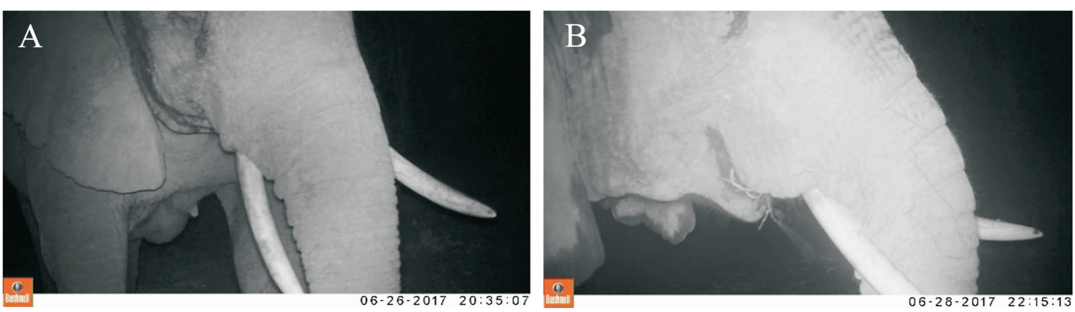

Fig. 5. Apart from the differences in curve between the two tusks, with the left tusk curved more upwards, it also has a chip on its tip, presumably reflecting a previous break which has subsequently grown back (**A** and **B**).

suggested the existence of a calf, based on one dung size measurement, and by inference, at least one breeding bull, although no concrete evidence was provided (Eggert, Patterson & Maldonado, 2007).

Of the non-invasive DNA sources, dung is the most commonly used in ecological studies across the world (Fernando, Vidya, Rajapakse, Dangolla & Melnick, 2003). Using dung simplifies studies and time spent in the field because all animals defecate regularly, and finding dung is typically simple and the collection, storage and transport require little technology or expense (Fernando, Vidya, Rajapakse, Dangolla & Melnick, 2003). A number of problems using genotyping of non-invasive samples to determine population sizes have, however, surfaced since its initial applications (McKelvey & Schwartz, 2004), especially when using source material containing low amounts of DNA such as dung (Taberlet, Waits & Luikart, 1999). These problems are referred to as genotyping errors and include low amounts of DNA extracted (Frantzen, Silk, Ferguson, Wayne & Kohn, 1998) and DNA degradation leading to non-amplification, false alleles, and allelic dropout (Taberlet, Waits & Luikart, 1999), all of which can be affected by the freshness of samples (Fernando, Vidya, Rajapakse, Dangolla & Melnick, 2003), which in turn biases the survey result.

Recent studies indicate that for reliable elephant population estimations and demographic studies using DNA extracted from dung, samples are less than 24 hours old (Schuttler, Philbrick, Jeffery & Eggert 2014). The freshness of dung has an effect on the quality and quantity of DNA in the sample (Fernando, Vidya, Rajapakse, Dangolla & Melnick, 2003). Similarly, hormone metabolite concentrations, used to analyse wildlife reproductive function and responses to stressors, decrease 20 hours after defecation (Webber, Henley, Pretorius, Somers & Ganswindt, 2018). Dung that remains in the field for too long before collection can become degraded and difficult to amplify (Taberlet, Waits & Luikart, 1999; Fernando, Vidya, Rajapakse, Dangolla & Melnick, 2003). The level of degradation of the DNA in a sample eventually affects the level of genotyping error, which can cause population overestimations (Lukacs & Burnham, 2005). To ensure an acceptably low genotyping error, older samples should be excluded from analysis (Lukacs & Burnham 2005).

Of the 18 genotyped dung samples for the Knysna elephant DNA survey, five were older than five days and the rest were reported to be between one and four days old (Eggert, Patterson & Maldonado, 2007). It therefore appears that the samples were old, and hence might be expected to be of low quality. It is likely that this led to an overestimate of numbers. The effect of overestimations are especially detrimental in very small populations (Lukacs & Burnham 2005). Therefore, even though the DNA genotyping survey was undertaken 15 years ago, and since then, changes may have taken place in the population demography and size, we argue that DNA genotyping using dung is not a reliable survey technique to monitor the Knysna elephant population, unless fresh dung is reliably obtained from across the known elephant range.

Accurate data on elephant population sizes is becoming increasingly vital, as they are severely threatened due to habitat loss and fragmentation, poaching for ivory and other conflict with humans (Chase, Schlossberg, Griffin, Bouché, Djene, *et al.*, 2016). The current trend of declining, small and isolated elephant populations in some African countries predicts their extirpation in the near future (Chase, Schlossberg, Griffin, Bouché, Djene *et al.*, 2016). Elephant populations made up of only a few individuals, such as the Knysna elephant population, may therefore become prevalent. In this light, our study demonstrates the importance of designing rigorous survey approaches where only a few individual animals are present, as different survey techniques deliver disparate findings and overestimations could prolong urgently required management actions to prevent local extinction. In such cases, it must be recognized that all survey techniques have limitations and comparisons between surveys strengthens the conclusions.

Our finding raises a number of management questions such as: What led to the population declining to a single individual? Is the continued presence of elephants in the area possible and appropriate, and if so, what interventions could be made? How should the welfare of a single isolated adult female elephant be taken into consideration by conservation authorities?

The absence of fences and occurrence of the elephant range on four different landowners' land, present unique complexities regarding management decision-making for the Knysna elephant. This requires the co-management of the Knysna elephant and therefore agreement between all landowners on all levels of the management decision-making process. Additionally, in light of a failed attempt at introducing three young cull-orphaned cows, sourced from the Kruger National Park, in 1994 (Mackay, 1996), the confidence that previous mistakes will not be repeated, needs to be high. The reasons as to why the previous introduction attempt failed therefore require evaluation.

CONCLUSION

The camera trap survey of the Knysna elephant population provided robust and repeatable data that clearly demonstrates that only one elephant remains. As a consequence it must be recognized that the Knysna population is functionally extinct and future management must reflect either supplementation and/or addressing the welfare issues regarding the one remaining elephant.

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Supplementary material to:

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And Then There Was One: a camera trap survey of the declining population of African Elephants in Knysna, South Africa,

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Table S1. Detail of elephant capture events from the permanently- ($n = 141$) and temporarily-active ($n = 5$) camera trap stations including data and time of capture event, number of images and video clips per event and physical features visible and identifiable.

Date	Station code	Time (hh:mm)	No. photos or video clips in sequence	Ear notches: Both (B), right (R) or left ear (L), not visible (NV)	Tusks: Both (B), right(R) or left tusk (L), not visible (NV)	Sex: Mammary glands (M), genitals (G), both (B), not visible (NV)	Elephant ID	Temporal streaming: Yes (Y), no (N), not visible (NV)
19 Jul 2016	C18	18:06	172	R	B	M	KE1	Y
31 Jul 2016	C18	16:56	64	R	B	M	KE1	Y
31 Jul 2016	C17	22:06	2	R	L	G	KE1	Y
01 Aug 2016	C24	00:35	9	NV	B	M	KE1	Y
04 Sept 2016	C38	10:54	155	B	B	G	KE1	Y
07 Sept 2016	C38	15:03	33	R	R	NV	KE1	NV
07 Nov 2016	C23	18:50	3	B	B	B	KE1	Y
14 Nov 2016	C39	22:38	4	B	B	B	KE1	Y
26 Nov 2016	C36	21:53	21	L	B	B	KE1	Y
02 Dec 2016	C36	20:10	2	R	B	M	KE1	Y
02 Dec 2016	C43	21:31	7	B	B	G	KE1	Y
04 Dec 2016	C39	22:38	58	B	B	G	KE1	Y
06 Dec 2016	C41	01:23	3	R	R	G	KE1	NV
07 Dec 2016	C44	21:09	20	R	B	G	KE1	Y
08 Dec 2016	C21	23:00	25	L	B	G	KE1	Y
18 Jan 2017	C24	19:27	21	R	B	M	KE1	Y
20 Jan 2017	C18	00:32	17	NV	B	B	KE1	Y
29 Jan 2017	C13	00:14	45	R	B	M	KE1	Y
29 Jan 2017	C13	20:27	26	L	B	B	KE1	Y
06 Feb 2017	C7	22:41	18	NV	R	B	KE1	Y
08 Feb 2017	C2	23:46	10	NV	R	G	KE1	NV
09 Feb 2017	C3	01:17	44	R	R	B	KE1	Y
10 Feb 2017	C1	15:48	9	NV	NV	NV	Unidentifiable	NV
13 Feb 2017	C1	01:17	4	NV	B	M	KE1	Y
15 Feb 2017	C1	01:48	12	NV	L	G	KE1	Y
17 Feb 2017	C4	00:34	6	B	B	B	KE1	Y
18 Feb 2017	C5	20:24	10	NV	B	M	KE1	Y
18 Feb 2017	C5	23:00	2	L	B	B	KE1	Y
25 Feb 2017	C4	02:23	3	R	B	B	KE1	Y

Continued on p. S2

Table S1 (continued)

Date	Station code	Time (hh:mm)	No. photos or video clips in sequence	Ear notches: Both (B), right (R) or left ear (L), not visible (NV)	Tusks: Both (B), right(R) or left tusk (L), not visible (NV)	Sex: Mammary glands (M), genitals (G), both (B), not visible (NV)	Elephant ID	Temporal streaming: Yes (Y), no (N), not visible (NV)
27 Feb 2017	C4	01:01	15	R	B	B	KE1	Y
27 Feb 2017	C4	04:31	34	B	B	B	KE1	Y
28 Feb 2017	C1	07:49	3	B	B	G	KE1	Y
04 Mar 2017	C6	03:56	5	R	B	B	KE1	Y
04 Mar2017	C6	04:42	10	B	B	B	KE1	Y
09 Mar 2017	C3	00:16	52	L	B	B	KE1	Y
11 Mar 2017	C3	10:41	44	R	B	NV	KE1	NV
23 Mar 2017	C3	21:39	35	L	B	B	KE1	Y
23 Mar 2017	C2	23:53	4	L	B	NV	KE1	NV
24 Mar 2017	C7	19:50	10	R	B	G	KE1	Y
24 Mar 2017	C7	21:32	48	B	B	M	KE1	Y
25 Mar 2017	C7	18:38	4	R	R	G	KE1	Y
27 Mar 2017	C19	04:11	172	B	B	M	KE1	Y
28 Mar 2017	C13	01:11	8	B	B	B	KE1	Y
28 Mar 2017	C13	17:41	9	R	B	G	KE1	NV
29 Mar 2017	C13	03:48	72	L	B	B	KE1	Y
31 Mar 2017	C12	20:22	83	B	B	B	KE1	Y
31 Mar 2017	C14	22:54	9	B	B	B	KE1	Y
01 Apr 2017	C14	02:10	8	B	B	B	KE1	Y
03 Apr 2017	C12	19:26	49	R	B	B	KE1	Y
04 Apr 2017	C13	00:36	4	NV	B	M	KE1	Y
05 Apr 2017	C13	22:04	2	NV	B	NV	KE1	NV
07 Apr 2017	C13	22:30	3	NV	B	M	KE1	Y
08 Apr 2017	C13	21:08	5	L	B	M	KE1	Y
09 Apr 2017	C13	19:23	2	L	L	G	KE1	NV
09 Apr 2017	C13	20:22	1	R	B	M	KE1	Y
10 Apr 2017	C13	14:53	5	L	L	G	KE1	Y
11 Apr 2017	C13	23:35	5	NV	B	M	KE1	Y
14 Apr 2017	C13	00:32	2	NV	B	M	KE1	Y
15 Apr 2017	C13	10:08	6	L	L	G	KE1	Y

Continued on p. S3

Table S1 (continued)

Date	Station code	Time (hh:mm)	No. photos or video clips in sequence	Ear notches: Both (B), right (R) or left ear (L), not visible (NV)	Tusks: Both (B), right(R) or left tusk (L), not visible (NV)	Sex: Mammary glands (M), genitals (G), both (B), not visible (NV)	Elephant ID	Temporal streaming: Yes (Y), no (N), not visible (NV)
16 Apr 2017	C13	00:00	3	NV	B	M	KE1	Y
16 Apr 2017	C13	19:32	3	NV	B	M	KE1	Y
18 Apr 2017	C7	02:51	3	L	B	M	KE1	Y
20 Apr 2017	C2	01:41	4	B	B	G	KE1	Y
20 Apr 2017	C3	05:00	118	B	B	B	KE1	Y
22 Apr 2017	C6	19:40	67	B	B	B	KE1	Y
24 Apr 2017	C1	01:26	1	R	B	M	KE1	Y
25 Apr 2017	C2	21:07	9	L	B	M	KE1	Y
26 Apr 2017	C7	02:47	5	NV	B	G	KE1	Y
28 Apr 2017	C8	19:42	86	B	B	B	KE1	Y
28 Apr 2017	C19	20:30	5	NV	R	NV	KE1	NV
29 Apr 2017	C7	04:30	8	L	B	B	KE1	Y
01 May 2017	C7	17:10	8	B	B	B	KE1	Y
05 May 2017	C13	10:17	15	B	B	B	KE1	Y
05 May 2017	C14	20:37	4	L	B	M	KE1	Y
05 May 2017	C14	22:13	9	NV	B	G	KE1	Y
07 May 2017	C12	20:08	46	R	B	B	KE1	Y
08 May 2017	C19	03:59	33	NV	B	NV	KE1	Y
08 May 2017	C7	06:27	2	L	B	M	KE1	Y
08 May 2017	C2	22:55	6	B	B	B	KE1	Y
09 May 2017	C3	01:29	58	R	B	B	KE1	Y
12 May 2017	C6	23:22	26	R	B	B	KE1	Y
14 May 2017	C1	18:33	43	B	B	B	KE1	Y
14 May 2017	C6	22:18	147	NV	B	M	KE1	Y
01 Jun 2017	C1	21:18	11	R	B	M	KE1	Y
04 Jun 2017	C1	00:17	8	R	R	M	KE1	Y
06 Jun 2017	C2	01:53	14	B	B	M	KE1	Y
06 Jun 2017	C7	22:49	28	B	B	B	KE1	Y
07 Jun 2017	C7	20:51	3	L	B	B	KE1	Y
07 Jun 2017	C7	23:36	22	L	B	B	KE1	Y

Continued on p. S4

Table S1 (continued)

Date	Station code	Time (hh:mm)	No. photos or video clips in sequence	Ear notches: Both (B), right (R) or left ear (L), not visible (NV)	Tusks: Both (B), right(R) or left tusk (L), not visible (NV)	Sex: Mammary glands (M), genitals (G), both (B), not visible (NV)	Elephant ID	Temporal streaming: Yes (Y), no (N), not visible (NV)
10 Jun 2017	C7	13:10	5	B	B	B	KE1	Y
10 Jun 2017	C7	21:00	49	B	B	B	KE1	Y
10 Jun 2017	C7	19:30	1	NV	B	M	KE1	Y
10 Jun 2017	C7	23:32	10	R	B	G	KE1	Y
12 Jun 2017	C7	15:23	8	B	B	G	KE1	Y
12 Jun 2017	C7	19:28	3	NV	B	NV	KE1	NV
14 Jun 2017	C12	19:32	69	L	B	B	KE1	Y
16 Jun 2017	C7	23:58	4	L	B	NV	KE1	Y
16 Jun 2017	C12	15:39	58	R	B	B	KE1	Y
18 Jun 2017	C7	20:23	3	NV	B	M	KE1	Y
19 Jun 2017	C7	16:25	15	B	B	B	KE1	Y
19 Jun 2017	C7	20:15	36	B	B	B	KE1	Y
19 Jun 2017	C7	22:25	3	L	B	G	KE1	Y
26 Jun 2017	C7	20:29	8	B	B	M	KE1	Y
28 Jun 2017	C7	01:21	11	L	B	G	KE1	Y
28 Jun 2017	C7	22:15	3	R	B	NV	KE1	Y
29 Jun 2017	C7	18:14	2	NV	L	NV	KE1	NV
30 Jun 2017	C7	10:56	2	L	B	NV	KE1	NV
30 Jun 2017	C7	20:45	2	L	B	G	KE1	Y
30 Jun 2017	C7	00:33	2	NV	NV	NV	Unidentifiable	NV
30 Jun 2017	C7	09:57	7	R	B	G	KE1	Y
01 Jul 2017	C7	01:44	2	R	B	G	KE1	Y
02 Jul 2017	C7	01:44	1	L	B	G	KE1	Y
02 Jul 2017	C7	22:01	2	NV	L	NV	Unidentifiable	NV
03 Jul 2017	C7	08:51	1	L	NV	G	KE1	Y
04 Jul 2017	C7	03:12	1	NV	B	NV	KE1	NV
07 Jul 2017	C11	17:39	549	B	B	B	KE1	Y
10 Jul 2017	C7	08:32	2	L	L	G	KE1	Y
10 Jul 2017	C19	19:31	8	NV	B	G	KE1	NV
11 Jul 2017	C13	00:35	3	NV	B	M	KE1	Y

Continued on p. S5

Table S1 (continued)

Date	Station code	Time (hh:mm)	No. photos or video clips in sequence	Ear notches: Both (B), right (R) or left ear (L), not visible (NV)	Tusks: Both (B), right(R) or left tusk (L), not visible (NV)	Sex: Mammary glands (M), genitals (G), both (B), not visible (NV)	Elephant ID	Temporal streaming: Yes (Y), no (N), not visible (NV)
12 Jul 2017	C12	21:04	174	L	B	M	KE1	Y
14 Jul 2017	C12	15:46	61	R	B	M	KE1	N
14 Jul 2017	C13	21:00	2	R	B	M	KE1	Y
26 Jul 2017	C12	16:01	66	B	B	M	KE1	Y
26 Jul 2017	C7	20:15	12	L	B	G	KE1	Y
26 Jul 2017	C7	21:35	4	NV	B	B	KE1	Y
02 Aug 2017	C2	23:12	8	L	B	G	KE1	Y
03 Aug 2017	C4	22:28	362	B	B	G	KE1	Y
03 Aug 2017	C3	01:35	64	R	B	B	KE1	Y
03 Aug 2017	C4	23:32	52	R	B	B	KE1	Y
08 Aug 2017	C6	20:32	45	R	B	B	KE1	Y
13 Aug 2017	C1	20:54	8	NV	B	M	KE1	Y
20 Aug 2017	C1	16:05	39	L	B	G	KE1	Y
21 Aug 2017	C1	15:26	90	B	B	M	KE1	Y
21 Aug 2017	C1	19:17	12	NV	L	G	KE1	NV
23 Aug 2017	C4	20:41	30	R	B	B	KE1	Y
24 Aug 2017	C4	00:22	32	R	B	B	KE1	Y
25 Aug 2017	C2	02:23	26	L	B	B	KE1	Y
25 Aug 2017	C7	18:58	6	NV	NV	NV	Unidentifiable	NV
26 Aug 2017	C7	19:03	3	L	B	B	KE1	Y
26 Aug 2017	C7	00:11	2	NV	B	M	KE1	Y
26 Aug 2017	C7	20:04	2	NV	B	G	KE1	Y
29 Aug 2017	C14	20:57	496	B	B	B	KE1	Y
29 Aug 2017	C12	19:40	38	L	B	B	KE1	Y
03 Sept 2017	C18	21:47	18	R	B	M	KE1	Y
04 Sept 2017	C24	02:54	83	NV	B	B	KE1	Y
19 Sept 2017	C25	03:17	10	B	B	B	KE1	Y
06 Oct 2017	C38	14:28	6	NV	B	NV	KE1	NV
07 Oct 2017	C38	00:42	256	B	B	M	KE1	Y
14 Oct 2017	C38	08:37	9	NV	R	NV	KE1	NV