Twisting collars on male elephants in shrub terrain: animal welfare considerations for researchers, managers and manufacturers

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Abstract

For the purposes of testing the impacts of habitat expansion on elephant movement, six XL LoRa elephant radio collars were fixed on three adult male elephants and three adult female elephants prior to a fence being removed at Kariega Game Reserve, South Africa. While none of the collars on female elephants twisted, within five months, all the male elephant collars had twisted, with some triple and double twisting. Behavioural monitoring revealed indications of irritation that resulted in the removal and/or replacement of all twisted collars. It was discovered that two of the male elephants had developed wounds underneath their twisted collars, therefore, only one elephant was re-collared, with a collar that was modified to minimize further risk of twisting, however it twisted again. To investigate this rare incidence of elevated collar twisting, our study assessed the following: elephant behaviour to guide decision-making around interventions and well-being; when, where and how these incidents occurred to investigate the mechanism of twisting and the likelihood of human error; collar design and refurbishment to develop recommendations to minimize the likelihood of twisting; and data obtained from organizations using elephant collars for comparison. From this, it was theorized that browsing behaviour in bulls in dense vegetation, and inadequate collar design were the likely causes in twisting occurrence. We urge organizations using LoRa elephant collars to emphasize post-application monitoring, and exercise caution, when attaching on bulls in dense vegetation. We encourage collar manufacturers to thoroughly investigate twisting incidents and adjust collar structures accordingly and inform clients about the possibility of twisting. By addressing these issues, we can better ensure the well-being of elephants, research success, and improved device safety and efficacy.

Additional Keywords: *Loxodonta africana*; wildlife reserve; conservation research; tracking equipment African elephant

Résumé

Afin d'évaluer l'impact de l'expansion des habitats sur leurs déplacements, six éléphants adultes (trois mâles et trois femelles) ont été équipés de colliers radio XL reposant sur le protocole LoRa, avant le retrait d'une clôture dans la Réserve de Kariega Game en Afrique du Sud. Aucune des femelles n'a vu son collier se retourner, tandis qu'en l'espace de trois mois, les dispositifs des mâles avaient tous montré des torsions, doubles voire triples. Lors du suivi comportemental, des signes d'irritations ont été constatés et il a été décidé d'ôter ou de remplacer tous les colliers concernés. Deux des trois mâles avaient développé des plaies sous leur collier, qui a donc été complètement supprimé. Un nouveau collier, modifié de manière à minimiser les risques, a été posé sur le dernier mâle. Il s'est néanmoins retourné de nouveau. Pour une meilleure compréhension des facteurs à l'origine de ces torsions, rarement observées à un tel niveau de récurrence, notre étude s'est penchée sur les points suivants : évaluation de la prise en compte du comportement des éléphants dans les choix des interventions et du bien-être des animaux ; identification des circonstances (où, quand et comment) durant desquelles ont eu lieu ces incidents afin d'analyser les mécanismes des retournements et la probabilité de l'erreur humaine ; examen de la conception des colliers et de leur réparation dans le but de constituer des recommandations pour éviter ce type de situation ; et étude des données issues d'autres organisations déployant ces dispositifs sur les éléphants pour obtenir une base de comparaison. Il en a été déduit que le comportement des mâles pendant de la recherche de nourriture, notamment dans des espaces de végétation dense, ainsi que la conception du collier, étaient potentiellement les causes des retournements. Nous appelons les utilisateurs de systèmes reposant sur le protocole LoRa à intensifier la surveillance consécutive à la pose de ces dispositifs spécifiques (de faible épaisseur) et à user de précautions lors de leur mise en place sur des éléphants mâles et dans des conditions de végétation dense. Nous encourageons leurs concepteurs et fabricants à enquêter sur ces incidents, à ajuster les structures en fonction des conclusions relevées et à informer les clients de cette problématique de torsions. En prenant ces questions en compte, nous pourrons mieux assurer le bien-être des animaux sauvages ainsi que les progrès de la recherche, et améliorer la sécurité et l'efficacité de ces dispositifs.

Mot-clés supplémentaires: *Loxodonta africana*; réserve naturelle; recherche et conservation; équipement de suivi de l'éléphant d'Afrique

Introduction

Globally, range expansion and increased connectivity are considered priority elephant conservation strategies, as they promote ecological processes and reduce the need for elephant management interventions (CITES 2010; Department of Environmental Affairs 2014; Zungu and Slotow 2022). South Africa's Protected Area (PA) Expansion Strategy aims to increase PAs to enhance biodiversity conservation, ecological sustainability and resilience to climate change (Department of Environmental Affairs 2016), and the strategy especially includes increasing connectivity in small, fenced reserves. In the Eastern Cape, South Africa, the Indalo private game reserves (GR) are actively working to establish a corridor interlinking the three sections of their reserve. This started with the removal of internal fences between the private sanctuary of Kariega GR in South Africa which holds 75 elephants (Fig. 1), and necessitated a study on elephant movement.

Elephant movement is currently best studied through tracking devices that use GPS signals to provide location points (Pastorini et. al. 2015). For elephants, tracking devices can only be anchored on collars which are placed around the neck, which is an effective mechanism for studying movement and behaviour, without any confirmed impact on the overall behavioural patterns of elephants (Horbeck et. al. 2012). Collaring can be used for research, security and anti-poaching purposes, decreasing human-elephant conflict (HEC), ecological monitoring, and to streamline management interventions.

Although GPS collaring of wildlife provides crucial information for conservation, management, and research, transparency in the development and use of these mechanisms is vital to prevent adverse consequences. Therefore, it is important to properly investigate equipment successes and failures to advance the field of wildlife tracking technology (Matthews et al. 2013). To date, no reports on collar twisting or malfunctioning have been published, despite the fact that elephant collaring is highly used in conservation management; and equipment failure is financially costly, time intensive and can greatly impact research outcomes and welfare and thus is of concern among researchers using tracking devices. In a study in Sri Lanka (Pastorini et al. 2015) researchers tested the effectiveness and safety of six different types of GPS models.

Long-range radio collars (LoRa) have been developed by African Wildlife Tracking in conjunction with EarthRanger software (who were not involved in collar development) and were used in Kariega GR to more effectively monitor the movements of elephants. A LoRa tracking device that uses long-range and ultra-high frequency provides near real-time GPS tracking with the aid of a small low-power ultra-high frequency transceiver (African Wildlife Tracking 2023). LoRa collars are a relatively new development in wildlife tracking equipment, as an alternative to standard GPS collar systems, and are gaining popularity for wildlife tracking and monitoring due to their advanced tracking ability and reduced cost (however, initial capital is required for tower development).

When trialling new wildlife tracking equipment, it is vital to closely observe the suitability of new devices, which can be difficult to assess and test prior to field deployment. While elephant collaring is widely considered a safe tracking method, it is essential to consider potential problems such as equipment failure, intervention stress and injury, and changes in behavioural and social dynamics before initiating a collaring study. Given the key role of wildlife tracking for conservationists across diverse African (and increasingly Asian ecosystems), the necessity of continuous monitoring and refinement of tracking devices is essential; as is sharing the experiences and unintended consequences of using tracking devices, or any wildlife research equipment, especially when new technologies are developed. This approach will ensure best practices in wildlife research and monitoring.

To study the spatial behaviour of the resident elephant population in response to range expansion, researchers from *Bring the Elephant Home* and King Mongkut's University of Technology Thonburi (Bangkok, Thailand) in partnership with Kariega GR, used AWT LoRa collars to track six elephants. Upon completion of the collaring interventions, we encountered a rare and challenging equipment failure: twisting collars, often with multiple twists, on all three male elephants collared, comprising half of the subjects of our study. This situation presented both an opportunity and a necessity to investigate the causes and nature of these twisting events and to assess the welfare implications.

After the twisting of the collars was observed, we assessed: 1) the elephant's behaviour using determined well-being parameters to guide intervention decision-making; 2) data from accelerometers embedded in the collars to analyse underlying factors that caused the twisting of these collars, including when and in what specific types of vegetation these incidents occurred, as well as the possibility of human error; 3) collar design to identify equipment failure and specifications for collar refurbishment to prevent future collar twisting and mitigate welfare concerns; and 4) data collected through a short questionnaire administered to other organizations using elephant collars to determine the frequency, nature and severity of twisting and subsequent injury (if any), and the specifications of collars that have twisted.

Materials and methods

Study site

The Kariega GR is a fully fenced area of 8,192 ha and classified as a subtropical thicket biome, consisting of eastern thorn bushveld, secondary acacia thicket, coastal forest, valley thickets, and characterized by sparse to dense, spiny, evergreen shrub vegetation (Parker and Bernard 2005; Kerley and Landman 2006; Figs. 1 and 2). The vegetation in Kariega GR has been classified as one of the most diverse vegetation types in this region of Africa (Lubke et al. 1986), and among 41 South African reserves, Kariega GR received one of the highest environmental heterogeneity scores (Purdon et al. 2022). Diversity in vegetation composition and structure enhances the availability of ecological niches, allowing multiple species to co-exist successfully in smaller reserves (Beier and de Albuquerque 2015).

Collaring

Six XL LoRa radio collars purchased from African Wildlife Tracking (AWT) were used to facilitate GPS monitoring and research of three adult male and three adult female elephants before and after the removal of an internal fence at Kariega GR in South Africa to study the impacts of range expansion on elephants.

The collaring procedures were conducted in August and September 2022 with a veterinary team under the supervision of Dr William Fowlds and Vets Go Wild, a measurement and research team from *Bring the Elephant Home* (BTEH) and *Elephant Reintegration Trust*, and a ground safety team from Kariega GR. The elephants were darted from a helicopter and collared while lying on their side. The tightness of the collar was decided by the veterinarian according to the manufacturer's

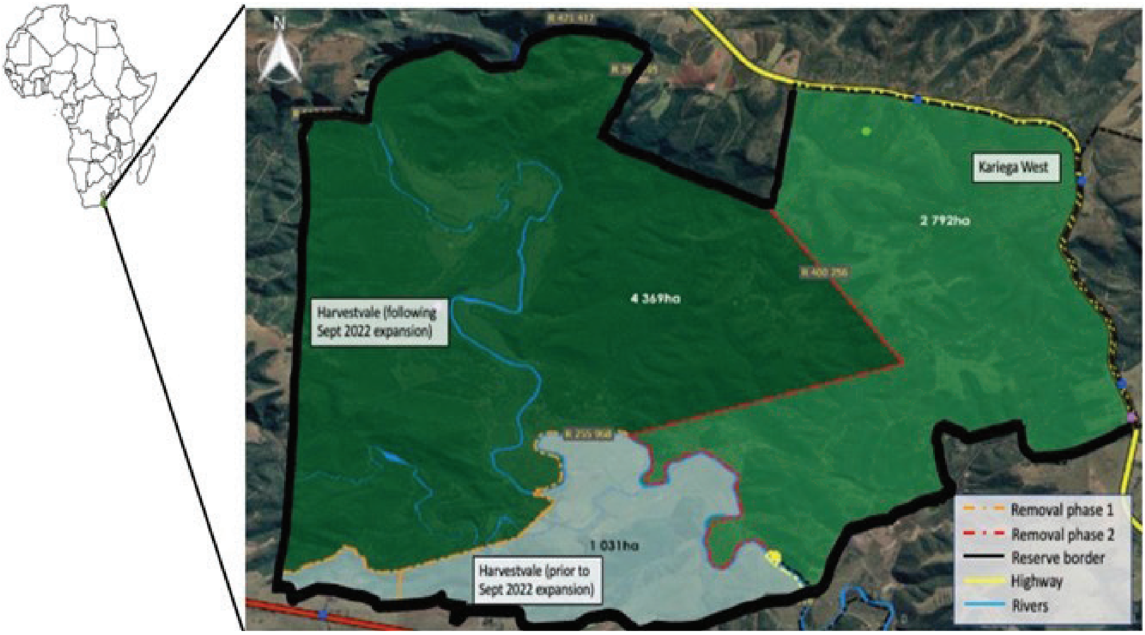

Figure 1. Map of the Eastern Cape, South Africa showing the distribution and sizes of the sections of Kariega GR where collaring occurred. The fenced Reserve (8,192 ha) is separated into three sections that are divided by internal fencing, of which two sections (coloured light green and dark green) hold a total number of approximately 75 elephants. The grey section in the south was added in September 2022, and the internal fence that is scheduled to be removed in November 2023 is indicated by the red dotted line. In August–September 2022, two male and two female elephants were collared on Kariega West (light green), and one male and one female in the Harvestvale section (dark green).

Figure 2. Images of elephants in Kariega GR surrounded by subtropical thicket biome vegetation, which frequently reaches or nearly reaches the height of an elephant's head. (© *Brooke Friswold*)

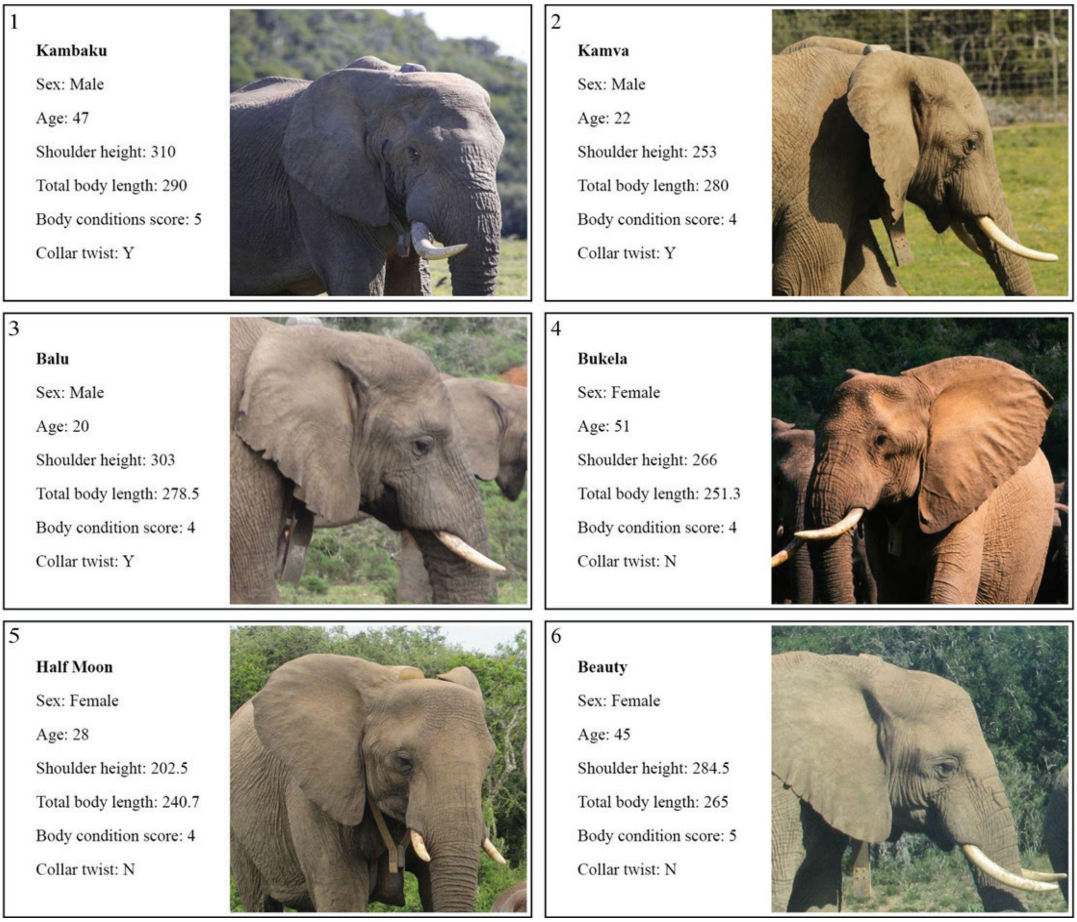

Figure 3. Profiles of the six collared elephants; height and length in cm. Body condition score from 1 to 5 (Morfeld et al. 2016). Twisting of collars occurred on all male elephants (1–3), while none of the female elephants (4–6) experienced twisting. (© *Brooke Friswold, Jaco Mitchell, Ram Marsi and Emma Hankinson*)

parameters and affixed based on considerations of body and neck size, expected growth over 2.5 years (the length of the study), and neck swelling while in musth (for males). All collars were fitted with a 4-kg counterweight and applied as directed by the veterinarian team (Fig. 3).

Results

Monitoring elephant behaviour to guide intervention decisions

Within five months of application, all the collared male elephants experienced various degrees of collar twisting, while none of the female elephant collars showed any signs of twisting or irregularities. All elephants with twisted collars required regular monitoring to assess any behavioural signs of irritation to the elephants from the twisted collars (e.g. sand dusting, mud packing, frequently touching, head shaking, shoulder shrugging, and other stress responses). Wounds caused by collar twisting, collar rubbing, or mud compaction can develop underneath the collar unit or along the collar strapping where it makes contact with the skin, which are often not visible without removing the collar. In some cases, collars untwisted without intervention (Mitchell, pers. obs., 2022). Therefore, it was decided to monitor closely the elephants' behaviour for visible signs of distress to guide the timing of any intervention, allowing for the possibility that the collars could naturally untwist over time. Unfortunately, for all three elephants, untwisting did not occur after 2 to 5 months, and it was decided to remove and/or replace all the twisted collars.

Collared elephants under study:

Kambaku (Fig. 4a and b). At six months (January to March 2023), *Kambaku* had developed a triple twist and started showing signs of irritation through mud-packing on the collar and continuously twitching his ears. Due to the location of the twist high along the neckline and the signs of irritation, it was decided to remove the collar on 9 March 2023. During removal, it was discovered that a skin-breaking laceration had formed on the left side of the neck, specifically in the area where the collar had twisted and cut into the skin behind the upper portion of the ear (Fig. 5a, b and c). Due to the position of the elephant after darting, it was not possible to assess for potential wounds on his right side. Following the removal of the collar and wound treatment, it was found that mud had compacted underneath the collar, potentially causing additional discomfort. In other studies, 2% of the fitted collars were observed to cause skin ulcerations, resulting from mud compacting beneath the collar (Delsink, pers. obs., 2008). After removal, we found that the collar material was extremely pliable and held its twisted shape (Fig. 5e)— making reapplication, if desired, not possible due to the high likelihood of it reforming into that shape and twisting again. As a consequence, the collar was ultimately removed and not replaced, leading to the exclusion of *Kambaku* from the study despite his importance as a key study subject.

Kamva (Fig. 4c and d) In April 2023, three months after developing a double twist in February 2023, *Kamva* was sighted with a wound developing underneath the collar on the left side behind his ear (Fig. 5d). Based on this observation and the extent of the wounds discovered under *Kambaku's* collar, an emergency intervention was organized to remove *Kamva's* collar on 21 April 2023. The wound was less deep than *Kambaku's*, likely because *Kamva's* collar had only twisted twice and not three times, as was the case with *Kambaku's* collar.

Balu (Fig. 4e and f) Prior to the intervention, *Balu*, who had developed a triple twist in October to December 2022, had not exhibited any signs of discomfort as *Kambaku* had, nor any visible wounds, as *Kamva* had. However, it was decided to intervene as wound development was likely based on the other twisted collars, and the fact that if the collar twisted again, it could also tighten around the neck. Meetings were held with collar manufacturer personnel to discuss the refurbishment options of *Kambaku's* collar with reconstruction in a way that would reduce the likelihood of twisting (thicker belting, changes in upper unit dimensions) to replace *Balu's* twisted collar. A refurbished collar developed from *Kambaku's* collar replaced *Balu's* twisted collar on 10 May 2023, so that one bull could remain in the study. Upon removal of the collar, no wounds or abrasions had developed. The refurbished collar was applied slightly tighter than previously and contained thicker belting and an elongated width of the upper unit (Table 1; Fig 8). However, the researchers suggested refurbishment changes to the manufacturers that included upper unit dimension alterations by either increasing height to reduce the ability for rotation, or decreasing the height to reduce the likelihood of catching on an object but these modifications were not amended as requested. On 1 October 2023, less than five months after collar replacement the refurbished collar again twisted, and the situation is currently being monitored for next steps.

Assessment of twisting mechanisms and locations

Accelerometer data (Fig. 6) from the collars were used to determine whether the twisting of the collars originated from the bottom, which would suggest that the twisting was potentially caused by elephants manipulating them with their trunks. Should elephants twist their collar by interacting with the bottom weight, the upper unit will likely remain upright, with the twists originating from below and hanging lower on the elephant's neck, as has been observed by other elephant researchers (Henley, pers. obs., 2008). A twist originating at the top unit of the collar would likely indicate that the collar rotated as the elephant moved through dense vegetation, catching branches with the upper unit and pushing the unit resulting in a twist. Such twists could pose a greater risk to the elephant, as they occur higher up on the neck, with the edges of the collar more likely to press against the skin. If the collar had inverted at the upper unit, accelerometer data would shift to a negative frequency to indicate that the upper unit had rotated downward and a return to a positive frequency would confirm that the unit had resumed its upright position after completing the twist. It was confirmed via accelerometer data that all twisted units, and for

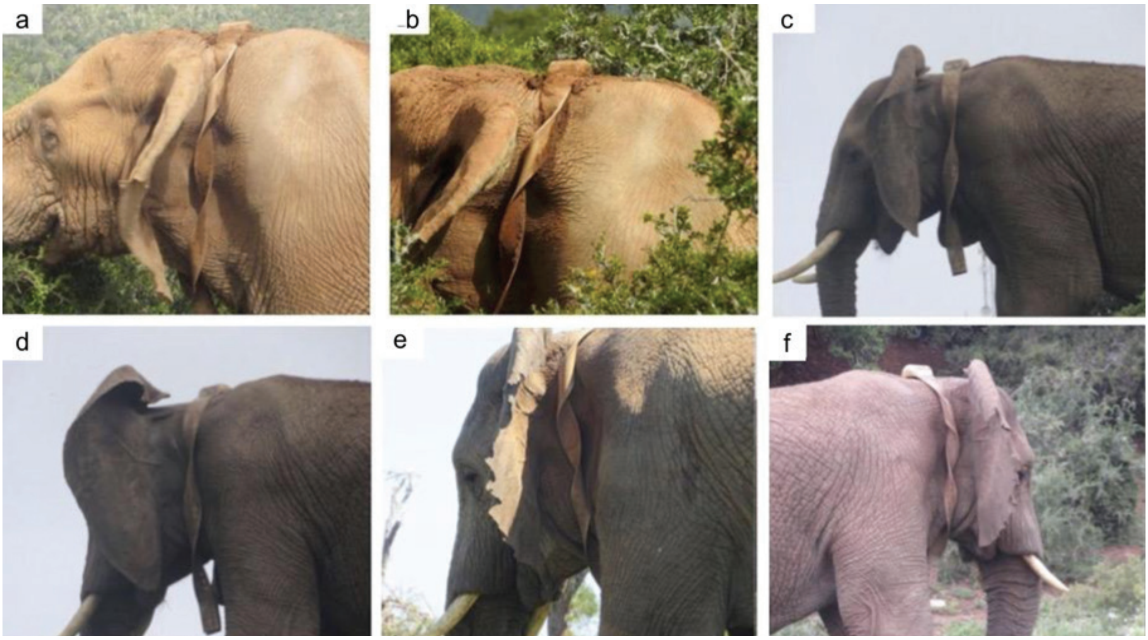

Figure 4a and b. *Kambaku's* collar with triple twists. Figure 4c and d. *Kamva's* collar with double twists. Figure 4e and f. *Balu's* collar with triple twists. (© *Brooke Friswold and Jaco Mitchell*)

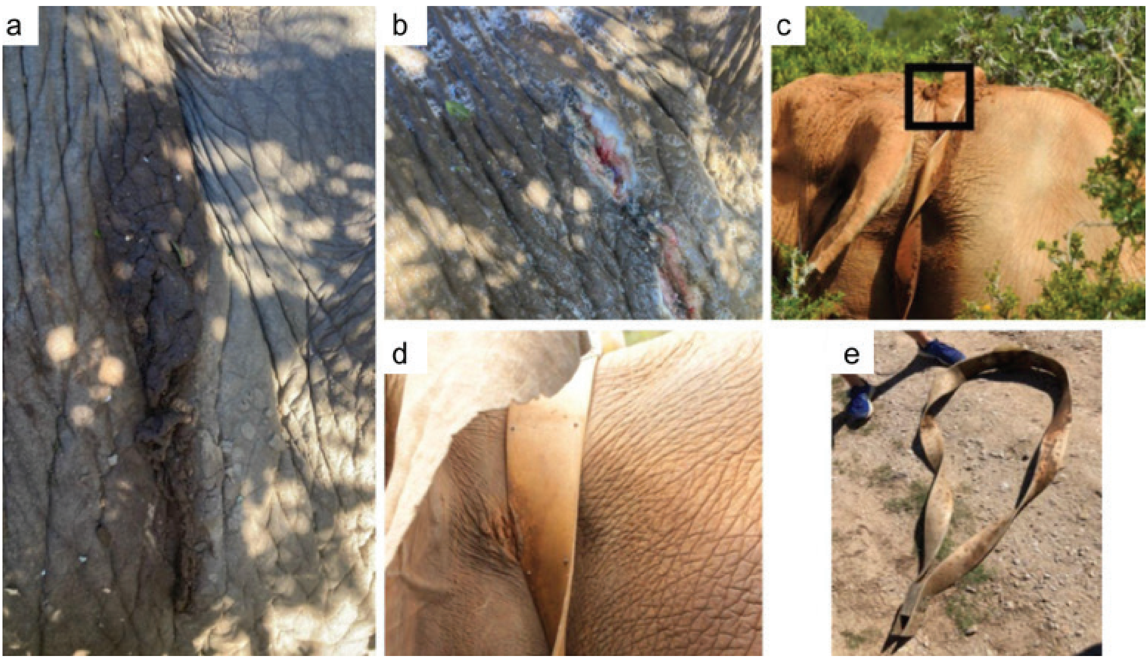

Figure 5a. The wound underneath *Kambaku's* collar before flushing. Figure 5b. The wound underneath *Kambaku's* collar after flushing. Figure 5c. The location of *Kambaku's* wound underneath the collar. Figure 5d. The wound underneath *Kamva's* collar is visible with the naked eye. Figure 5e: *Kambaku's* collar after removal holding a twisted shape. (© *Brooke Friswold and Jaco Mitchell*)

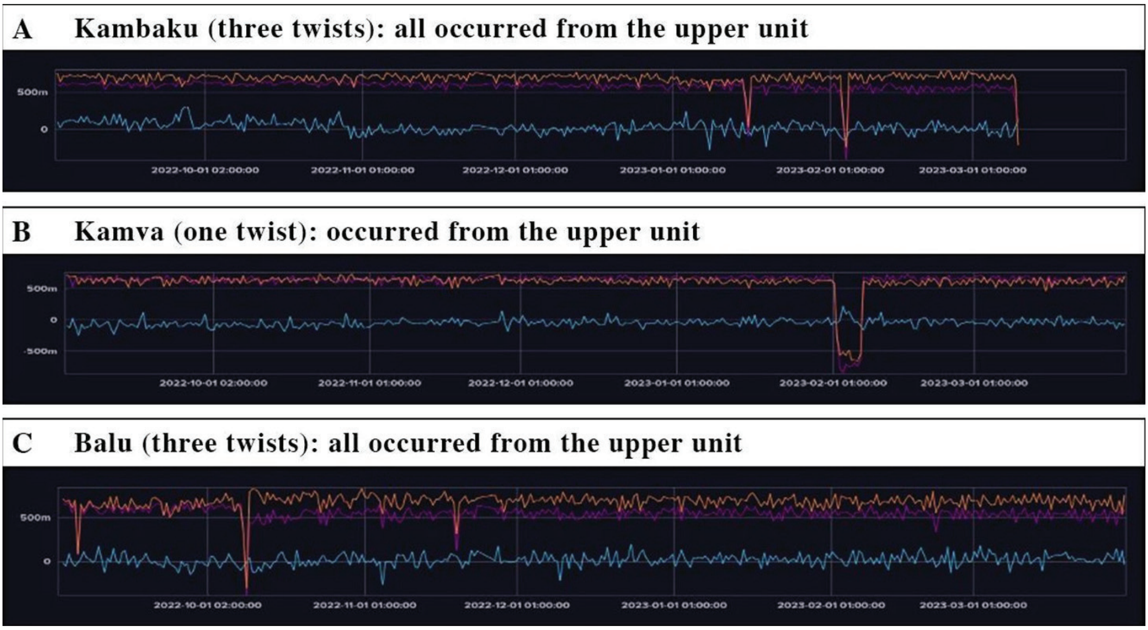

Figure 6. Using accelerometer data from the collars, we were able to determine the exact time and location of the twists and whether they were caused by the position of the upper unit. A shift to a negative frequency would indicate that the upper unit had rotated downward, and a return to a positive frequency would confirm that the unit had resumed its upright position. (*Images obtained using EarthRanger software (2023), Brooke Friswold*)

each twist (including on the refurbished collar) had originated at the upper unit indicating that the twists were not done through manipulation by the elephant but likely through movement through vegetation.

The time stamps of the upper unit inversions were then paired with their GPS locations to determine when twisting occurred (Fig. 7). From this, the time stamps could then be paired with their GPS points to determine where twisting occurred using ArcGIS Online (ESRI 2023). GPS points from the collars were taken every 30 minutes, which offered a relatively small degree of variability to pinpoint the timing and location of the collar twisting. Data points were selected as those closest to the moment the unit flipped and then cross-referenced with locations recorded minutes before and after unit rotation to assess whether the elephants were in areas of dense thicket and/or other vegetation types during the period the twisting occurred. All twists except for *Kamva's* were clearly confirmed to have occurred in dense thicket or thicket edges. However, *Kamva's* twist occurred within the 30-minute window, when he was in open terrain but near thickets and it was not possible to determine the exact location at the moment of twisting, although thicket clumps nearby suggested the possibility of twisting by movement through vegetation.

Collar design and refurbishment

The collar manufacturer reported that they have developed and sold approximately 100 LoRa collars without receiving any previous reports of twisting events (other than the four incidents in our study). Batteries are a determining factor in the final dimension size of the unit, as well as the bottom weight. Therefore, GPS and LoRa collar dimensions are not entirely standardized and can vary according to client requirements and manufacturer advice. Given the 57% rate of collar twisting observed in our study, we suggested revisiting the initial dimensions of the collars with which we were provided. Specifically, the issues could have been: 1) insufficient weight requirements; 2) the length and depth of the strap being too thin and malleable; 3) design issues in the height and length of the upper unit, which increases the risk of it catching on branches and/or allowing for rotation.

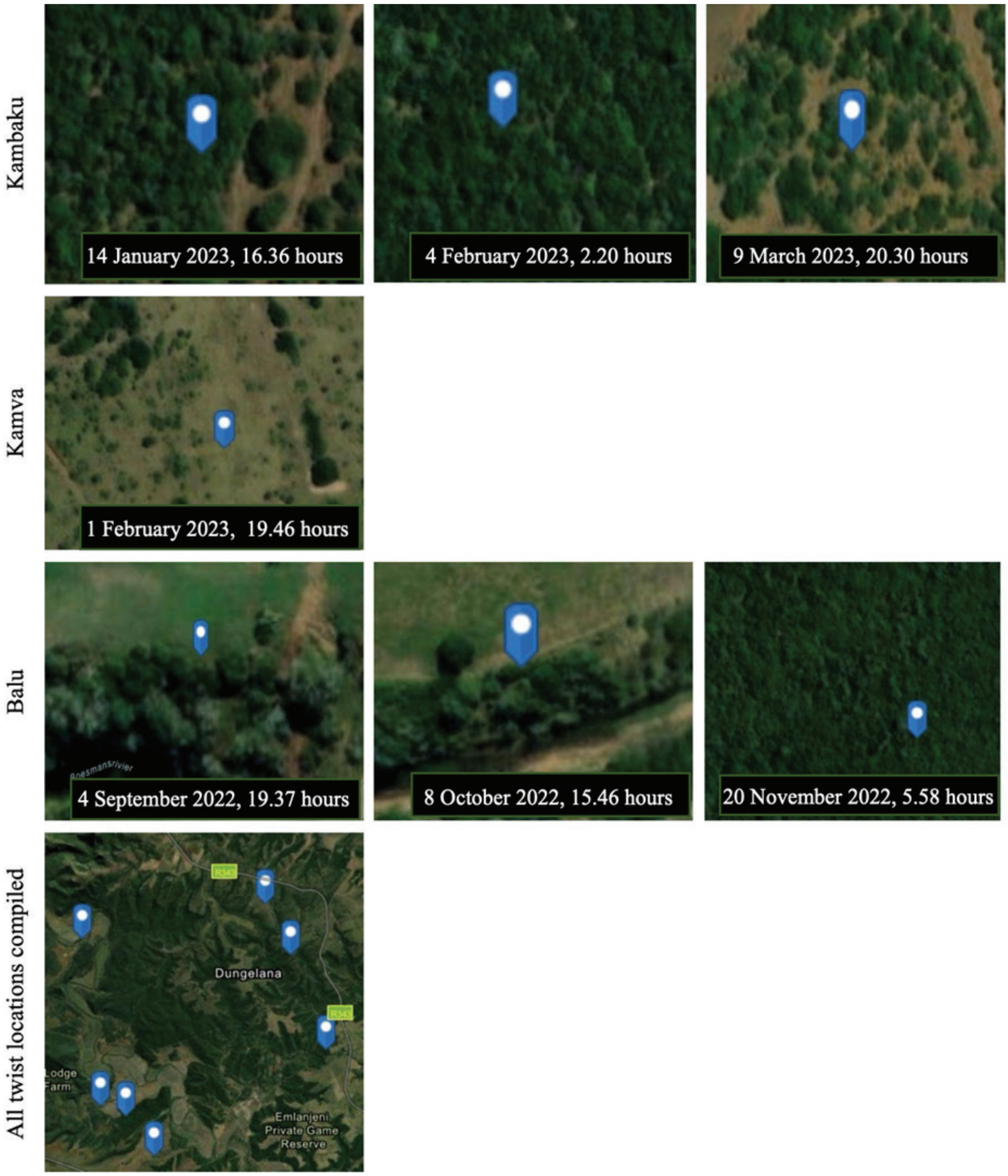

Figure 7. By comparing the timestamps of the collar inversions from the accelerometer data with GPS location data, we were able to identify the locations where collar twisting occurred. The analysis suggests that the twisting was primarily caused by male elephants moving through dense vegetation. Images obtained via ArcGIS Online (ESRI, 2023) (© *Brooke Friswold*)

The refurbished collar that was provided by the collar manufacturer and developed in conjunction with BTEH had a wider and thicker belt (Fig. 8) and slightly elongated upper unit dimensions in an attempt to prevent twisting (Table 1). Unfortunately, not all the specifications requested by the researchers for the refurbished collar upper unit dimensions—whether to be increased or decreased in height—were incorporated by the collar manufacturer, neither were we made aware of this until after collaring had taken place, likely increasing the risk of re-twisting. In discussions with the collar manufacturer, reviewing photos, and consulting with the veterinarian and support team on the ground during collaring, it was recognized that the collars were placed at the correct tightness considering elephant safety (musth neck swelling, growth over time, etc.) therefore displaying that human error was not the primary cause in twisting, suggesting instead collar structure and design. The collar manufacturer's recommendation was that the weight of the collar is in line with the bottom of the ear when viewed from the side, which was confirmed by photos (Fig. 3), and that *Balu* could potentially have benefitted from a slightly tighter fitting collar. Furthermore, the fact that double and triple twists occurred showed how tightness would not alleviate the twisting issue—as the tightness of the collar increased with each twist.

Because the collar application was determined not to be the likely cause of twisting and as the elephants are not twisting it themselves, we believe that redesign and restructuring of the LoRa collar are needed to fully alleviate the issue of twisting. We recommend the modification of collars to prevent twisting before future use by researchers and participating organizations; these modification recommendations are: 1) a thickened width or denser strap material that does not twist easily and which stays in position to avoid changing shape, such as the belting used for GPS collars; 2) a mechanism that prevents the flipping of the upper unit by increasing it in height (similar to the height of the GPS collars) or attaching a piece of belting or other material at the top sides of the unit to prevent flipping. On the contrary, the upper unit could be flattened to reduce the risk of catching on branches and being flipped over; 3) a mechanism that allows for twisting at the bottom if the strap twists at the top so that the twist does not retain permanently and/or cause harm, although this would be difficult considering an elephant's strength; and 4) a heavier counterweight to reduce collar mobility.

Considering that LoRa collars are fairly recent in their development, it seems likely that the specifications used for GPS collars, which have been adapted and corrected over the last three decades, are potentially less likely to twist due to these differences in structure (Table 1).

Collar twisting history and demographics obtained from other organizations

Input from a variety of organizations that have conducted elephant collaring has been acquired to provide insight into the prevalence and conditions of collar twisting. It should be noted that this list is not exhaustive, and there are likely other collar twisting and malfunction events that we were not able to record as we were unable to retrieve collaring data fully from all organizations, warranting the need for further research in this area. The Elephant Reintegration Trust collared 15 elephants using AWT GPS collars and reported only one twisting event on a mature male elephant.

This twist was observed at the time of occurrence and was caused by the collar's upper unit catching on the top of a translocation truck when the elephant was being loaded (Mitchell, pers. obs. 2022). Researchers were able to closely monitor the elephant to determine if the twist was causing a problem and the collar untwisted by itself after one month.

Elephants Alive, under the supervision of Dr Michelle Henley, has fitted more than 200 collars to elephants, primarily AWT GPS collars, and experienced two twisting events. On one occasion, the collar was fitted relatively loosely on an adult male elephant that was still growing and needed extra space to accommodate the swelling of the neck during musth. The male elephant would lift the collar with his trunk and push it through the rest of the collar's loop which gradually twisted the collar (Henley, pers. obs., 2022). The elephant was darted to allow a vet to untwist the collar, but due to the animal's behaviour, the collar twisted again, after which the elephant was darted a second time, and the collar was ultimately removed. All organizations contacted have confirmed that the high prevalence of twisting experienced in this study is alarming and should be addressed as a matter of urgency due to serious impacts on elephant fitness, survival, and reproduction.

Table 1. The dimensions of the original LoRa collars that were deployed and then twisted compared against the GPS collar dimensions (provided by Elephant Reintegration Trust not used in this study), and the refurbished LoRa collar dimensions that were reapplied following removal. These measurements were obtained by those involved in this study and were not provided by the collar manufacturer

	LoRa collar	GPS collar	Refurbished LoRa collar
Belt width	115 mm	115 mm	120 mm
Belt depth	8 mm	8 mm	14 mm near unit tapering to 8 mm
Unit length	150 mm	160–170 mm	190 mm
Unit width	150 mm	150 mm	120 mm
Unit height	65 mm	80 mm	65 mm
Bottom weight	4 kg	6 kg	4 kg

Figure 8. The original XL LoRa collar after it was removed from *Kamva* (left) and the refurbished LoRa collar that was fitted on *Balu* (right). (© *Chris Reynecke*)

Table 2. Information on elephant collar deployment and subsequent twisting provided by various organizations engaging in elephant collaring in other regions of Africa. Collar information includes all manufacturers and models of elephant collars. Note that this list is not exhaustive of all organizations involved in elephant collaring in Africa

Organization	No. collars deployed	Manufacturer and model of collars deployed	No. collars twisted	Manufacturer and model of twisted collar(s)
Elephant Reintegration Trust	14	AWT GPS, Iridium Satellite	1	AWT GPS
Elephants Alive	200+	AWT, African Savannah Tracking, VHF, GSM, Iridium and Inmarsat	2	AWT GPS
Humane Society International-Africa	55	AWT and Vectronics GPS, VHF, UHF, Iridium Satellite	0	N/A
Selati Game Reserve	7	AWT LoRa	0	N/A
Save the Elephants and The Elephant Crisis Fund	600–800	Various brands and models	1	GPS
Mara Elephant Project	82	GPS collars (AWT, Vectronics, Savannah Tracking and Followit)	1	GPS
Smart Parks		ElephantEdge	0	N/A
African Wildlife Tracking	1000+	AWT GPS, UHF, VHF	1%	AWT GPS, UHF, VHF
African Wildlife Tracking	*~100*	AWT GPS, UHF, VHF	*4 (this study)*	*LoRa*

Discussion

Considering that all the male elephants in the study had twisted collars, while none of the females experienced equipment failure of this kind, may be due to sexually dimorphic physical and behavioural differences. Male elephants pushing through dense vegetation may be more likely to hook the upper collar unit on a branch and fully rotate it due to foraging behaviour and body strength/mass. Furthermore, the direction of the twist is indicative of a forward movement due to the twist showing a 360-degree distal rotation toward the rear of the elephant, further supporting collective agreement that vegetation was playing a role in twisting. Kariega GR possesses a diverse range of vegetation characterized by many strong and low-hanging branches, making it particularly likely for collars to become hooked on branches. If the collar structure and belting are not robust enough or designed in such a way to mitigate this, the risk of twisting increases. When designing wildlife equipment for the greatest safety and efficacy these behavioural and ecological conditions should be considered so that they will not impact the effectiveness of equipment or increase twisting risk.

Male elephants may be more likely to push forcefully through dense vegetation during locomotion and browsing (Friswold, pers. obs., 2022), whereas a female in a herd may walk around dense vegetation and be less forceful due to the presence of calves. Furthermore, as other studies confirm, male elephants consume a higher diversity of plants and break larger stem diameters when foraging (Stokke and du Toit 2000), suggesting a preference of foraging in denser vegetation areas. Male elephants may also be more likely to twist their collars in dense vegetation due to their larger mass size as foraging behaviour has been shown to be dimorphic in elephants and that elephant herd foraging strategies were driven by body size, age-specific nutritional requirements, and intraspecific competition (Woolley et al. 2011). Research has also shown that larger-bodied bulls can tolerate a wider range of forage quality and can thus use a wider range of habitats (du Toit and Owen-Smith 1989).

Avoidance behaviour in musth bulls has shown that bulls use widely scattered feeding 'hotspots' while family units congregate near permanent water, which may further highlight browsing behaviour as a factor in collar twisting in bulls (Stokke and du Toit 2000). Additionally, movement behaviour in male elephants is faster and more directed during musth periods, which could increase the possibility of pushing through vegetation (Poole 1989). *Kambaku* showed clear signs of musth during the period he was collared, whereas the other elephants did not. Due to these differences and the observed phenomenon in this study of collar twisting occurring only on males, additional care should be taken when considering collaring bulls, especially in areas of dense vegetation, and post-collaring monitoring should form an integral part of elephant collaring studies to ensure that twisting has not occurred.

Post-collaring monitoring and awareness

Researchers and organizations that conduct collaring procedures for male elephants, especially those in dense shrub, should be aware that LoRa collars in their current state have the possibility of twisting, which can cause wounds and other welfare concerns. Elephants with LoRa collars should be monitored at close range regularly, as well as checking accelerometer data, to ensure that no twisting occurs, and that the welfare of elephants is considered. In our case, our ability to monitor these elephants closely and regularly allowed us to detect instances where the collars had twisted and were causing negative impacts on the elephants under study. However, we faced challenges as the twists were not easily observable from a distance, specific angles, or from a helicopter, often remaining concealed behind the ear/underneath the collar. The visibility of these twists was only evident at close range when the elephant flapped its ears open. However, often the ability to regularly monitor elephants at close range is not possible in many collaring studies, which limits researchers' awareness of potential problems and hinders their ability to address effectively and mitigate concerns related to collar malfunction and elephant welfare and safety.

Impact

Due to significant concerns about the twisting of LoRa collars and its impact on elephant well-being, we were compelled to remove the collars from two male elephants with no intention of replacing them. Collar removal took place before the fences were dismantled, the key event in our comparative study. As male elephants are trailblazers and the first to explore new territory (Bedetti et al. 2020), the bulls were vital individuals in our study design (Allen et al. 2020). However, it was decided not to recollar *Kambaku* due to his wounds and *Kamva* due to not having a replacement collar in time for the intervention. The removal of two key elephants resulted in a loss of 33% of the study data and will potentially increase the level of uncertainty for interpreting the impacts of the study.

Another factor that influenced our decision not to recollar two of the elephants was the ethical consideration of subjecting elephants to additional interventions within a three to six-month period instead of the anticipated three years, which would cause undue stress on the elephants, surrounding herds, and other wildlife within the reserve. Additionally. The risks associated with each elephant management intervention to elephant and human life and well-being are considerable, often indirect, and unintended, which need to be carefully weighed against the value of the research gained and the positive implications the findings can have on future elephant conservation strategies (Van de Water et al. in prep; Zungu and Slotow 2022). Furthermore, the financial costs for elephant interventions are immense, with significant cost and time incurred for helicopters, the refurbished and unusable collars, vet teams, ground safety teams, and transport for researchers. This all requires substantial funding and is especially challenging for NGOs that rely almost entirely on grant funding for research.

Conclusion

Elephant management interventions that potentially impact elephant well-being, such as twisting of collars, should be adequately investigated and mitigated by collar manufacturers to avoid future animal well-being issues, loss of research efforts, and damaging financial repercussions. We strongly urge researchers and organizations embarking on collaring procedures to exercise caution in their application, especially with male elephants ın dense vegetation, and always to employ regular post-collaring monitoring. Because LoRa collars are a relatively new product in wildlife tracking equipment, we consider our experience potentially indicative of key issues in quality management, unit design, and equipment breakdown that were not able to be tested prior to distribution and thus requires attention from manufacturers and consumers alike. We encourage collar manufacturers to investigate these events further, and to inform conservation partners of this occurrence and the possibility of twisting. Although elephant collaring serves as an invaluable tool for research and conservation, it is crucial to investigate, share outcomes and challenges, and address any instances where the equipment compromises the well-being of study subjects. It is our hope that these findings will contribute to the efforts of wildlife conservation and management practitioners to continually develop more ethical and effective wildlife monitoring tools.

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References

Allen CRB, Brent LJN, Motsentwa T, Weiss MN, Croft, DP. 2020. Importance of old bulls: Leaders and followers in collective movements of all-male groups in African savannah elephants (*Loxodonta africana*). Scientific Reports 10 (1): Article 1. https://doi.org/10.1038/s41598-020-70682-y

Bedetti A, Greyling C, Paul B, Blondeau J, Clark A, Malin H, Horne J, Makukule R, Wilmot J, Eggeling T, Kern J, Henley M. 2020. System for Elephant Ear-pattern Knowledge (SEEK) to identify individual African elephants. *Pachyderm* 61: 63–77.

Beier P, de Albuquerque FS. 2015. Environmental diversity as a surrogate for species representation. *Conservation Biology: The Journal of the Society for*

Conservation Biology 29 (5): 1401–1410. https://doi.org/10.1111/cobi.12495

CITES. 2010. African Elephant Action Plan. *CoP15 Inf.*, 68: 1–23.

Department of Environmental Affairs. (2014). *South Africa National Elephant Research Strategy 2014–2024*. Department of Environmental Affairs, South Africa. https://www.dffe.gov.za/sites/default/files/docs/elephant_research_strategy2014to2024.pdf

Department of Environmental Affairs. 2016. *National Protected Areas Expansion Strategy for South Africa 2016*.

EarthRanger. Allen Institute for Artificial Intelligence. Overview. [Online] Vulcan LLC. 2023. https://www.earthranger.com [Accessed 4 June 2023]

du Toit JT and Owen-Smith N. 1989. Body size, population metabolism, and habitat specialization among large African herbivores. *The American Naturalist* 133 (5): 736–740.

Esri. ArcGIS Online. Overview. [Online] Esri. 2022. https://www.esri.com/en-us/arcgis/products/arcgis-online/overview [Accessed 4 June 2023]

Garai ME, Roos T, Eggeling T, Ganswindt A, Pretorius Y, Henley M. 2022. Developing welfare parameters for African elephants (*Loxodonta africana*) in fenced reserves in South Africa. *PLoS One* 17 (3): e0264931. https://doi.org/10.1371/journal.pone.0264931

Horback KM, Miller LJ, Andrews J, Kuczaj II SA, Anderson M. 2012. The effects of GPS collars on African elephant (*Loxodonta africana*) behaviour at the San Diego Zoo Safari Park. *Applied Animal Behaviour Science* 142 (1–2): 76–81. https://doi.org/10.1016/j.applanim.2012.09.010

Kerley GI and Landman M 2006. The impacts of elephants on biodiversity in the Eastern Cape Subtropical Thickets: elephant conservation. *South African Journal of Science* 102 (9): 395–402.

Lubke RA, Everard DA, Jackson S. 1986. The biomes of the Eastern Cape with emphasis on their conservation. *Bothalia* 16 (2), Article 2. https://doi.org/10.4102/abc.v16i2.1099

Matthews A, Ruykys L, Ellis B, FitzGibbon S, Lunney D, Crowther MS, Glen AS, Purcell B, Moseby K, Stott J, Fletcher D. 2013. The success of GPS collar deployments on mammals in Australia. *Australian Mammalogy* 35 (1): 65–83. https://doi.org/10.1071/am12021

Morfeld KA, Meehan CL, Hogan JN, Brown JL. 2016. Assessment of Body Condition in African (*Loxodonta africana*) and Asian (*Elephas maximus*) Elephants in North American Zoos and Management Practices Associated with High Body Condition Scores. *PLoS One* 11 (7). https://doi.org/10.1371/journal.pone.0155146

Parker DM and Bernard RTF. 2005. The diet and ecological role of giraffe (*Giraffa camelopardalis*) introduced to the Eastern Cape, South Africa. *Journal of Zoology* 267 (2): 203–210. https://doi.org/10.1017/S0952836905007399

Pastorini J, Prasad T, Leimgruber P, Isler K, Fernando P, 2015. Elephant GPS tracking collars: Is there a best? *Gajah* 43: 15–25.

Poole JH. 1989. Announcing intent: the aggressive state of musth in African elephants. *Animal Behaviour* 37: 140–152. https://doi.org/10.1016/0003-3472(89)90014-6

Purdon A, Mole MA, Selier J, Kruger J, Mafumo H, Olivier PI. 2022. Using the Rao's Q diversity index as an indicator of protected area effectiveness in conserving biodiversity. *Ecological Informatics* 72 101920. https://doi.org/10.1016/j.ecoinf.2022.101920

Stokke S and Du Toit JT. 2002. Sexual Segregation in Habitat Use by Elephants in Chobe National Park, Botswana: Sexual Segregation in Habitat Use by Elephants. *African Journal of Ecology* 40: 360–371. https://doi.org/10.1046/j.1365-2028.2002. 00395.x

Van de Water A, Garaï M, Burnet M, Henley MD, Di Minin E, Streicher J, Bates L, Slotow R. Consequences of elephant management interventions: A 'One well-being' approach. In Prep.

Woolley LA, Page B, Slotow R. 2011. Foraging strategy within African elephant family units: why body size matters. *Biotropica* 43 (4): 489–495. https://doi.org/10.1111/j.1744-7429.2010.00733.x

Zungu M and Slotow R. 2022. A Systematic review of the success and unintended consequences of management interventions on African elephants. *Pachyderm* 63: 99–139.