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Undermining game fences: who is digging holes in Kalahari sands?

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Abstract

The effectiveness of game fencing as a tool to promote coexistence between humans and wildlife is highly dependent on the maintenance of fences. It is vital to identify animal species, which dig holes under fences, and their digging behaviour to maintain game fences appropriately. We provide data on some of southern Africa's major hole-digging animal species for a simple albeit effective method enabling stakeholders to categorize species that are digging holes underneath game fences in deep sand habitats by species-specific knowledge on sizes and shapes of holes. Using Botswana's Khutse Game Reserve/ Central Kalahari Game Reserve fence as an example, we highlight the temporal aspect in the process of hole digging and enlargement. We present a method to determine the pressure a fence experiences by a number of hole-digging species. Furthermore, we provide data on the time frame of necessary maintenance actions, required to prevent large predators from transgressing this specific fence line. We were especially interested in the effectiveness of fences in excluding African lions from human-dominated areas. The predators proved to be very difficult to fence in and extremely opportunistic. They mostly utilized holes that were initially excavated by other, even very small species.

Key words: fencing, hole digging, maintenance

Résumé

L'efficacité de la pose de clôtures pour favoriser la coexistence entre hommes et faune sauvage dépend beaucoup de l'entretien des clôtures. Il est essentiel d'identifier les espèces animales qui creusent des trous sous les clôtures et la façon dont elles les creusent pour entretenir les clôtures correctement. Nous fournissons des données sur certaines des principales espèces animales qui creusent des trous pour proposer une méthode simple mais efficace qui permettra aux parties prenantes de classer les espèces qui creusent des trous sous les clôtures destinées à la faune sauvage, dans des habitats sableux profonds, grâce à des connaissances spécifiques sur la taille et la forme des trous. Prenant comme exemple la clôture qui sépare, au Botswana, la Réserve de faune de Khutse de la Réserve de faune de Central Kalahari, nous soulignons l'aspect temporel du creusement des trous et de leur élargissement. Nous présentons une méthode pour déterminer la pression que subit une clôture de la part d'un certain nombre d'espèces fouisseuses. De plus, nous apportons des données sur le calendrier des mesures d'entretien nécessaires pour empêcher les grands prédateurs de franchir cette ligne de démarcation spécifique. Nous étions particulièrement intéressés par l'efficacité des clôtures qui doivent exclure les lions de zones à forte présence humaine. Ces prédateurs se sont avérés très difficiles à repousser et extrêmement opportunistes. Ils utilisent principalement des trous qui ont été creusés par d'autres espèces, même par des espèces très petites.

Introduction

Fencing has been widely used as a conservation tool to separate humans and wildlife to promote coexistence (Hayward & Kerley, 2009; Ferguson & Hanks, 2010; Somers & Hayward, 2012). Its effectiveness is highly dependent on the fence design, maintenance, ecological aspects of the surrounding habitat (e.g. soil structure, vegetation cover) and the abundance of wildlife in the area that is likely to damage the fence. To gain a broader understanding on the effects of wildlife-caused damage, it

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is vital to have a detailed look at the fences themselves. Particular focus should be on damage that will counteract the effectiveness of fences and transgression frequencies of different animal species. Bonnington *et al.* (2010), Ferguson, Adam & Jori (2012) and K. M. Kesch, D. T. Bauer & A. J. Loveridge (in prep.) developed methods to monitor the permeability of fences to wildlife enabling detailed studies of fences themselves. Funston (2001) pointed out significant differences between South Africa/Namibia and Botswana concerning the financial and temporal investment in the maintenance of the Kgalagadi Transfrontier National Park fence and the resulting difference in the permeability of the fence and therefore livestock predation in the areas surrounding the park. Poor fence maintenance and thus the increased conflict with wildlife are often the cause for negative attitudes towards protected areas by neighbouring communities (Gupta, 2005; Anthony, 2007; Chaminuka, 2010). However, the degree of maintenance efforts on a certain fence is highly dependent on the length of fencing, the type of damage to the fence, the objective of the fence, the costs of incursion, the costs of management and the total management budget.

Fences are built to withstand pressure by a variety of animal species. Some species, such as elephants, have the ability to break down entire sections (Graham & Ochieng, 2010; Grant, 2010; Ferguson, Adam & Jori, 2012) or are known to be exceptional jumpers (e.g. kudus) and can clear fences of remarkable height (Van Rooyen, Du Toit & Van Rooyen, 1989). Primates and a number of carnivore species are able to climb certain fence designs and are generally very difficult to exclude entirely from restricted areas (Van Rooyen, Du Toit & Van Rooyen, 1989; Bonnington *et al.*, 2010; Ferguson, Adam & Jori, 2012). Furthermore, there are species that are known to undermine the structural integrity of fences such as hyaenas (Dale, 1982; Van Rooyen, Du Toit & Van Rooyen, 1989). To maintain a game fence appropriately, the knowledge of which animal species are causing damage to a fence in a certain area is vital. However, when it comes to smaller hole-digging animals, special skills are required to identify the species and implement suitable damage prevention actions. As these species are often cryptic and nocturnal, their occurrence can best be determined by the presence of tracks.

This study aims to bring light into several fence management issues. Firstly, we developed a reliable manual in cooperation with experienced San trackers, who are well known for their outstanding tracking abilities (Stander *et al.*, 1997). The manual helps to identify and categorize hole-digging species by the size and shape of holes underneath fences in deep sand habitats. Further, with the example of the fence line of Khutse Game Reserve/Central Kalahari Game Reserve in southern Botswana, this study presents a method to determine the pressure of hole digging a fence experiences by certain species and gives advice on how frequent maintenance actions are required to prevent large predators from transgressing this specific fence line.

Methods

Study sites

The study was carried out along two game fences in Khutse Game Reserve (KGR)/south-eastern Central Kalahari Game Reserve (CKGR) and Makgadikgadi Pans National Park (MPNP), Botswana. The country is characterized by a cold dry season from April to September and a hot rainy season from October to March.

Located between 20–21°S and 24–26°E (Thomas & Shaw, 1991), the MPNP is 4900 km² in size. The annual rainfall averages 450 mm (Meynell & Parry, 2002), and annual temperatures range between a minimum of 6.9–19.9°C and a maximum of 25.3–35.2°C (Alexander *et al.*, 2002). The area west of the Park is one of the highest human–wildlife conflict areas in Botswana (Ecological Support Services, 2002). In 2004, an electrified double game fence (2.7 m wire netting fence with the lowest of four electrified wires 10 cm off the ground; 1.5 m wire netting cattle fence) was installed, crisscrossing the Boteti river bed, which forms the western boundary of the park.

The KGR (2600 km^2) is situated between 23–24°S and 24–25°E (Thomas & Shaw, 1991) in southern Botswana and borders the CKGR (52,000 km^2) to the north. The average annual rainfall is 300 mm (de Vries, Selaolo & Beekman, 2000), and average monthly temperatures range between 8.5 and 35.5°C (Thomas & Shaw, 1991). In October 2009, an electrified double game fence (same design as in MPNP) was completed to stop livestock predation by African lions (*Panthera leo*, Linnaeus) in the area. The fence alignment follows the southern and eastern border of KGR and around the south-eastern corner of CKGR, resulting in a total length of about 300 km.

Potential hole-digging species (>5 kg) along both fences include lion, brown hyaena (*Hyaena brunnea*, Thunberg), spotted hyaena (*Crocuta crocuta*, Erxleben), cheetah (*Acinonyx jubatus*, Schreber), leopard, caracal (*Caracal caracal*, Schreber), serval (*Leptailurus serval*, Schreber), bat-eared fox (*Otocyon megalotis*, Desmarest), black-backed jackal (*Canis mesomelas*, Schreber), wild dog (*Lycaon pictus*, Temminck), warthog, aardvark, honey badger (*Mellivora capensis*, Schreber) and porcupine.

Hole count survey and hole sizes by species

With the help of experienced San trackers, data were collected on a stretch of 120-km fence line in KGR/CKGR (October 2009–July 2010) and 95-km fence line in MPNP (November 2010–September 2011). The San people are well known for their outstanding tracking abilities (Stander *et al.*, 1997). The trackers participating in this study spent most of their lives in the CKGR as hunters and gatherers, following an ancient tradition of tracking and spoor (tracks/signs) reading. Further, they had extensive tracking experience in various research projects, and their skills were thoroughly tested (D. T. Bauer, M. Schiess-Meier, D. R. Mills and M. Gusset, in prep.; M. Schiess-Meier, unpublished data).

The fence line was driven with an average speed of 10–15 km h^{-1} with trackers sitting on the roof and on the bonnet of a 4 × 4 vehicle, scanning for tracks on the road ahead and for holes underneath the fence. Data were collected in the early morning hours, when the road and soil surface at the fence were still undisturbed by vehicles, rain or wind. All holes underneath the fence, of which the species that initially dug or enlarged the hole in order transgress the fence line could be reliably determined by tracks (spoor, fur, scratch marks of claws or quills), were numbered. Furthermore, GPS coordinates and measurements of holes (depth, width) were also recorded. Depth was defined as the distance from the lowest horizontal wire of the fence to the deepest point of the hole. Width was described by the distance from one edge of the hole to the other edge, on soil surface level (Fig. 1).

The cross section of the hole between its deepest point and the lowest fence wire was defined as hole size (HS; in cm^2). Hole sizes were calculated using the formula for half a circle's surface area: $HS = 1/2(\pi * r^2)$. Every hole's radius r is given by the mean between the depth and half the width of each hole (Fig. 1). Performing a Mann–Whitney U test (two-tailed), we tested for differences between species, and the holes were grouped into different hole size categories. The same test was performed for depths and widths of all holes and compared between species. To further distinguish between holes of different species, we had a detailed look at the overall shapes of holes, concentrating on the following criteria: slope, angle to fence, edges of the hole at the deepest point.

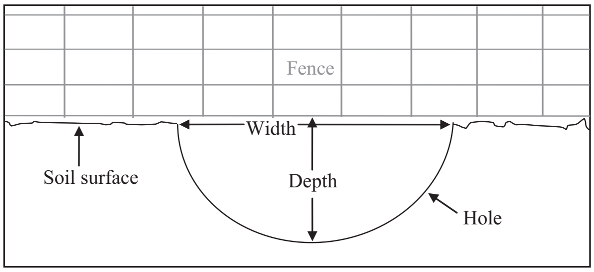

Fig 1 Schematic diagram of a hole under the fence with measurements (width, depth)

Species-specific time frames for the establishment of holes

In KGR/CKGR, all holes were filled with soil on a monthly basis to simulate maintenance, and weekly and monthly densities of new holes were calculated to describe the general and species-specific pressure the fence experiences by hole-digging species every week/month. The general term 'density of new holes' (DNH) was defined as the number of new holes per 100 km $week^{-1}$ per month. The term 'density of new holes by species x' (DNHS) is the number of new holes dug/caused by a certain species x per 100 km $week^{-1}$ per month. At the same time, existing holes were monitored weekly for enlargements by species classified in a larger hole size category. Besides recording tracks in the holes, the width and depth of every hole were measured to monitor enlargement even without visible tracks, following the hole size category method. In MPNP, new and pre-existing holes were only recorded to determine which species enlarged them.

All species were classified differently, depending whether they initiated the hole-digging process themselves or enlarged pre-existing holes: 'enlarging specialists' (mostly enlarge existing holes), 'opportunists' (initiate digging process but also enlarge holes), 'digging specialists' (mostly initiate hole-digging process themselves).

Data were tested for normality with the Kolmogorov–Smirnoff test and tested for differences performing a two-tailed Mann–Whitney U test.

Results

We were able to record and analyse data for lion, brown hyaena, aardvark, porcupine, honey badger and black-backed jackal.

Hole sizes by species

The comparison of hole sizes between species revealed four different hole size categories (Table 1). The underlying statistics are presented here:

1 lion (>1500 cm^2; lion–hyaena: $Z = -4.856$, $n = 154$, $P < 0.001$; lion–aardvark: $Z = -9.293$, $n = 193$, $P < 0.001$; lion–porcupine: $Z = -10.695$, $n = 432$, $P < 0.001$; lion–honey badger: $Z = -7.267$, $n = 95$, $P < 0.001$; lion–jackal: $Z = -9.112$, $n = 121$, $P < 0.001$).

2 hyaena (900–1500 cm^2; hyaena–aardvark: $Z = -8.076$, $N = 231$, $P < 0.001$; hyaena–porcupine: $Z = -10.076$, $n = 470$, $P < 0.001$; hyaena–honey badger: $Z = -6.343$, $n = 133$, $P < 0.001$; hyaena–jackal: $Z = -9.43$, $n = 159$, $P < 0.001$).

3 aardvark and porcupine (650–900 cm^2; aardvark–porcupine: $Z = -0.457$, $n = 509$, $P = 0.648$; aardvark–honey badger: $Z = -2.417$, $n = 172$, $P = 0.016$; aardvark–jackal: $Z = -5.409$, $n = 198$, $P < 0.001$; porcupine–honey badger: $Z = -2.47$, $n = 411$, $P = 0.014$; porcupine–jackal: $Z = -5.993$, $n = 437$, $P < 0.001$).

4 honey badger and jackal (400–650 cm^2; honey badger–jackal: $Z = -0.968$, $n = 100$, $P = 0.333$).

A more detailed investigation of the depths and widths of the holes showed the necessity to take more than one measurement into account in order to distinguish between different species (Table 1). For example, while honey badger and jackal belong to the same hole size category, their holes do not show any difference in the depths ($Z = -0.387$, $n = 100$, $P = 0.699$), but there is a significant difference in the widths ($Z = -3.084$, $n = 100$, $P = 0.002$).

Besides measurements, the overall shape of the hole can be very useful to determine between species. There are species-specific differences in the shape of holes of black-backed jackal, honey badger, porcupine and aardvark (Fig. 2). Jackal holes are very narrow, and the deepest point forms a V-shape in the middle of the hole. A honey badger hole is more of a box shape and often bends to one side. Furthermore, while all other species dig perpendicular to the fence, honey badgers generally do not show this characteristic. Whereas porcupine holes are generally shallow and wide, aardvarks tend to dig more in a U-shape, and distinctive claw marks are usually present in the edges at the deepest point of the holes.

Table 1 Comparison of hole sizes (HS), hole depths (HD) and hole widths (HW) between species. Values include median, 1st & 3rd quartile, sample size n and level of significance (Sig)

	HS (cm^2)	Sig	HD (cm)	Sig	HW (cm)	Sig
Lion (n = 58)	Median = 1842.7 1.quartile = 1413.7 3.quartile = 2482.3		Median = 32.5 1.quartile = 29 3.quartile = 35		Median = 70 1.quartile = 57.3 3.quartile = 93	
		***		***		***
Hyena (n = 96)	Median = 1275.9 1.quartile = 942.9 3.quartile = 1640.1		Median = 28 1.quartile = 24 3.quartile = 34		Median = 54 1.quartile = 45.8 3.quartile = 66	
Aardvark (n = 135)	Median = 726.1 1.quartile = 567.1 3.quartile = 962.2		Median = 23 1.quartile = 19 3.quartile = 28.5		Median = 39 1.quartile = 34 3.quartile = 44	
		ns		***		***
Porcupine (n = 374)	Median = 709.3 1.quartile = 537.6 3.quartile = 942.9		Median = 20 1.quartile = 17 3.quartile = 23		Median = 45 1.quartile = 47 3.quartile = 57	
		*		ns		***
Honey badger (n = 37)	Median = 567.1 1.quartile = 402.1 3.quartile = 831		Median = 21 1.quartile = 15 3.quartile = 24	ns	Median = 35 1.quartile = 31 3.quartile = 42	
		ns		ns		**
Jackal (n = 63)	Median = 481.1 1.quartile = 421.2 3.quartile = 636.2		Median = 20 1.quartile = 18 3.quartile = 23		Median = 28 1.quartile = 25 3.quartile = 37	

ns, not significant.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

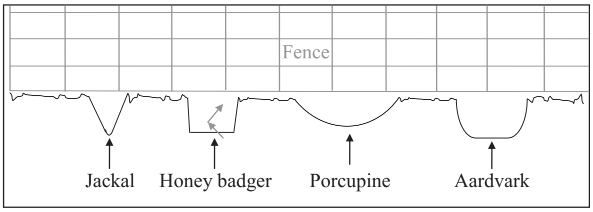

Fig 2 Diagram of hole shapes of black-backed jackal, honey badger, porcupine and aardvark

Species-specific time frame for the establishment of new holes

We recorded 371 newly dug holes and followed the hole enlargement process on 68 (18.3%) of them. The hole-digging species, of which we had sufficient data, were classified by their digging behaviour:

'enlarging specialists' (hole size category 1): African lion. Lions mostly enlarged pre-existing holes and only initiated the digging process in 36% of the cases.

'opportunists' (hole size category 2): brown hyaena. Hyaenas initiated the hole-digging process themselves in 67.4% of the cases, but also enlarged pre-existing holes (32.6%).

'digging specialists' (hole size category 3 & 4): black-backed jackal, honey badger, porcupine, aardvark. These species mostly initiated the digging process themselves (jackal: 100%, honey badger: 100%, porcupine: 94.8%, aardvark: 89.6%).

We were able to calculate monthly and weekly DNH and DNHS for porcupine, brown hyaena, black-backed jackal and aardvark for the KGR/CKGR fence (Table 2). The overall DNH was 66.2 holes per 100 km per month. The DNHS for porcupine and hyaena increased with every week of data collection, whereas the DNHS for jackal and aardvark decreased after 3 weeks of data collection. A decrease in the DNHS occurs when the number of new holes is smaller than the amount of old holes that have been enlarged by larger species and therefore belong to a different DNHS. Unfortunately, there was not enough data to integrate lion and honey badger into the calculations of DNHS.

Discussion

This study provides data on a first set of six animal species for a simple albeit effective method enabling stakeholders to determine categories of species that are digging holes underneath game fences and their digging behaviour in deep sand habitats (Table 1). We determined four different hole size categories: (1) lion; (2) brown hyaena; (3) aardvark & porcupine; and (4) honey badger & black-backed jackal (Table 3). Species-specific hole shapes were described, and the categories were classified as either 'enlarging specialists' (category 1), 'opportunists' (category 2) or 'digging specialists' (categories 3 & 4). However, further research is needed to describe shapes and measurements of holes and the digging behaviour of additional species in various habitats and soil types. The presented data set must therefore be seen as a start to help stakeholders to identify the type of digging behaviour and the species involved at their specific fence based on hole sizes and shapes. This study allows them to match measurements with hole size categories and certain digging behaviour and therefore plan their fence maintenance efforts accordingly.

To plan fence maintenance actions or classify the extent of direct and facilitated fence permeability, stakeholders can use the method of calculating weekly/monthly DNH and DNHS in their areas. The DNH and DNHS are a measure to describe the hole-digging pressure on game fences by specific species. In the case of KGR/CKGR,

Table 2 Density of new holes (DNH) and density of new hole per species x (DNHS) for porcupine, brown hyaena, black-backed jackal and aardvark 1, 2, 3, 4 and 5 weeks after filling of holes and percentage of DNH/DNHS after 1 month in Khutse Game Reserve/Central Kalahari Game Reserve

	% of total holes after 5 weeks (hole density = no. of holes/100 km ± SE)				
Weeks after filling holes	Total	Hole density porcupine	Hole density hyaena	Hole density jackal	Hole density aardvark
1	25.7 (38.8%)	22.6 (48.3%)	3.6 (25.9%)	1.3 (32%)	0 (0%)
2	41.9 (63.3%)	25.8 (55.2%)	9.3 (67.7%)	3.5 (86.4%)	1.7 (100%)
3	49 (74%)	33 (70.7%)	11.5 (83.3%)	2.9 (73.6%)	0 (0%)
4	58.8 (88.8%)	41.9 (89.7%)	11.8 (85.2%)	3.5 (86.4%)	1.7 (100%)
5	66.2 ± 7.7	46.7 ± 6.2	13.8 ± 3.9	4 ± 1.4	1.7 ± 0.7

Table 3 Hole size categories, transgression time frames and recommended maintenance time frames for the KGR/CKGR fence

	Black-backed jackal (*Canis mesomelas*)	Honey badger (*Mellivora capensis*)	Porcupine (*Hystrix africaeaustralis*)	Aardvark (*Orycteropus afer*)	Brown hyaena (*Hyaena brunnea*)	African lion (*Panthera leo*)
HS category 1 (1500–3000 cm^2)						X
HS category 2 (900–1500 cm^2)					X	
HS category 3 (725–900 cm^2)			X	X		
HS category 4 (500–725 cm^2)	X	X				
Time to transgress	0–1 week	0–1 week	0–1 week	0–1 week	0–1 week	1–2 weeks
Maintenance	Daily	Daily	Daily	Daily	Daily	Daily

aardvark, jackal and hyaena did not initiate many new holes within the first week after simulated maintenance (filling of all the holes underneath the fence with sand). However, within the first week, the DNHS of porcupines almost reached 50% of the total DNHS after 1 month.

Partially dug holes of black-backed jackal, honey badger, aardvark or brown hyaena were hardly ever encountered during the study. We therefore assume that these species are very likely to dig a hole under a fence in one night. The first complete lion holes were found about 2 weeks after simulated maintenance. However, many incomplete lion holes and scratch marks along long stretches of fence were recorded and made us assume that lions avoided digging when possible and rather walked long distances to find a suitable hole. Interestingly, they were recorded to use holes down to the size of honey badger holes and were able to lift the entire fence construction up while squeezing through a hole (K. M. Kesch, pers. observation). Hence, despite digging the largest holes underneath game fences, lions seem very reluctant to initiate the digging process themselves and are completely opportunistic in the utilization of different species' (even very small) holes to transgress the fence line. Therefore, this species is very difficult to fence in, and special attention is required in areas where there are 'digging specialists' present. Hoare (1992) only categorized lions as 'potential climbers'. However, this and other studies (Reed & Sautereau, 2005; Ferguson, Adam & Jori, 2012) show that they dig or enlarge holes under electrified fences to exit protected areas.

Different fences obviously have different objectives and hence require different maintenance efforts. The extent of these efforts is dependent on a variety of factors, such as the total fence management budget, the costs of incursions compared with the costs of maintenance, the length of the fence, the DNH and the types of digging species present. In our case study in KGR/CKGR, where lions caused the major part of livestock predation outside the protected area (Schiess-Meier *et al.*, 2007), the fence was supposed to be an impermeable exclusion fence and separate lions from human-dominated areas completely. As lions were recorded to squeeze through holes down to the size of honey badgers, maintenance efforts have to be planned according to the appearance time frame of these holes. In practice, this means that the fence should be patrolled and repaired on a daily basis (Table 3). Further, to improve the design, the fence should be partly buried into the ground.

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