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Detection success of cheetah (*Acinonyx jubatus*) scat by dog-human and human-only teams in a semi-arid savanna

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ABSTRACT

The cheetah (*Acinonyx jubatus*), like many other terrestrial large carnivores, exhibits elusive behaviour, occurs in low numbers over large home ranges, and has experienced population decline and range contraction. Therefore, long-term conservation strategies are needed which rely on accurate ecological data. Surveys using scat collection and analysis can generate these data and using scat detection dogs (*Canis familiaris*) is an effective method to gather scat samples. However, transect dimensions, local weather conditions and vegetation can influence the scat detection success. We conducted an experiment evaluating the influence of these factors on a scat detection dog-handler team, to assist the planning of optimal survey designs. We placed cheetah scat along transects of varying sizes established in different vegetation conditions and recorded environmental parameters during searches. Additionally, we evaluated the dog's performance compared to that of human searchers on one identical set of transects. The dog had an average detection rate of 45% and an accuracy rate of 100% over all trials. Increasing search time and decreasing transect width had the strongest positive influences on the detection rate. If transect dimensions did not exceed 100 m in length and 25 m in width, the dog achieved a detection rate of 93.3%, resembling the effective search area. We found no significant influences of weather conditions and vegetation cover. Human searchers achieved a detection rate of 22% and an accuracy rate of 55% compared to a 75% detection rate and 100% accuracy rate for the dog on the identical transects. To increase sample return, we recommend the calibration of study designs for individual dog-handler teams, as well as more frequent use of scat detection dogs for surveying populations of rare carnivores.

Keywords: canine; carnivore survey; cheetah; conservation; detection dog; Namibia; non-invasive survey; scat; wildlife monitoring

INTRODUCTION

Many large carnivores are elusive, occur in low numbers and roam over large home-ranges, which makes it difficult to monitor their population status (Becker *et al.* 2017). The cheetah (*Acinonyx jubatus*) is a prime example of such a carnivore, with home-range sizes on Namibian farmlands averaging 1 651 km² (Marker *et al.* 2008): 379 km² for males with stable home-ranges in the form of small territories, 1 595 km² for males ranging over large areas and 650 km² for females (Melzheimer *et al.* 2018). With the majority of their population living on livestock farmland (Marker-Kraus & Kraus 1994), cheetahs are unique among predators in southern Africa in that they sometimes benefit little from protected areas (Cristescu *et al.* 2017). Nonetheless, on farmland, the potential for human-wildlife conflict is high, leading to death or persecution of the animals (Marker *et al.* 2003a) with an effective annual removal of 0.59 individuals per 100 km² over all ages and sexes (Weise *et al.* 2017).

To assist carnivore conservation and management, ecological data including population density, habitat use, home-range size, and resource use information is needed and predator scat surveys can facilitate these outcomes (Wasser *et al.* 2004; Davidson *et al.* 2014). Additionally, scat can provide species and gender identification (Harrison 2006; Hollerbach *et al.* 2018), as well as insights on reproduction and health (Rolland *et al.* 2006). Scat samples can also be used to determine a predator's diet which is a vital tool to evaluate human-wildlife conflict situations (Marker *et al.* 2003b).

Scat of territorial male cheetahs can be found close to and on scent marking areas that are prominent landmarks such as trees ('play trees'), termite mounds or rocks (Caro 1994). When those are known, the collection and identification of cheetah scat from territorial males is feasible, but female individuals and non-territorial males will likely remain undetected (Melzheimer *et al.* 2018). These latter samples are essential to achieve a dataset not limited by the hierarchy and spatial tactic of an individual cheetah or a specific gender, making it necessary to find samples away from scent marking areas.

Scat detection dogs (*Canis familiaris*) have been shown to efficiently find scat samples in a minimally invasive fashion, and thus their use is becoming popular in modern research (Beebe *et al.* 2016). Scat detection dogs have been used to find scats from a variety of species including bobcats (*Lynx rufus*) in North America (Harrison 2006), bush dogs (*Speothos venaticus*) in South America (Matteo *et al.* 2009), Eurasian lynx (*Lynx lynx*) in Europe (Hollerbach *et al.* 2018), non-human primates in Asia (Orkin *et al.* 2016), koalas (*Phascolarctos cinereus*) in Australia (Cristescu *et al.* 2020) and Cross River gorillas (*Gorilla gorilla diehli*) in Africa (Arandjelovic *et al.* 2015), but the effort and costs involved in using detection dogs are often higher compared to other survey methods or human searchers. Long *et al.* (2007a) calculated an average of US$ 153 per site when using hair snares, US$ 214 when using camera traps, and US$ 316 when using a leased detection dog to survey carnivores. In another study costs per scat sample were US$ 1479 when using a dog and only US$ 224 when using human searchers (Arandjelovic *et al.* 2015). However, this cost can be offset by an increased sample detection rate (Rolland *et al.* 2006; Arandjelovic *et al.* 2015) and more precise sample identification (accuracy rate) (Cristescu *et al.* 2015). Because funding resources are often limited in conservation research (Orkin *et al.* 2016), studies need to be designed to promote the potential of the individual dog-handler team (MacKay *et al.* 2008). Therefore individual working characteristics need to be identified in field experiments mimicking real search conditions, to quantify the search area where detection and accuracy rates are high (Reed *et al.* 2011). The aim of a study defines the rates necessary, for example, if the goal is to detect presence of a common species a lower detection rate can be tolerated (MacKay *et al.* 2008), while eradication of invasive species may rely on 100% detection rate (Glen & Veltman 2018). Important variables impacting the effectively searched area are the perpendicular distance from a transect line to a detected target (detection distance) (Glen & Veltman 2018), the distance from the start of a transect to a detected sample, and the search time per area (Bennett *et al.* 2020).

Detection dogs may also be influenced by local weather conditions, such as wind direction, wind speed, temperature and humidity (Wasser *et al.* 2004; MacKay *et al.* 2008; Kapfer *et al.* 2012; Beebe *et al.* 2016). These factors influence the scat, for example temperature affects bacterial activity leading to an increase or decrease of the amount and diffusion of odour (Wasser *et al.* 2004) while they also affect the dog, for example low humidity can cause dry nasal tissue leading to a reduced scenting ability (MacKay *et al.* 2008). Wind is considered important because the scent cone leading to the scat can be diffused and therefore impact the detection distance (MacKay *et al.* 2008). Vegetation structure is another important aspect as it affects the dispersal of scent (Wasser *et al.* 2004) and the ability of the dog-handler team to manoeuvre in the search area (Leigh *et al.* 2015). Closer investigation of those factors has been suggested (Long *et al.* 2007a; Reed *et al.* 2011), but to date the amount of research quantifying them is limited (Nussear *et al.* 2008; Reed *et al.* 2011; Leigh *et al.* 2015).

Dogs can find more samples in a shorter period of time (Oliveira *et al.* 2012) and are more accurate in identifying the species that deposited the scat than human searchers (Cristescu *et al.* 2015). Humans tend to search where higher sample abundance is expected, such as scent marking areas. This can lead to a bias in the spatial coverage of the search area and towards individuals with different spatial tactics (Arandjelovic *et al.* 2015). The collection of cheetah scat around marking areas is not sufficient to display the entire population in an area and therefore samples need to be found away from marking areas. It is therefore of particular interest to test scat detection dogs in comparison with human searchers in their ability to find those samples.

We conducted an experiment to assist with calibration of field efforts for detecting cheetah scat in a savanna system in north-central Namibia and to test the hypotheses that: (1) transect dimensions impact the detection rate, (2) an experienced dog can achieve stable detection rates under changing weather and vegetation conditions, and (3) a scat detection dog outcompetes humans when searching for scat.

METHODS

Study Area

The study area was located 45 km east of Otjiwarongo in north-central Namibia (20.436S, 17.100E) (Figure 1). The habitat is classified as semi-arid thorn bush savanna with an annual rainfall of approximately 400 to 500 mm (Buyer *et al.* 2016). More than 90% of the precipitation occurs in the hot wet season (15 September to 14 April) (Marker *et al.* 2008). We conducted our study in the cold dry season (15 April to 14 September) between 28 July and 25 August 2017. Lower temperatures increased the daily working hours of the dog, and the activity of dung beetles, which are known to remove the samples, was reduced (Becker *et al.* 2017). High precipitation rates can destroy scats (Arandjelovic *et al.* 2015), therefore the dry season with lower temperatures and nearly no rainfall provided ideal circumstances for our investigation.

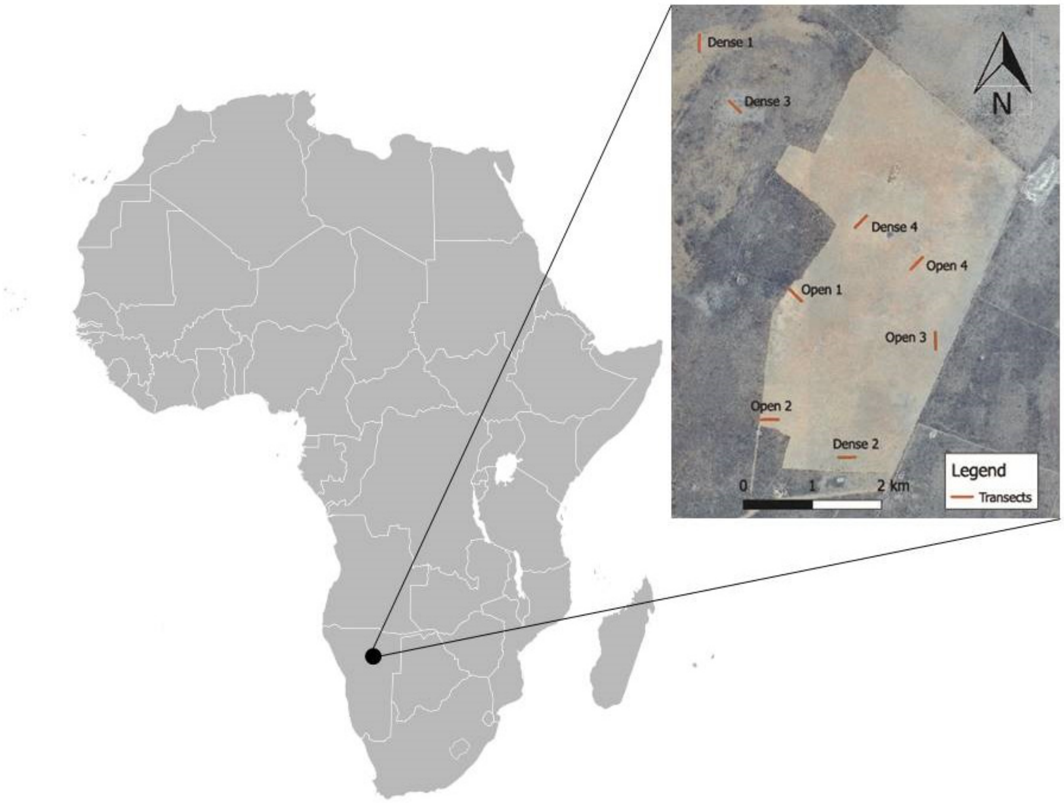

Figure 1*: Study area (farm Elandsvreugde) with the locations of the four transects in dense vegetation and the four transects in open vegetation that were searched by the human-dog and human-only team.*

Transects

We established eight transect lines (Figure 2, Table 1), four in open/low, predominantly grassy vegetation and four in dense/high vegetation. To find five randomly deposited cheetah scats, each transect was searched over four trials by a human-dog team and in one additional trial by human searchers (Table 1). The directions of the transects were fixed but their starting points were selected at random. They ran North to South, East to West, North-East to South-West and South-East to North-West to ensure working under variable wind directions. Transects were located approximately 1 540 m above sea level and their difference in elevation was negligible. The distance between transects was more than one km (mean ± SD; 1.26 ± 0.49 km) to prevent scent spreading across transects, assuming that average detection distances for dogs on terrestrial surfaces are below that threshold (Cablk *et al*. 2008; Leigh *et al*. 2015). Subsequent searches on transects were conducted at least two days (6.58 ± 2.04 days) after previous searches to reduce the presence of scent from sample remains. Transects were 250 m long but the search area changed with their strip width (Table 1), which is defined as the maximum distance where samples were deployed, perpendicular to both sides of the transect line. The first and second trial had a strip width of 50 m leading to a total search area of 2.5 ha (big transects), the third trial had a strip width of 25 m leading to 1.25 ha of search area (medium transects), and the fourth and the fifth trial had a strip width of 12.50 m leading to 0.63 ha of search area (small transects).

Table 1: *Experimental design with the dimensions of the cheetah scat detection transects and search area, the number of transects per habitat type, the search team and the resulting total number of searches for each trial.*

Trial ID	Total transect width [m]	Search area [ha]	Number of transects in		Search team	Number of searches
			open habitat	dense habitat		
1	100	2.50	4	4	Human-dog	8
2	100	2.50	4	4	Human-dog	8
3	50	1.25	4	4	Human-dog	8
4	25	0.63	4	4	Human-dog	8
5	25	0.63	4	4	Human-only	8

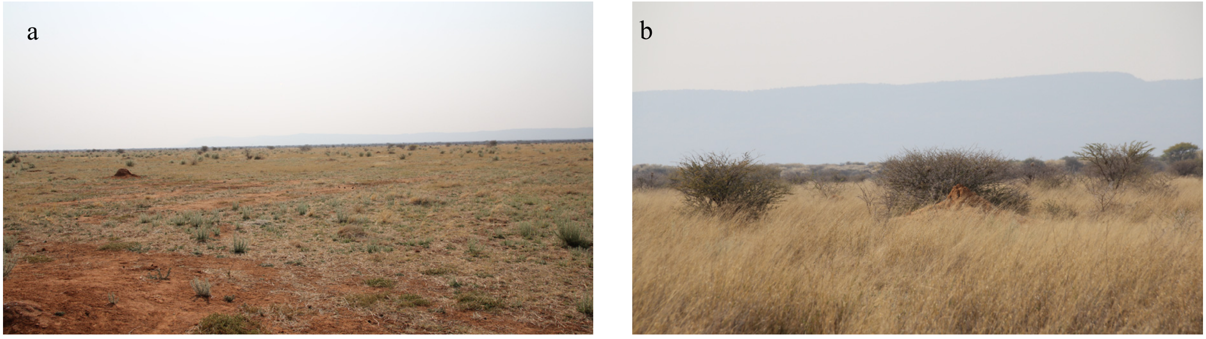

Figure 2: *Examples of cheetah scat detection transects: (a) an open habitat transect characterised by bare soil and sparse vegetation, and (b) a transect in dense habitat characterised by a higher and denser grass layer with some bushes/trees.*

Samples

Fresh target samples (~24 hours old) were collected from 13 captive cheetahs at the Cheetah Conservation Fund (CCF). Each sample consisted of a complete excrement and therefore differed in shape, size and consistency. Cheetahs were fed raw donkey (*Equus asinus*) or horse (*Equus ferus caballus*) meat with predator powder (©Health Tech Laboratories) supplement providing vitamins and minerals. Cheetahs of different age, sex and status of relatedness were chosen to reduce the effect of single odour components associated with an individual (Smith *et al*. 2003). Samples were collected with single-use gloves and immediately placed into separate, sealable plastic bags to be frozen. Freezing conserves the odour pattern (Goss 2019), but the process of thawing might influence the scent of the samples (MacKay *et al*. 2008). We decided to freeze to reduce the influence of different ages of the collected samples, as was also done by other authors (Reed *et al*. 2011; Oliveira *et al*. 2012). The transects were not cleared of existing scats from large carnivores present in the study area such as leopard (*Panthera pardus*), brown hyaena (*Parahyaena brunnea*), black-backed jackal (*Canis mesomelas*) and caracal (*Caracal caracal*), which acted as natural non-target scats. We avoided establishing transects near cheetah play trees to minimise the likelihood of encountering wild cheetah scat.

Sample placement

The orienteer, wearing single-use plastic gloves, placed five scat samples per transect. The location of each sample was created randomly, using the research tool ‘random points inside polygon’ with no set maximum distance between the points in a GIS (QGIS Development Team 2016), inside a buffer which differed in size depending on the trial. The fourth and the fifth trials, which acted as the comparison between human searchers and the dog, were conducted with the same locations to eliminate bias due to sample positions. Coordinates were uploaded into a GPS (Garmin GPSMAP 60CSx) allowing placing the sample at the correct position, however, the inaccuracy of a GPS can lead to a bias in the target’s position (MacKay *et al*. 2008). The orienteer walked randomly over the whole search area reducing the chance for the dog to follow his footsteps to the targets (Leigh *et al*. 2015). Placement was done within 7 to 24 (17.1 ± 4.82) hours before the trial began, to reduce the presence of human scent and to allow the scent of the scat to disperse. The time we chose exceeds the time used in another similar study (Reed *et al*. 2011).

Human-dog team

The human-dog team consisted of the dog, the dog handler, and the orienteer. The dog was an experienced, ten-year-old, male border collie that had been trained for his first two years of age on frozen cheetah scat, and was used for field searches in the study area for the next six years. His training followed the general principles in this field of research (Wasser *et al*. 2004; MacKay *et al*. 2008). The dog displays an indication behaviour, sitting, to communicate the detection of a target scat to the handler, and is then rewarded with a play session. The dog’s drive and focus on the task aids quick learning and successful identification of target and non-target samples. For two years before this study, the dog was used regularly for short training sessions but not for field searches. The dog was handled by CCF’s scat dog handler and trainer, who had two years of experience working with detection dogs in the private security sector. Orientation and data collection were carried out by the lead author.

Trial procedure

We conducted trials on three sequential days, followed by a one-day break to rest the dog. Trials took place from 06h00-10h00 and 15h00-18h00 to avoid the hottest time of the day. The dog walked off leash in front of the handler. To mimic field conditions, the dog handler was only given the transect direction and no time limit; therefore, the handler decided independently how much time was spent on each transect, defined as ‘search time’.

The trial procedure followed the general strategy in this field of research (Wasser *et al*. 2004; Long *et al*. 2007b; Nussear *et al*. 2008). The handler sent the dog in specific directions or walked with the dog to either side of the transect line to make sure the dog covered the area sufficiently. The orienteer stayed a few metres behind the dog handler and kept the team on track using a handheld GPS (Garmin GPSMAP 60CSx). If scat was detected, the dog sat and waited for the handler to arrive and check the scat sample. If the handler approved the dog's findings, the orienteer marked his position on the transect line and approached the team. Once the orienteer confirmed the scat as a target sample, the dog was rewarded with a short playing session and the orienteer collected the scat. The team then returned to the marked point on the transect line and continued with the trial. Each trial ended when the team reached the end of the transect line.

Before the start of each transect, at every detected sample and at the end of each transect, the environmental variables temperature, humidity, wind speed and wind direction were recorded, using a hand held weather station (Kestrel 4500nv Pocket Weather Tracker) with a precision of one decimal unit. All variables were measured at 1.30 m height, but at the scat positions at 0.30 m height.

Human-dog vs. human-only

The comparison between the human-dog team and the human-only team was done on one set of eight small transects. Three human participants with experience in identifying cheetah scat searched after the dog on those transects. Searcher One had worked for five years as large carnivore keeper in a safari park, Searcher Two had worked for two years analysing cheetah scat in a genetics laboratory, and Searcher Three was a qualified field guide with one year of experience. The trial procedure was consistent with the dog team’s trials, but the searchers were not told if the samples they pointed out were correct until the end of the trial, to avoid influencing their search morale. No weather data was recorded because the effect on human performance was assumed negligible in the moderate weather conditions worked in (Nussear *et al*. 2008).

Analysis

Detection rate was defined as the number of targets found, divided by the number of targets available. Accuracy rate was defined as the total number of correctly indicated samples divided by the total number of indications. The perpendicular distance from each sample to the transect line (‘detection distance’) and the distance from the starting point of the transect to the sample’s location (‘distance from start to target’) were calculated using QGIS 2.18 Las Palmas.

We tested for significant differences between groups using Mann–Whitney U tests (*U*) and Kruskal-Wallis-Rank Variance Analysis with multiple *post hoc* tests (*H*), as well as correlations between variables with Spearman's Rank Correlations (r_s) (Bortz *et al*. 1990). All calculations were performed using STATISTICA 13.3 (Tibco Software Inc. 2017). The alpha level of statistical significance for all our calculations was set to 5% ($p < 0.05$).

RESULTS

Dog performance

The dog indicated 72 out of 160 possible samples at a rate of 2.3 (± 1.3) samples per transect resulting in a detection rate of 45% (Table 2). This rate differed between the transect sizes; the dog indicated 3.8 (± 0.5) available targets on the small transects (75% detection rate), 2.9 (± 0.6) samples on the medium transects (58% detection rate) and 1.2 (± 0.9) samples on the big transects (24% detection rate). The detection rate differed significantly (*H* = 22.57, df = 2, p = 0.000; n = 32) between the big transects compared to the medium (p = 0.015) and small transects (p = 0.000), but not between the medium and the small transects (p = 0.485). The dog never indicated a non-target scat and no wild cheetah scat was encountered during the study; the accuracy rate was 100%.

The average search time over all transects was 23.0 (± 15.3) min/ha; 46.0 (± 5.4) min/ha on small transects, 25.6 (± 1.4) min/ha on medium transects and 10.1 (± 2.9) min/ha on the big transects. The search time differed significantly (*H* = 26.23, df = 2, p = 0.009; n = 32) between the big transects compared to the medium (p = 0.009) and small transects (p = 0.000) but not between the medium and the small transects (p = 0.264).

The detection (n = 72) and non-detection (n = 88) distance ranged from 0 m to 44 m and differed over all transects widths (*U* = 1409.50, p = 0.000; n = 160). Detected samples were on average 10.1 (± 9.7) m away from the transect line and undetected samples 22.3 (± 14.1) m. Samples were detected (n = 30) on the small transects at a distance of 5.5 (± 3.6) m and not detected (n = 10) at 9.0 (± 2.4) m (*U* = 64.00, p = 0.007; n = 40). On the big transects, samples were detected (n = 19) at a distance of 17.7 (± 13.7) m and undetected (n = 61) at a distance of 26.7 (± 14.3) m from the line (*U* = 365.00, p = 0.016; n = 80). A similar pattern was found for the average distance from the start to detected targets over all trials, but it

Table 2: *Key values describing the performance of human-dog and human-only teams in detecting cheetah scat under field conditions, including average and total numbers for detection of target and non-target samples, and distance values for detection and non-detection of samples from the transect line and the start to the targets (means with standard deviations).*

Transect	Trial	Number of searches	Total number of available samples	Total number of detected samples	Average number of detected samples per transect	Total detected non-target samples	Average number of non-target samples detected per transect	Average search time per transect [min/ha]	Average distance of detected targets to the transect line [m]	Average distance of undetected targets to the transect line [m]	Average distance from the start to detected targets [m]	Average distance from the start to undetected targets [m]
Big	1 & 2	16	80	19	1.2 (± 0.9)	0	0.0	10.1 (± 2.9)	17.7 (± 13.7)	26.7 (± 14.3)	117.0 (± 78.8)	115.8 (± 75.6)
Medium	3	8	40	23	2.9 (± 0.6)	0	0.0	25.6 (± 1.4)	9.7 (± 7.3)	14.5 (± 8.4)	110.8 (± 68.2)	152.4 (± 70.0)
Small	4	8	40	30	3.8 (± 0.5)	0	0.0	46.0 (± 5.4)	5.5 (± 3.6)	9.0 (± 2.4)	113.5 (± 69.5)	163.6 (± 75.1)
Overall	5	32	160	72	2.3 (± 1.3)	0	0.0	23.0 (± 15.3)	10.1 (± 9.7)	22.3 (± 14.1)	113.6 (± 70.7)	128.3 (± 76.1)
Human	5	8	40	9	1.1 (± 1.0)	7	0.9 (± 1.4)	40.6 (± 2.3)	6.3 (± 3.7)	6.4 (± 6.4)	124.0 (± 87.0)	127.0 (± 70.5)

was only found significant on the small transects ($U = 84.00$, $p = 0.041$; $n = 40$), with a detection distance of 113.5 (± 69.5) m and a distance for undetected samples of 163.6 (± 75.1) m. The average distance for undetected samples increased with decreasing transect width but was only found significant between the big ($n = 61$) transects compared to the grouped small and medium ($n = 27$) transect ($U = 554.50$, $p = 0.015$; $n = 88$). It was 163.6 (± 75.1) m for the small transects, 152.4 (± 70.0) m for the medium transects and 115.8 (± 75.6) m for the big transects. The effective searched area (Box in Figure 3) was 100 m in length and 25 m in width where the dog achieved a detection rate of 93.3%, and an accuracy rate of 100%.

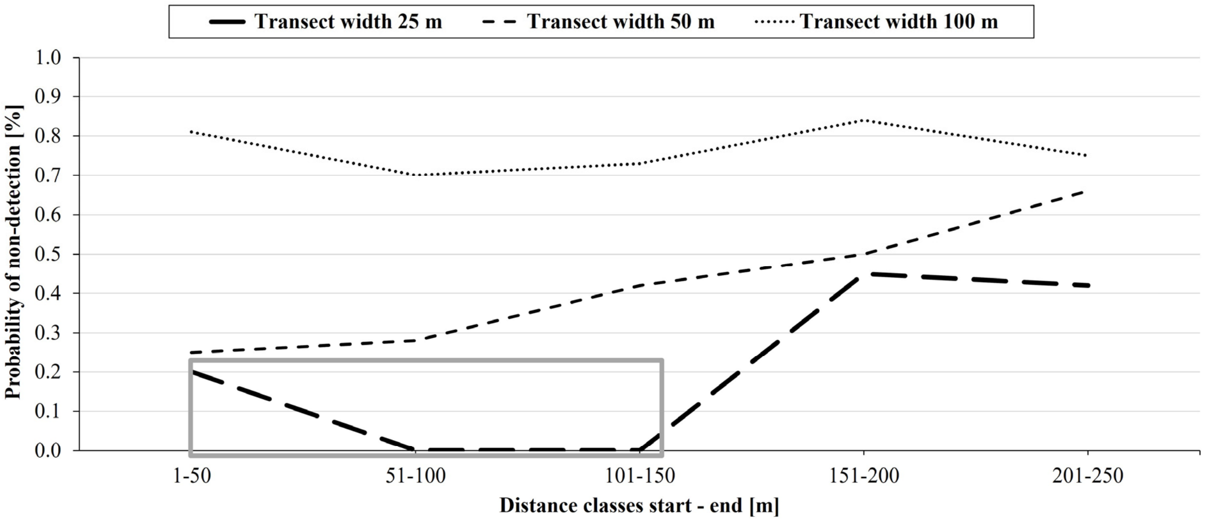

Figure 3: *Probability [%] of non-detection for scat samples at different transect widths (small, medium and big) dependent on the distance from the start point to the samples; box indicates a 93.3% detection rate.*

***Table 3**: Environmental factors (windspeed and direction, temperature and humidity) measured at the start and end of the transects at chest height and at dog nose height (0.3 m) at every detected sample (means with standard deviations, minima and maxima).*

	Temperature [°C]			**Humidity [%]**			**Windspeed [m/s]**		
	Average	**Min.**	**Max.**	**Average**	**Min.**	**Max.**	**Average**	**Min.**	**Max.**
Transect (1.3 m height)	23.9 (± 4.4)	5.4	32.1	18.0 (± 6.0)	0.2	37.9	1.4 (± 1.0)	0.1	3.7
Scat (0.3 m height)	23.9 (± 5.2)	2.6	31.8	19.0 (± 7.0)	9.1	37.8	1.5 (± 1.1)	0.1	4.9

Weather and vegetation

Environmental values measured at the beginning and at the end of the transect, and at the scat positions are listed in Table 3. None of the environmental factors nor the vegetation categories had a significant influence on the detection success of the dog (H, U, r_s, $p \geq 0.05$).

Human vs. Dogs

The dog detected 30 samples at a rate of 3.8 (± 0.5) samples (75% detection rate) per transect, while humans found 9 samples at a rate of 1.1 (± 1.0) samples (22% detection rate) per transect ($U = 1.00$, $p = 0.001$; $n = 16$) (Figure 4). The dog never indicated a non-target scat, while humans indicated 7 non-target scats, resulting in 0.9 (± 1.4) false indications per transect, and an accuracy rate of 56%, compared with 100% for the dog. Both teams spent similar time searching (46 min/ha and 40.6 min/ha, respectively). There was no statistically significant influence of vegetation on the performance of human-dog or human-only teams (U, $p \geq 0.5$).

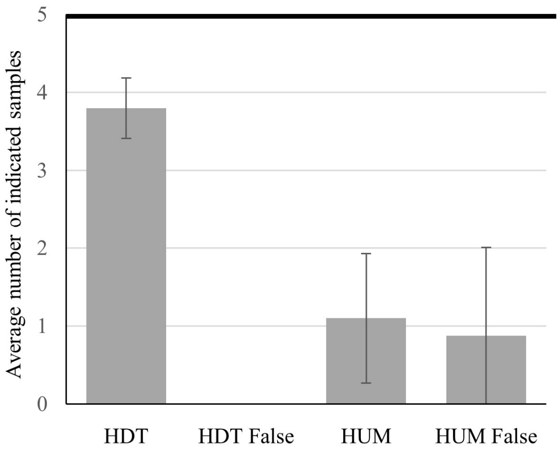

***Figure 4:** Average number of detected target and non-target (false positive) scat samples by the human-dog team (HDT) and the human-only team (HUM) per transect; line indicates the maximum number of available targets; error bars indicate the 95% confidence interval.*

DISCUSSION

Dog performance

The tested dog-team reached 93.3% detection and 100% accuracy rate under transect dimensions of 100 m in length and 25 m in width, which we consider the effective search area. Transect dimensions drastically influence the performance of a scat detection dog but can be calibrated to achieve a higher detection success; this proved our first hypothesis. This experiment was executed with only one dog and the impact of the individual might change results drastically. However, our results align with those found by other authors.

Detection rate

Although the overall detection rate in this study of 45% is low compared to most previous research showing 68% and 77% (Reed *et al*. 2011), 83% and 87% (Leigh *et al*. 2015) and 97% (Cristescu *et al*. 2015), the highest rate of our dog, 75% on the small transects, is within those ranges. One study showed a lower overall detection rate of 29% (Oliveira *et al*. 2012), These results are difficult to compare as they did not follow a common testing design and information on training, age of dog and experience of the team was not always communicated (Oliveira *et al*. 2012; Cristescu *et al*. 2015). Our dog was ten years of age and had been performing short training sessions in the year before the experiment. A decrease in drive and agility, which are known as key characteristics for the success of a scat detection dog (MacKay *et al*. 2008) had been observed due to his age. Additionally, this study was the first time this human-dog team worked together and therefore they might perform better once a familiarity is established (Smith *et al*. 2003). Together with the transect width, the target abundance also differed, because we always placed five samples independent of the transects' width. This led to increasing target abundance with decreasing transect size. To avoid that, we would either have to deposit more samples on the big transect, which was not feasible in the given time frame, or less on the smaller transects, which would have made it difficult to draw sound statistical conclusions. We believe that the transect size had a stronger influence on the dog's performance than the target abundance, even though we cannot prove that statistically. If the motivation resulting from reward shows a stronger impact on the dog's performance than we observed, the orienteer should place training scats while searching, to keep the dog's search morale high, even if scat is encountered at a very low rate (MacKay *et al.* 2008).

Search time

The search time had the strongest positive influence on the dog's detection rate and was chosen by the dog handler. The handler decided when the area is covered sufficiently (MacKay *et al.* 2008); we did not set a time limit as it is not advisable to interfere with the dog-team's work (Wasser *et al.* 2004). Also, we wanted to study the team under real working conditions, where time limits are usually not applicable (Hollerbach *et al.* 2018; Cristescu *et al.* 2020). The handler spent a similar time on each transect independent of its width, leading to lower search time per ha on the big transects. We assume that an increased search effort would have led to higher detection rates increasing the effective search area. Dog errors are often due to handler errors (Wasser *et al.* 2004), which stresses the importance of a well-functioning team with an experienced handler (Orkin *et al.* 2016). Our handler was a professional dog handler and trainer but was not experienced with the search system applied in this investigation. Other researchers successfully recruited dog handlers from different backgrounds, for example police, after some initial training (Arandjelovic *et al.* 2015), or had dogs trained by the military police (Oliveira *et al.* 2012). We recommend further exploring the utilisation of handlers and dogs from different backgrounds but emphasising the importance of intense training to reduce errors (MacKay *et al.* 2008).

Accuracy rate

The 100% accuracy demonstrated by our dog is above the rates given by other authors ranging between 64% (Clare *et al.* 2015), 60% and 85% (Vynne *et al.* 2011), 72% (Harrison 2006) and 81% (Orkin *et al.* 2016). These accuracy rates are often based on genetic analysis of scat (Smith *et al.* 2003; Harrison 2006; Long *et al.* 2007b; Clare *et al.* 2015) and researchers may discard samples that can not be genetically assigned to a particular species (Long *et al.* 2007b), which makes it impossible to calculate exact accuracy rates. For example, Smith *et al.* (2003) found an accuracy rate of 100% for each of the five dogs used in their investigation, but DNA could not be extracted from all the scats. Long *et al.* (2007b) only analysed samples that were promising for species identification and over 38% of the samples failed to extract DNA. Exact accuracy rates can only be calculated from an experimental study where the exact number of target samples is known or when genetic analysis is 100% successful.

We did not deposit non-target samples, but scat of other large carnivores acted as natural non-target samples. Our dog was initially trained on frozen samples which were also used in this experiment. Temperature affects bacterial activity in the scat (Wasser *et al.* 2004) and freezing/thawing might influence the odour pattern. It is possible that non-target samples manipulated identical to the target samples might have influenced the accuracy of the dog. Freezing conserves the odour pattern (Goss 2019) and if the dog is only trained on 'fresh' samples it might not have generalised older samples (Leigh *et al.* 2015) which could also affect the accuracy. Additionally, the diet of the captive animals differed from the wild, which introduces another source of difference in scent between training samples and wild samples (MacKay *et al.* 2008). We recommend that future studies deploy non-target samples that were manipulated identically to the target samples to test for the dog's accuracy.

We did not observe the dog ground scenting a certain path (MacKay *et al.* 2008), therefore assume that the accuracy rate was not influenced by scent trails left behind during sample placement. The random movement while deploying the samples and the time elapsed between placing and searching were therefore sufficient.

Detection distance

We found that indicated samples were closer to the transect line than undetected samples and that this distance increased with transect width. The latter is intuitive as samples were on average further away as the transect width increased, so this is not necessarily a trend linked to the dog's performance. It is important to keep in mind that the distance analysed is the perpendicular distance from the transect line to the sample, not the distance from where the dog caught the scent, indicated by a change of behaviour, which could therefore differ (Reed *et al.* 2011). The average value over all transects of 10.1 m is comparable to the distances found by other authors ranging from 4.8 m (Ralls & Smith 2004), 7.2 m (Oliveira *et al.* 2012) to 9.6 m and 10.4 m (Reed *et al.* 2011). Studies that measured the detection distance, indicated by a change of behaviour, give average values of 13.9 m (Cablk *et al.* 2008), 12.9 m and 15.4 m (Leigh *et al.* 2015). Despite our dog's age and lack of field searches before the investigation, the distance values align with other studies. Therefore, we must assume that these values are accurate despite the variation given by the individual teams and should be considered when planning search efforts.

The average distance from the start to undetected samples increased with a decreasing transect width, and the difference between detected and undetected samples was most prominent on the small transects. Considering that transects differed in their width but not in their length these findings have practical application. By working a smaller width, the dog is also able to work a longer transect effectively (Box in Figure 3). One reason for the decrease of detection rate could be fatigue, as an increase in panting reduces the dog's scenting ability (Smith *et al.* 2003). Motivation might also decrease over time and distance (MacKay *et al.* 2008). Cristescu *et al.* (2015) investigated the effect of the distance from the start to a target and did not find a negative trend like we did; however, their transect length was only 25 m. Our findings show that the transect width and length influence the detection success. We recommend that transect dimensions should be kept small. Using dogs that exhibit a high drive and a high accuracy rate will allow researchers to use larger dimensions without diminishing the effectiveness (Beebe *et al.* 2016).

Weather and vegetation

We found no significant effects of vegetation and weather parameters, supporting our second hypothesis that an experienced dog can compensate for varying environmental conditions. One explanation is that we chose the cooler time of day and year for our experiment. Also, the vegetation categories were different but showed an overall similar character as this displayed the real search environment. Testing under extreme weather and vegetation conditions might have revealed thresholds that limit the dog (MacKay *et al.* 2008) therefore studies should always be designed in a way that supports the dog rather than restrict it (Reed *et al.* 2011). Working under real field conditions helped us develop reasonable transect dimensions. Dog and handler were not restricted to the transect line, and the dog worked off leash which allowed the dog to catch wind from different angles and for the handler to send the dog anywhere over the search area. It is therefore advantageous to allow the dog this freedom of movement (MacKay *et al.* 2008). Our findings are supported by other authors who also did not detect a significant influence of wind on the detection success working under comparable conditions (Long *et al.* 2007b; Nussear *et al.* 2008; Reed *et al.* 2011; Leigh *et al.* 2015).

Human vs. dog

In our study, the dog detected 3.5 times as many samples as the human searchers did while never indicating a non-target scat, proving our third hypothesis that dogs are more effective when searching for scat. Our findings align with previous research investigating the detection of bird/bat carcasses around wind turbines, in which dogs indicated 96% and 75% of the available targets and humans indicated 9% and 20% (Paula *et al.* 2011; Mathews *et al.* 2013). Other studies reported the same trend (Cablk & Heaton 2006; Kapfer *et al.* 2012), while some found equal detection rates for dogs and humans (Nussear *et al.* 2008; O'Connor *et al.* 2015), but no research was found that showed humans to perform better than dogs. When dogs are used to detect scat by smell a clear advantage, regardless of the target species, is observed (Arandjelovic *et al.* 2015), since humans can only detect scats by sight (Smith *et al.* 2003) and this can be difficult because of the often similar colour of the soil, the target samples and the vegetation cover.

Our human searchers reached an accuracy rate of 56% because they also found natural non-target scats from other carnivores. This is consistent with previous research, showing a 153% increase in accuracy by dogs compared to humans (Cristescu *et al.* 2015) and only 45% genetically proven accuracy by humans compared to 81% by dogs (Orkin *et al.* 2016). The ability of humans to identify scat is limited, especially when differentiating between scat with similar morphological appearance (Matteo *et al.* 2009).

We did not deploy scats at potential marking sites such as trees, which are more intensely searched by humans than by the dog, as observed in our study and mentioned by other authors (MacKay *et al.* 2008; Arandjelovic *et al.* 2015). This might have increased the chances for humans to detect samples, but we wanted to test the ability of human observers to find samples randomly in the landscape.

Considering both detection and accuracy rate, we found that the human-dog team was both more efficient and more accurate than the human-only team. Therefore, we highly recommend the use of scat detection dogs to increase the sample detection rate and decrease false sample identification, especially when samples independent of marking sites are needed.

CONCLUSION

Changes to the search area, as exemplified by our experimental manipulation of transect widths, have a strong influence on the detection rate, therefore search designs should be calibrated individually for each dog team. Scat detection dog surveys should report in detail the characteristics of the survey design and methodology, including but not restricted to season, time of the day, transect dimensions, and search time. Detection dogs can work with constant success under variable environmental conditions related to vegetation structure and microclimate in a semi-arid savanna. The advantages of detection dogs are not only a higher sample return but also an increased accuracy in target identification.

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