Journal of Arid Environments 141 (2017) 16–24

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

A pilot study to survey the carnivore community in the hyper-arid environment of South Sinai mountains

Lisa V. Gecchele [a,*,1], Samantha Bremner-Harrison [b], Francis Gilbert [a], Alaaeldin Soultan [c,2,3], Angus Davison [a], Kate L. Durrant [a]

[a] School of Life Sciences, University of Nottingham, Nottingham, NG7 2RD, United Kingdom
[b] School of Animal, Rural and Environmental Sciences, Nottingham Trent University, NG25 0QF, United Kingdom
[c] Protectorate Management Unit, St. Katherine Protectorate, South Sinai, Nature Conservation Sector, EEAA, Egypt

ARTICLE INFO

Article history:
Received 20 June 2016
Received in revised form
18 October 2016
Accepted 18 January 2017

Keywords:
Carnivores
Conservation
Pilot study
Non-invasive methods
Scat collection
Camera trapping
Arabian wolf
Striped hyena
Red fox

ABSTRACT

Carnivores are one of the taxa most affected by habitat fragmentation and human persecution; as a result, most carnivore species are declining; for this reason monitoring changes in carnivore population is paramount to plan effective conservation programs. Despite being one of the most threatened habitat, arid environment are often neglected and the carnivore species living in this environment are generally poorly studied.

We conducted a pilot study to survey the carnivore guild in the St Katherine Protectorate, the largest Egyptian national park and a hotspot for biodiversity and conservation in an arid environments. Three species were detected using both camera trapping and morphological identification of scats: Red fox, Striped hyena and Arabian wolf, while through genetic analysis we were able to confirm the presence of Blandford fox as well. Arabian wolf appeared to be the most elusive and rarer species and should be a conservation priority.

We also provide guidelines for a monitoring program: we estimated that a survey period of 8–10 weeks would be enough to detect foxes and hyenas with a 95% probability, but it would take at least 26 weeks to detect the presence of wolves. This is the first comprehensive carnivore survey in South Sinai and provides an important baseline for future studies in this unique hyper-arid environment at the conjunction between the African and Eurasian continents.

1. Introduction

Many carnivore species have recently experienced a drastic declines, due principally to anthropogenic pressure and habitat fragmentation, so that long-term monitoring is essential to support effective conservation plans. Large carnivores tend to be particularly vulnerable given their generally low population density, slow population growth rate and large area requirements (Dalerum et al., 2009); for the same reasons, they are also difficult to study (Minta et al., 1999; Gese, 2001). A deep understanding of the ecology and distribution of carnivores and the way they interact with other species is essential to plan effective conservation programmes (Naves et al., 2003). However, the costs of large-scale monitoring programmes can be prohibitively high. Pilot surveys can provide information that can be used to plan more effective long-term monitoring and conservation studies (Long and Zielinski, 2008), in order to optimise effort and reduce costs.

Unfortunately, many pilot studies do not include detectability, and this means that they can only report observed occupancy (O'Connell et al., 2006), which is likely to vary across site, time and detection methods (Bailey et al., 2004; O'Connell et al., 2006). Including occupancy and detectability is an effective way to provide an estimation of the proportion of area occupied by (Pollock et al., 2002; Bailey et al., 2004) and therefore the abundance of the species. Presence-absence data utilised for the estimation of these parameters are relatively easy to obtain, allowing this kind of

* Corresponding author.
E-mail address: lisa.gecchele@ed.ac.uk (L.V. Gecchele).
[1] Current address: Institute of Evolutionary Biology, Ashworth Laboratories, Charlotte Auerbach Road, Edinburgh, EH9 3FL.
[2] Current affiliation: Department for Migration and Immuno-ecology, Max Plank Institute for Ornithology, Am Obstberg 1, 78315 Radolfzell, Germany.
[3] Current affiliation: Department of Biology, University of Konstanz, 78464 Konstanz, Germany.

http://dx.doi.org/10.1016/j.jaridenv.2017.01.009
0140-1963/

analysis within most studies; incorporating detection probability in pilot studies can help obtaining more accurate estimates of site occupancy, and provides the foundation stone for effective survey and monitoring programmes (O'Connell et al., 2006).

The St Katherine Protectorate is located in South Sinai, Egypt, and covers an area of about 4350 km^2. It was created in 1996 in order to protect the environment and the high biodiversity of the area (Grainger and Gilbert, 2008). The importance of the Protectorate derives mainly from its peculiar geographical position and the region's unusual microclimate, due to its prominent mountain formation (Guenther et al., 2010). This reflects in the structure of the carnivore community of this area: species from both African and Eurasian continents coexist. For a desert environment, an exceptionally high number of carnivore species have historically been recorded (Osborn and Helmy, 1980). Three species of foxes are present in the protectorate: Blanford's fox (*Vulpes cana*) and Rüppell's sand fox (*Vulpes rueppellii*), are native to South Sinai (Osborn and Helmy, 1980), while the Red fox (*Vulpes vulpes*) is not a native species (Osborn and Helmy, 1980) and colonised Sinai following the Israeli invasion in 1967 (cf. Ginsberg, 2001). The Arabian leopard (*Panthera pardus nimr*), has been hunted to extinction and has not been recorded in Sinai since the 1960s (Al-Johany, 2007). Arabian wolf (*Canis lupus arabs,* Gaubert et al., 2012), Golden jackal (*Canis aureus*) and Striped hyena (*Hyaena hyaena,* Osborn and Helmy, 1980) are considered to be still present in the Protectorate. Caracal (*Caracal caracal*) has been considered locally extinct for many years but recently, signs of the presence of a medium-sized feline compatible with a Caracal have been recorded (A. Soultan, pers.comm.). Finally, wild cats (*Felis silvestris lybica*) live in the southern part of the Protectorate (El Alqamy et al., 2002).

We undertook a preliminary survey of the carnivore community of the St Katherine Protectorate, as such our work can be considered as a first step in the direction of a continuous programme of carnivore monitoring within the Protectorate. We also provide detectability estimates in order to maximise the amount of data about carnivores in the study area. We hope this may result in a carefully planned long-term monitoring project and to optimise carnivore conservation programs in this area.

2. Methods

Given the lack of previous data on the carnivore community of the protectorate, we used two commonly used non-invasive techniques, camera trapping and scat collection, to carry out a pilot study surveying the carnivore community of the St Katherine protectorate. Integrating multiple methods is useful as it increases the probability of detection and reduces bias of derived population estimates (Campbell et al., 2008). In this case it seemed to be particularly advantageous since this was a pilot study conducted to assess the presence of multiple species (Gompper et al., 2006; Long, 2006). Fieldwork was conducted within the boundaries of the St Katherine Protectorate, within a radius of 20 km from the town of St. Katherine (28°34′30.6″N, 33°59′45.9″E). The survey period was over three months, between May and July 2012.

Scent and food lures were used at every site and sampling occasion to maximise the probability of detecting target species. Although we recognise that this has probably positively biased our estimates of detectability and occupancy (Garrote et al., 2012), we judged it necessary to use attractants to achieve our objectives (Garrote et al., 2012), given our limited survey period, the large area to be sampled and the lack of available biological data for the study area.

2.1. Study area

We selected two desert regions: the Blue Desert (five sampling sites) and Sheikh Awad (six sampling sites), each covering about 100 km^2, and an urban region surrounding St. Katherine (four sampling sites) with an area of about 25 km^2 to assess the presence of carnivores in urban areas (Fig. 1). The survey area of the two desert regions was chosen to be larger (Long and Zielinski, 2008) than the likely home range of the two largest species expected to be found in Sinai, the Arabian wolf and the Striped hyena, which have territory sizes up to 60–70 km^2 (Hefner and Geffen, 1999; Wagner et al., 2008).

2.2. Camera-trapping survey

We used a total of 14 cameras for our survey. Eleven were equipped with infra-red flash (nine Bushnell Trophy Cam Trail Cameras, Bushnell, USA; two Reconix HC600 Hyperfire cameras, Reconix, USA) providing lower-quality pictures but with minimal impact on wildlife (Schipper, 2007). These were used in the desert regions where we expected animals to be less tolerant of anthropogenic disturbance. Three devices (Cuddeback Attack cameras, Cuddeback, USA) had a white flash which produced high-quality pictures at night, although the potential for disturbance was high. This kind of devices can cause avoidance behaviours in wild animals (Schipper, 2007), for this reason these cameras were only used in urban sites, where animals are more habituated to disturbance.

Overheating is a common issue in the desert and can cause malfunction in the cameras, for this reason we made sure the cameras were always properly shaded, sometimes building a shelter around the camera with rocks and other material found on site. Heat can also shorten battery life; to prevent this, we used external 12-V batteries and cables that we placed under rocks to make them inaccessible to wild animals.

2.3. Scat survey

We selected five transects according to each region's habitat features, trying to represent different environments evenly. According to this principle we selected two transects in the urban and Sheikh Awad region respectively, while only one was selected for the Blue Desert, given the more uniform nature of this region. The two transects in the urban region were walked once per week, while the three transects in the desert regions were walked every two weeks. In addition we also collected scats opportunistically (e.g. at camera trap sites) in order to maximise the amount of samples collected.

We performed a species identification in the field of every scat found, based on its size and morphology. As morphological identification is frequently not accurate (Davison et al., 2002; Prugh et al., 2005), we also performed a genetic species identification on a subset of the better-preserved of scats to determine their origin to species level.

DNA material was extracted using the QIAmp™ stool kit (Qiagen, Germany), following the manufacturer's protocols. In order to monitor any contamination, each group of 12 extractions included a negative control (Waits and Paetkau, 2005). Two different primer pairs were used for PCR, both specific for the 3′ ending flanking domain of the regulatory D-loop region: LRCB 1/MARDH (Davison et al., 2002) and KFSpid F/KFSpid R (Bozarth et al., 2010). The PCR mastermix contained 1 μl of each primer solution (10 mM), 1.6 μl of dNTPs solution (200 μM), 2 μl reaction buffer, 1.2 μl $MgCl_2$ solution (25 mM), and 0.5 units of *Amplitaq Gold* (Perkin Elmer, USA) in a 20 μl reaction volume with 1 μl of DNA extract. The reaction profile was the same for both primers: 95 °C for 10 min, followed by 35 cycles of 95 °C for 30 s, 50 °C (annealing temperature) for 30 s and 72 °C for 1min; and a final extension at 72 °C for 5 min. Following electrophoresis on a 1.5% agarose gel, clean PCR products (54

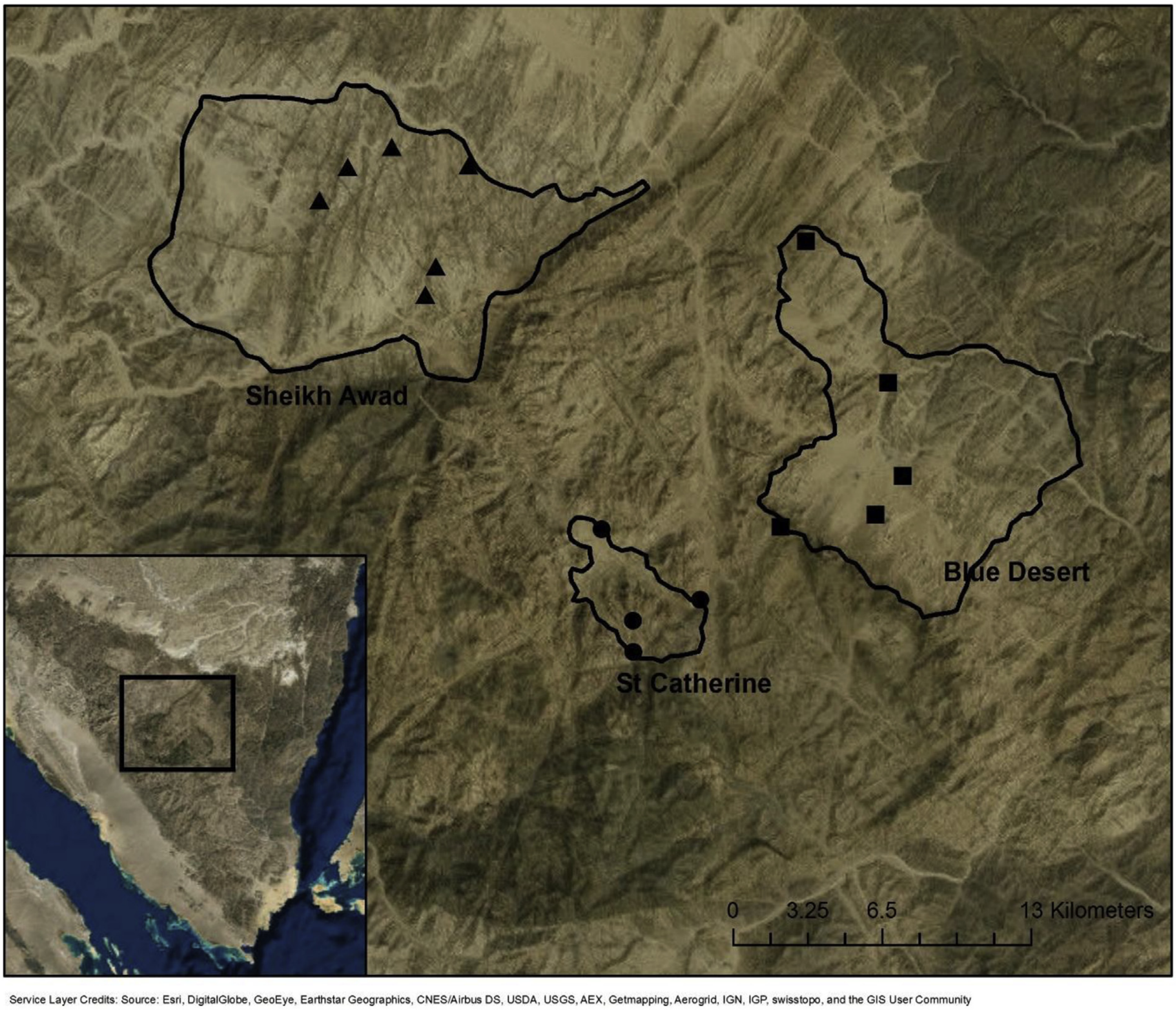

Fig. 1. Study Area. Location of the St Katherine Protectorate study site around the town of St Katherine (inset). Map of the three study locales and sites where camera traps were set.

samples, 45.37% of extracted samples) were purified and then sequenced (DBS Genomics, UK). The sequences were analysed using BioEdit (Hall, 1999), aligned by eye and then compared with other sequences in GenBank. Since there are no Blanford's fox or Rüppell's sand fox mtDNA sequences on GenBank, we extracted, amplified, and then sequenced two Blanford's foxes and one Rüppell's sand fox tissue samples from museum specimens for comparison (see Acknowledgements).

2.4. Occupancy and detectability estimation

We used the programme PRESENCE (downloaded from www.mbr-pwrc.usgs.gov; MacKenzie *et al.*, 2002) to infer detectability and occupancy for each of the three non-domestic species captured. We also compared the two methods used (camera-trap vs. scat collection) to assess their efficiency for each species sampled. Calculating occupancy and detectability using this method requires some assumptions: the main one is that the population needs to be closed and not subject to change via animal movement during the survey period; this is relatively easily achieved in single-season surveys such as the present study. A further assumption is that survey methods used must never give a false presence of a species, implying no misidentifications. The use of additional analyses to verify identifications (e.g. molecular identification) helps avoid this problem. Finally, detection histories must be independent among locations. Adequate spatial spacing between survey sites prevented the violation of this assumption. Field sites were chosen on the basis of separation by physical barriers (e.g. mountains, roads, etc.) to prevent the movement of individuals between survey areas.

3. Results

3.1. Species found

Three species of carnivores were recorded in the study area using both camera-traps and morphological identification of scats: Red fox (*Vulpes vulpes*), Arabian wolf (*Canis lupus Arabs*) and Striped hyaena (*Hyaena hyaena*) (Fig. 2). The same species, plus a possible Blanford's fox (*Vulpes cana*), were also identified based on genetic analysis of scats (see below).

3.2. Camera-trap surveys

We collected a total of 7077 pictures from the three regions and 12 sites surveyed: 2328 from St Katherine, 4142 from Sheikh Awad and 607 from the Blue Desert. Of these, 3743 captured one of the targeted species: 855 in St Katherine, 2552 in Sheikh Awad and 336

Fig. 2. Target species. Pictures of the three target species taken during the survey period plus a picture of a domestic dog roaming in the same area: (a) Arabian wolf, (b) Domestic dog, (c) Striped hyena, (d) The fur colouration and the shape of the tail make it easy to distinguish between wolves and dogs in pictures.

in the Blue Desert (Table 1). There were no visible animals in 1900 images, and the camera was likely triggered by wind-blown material or by the heat.

The most common species recorded was Red fox, both in terms of the number of sites, and of pictures obtained: 45.20% of the all pictures taken represented this species and it was recorded in each region and all but two survey sites. The Arabian wolf was recorded in all three regions at a very low frequency. Only 65 (10.71%) of the Blue Desert pictures and 6 (0.14%) of the Sheikh Awad pictures were of Arabian wolves, interestingly we also obtained one picture of an adult wolf from the urban region (Fig. 2). Striped hyenas were found only in Sheikh Awad, and not detected in the other two regions. We recorded 472 pictures of hyenas from four of the five Sheikh Awad sites, representing 11.40% of the pictures taken in this region.

3.3. Scat survey

We collected a total of 484 scats in all regions (Table 2); of these, 370 were found along the 5 transects, while the remaining 114 were collected opportunistically. Even though the number of samples found opportunistically is relatively low compare to transect, we decided to include these samples in our analysis as the vast majority of the samples found along transects (363 out of 370) were morphologically assigned to foxes. We were only be able to find 3 and 4 samples assigned to wolf and hyena respectively along transects during our survey period. The proportions of scats found opportunistically was very different from the proportion of scats assigned to the three species that were found along transects: out of 114 samples collected opportunistically, 64 were assigned to fox, 48 to hyena and two to wolf (Fig. 3).

3.4. Genetic verification of morphological assignment

We selected 119 (24.58% of the total) scat samples for genetic analysis based on the degree of degradation. Of these, 63 samples (52.94%) were successfully identified to species level.

Out of 57 samples morphologically assigned to Red fox, 55 were confirmed by genetic analysis, one was assigned to a domestic dog, and the other sequence matched the Blanford's fox mtDNA reference sequence extracted from a museum specimen. All the four samples morphologically assigned to Striped hyena were confirmed by genetic analysis. However, only four out of 12 samples were successfully amplified and sequenced for hyenas. Two out of six

Table 1
- Summary of pictures taken using camera traps in the three regions.

Species	St Katherine	Sheikh Awad	Blue Desert
Red Fox	854	2074	271
Arabian Wolf	1	6	65
Striped Hyena	0	472	0
Other Animals	509	553	45
People	132	185	10
Empty	832	852	216
Total	**2328**	**4142**	**607**

Table 2
- Summary of scat collection survey by region. The results presented are based on morphological identification.

Species	St Katherine	Blue Desert	Sheik Awad
Red fox	231	53	143
Striped hyena	0	0	51
Arabian wolf	0	5	1
Total	**231**	**58**	**195**

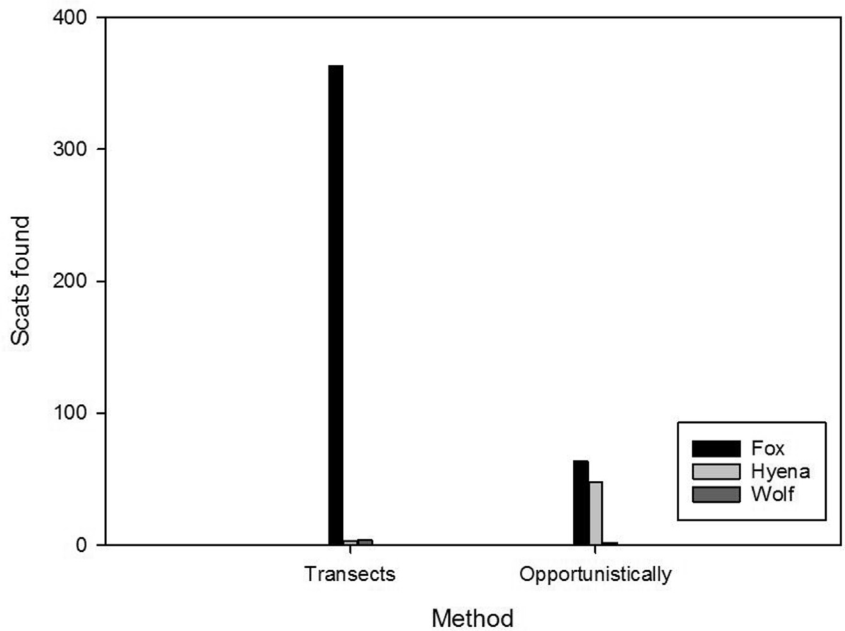

Fig. 3. – **Scats collection results.** Number of scats found along transects and opportunistically.

samples morphologically assigned to wolf were successfully amplified for mtDNA. Of these, one was assigned to a possible domestic dog (perfectly matching sequences sampled from Egyptian, Namibian and Ugandan village dogs; Boyko et al., 2009), and another to a possible Arabian wolf (perfectly matching sequences sampled from an Arabian wolf in South Sinai and another from Israel; Gaubert et al., 2012).

3.5. *Estimates of occupancy and detectability*

We constructed models for the target species, considering separately the two detection methods (Table 3), and assuming detectability and occupancy were constant across all sites. These assumptions are not the most likely representation of reality, but allow a comparison between detection methods amongst species (Boulinier et al., 1998). Table 3 also shows the observed occupancy, representing the minimum known proportion of occupied sites (Bailey et al., 2004). In every case the observed occupancy was within one standard error of the estimated occupancy, indicating the occupancy data are reasonably accurate. Estimations for the Red fox proved accurate (S.E. within 15% of the estimate value), for both camera-trap and scat collection surveys (Table 3). For the scat surveys, the occupancy estimate was close to one because we detected foxes at almost every site. Camera-trap data of Arabian wolves were scarce, resulting in large standard errors, compromising the accuracy of the estimation. We therefore excluded wolf from the scat detection model for two reasons: (1) the total amount of samples found in the field was too low to allow a reliable comparison and (2) the genetic analysis did not confirm the reliability of morphological identification for this species. For Striped hyenas, there was a fairly good estimate of detectability, but occupancy was low (Table 3). This is due to hyenas only being detected in three sites in one region, while the other two species were more widespread.

3.6. *Cumulative detection probability and suggested survey guidelines*

Based on data averaged across sites, we constructed species-specific cumulative detection probability charts to compare the two field methods, and give guidance for planning further studies in the area (Figs. 4 and 5). The cumulative detection probability showed that foxes and hyenas have a similar detection rate, for both detection methods used. The survey period necessary to achieve 95% detection probability is slightly shorter for scat collection survey than camera-trapping (6 weeks vs 8 weeks), but overall comparable.

The estimated detectability for wolves using camera-traps was probably biased to some extent given the low number of pictures taken: this should be kept in mind before using the detection curves to plan a monitoring project. With this caveat, based on our inferred detection probability, remote cameras should be kept in

Table 3
- Occupancy and detectability (±S.E.) of carnivore species found in all sites combined. Observed occupancy, estimated occupancy and estimated detectability are reported for each species and each method. Wolf scat collection data are omitted given unreliability of morphological identification and the scarcity of genetic data.

Species	Method	Observed occupancy	Estimated occupancy	Estimated detectability
Red fox	Camera-Traps	0.83	0.85 ± 0.11	0.63 ± 0.07
	Scat Collection	0.86	0.86 ± 0.13	0.79 ± 0.10
Striped hyena	Camera-Traps	0.34	0.35 ± 0.14	0.57 ± 0.14
	Scat Collection	0.43	0.45 ± 0.19	0.65 ± 0.15
Arabian wolf	Camera-Traps	0.29	0.50 ± 0.33	0.22 ± 0.16
	Scat Collection	–	–	–

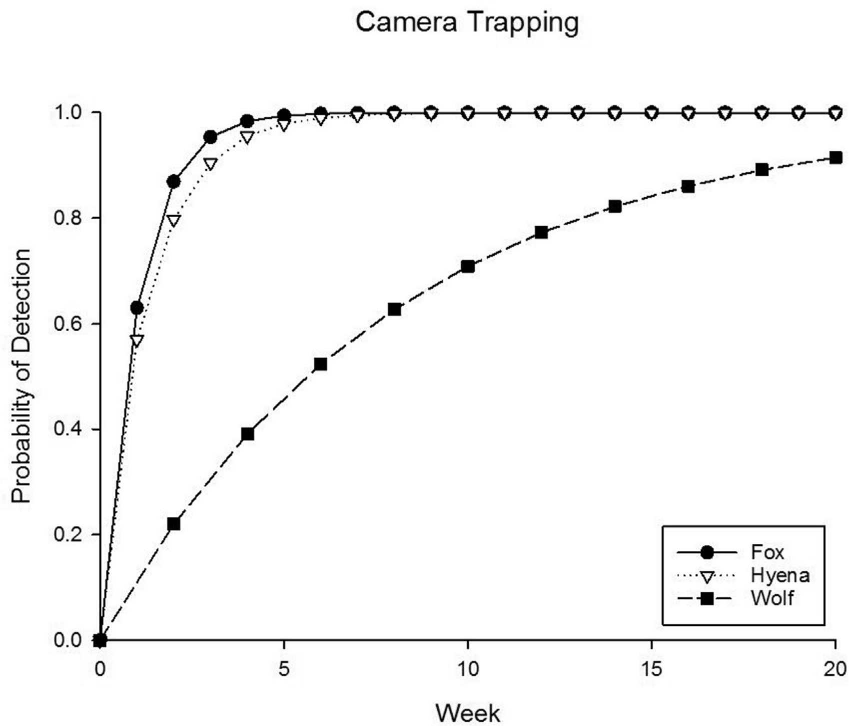

Fig. 4. Camera trapping cumulative probabilities of detection.

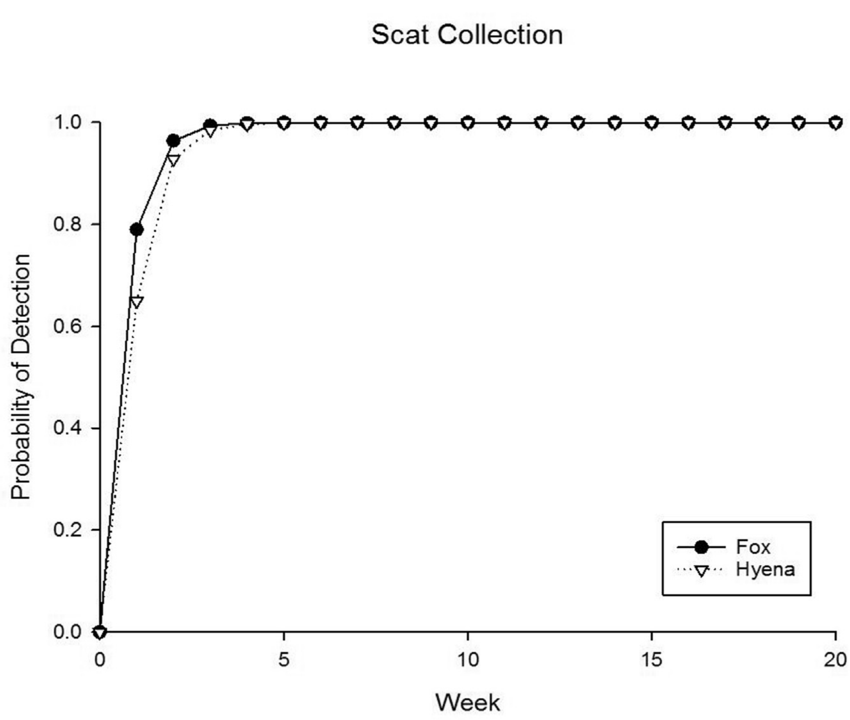

Fig. 5. Scat collection cumulative probabilities of detection. The data for wolves are not shown because of unreliable morphological identification and small sample size.

the field for not less than 26 weeks to achieve a 95% probability of recording the presence of wolves in the area (Fig. 4).

4. Discussion

4.1. Species found

Three species of carnivores were confirmed to be present in the study area: the presence of Red fox, Striped hyena and Arabian wolf was detected by both survey methods.

There was no evidence of other carnivores suspected to be locally extinct (particularly Arabian leopard and Caracal). We did not detect any sign of presence of Golden jackals, which reportedly live in the Protectorate, and have been confirmed both in Egypt (Osborn and Helmy, 1980) and Israel (Borkowski et al., 2011). Furthermore, on talking with local Bedouin, it became clear that Golden jackals are not habitually present in the area, explaining why they were not recorded in our survey. The reason for the absence of this species could due to a number of factors: (1) a geographical barrier preventing colonisation of the Protectorate, (2) the environment may be unsuitable (we cannot exclude the possibility that this species is present in the south-eastern, less mountainous part of the Protectorate) or (3) competitive exclusion by other carnivore species, in particular larger carnivores such as wolves and hyenas. A more extensive monitoring program will be needed to assess whether Golden jackal is completely absent from the Protectorate area and the reasons for this absence.No sign of Rüppell's sand fox was detected and no picture of Blanford's fox were recorded, but one genetic sequence was assigned to this species. There are records of Blanford's fox from the Protectorate dating 10 years ago (El Alqamy et al., 2002) and pictures of this species were taken in 2009 and 2011 (A. Soultan, pers.comm.), but there are no recent data recording Rüppell's sand fox in this area; for this reason, we do not believe this species to be present in the study area, although further studies will be needed to confirm its absence from the entire Protectorate.

The total human population in the Protectorate (alongside with the rest of Sinai), has increased significantly in the last few decades (EEAA SEAM Programme 2003); while native species tend to avoid human settlements, invasive species can have an advantage in human-dominated landscapes (Mack et al., 2000) and the capacity of Red foxes to tolerate anthropogenic disturbance and thrive in urban environments is well documented (Bateman and Fleminga, 2012). The combination of increased anthropogenic disturbance and competitive exclusion by an invasive species could be the reason for the disappearance of the two native fox species.

The sample genetically assigned to Blanford's fox was collected along one of the urban region transects, in a relatively densely human-populated area. Since we did not record any pictures of individuals phenotypically compatible with Blanford's fox, we cannot exclude the possibility that this sample belongs to a hybrid fox. In support of this suggestion, in the wider Red fox clade there is mtDNA evidence of possible historical introgression between Rüppell's sand fox and North African (but not Eurasian) populations of Red fox, although the species are still clearly distinguishable on the basis of nuclear DNA (Leite et al., 2015). However, hybridisation between Blanford's and Red foxes has never been recorded to our knowledge and more usual outcome for smaller fox species upon coming into contact with Red fox populations appears to be competitive exclusion rather than hybridisation (Tannerfeldt et al., 2002; Sillero-Zubiri et al., 2004, and references therein). Further analysis sequences from nuclear loci or photographs are needed to identify definitively whether hybridisation between Red and Blanford's foxes is happening.

Hybridisation between wolves and domestic dogs is a widely documented phenomenon in Europe (Lucchini et al., 2004; Iacolina et al., 2010; Hindrikson et al., 2012) and North America (Roy et al., 1994; Hailer and Leonard, 2008), but data from the Middle East (Bray et al., 2014) are limited. Photographic data did not show any animal with ambiguous physical characteristics: local domestic dogs were strikingly different from wolves in both morphology and size (see Fig. 2), and our findings from the mitochondrial sequences are consistent with this identification. However, we cannot rule out the possibility that some photographed individuals were dog-wolf hybrids, again necessitating further genetic analysis. Hybridisation and introgression between domestic dogs and Grey wolves occurs frequently, so that it is not possible to identify wolves (or dogs) definitively based on mitochondrial DNA alone. Confirmation of hybridisation would require the use of nuclear markers (Bray et al., 2014). However, a pattern emerged from our study indicating a behavioural separation between dogs and wolves: animals with a dog-like phenotype were only photographed in daylight and never far away from human settlements, while wolf-like animals only appeared in night-time pictures and away from houses (with one exception where we took a picture of a wolf-like individual very close to St. Katherine town during the night). For this reason, we strongly suspect that the *Canis lupus arabs* is still extant in the region.Hybridisation is widely recognised as one of the biggest threats to the genetic integrity of wild canids (Hailer and Leonard, 2008). More extensive genetic analysis would obtain valuable information on the introgression of domestic dog or Red fox DNA into the wild canid species living in St Katherine Protectorate and Sinai more generally.

4.2. Detecting carnivores in hyper arid environments

Our results show that the detection probability estimated from scat survey data was higher than camera-trap data for both Red fox and Striped hyena; however, this technique failed to provide enough data to estimate the occupancy and detectability of Arabian wolves.

The collection rate along transects and opportunistically show a significantly different scat collection rates amongst species: while fox's scats were predominant along transects and other species' virtually absent, the number of hyena scats collected opportunistically is comparable to fox's (Fig. 3). The reason for this discrepancy is probably due to different marking patterns in the three target species. Foxes have been found to scatter faecal marks uniformly in their territories (MacDonald, 1980), which probably explains the very high amount of fox scats found along transects, give the high population density of this species. Data from Israel indicates that Striped hyenas tend to form latrines in proximity of feeding and denning sites until cubs are adult (MacDonald, 1978), contrary to what was observed in the Serengeti, where this species is more solitary. This pattern of forming latrines could explain the higher number of hyena scats collected opportunistically: one of our cameras was placed in proximity to a known hyena den site and most of the samples were collected there. Finally, wolf scat deposition patterns have been studied in Europe, where wolves tend to use man-made tracks and roads to move efficiently across woodlands and deposit faecal marks preferentially at crossroads, where they accumulate (Barja et al., 2004). However, data is absent for wolves in desert environments, where man-made tracks do not facilitate wolf movement so we can only speculate as to the reason for the very low number of samples found. If South Sinai wolves do not create latrines, then the low density of this species could explain the very few scats found (although we were able to obtain pictures of wolves); if they create latrines, we probably did not manage to include one in the transects nor in any of the opportunistic sites and this explains why the number of scats found was so low. This discrepancy in the collection rate of different collection approaches weakens the validity of transects as survey method as, according to our findings, they might tend to underestimate the density of species that do not deposit scats uniformly.Identification of scats in the field also proved problematic for two of our target species: morphological identification did not prove reliable to distinguish between wolves and dogs and between different fox species, requiring the use of genetic analysis to identify species; however, the use of dogs to detect scats could improve the rate of detection and the reliability of identification of the scats (Oliveira et al., 2012). Performing genetic analysis on scat samples is expensive, but additional information can be obtained that would prove valuable to plan effective conservation efforts such as hybridisation status and inbreeding of rarer species.Camera-trapping was the most reliable method in assessing occupancy across all the species, including the most elusive. Current models do not provide reliable estimates of occupancy when the detection probability is low (<0.15). In this case, it becomes hard to distinguish between sites where a species is present and not detected, and those where the species is truly absent (MacKenzie et al., 2002). Rare species with wide distributions, such as the Arabian wolf in Sinai, can be particularly problematic (O'Connell et al., 2006). In our case the estimated detectability for wolf (0.22 ± 0.16) is slightly higher than the cut-off probability of 0.15, but the large standard error does not make this estimation overly robust. Using remote cameras requires minimal effort and provides relatively abundant data (Kays and Slauson, 2008), but requires substantial initial investment, and the environmental conditions of the Protectorate make it necessary to adopt unconventional strategies to prevent technical and electronic problems caused by the hyper-arid conditions. After the initial expense, running costs are relatively low, since a single operator can check several devices and collect the data in a short period of time.

4.3. Implications for conservation

From our survey, it appeared that native fox species and the Arabian wolf population are the species that should be prioritised in conservation programmes. An extensive survey of the entire area of the Protectorate is necessary in order to determine whether Rüppell's and Blanford's fox are extant, and measures should be implemented to mitigate competitive exclusion and anthropogenic disturbance. Of the recorded species, Arabian wolf appeared to be the rarest and most elusive by far, with very little data collected during the survey period. Arabian wolves tend to be heavily persecuted throughout the Middle East due to conflicts with local farming and herding (Harrison and Bates, 1991). Although no wolf was killed (to our knowledge) during the survey period, anecdotal evidence of wolf persecution was provided by local Bedouins. For this reason, the first priority of any conservation program should be implementing mitigation measures in order to reduce the conflict between Bedouin farmers and wolves.

Biological monitoring surveys in hyper-arid environments are difficult for both logistical and scientific reasons. The nature of the desert ecosystem means that species are often rare and widely dispersed, and therefore difficult to survey accurately, while the extremes of heat and cold can make working conditions difficult for fieldwork and for the reliable operation and life-span of equipment. Camera-trapping survey proved the most effective method in detecting carnivore species, but important information can come from genetic analysis of scat samples; genetic tools can be used to assess the status of a population and obtain data on hybridisation and inbreeding.

Acknowledgements

We wish to thank all the people who assisted with this project. We thank the Egyptian Environment Affairs Agency, Mohamed Kotb and the rest of the St. Katherine Protectorate officers for permits and permissions, and their logistical and practical support during the field work; and Mohammed Khedr and Abdullah Nagy for assisting us with their knowledge of the territory. Dr Andrew Kitchener of the National Museum of Scotland kindly provided three tissue samples from their collection. We also thank Stephen Harrison for useful discussions throughout.

References

Al-Johany, A.M.H., 2007. Distribution and conservation of the arabian leopard *Panthera pardus nimr* in Saudi Arabia. J. Arid Environ. 68 (1), 20–30.
Bailey, L.L., Simons, T.R., Pollock, K.H., 2004. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. Ecol. Appl. 14 (3), 692–702.
Barja, I., De Miguel, F.J., Bárcena, F., 2004. The importance of crossroads in faecal marking behaviour of the wolves (*Canis lupus*). Naturwissenschaften 91 (10), 489–492.
Bateman, P.W., Fleming, P.a., 2012. Big city life: carnivores in urban environments. J. Zool. 287 (1), 1–23.
Borkowski, J., Zalewski, A., Manor, R., 2011. Diet composition of golden jackals in Israel. Ann. Zool. Fenn. 48, 108–118.
Boulinier, T., et al., 1998. Estimating species Richness: the importance of heterogeneity in species detectability. Ecology 79 (3), 1018–1028.
Boyko, A.R., et al., 2009. Complex population structure in African village dogs and its implications for inferring dog domestication history. Proc. Natl. Acad. Sci. 106 (33), 13903–13908.
Bozarth, C.A., et al., 2010. An efficient noninvasive method for discriminating among faeces of sympatric North American canids. Conserv. Genet. Resour. 2 (1), 173–175.
Bray, T.C., et al., 2014. Genetic variation and subspecific status of the grey wolf (*Canis lupus*) in Saudi Arabia. Mamm. Biol. 79, 409–413.
Campbell, L.A., Long, R.A., Zielinski, W.J., 2008. Integrating Multiple Methods to Achieve Survey Objectives. In Noninvasive Survey Methods for Carnivores, pp. 223–237.
Dalerum, F., et al., 2009. Diversity and depletions in continental carnivore guilds: implications for prioritizing global carnivore conservation. Biol. Lett. 5 (1), 35–38.
Davison, A., et al., 2002. On the origin of faeces: morphological versus molecular methods for surveying rare carnivores from their scats. J. Zool. 257 (2), 141–143.
El Alqamy, H. et al., 2002. Camera traps, a non-invasive sampling technique to redefine the large mammals fauna of South Sinai. In First International Egyptian Conference of Protected Areas. Sharm el-Sheik.
Garrote, G., et al., 2012. The effect of attractant lures in camera trapping: a case study of population estimates for the Iberian lynx (*Lynx pardinus*). Eur. J. Wildl. Res. 58 (5), 881–884.
Gaubert, P., et al., 2012. Reviving the African wolf *Canis lupus lupaster* in North and West Africa: a mitochondrial lineage ranging more than 6,000 km wide. PloS One 7 (8), e42740.
Gese, E.M., 2001. Monitoring of Terrestrial Carnivore Populations. In Carnivore Conservation. Cambridge University Press, pp. 372–396.
Ginsberg, J.R., 2001. Setting Priorities for Carnivore Conservation: what Makes Carnivores Different? in Carnivore Consevation. Cambridge University Press, pp. 498–523.
Gompper, M.E., et al., 2006. A Comparison of Noninvasive Techniques to Survey Carnivore Communities in Northeastern North America, vol. 34. Wildlife society bulletin, pp. 1142–1151.
Grainger, J., Gilbert, F., 2008. Around the sacred mountain: the St Katherine Protectorate in South Sinai, Egypt. Protected Landscapes and Cultural and Spiritual Values. Volume 2 in the series Values of Protected Lands-capes and Seascapes, IUCN, GTZ and Obra Social de Caixa Catalunya.
Guenther, R., et al., 2010. Vegetation and grazing in the St. Katherine protectorate, South Sinai, Egypt. Egypt. J. Biol. 7, 55–66.
Hailer, F., Leonard, J.A., 2008. Hybridization among three native North American Canis species in a region of natural sympatry. PloS One 3 (10), e3333.
Hall, T.A., 1999. BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucleic Acids Symp. Ser. 41 (41), 95–98.
Harrison, D.L., Bates, P.J.J., 1991. The Mammals of Arabia. Harrison Zoological Museum, Kent, England.
Hefner, R., Geffen, E., 1999. Group size and home range of the Arabian wolf (*Canis lupus*) in Southern Israel. J. Mammal. 80 (2), 611–619.
Hindrikson, M., et al., 2012. Bucking the trend in wolf-dog hybridization: first evidence from Europe of hybridization between female dogs and male wolves. PLoS One 7 (10), e46465.
Iacolina, L., et al., 2010. Y-chromosome microsatellite variation in Italian wolves: a

contribution to the study of wolf-dog hybridization patterns. Mamm. Biol. 75 (4), 341–347.
Kays, R.W., Slauson, K.M., 2008. Remote Cameras. In Non-invasive Survey Methods for Carnivores, pp. 110–140.
Leite, J.V., et al., 2015. Differentiation of North African Foxes and Population Genetic Dynamics in the Desert-insights into the Evolutionary History of Two Sister Taxa, Vulpes Rueppellii and *Vulpes Vulpes*. Organisms Diversity and Evolution, vol. 15, pp. 731–745.
Long, R.A., 2006. Developing Predictive Occurrence Models for Carnivores in Vermont Using Data Collected with Multiple Noninvasive Methods. University of Vermont.
Long, R.A., Zielinski, W.J., 2008. Designing Effective Noninvasive Carnivore Surveys. In Noninvasive Survey Methods for Carnivores, pp. 8–44.
Lucchini, V., Galov, A., Randi, E., 2004. Evidence of genetic distinction and long-term population decline in wolves (Canis lupus) in the Italian Apennines. Mol. Ecol. 13 (3), 523–536.
MacDonald, D.W., 1978. Observations on the behaviour and ecology of the striped hyaena, *Hyaena hyaena*, in Israel. Israel J. Zool. 27 (4), 189–198.
MacDonald, D.W., 1980. Patterns of Scent Marking with Urine and Faeces Amongst Carnivore Communities. In Symposia of the Zoological Society of London, pp. 107–139.
Mack, R.N., et al., 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Bull. Ecol. Soc. Am. 86 (4), 249–250.
MacKenzie, D., Nichols, J., Lachman, G., 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83 (8), 2248–2255.
Minta, S.C., Karieva, P.M., Curlee, A.P., 1999. Carnivore Research and Conservation: learning from History and Theory. In Carnivores in Ecosystems: the Yellowstone Experience. Yale University Press, New Haven, pp. 323–404.
Naves, J., et al., 2003. Endangered species constrained by natural and human factors: the case of brown bears in Northern Spain. Conserv. Biol. 17 (5), 1276–1289.
Oliveira, M.L.D., et al., 2012. Dogs can detect scat samples more efficiently than humans: an experiment in a continuous Atlantic Forest remnant. Zool. (Curitiba) 29 (2), 183–186.
Osborn, D.J., Helmy, I., 1980. The Contemporary Land Mammals of Egypt (Including Sinai). Field Museum of Natural History, Cairo.
O'Connell, A.F., et al., 2006. Estimating site occupancy and detection probability parameters for meso- and large mammals in a coastal ecosystem. J. Wildl. Manag. 70 (6), 1625–1633.
Pollock, K.H., et al., 2002. Large scale wildlife monitoring studies: statistical methods for design and analysis. Environmetrics 13 (2), 105–119.
Prugh, L.R., et al., 2005. Monitoring coyote population dynamics by genotyping faeces. Mol. Ecol. 14 (5), 1585–1596.
Roy, M.S., et al., 1994. Patterns of differentiation and hybridization in North American wolflike canids, revealed by analysis of microsatellite loci. Mol. Biol. Evol. 11 (4), 553–570.
Schipper, J., 2007. Camera-trap avoidance by Kinkajous Potos flavus: rethinking the "non-invasive" paradigm. Small Carniv. Conserv. 36, 38–41.
EEAA SEAM Programme, 2003. South Sinai Demographics and Population Projections.
Sillero-Zubiri, C., Hoffmann, M., MacDonald, D.W., 2004. Canids: foxes, Wolves, Jackals and Dogs. Status Survey and Conservation Action Plan. UK. IUCN, Oxford.
Tannerfeldt, M., Elmhagen, B., Angerbjörn, A., 2002. Exclusion by interference competition? The relationship between red and arctic foxes. Oecologia 132 (2), 213–220.
Wagner, A.P., Frank, L.G., Creel, S., 2008. Spatial grouping in behaviourally solitary striped hyaenas. Hyaena Hyaena. Anim. Behav. 75 (3), 1131–1142.
Waits, L., Paetkau, D., 2005. Noninvasive genetic sampling tools for wildlife biologists: a review of applications and recommendations for accurate data collection. J. Wildl. Manag. 69 (4), 1419–1433.