Mammal diversity survey in the Ibex Reserve, Saudi Arabia

Final Report (2016)

King Khalid Wildlife Research Centre (KKWRC), Saudi Wildlife Authority (SWA),

Zoological Society of London (ZSL)

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Cover page images: Clockwise from top left: Nubian ibex *Capra nubiana,* Wadi Ghabah. Arabian gazelle *Gazella arabica,* Wadi Nukhailan. Arabian grey wolf *Canis lupus arabs,* Wadi Ghabah. Rüppell's fox *Vulpes rueppellii*, Wadi Nukhailan.

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Contents

Summary

This report summarises the findings of four camera-trap surveys set up in the Ibex Reserve at Hawtah Bani Tamim, central Saudi Arabia. Camera grids were placed in summer and winter in two key sample areas: Wadi Ghabah at the core of the reserve, where the upper 8.6 km is protected by a camel exclusion fence and Wadi Nukhailan in more open habitat in the south-west of the reserve, where controlled camel grazing is allowed in the 14 km main wadi bed.

The main objective of the study was to establish baseline on the diversity and statusof medium-to-large size mammal community in the reserve to enable comparison and assess trends in future. In particular, the status of two flagship species, the Nubian ibex *(Capra nubiana)*, for which the reserve was established, and the Arabian gazelle (*Gazella arabica)* which has been re-introduced to the reserve, was assessed including the effect of season, and camel and livestock grazing. The study also assessed the suitability of camera-trapping for monitoring wildlife within the reserve.

Each survey consisted of 32 cameras at 1 km spacing. Survey effort ranged from 2,816 and 3,938 camera-trap days. Despite this level of sampling effort, species accumulation curves didn't reach an asymptote. Seventeen mammal species were captured on cameras with a medium-to-large mammal species richness of ten species. Species richness in both seasons was higher within Wadi Nukhailan.

The Nubian ibex was the most frequently encountered species. Ibex were significantly more abundant (based on trapping rate and occupancy) in the camel excluded zone of Wadi Ghabah in the heart of the reserve. Twenty years after their initial reintroduction, the Arabian gazelle showed higher occupancy and trapping rates within Wadi Nukhailan during the winter season when livestock were also encountered more frequently. Other significant findings were the first images of Arabian wolves in the Ibex Reserve, the first records of Blanford's fox in central Arabia and the first records of honey badger and bushy-tailed jird in the reserve.

The study showed that camera-trapping can be a useful complimentary method for long-term monitoring of mammals in the reserve as conventional methods such as distance sampling are often challenging in deserts because of low numbers and encounter rates, wide ranging movement, nocturnal and solitary behaviour.

1. Introduction

The deserts of Saudi Arabia, like all desert ecosystems, have received much less scientific research than forest systems (Durant et al., 2012). In particular, very few systematic camera-trap studies have been conducted (McCallum et al., 2013). There still remain significant gaps in our understanding of how biodiversity in these systems is changing with time due to lack of systematic monitoring (Davies et al., 2012). This is despite desert systems having similar overall biodiversity levels at the biome scale to forest systems (Durant et al., 2014), and ranked in the top three richest biomes for terrestrial vertebrates containing 25% of terrestrial vertebrate species (Millennium Ecosystem Assessment, 2005).

The deserts of Saudi Arabia contain a number of species highly adapted for the variable conditions of the desert including the Nubian ibex (*Capra nubiana – IUCN status Vulnerable),* Arabian oryx (*Oryx leucoryx – Reintroduced)*, Arabian grey wolf (*Canis lupus arabs – Least concern)* and the Blanford's fox (*Vulpes cana – Vulnerable*).

This report summarises results from camera-trap surveys across two sites over summer and winter within the Ibex Reserve, a protected area in central Saudi Arabia. Camera-trapping is a particularly suitable technique for longer term monitoring of medium-to-large size terrestrial mammals that are nocturnal, cryptic, solitary or occur in small groups, in low abundance and wide-ranging all of which are common traits of desert species (Silveira et al., 2003; Gompper et al., 2006; Kelly, 2008; Lyra-Jorge et al., 2008; Roberts, 2011; Amin et al., 2015).

The study objectives were as follows.

1. To establish baseline data on the diversity, and the status, distribution and behaviour of medium-to-large mammals in the Ibex Reserve.
2. To assess the status of Nubian ibex and Arabian gazelle in the Ibex Reserve.
3. To investigate the potential impact of camels and livestock on the abundance and distribution of the Nubian ibex and other medium-to-large mammal species.
4. To assess the suitability of camera-trapping as a wildlife monitoring technique in the Ibex Reserve.

## 2. Methods

2.1 Study area

The Ibex Reserve was established in 1988 by the National Commission for Wildlife Conservation and Development (NCWCD) to protect the only known relict population of Nubian ibex in the Tuwayq escarpment region (Child & Grainger, 1990). The reserve is located 180 km south of the capital Riyadh in central Saudi Arabia (Figure 1). It covers an area of approximately 2,369 km^2, extending between latitudes 23' 12º and 23' 35º N, and between longitudes 46' 15º and 46' 50º E. (Al-Khamis et al., 2012). The reserve is surrounded by several towns including Hawtah Bani Tamim and Al-Hilwa in the East, Al-Hariq in the north and Berk in the south (Al-Shaya et al., 2007).

The Ibex Reserve is largely an undulating stony, limestone plateau (800 – 1,100 m asl) dissected by several deep canyon wadis. Plant biomass is low on the plateau, but higher within the wadis and is dominated by *Acacia* (or *Vachellia) tortilis* (Wronski et al., 2011). Camel exclusion fences were erected in 1991 around four upper wadis within the interior of the reserve to reduce the intensity of camel grazing in these small high plant diversity zones.

There are two main seasons: summer (May – October) and winter (November – April). The summers are hot and dry with an average temperature of 40˚C (Wronski, 2010). There is no rainfall during the summer (Al-Khamis, 2012). However, during the winter the weather is cooler with an average temperature of 16˚C (Campbell, 1996) and rainfall is low and sporadic with an annual average of 78 mm (Robinson, 2008).

The two sites within the Ibex Reserve where the camera-trap study was undertaken were Wadi Nukhailan (referred to henceforth as Nukhailan) a 14 km stretch of relatively open wadi where limited camel and livestock grazing is permitted and Wadi Ghabah (referred to henceforth as Ghabah) a 8.6 km wadi with an exclusion fence preventing camel access to the wadi floor (Figure 1). Camels are however observed on the plateau surrounding the wadi (Barichievy pers. comm.).

Figure 1. Map of the study area in central Saudi Arabia (a); and detailed map of camera-trap grids relative to protected area boundaries at Ghabah and Nukhailan (b).
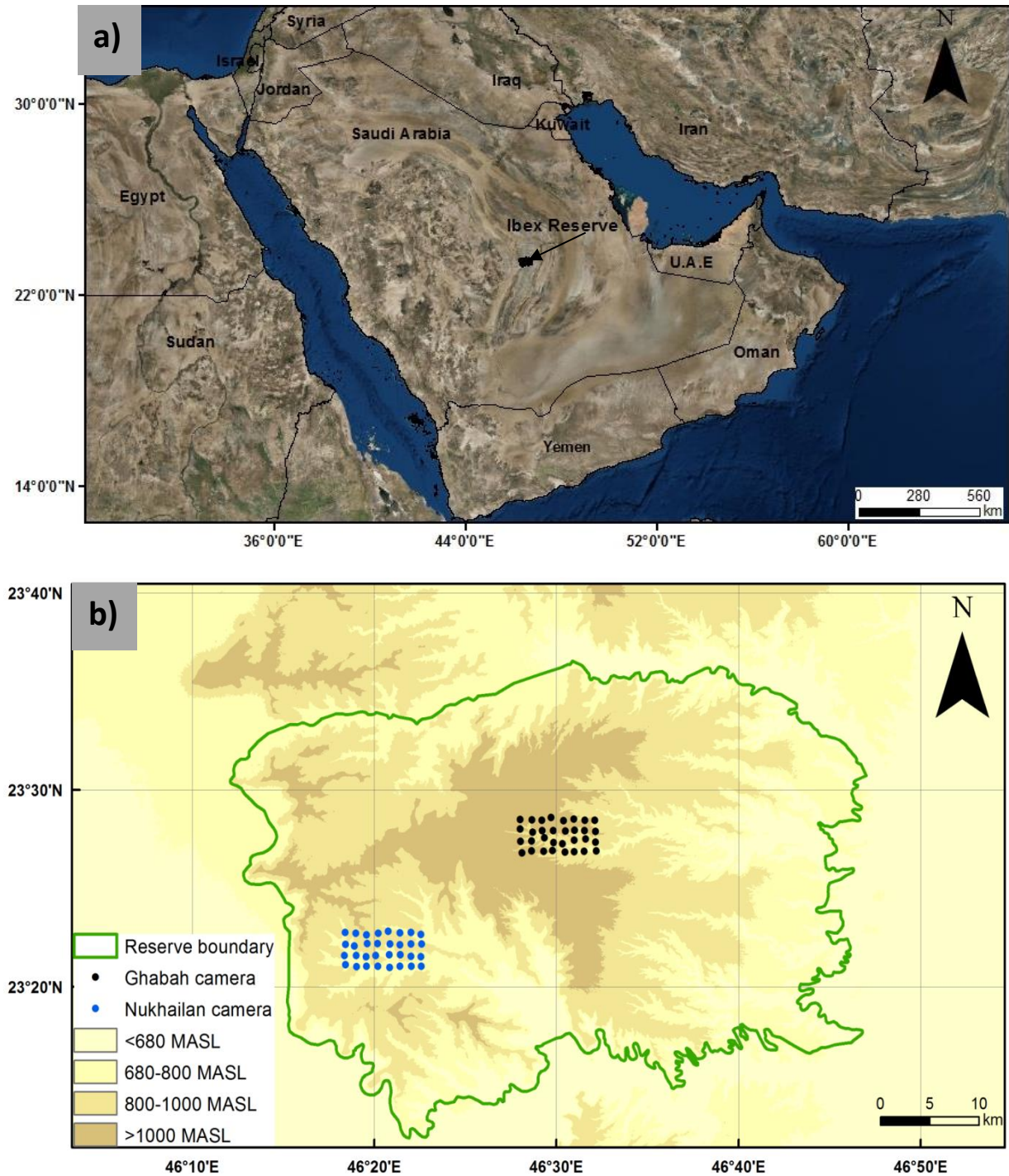
2.2 Survey design and camera deployment

Survey design at each of the two wadi sites within the Ibex Reserve consisted of 32 cameras systematically placed at one kilometre intervals. One / two km spacing is normally recommended for mammal community surveys (Amin et al., 2014). A single camera-trap was placed at a height of 35 – 40 cm on drainage lines and pathways likely to be used by mammals to maximize detection probability and with the aim of obtaining full body lateral images.

Scoutguard SG550 (Scoutguard, Santa Clara, California, USA) digital cameras were used. The cameras took three pictures per trigger with no delay and a detection range of approximately 23 m for larger

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mammals. The cameras used an infrared flash which minimised the risk of startling animals as would be the case with white flash.

Each site was surveyed in the summer season (May - October) and winter season (November - April). The camera installation protocol required each camera to be triggered by a field technician holding a white board with location ID, date and time upon activation and deactivation to verify camera function.

2.3 Data analysis

Data analysis was carried out using software developed at ZSL specifically to process data from camera-trap arrays (Amin et al., 2016). This requires creation of four standard format data source files in Microsoft EXCEL comprising 1) individual camera locations and information on associated fixed habitat variables; 2) individual camera settings and field configurations; 3) individual camera setup, service and recovery history and 4) image details for every photograph from each camera. To create the latter file, image EXIF information (image label, date, time) was extracted using Exiv2 software (Huggel, 2012; http://www.exiv2.org/index.html) and compiled into the standard EXCEL format. Image date and time information were cross-checked against setup, service and recovery field records. Details of each image content indicating image type (wildlife, livestock or preselected categories of 'other') and species identified (with information on number, age, sex and animal behaviour where appropriate) were then added.

Species trapping rates were calculated as the mean number of independent photographic "events" per trap day x 100. An "event" was defined as any sequence of images for a given species occurring after an interval of >=60 min from the end of the previous three-image sequence of that species (Tobler et al., 2008). Standard errors were calculated from the standard deviation of the daily trapping rate.

Single season occupancy analysis (MacKenzie et al., 2006) was used to estimate the proportion of area occupied by a species, within each of the survey grids. Occupancy estimates were corrected by detection probability (i.e. the likelihood that a species was detected when present) and are therefore a more rigorous index of abundance for both within and between species comparisons. This, however, is limited to surveys generating adequate data sets and where camera spacing is greater than the species home range, and occupancy is not confounded by changes in the home range (Efford & Dawson, 2012). Detection / non-detection history were constructed using a five-day period as the sampling occasion, for each species and camera per survey grid.

Mammal species richness Jackknife estimates were calculated for species >=0.5 kg in average adult body weight in order to minimize variation in capture probability associated with body size (smaller animals are less likely to consistently trigger cameras; Tobler et al., 2008).

Circadian (24 hour) activity patterns for each species were constructed by tallying the number of events per hour across each survey time period.

We used the species trapping rate at each camera site to generate simple distribution maps for each camera-trap grid.

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3. Results

3.1 Camera-trap survey effort

Ghabah summer and winter surveys

Total number of camera sampling sites: 32 repeated at the same locations over two seasons (two failed cameras in summer survey with one camera failing totally and the other operational for only five days. Five cameras totally failed in the winter survey)
Total number of days deployed: 7,493 (6,279 operational)
Total number of wildlife events: 1,869

Survey duration	Summer (04/05/2012 - 14/09/2012)	Winter (22/11/2013 - 20/03/2014)
Total number of camera sampling sites	32	32
Total number of days deployed	3,937 (3,463 operational)	3,556 (2,816 operational)
Total number of wildlife events	1,367	502

Nukhailan summer and winter surveys

Total number of camera sampling sites: 32 repeated at the same locations over two seasons (two partially failed cameras in summer survey, which were operational for 12 and 27 days. Two cameras totally failed in winter survey)
Total number of days deployed: 9,081 (8,538 operational)
Total number of wildlife events: 1,477

| Survey duration	Summer (15/06/2012 - 22/10/2012)	Winter (26/09/2012 - 01/03/2013)
Total number of camera sampling sites	32	32
Total number of days deployed	4,057 (3,514 operational)	5,024 (3,938 operational)
Total number of wildlife events	754	723

Habitat coverage

The habitats within Ghabah and Nukhailan study sites were classified into four categories: 1) flat ground of the wadi, 2) scree slope leading down into the wadi, 3) flat ground of the plateau, 4) scree slope leading down to plateau. Within Ghabah, the cameras were placed predominantly on scree slopes leading to plateau (19/32 cameras). Seven cameras were placed on plateaus, three cameras were located in the wadi bed and three were on scree leading into the wadi bed (Figure 2).
In comparison at Nukhailan cameras were distributed relatively evenly throughout the four major habitat types. Twelve cameras were placed in the wadi bed, four cameras on the scree down into the wadi, ten cameras on plateaus and six cameras were placed on patches of scree leading to a plateau (Figure 2).

Altitudinal coverage

At Nukhailan, cameras were located between 700 m and 951 m (range 251 m), while the cameras at Ghabah was located between 742 m and 1,115 m (range 373 m), with 23 of the Ghabah cameras at higher altitude than any in Nukhailan (Figure 2).

Figure 2. Altitudinal variation in camera sites across Ghabah (a) and Nukhailan (b), displaying the altitude, habitat type and the relative camera position within the camera grid.
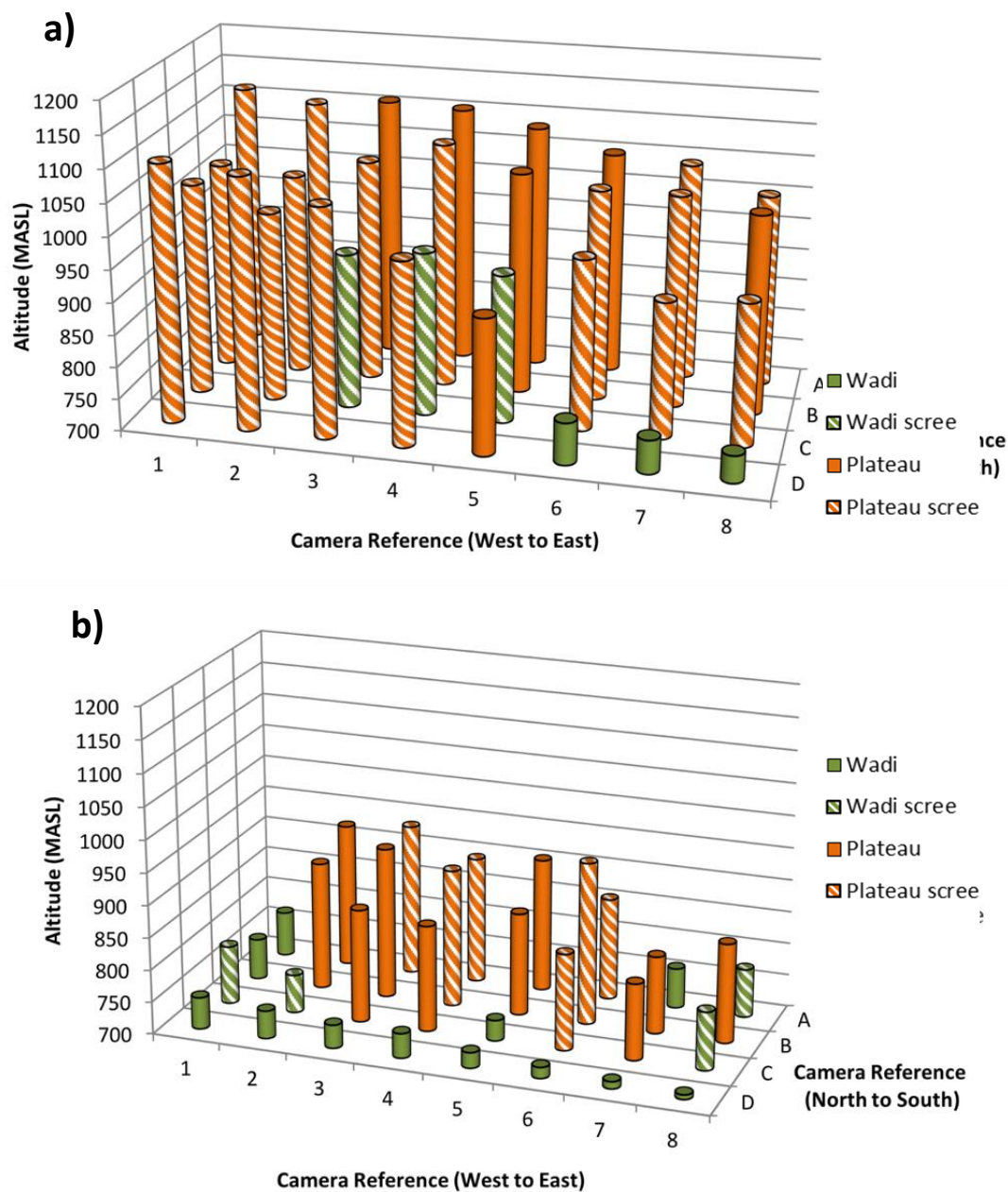
3.2 Mammal diversity

Twelve mammal species were photographed in the Ibex Reserve (nine species in Ghabah and twelve in Nukhailan) (Table 1). This included the Nubian ibex (*Capra nubiana*) and the Arabian gazelle (*Gazella arabica*), both 'Vulnerable' under IUCN Red List criteria. Domestic camels, donkeys and small stock (sheep and goats) were also recorded. Only two rodent species were distinctive enough to be reliably identified in the camera-trap images: the bushy-tailed jird (*Sekeetamys calurus)* and the Arabian spiny mouse (*Acomys dimidiatus)*. All other rodents were classified at a family level (Muridae). It was also often difficult to identify foxes to species level especially in infrared images and these images were classified at genus level (*Vulpes*).

Medium-to-large mammal species (>=0.5kg) expected in the study area according to available distribution maps and literature which were not detected by the camera-trap survey are also listed in Table 2.

Table 1. Mammal species recorded in the Ibex Reserve, Saudi Arabia (2012-2013).

Family	Species	Common name	GS	GW	NS	NW	IUCN Red List status	Average adult body mass (kg)
Bovidae-Caprinae	*Capra nubiana*	Nubian ibex	Y	Y	Y	Y	VU	50.0
Bovidae-Antilopinae	*Gazella arabica*	Arabian gazelle	Y	--	Y	Y	VU	15.0
Canidae	*Canis lupus arabs*	Arabian wolf	Y	Y	--	Y	LC	20.0
Canidae	*Vulpes cana*	Blanford's fox*	Y	Y	Y	--	LC	1.0
Canidae	*Vulpes rueppellii*	Rüppell's fox	--	--	Y	--	LC	1.5
Canidae	*Vulpes vulpes arabica*	Arabian red fox	Y	Y	Y	Y	LC	4.0
Felidae	*Felis silvestris*	Wild cat	Y	--	Y	--	LC	2.0
Leporidae	*Lepus capensis*	Cape hare	Y	Y	Y	Y	LC	2.0
Procaviidae	*Procavia capensis*	Rock hyrax	Y	Y	Y	Y	LC	1.0
Erinaceidae	*Paraechinus aethiopicus*	Desert hedgehog	Y	Y	Y	Y	LC	0.5
Muridae	*Sekeetamys calurus*	Bushy-tailed jird*	--	--	Y	Y	LC	0.2
Muridae	*Acomys dimidiatus*	Arabian spiny mouse	--	--	Y	Y	LC	0.1
Camelidae	Camelus dromedarius	Domestic camel	Y	Y	Y	Y	?	350.0
Equidae	*Equus asinus*	Donkey	--	--	Y	Y	?	100.0
Bovidae – Ovinae	*Ovis aries*	Sheep	--	--	Y	Y	?	35.0
Bovidae-Capinae	*Capra hircus*	Goat	--	--	Y	Y	?	35.0
Mustelidae	*Mellivora capensis*	Honey badger*†	--	--	--	--	LC	10.0

GS: Ghabah summer survey; GW: Ghabah winter survey

NS: Nukhailan summer survey; NW: Nukhailan winter survey

*: Recorded for the first time within the Ibex Reserve

†: Recorded on ancillary cameras within the reserve, but not during the systematic surveys

IUCN Red List categories: LC: Least Concern, VU: Vulnerable, ?: not assessed.

Table 2. Medium-to-large mammal species expected in the study area according to available distribution maps and literature, but not detected in the camera-trap surveys.

Family	Species	Common name	IUCN Red List status
Felidae	*Caracal caracal*	Caracal	LC
Canidae	*Canis aureus*	Golden jackal	LC
Hyaenidae	*Hyaena hyaena*	Striped hyaena*	NT
Erinaceidae	*Paraechinus hypomelas*	Brandt's hedgehog	LC
Hystricidae	*Hystrix indica*	Indian crested porcupine	LC

IUCN Red List categories: NT: Near Threatened, LC: Least Concern

* As the Ibex Reserve is peripheral to the striped hyena's range according to IUCN distribution maps (IUCN, 2015), and there hasn't been a local sighting recently it seems likely the striped hyaena has been extirpated from the reserve.

The species accumulation curves for medium-to-large (≥ 0.5 kg) terrestrial mammal species, the main target group for camera-traps placed at ground level are shown in Figure 3.

Nukhailan had slightly higher estimated species richness (summer eleven species, winter nine species) compared to Ghabah (summer ten species, winter eight species) for medium-to-large terrestrial mammal species. Both Ghabah and Nukhailan had the same number of species detected during both seasons.

Figure 3. Rarified species accumulation curves for medium-to-large terrestrial mammals in Ghabah and Nukhailan in the Ibex Reserve, Saudi Arabia.
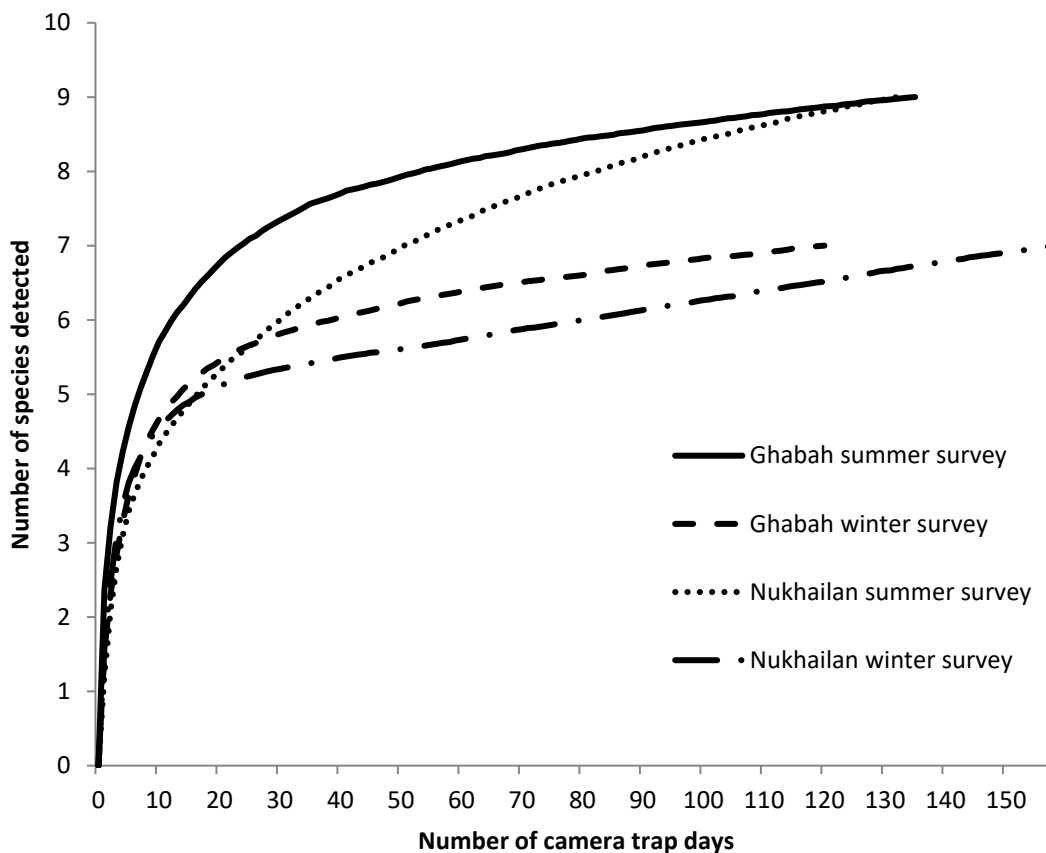
3.3 Species distribution, abundance and activity patterns

This section summarises the camera-trap survey results for each recorded mammal species. The results are grouped by ungulates, carnivores, lagomorphs, rock hyraxes, hedgehogs, rodents. Accounts for domestic species are also provided. The number of events and trapping rates, occupancy estimates, activity / temporal patterns, and distribution maps are provided for each species for each survey site and season. All species images are camera-trap images from the surveys.

Birds and reptiles recorded during the survey are listed in Annex I.

Analysis notes

For species trapping rates, only survey days with at least 75% of cameras working, were included in the calculation.

For species occupancy analysis, a 5-day sample period / occasion was used to generate the detection-non detection histories:
- Ghabah Summer 2012 – 24 occasions
- Ghabah Winter 2013 – 27 occasions
- Nukhailan Summer 2013 – 32 occasions
- Nukhailan Winter 2012 – 26 occasions

Brief explanation of population measures derived from camera-trap surveys

Species trapping rate: calculated as the mean number of independent photographic "events" per trap day x 100. An "event" was defined as any sequence of images for a given species occurring after an interval of equal to or greater than 60 min from the previous three-image sequence of that species. Standard errors were calculated from the standard deviation of the daily trapping rate.

Trapping rate provides a simple index of relative abundance with the assumption that a target species will trigger cameras in relation to their density, all other factors being equal. Trapping rates provide a comparative index within species, if a standardized protocol is used for the surveys, including consistent positioning and management of cameras to ensure detection probabilities are similar.

Species occupancy: is defined as the proportion of area occupied by a species. Naïve occupancy is defined as the number of cameras at which a species is detected divided by the total number of operational cameras. Modelled occupancy estimates are corrected by detection probability and are therefore a more rigorous index of abundance for both within and between species comparisons. This, however, is limited to surveys generating adequate data sets and where camera spacing is greater than the species home range (so that an individual is likely to be detected in only one camera), and occupancy is not confounded by changes in the home range. Factors influencing occupancy and detection probability can also be incorporated into occupancy modelling.

Species detection probability: the likelihood that a species is detected by a camera when present.

Species 24 hour activity pattern: derived from camera time of detection data.

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Species distribution map: Distribution maps for each camera-trap grid were generated using the species trapping rate at each camera site. On the map, the camera trapping rates were depicted as circular symbols at each camera site. The symbol size was weighted linearly.

1) NUBIAN IBEX (*Capra nubiana*)

Species notes
- Ibex recorded the highest number of events for any mammal in both sites and seasons.
- Recorded significantly more in Ghabah compared to Nukhailan.
- Many more events recorded in the wadi beds in the summer than winter, where food in the form of sparse shrubs and annuals is more abundant than on the plateau and access to water is easier during the hotter months.
- Distribution map highlights the dispersal of the Ibex in winter.
- The timing of camera encounters indicates the Nubian ibex is active throughout the 24 hour cycle with most activity during daylight and pronounced crepuscular peaks in winter.

Global conservation status:
Vulnerable (Alkon et al., 2008)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	27	757	8139
Ghabah Winter 2013	27	23	247	1446
Nukhailan Summer 2013	30	17	82	709
Nukhailan Winter 2012	30	18	75	486

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	23.46 (0.95)	0.9	0.9 (0.06)	0.38 (0.02)
Ghabah Winter 2013	8.43 (0.61)	0.85	0.85 (0.07)	0.35 (0.02)
Nukhailan Summer 2013	2.33 (0.23)	0.57	0.59 (0.09)	0.16 (0.02)
Nukhailan Winter 2012	1.87 (0.24)	0.6	0.65 (0.10)	0.12 (0.02)

Activity pattern
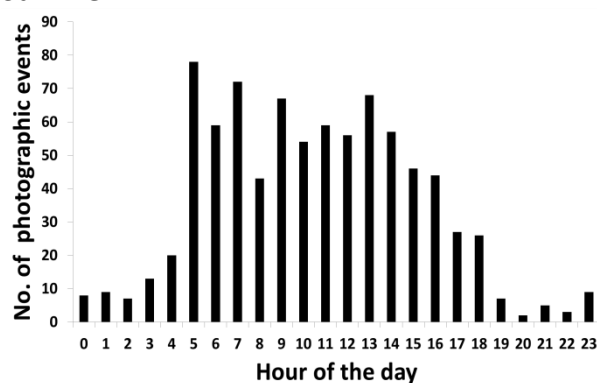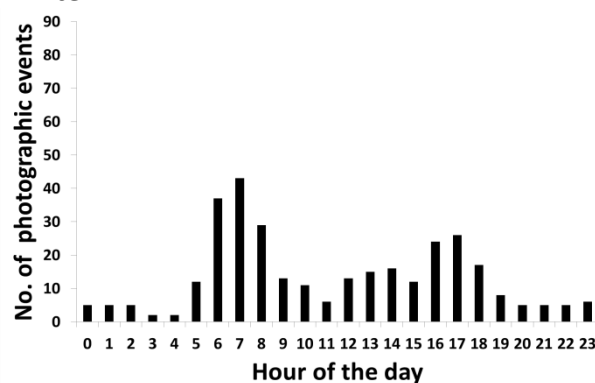
Summer

Winter

Distribution maps
Summer
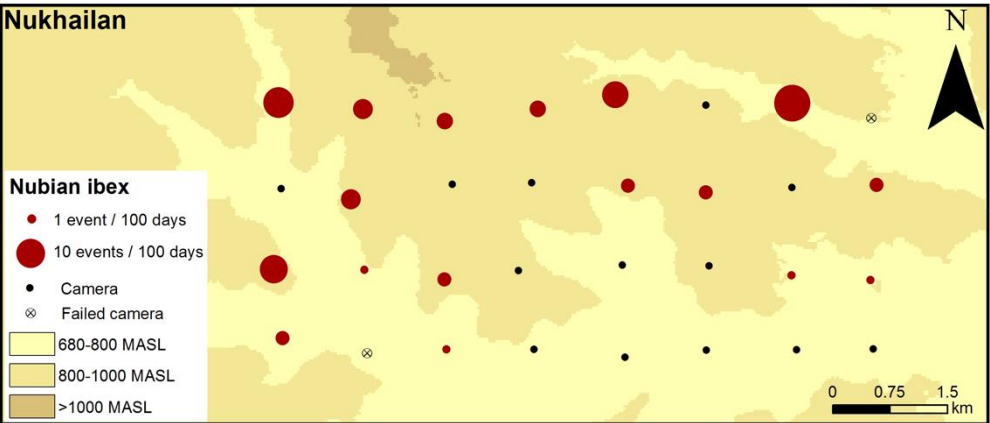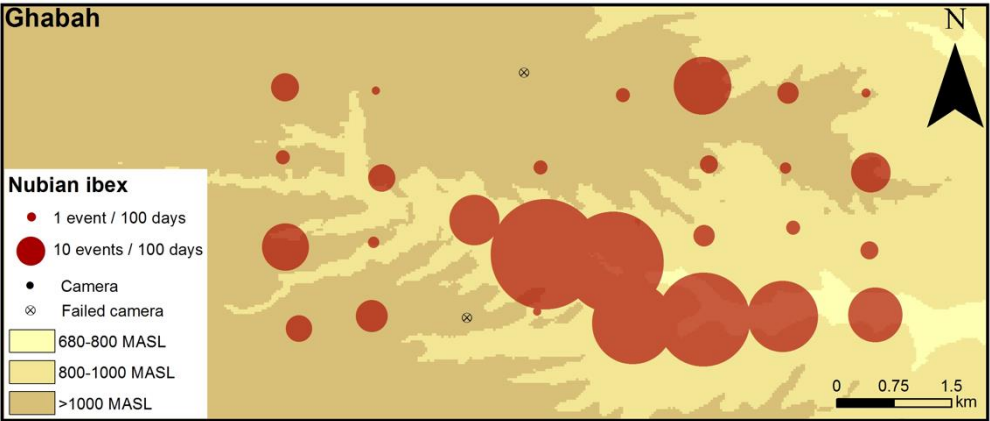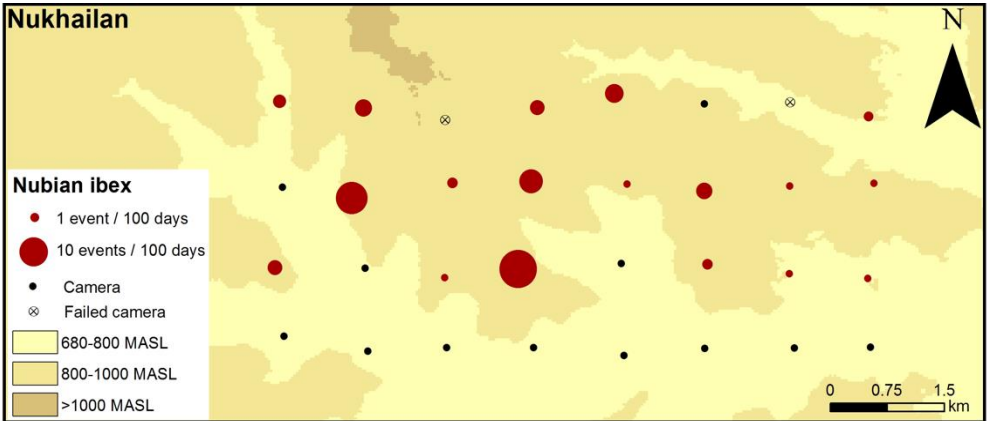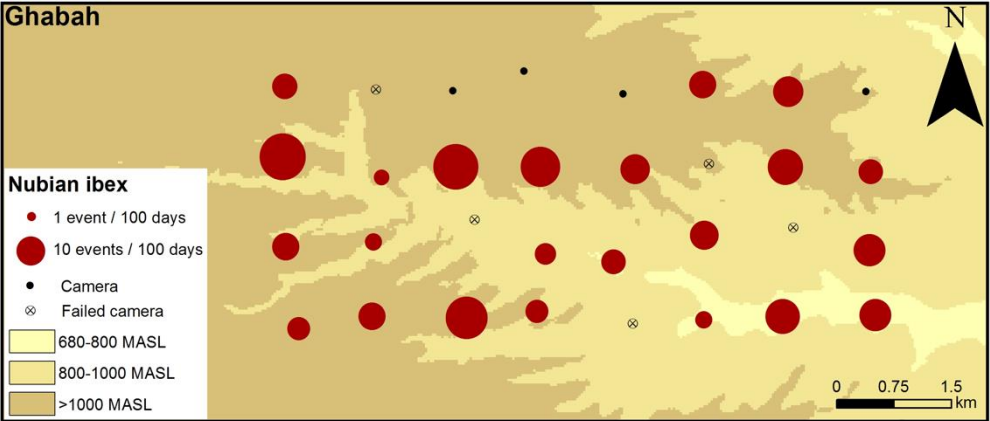
Winter

2) ARABIAN GAZELLE (*Gazella arabica*)

Species notes
- Confirms the persistence of this reintroduced species within the reserve.
- Most frequently recorded in Nukhailan during the winter, which is also when camel and other domestic species were encountered most.
- Timing of camera-trap encounters indicates 24 hour activity.
- The maximum group size observed was five individuals.
- An adult female with a single calf was observed at three different camera stations in Nukhailan on five occasions from mid-November to early February.

Global conservation status:
Data Deficient (Antelope Specialist Group, 2008)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	3	15	60
Ghabah Winter 2013	27	0	0	0
Nukhailan Summer 2013	30	5	9	33
Nukhailan Winter 2012	30	9	78	312

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0.47 (0.13)	0.1	0.1 (0.06)	0.25 (0.06)
Ghabah Winter 2013	0	0	N/A	N/A
Nukhailan Summer 2013	0.25 (0.11)	0.17	N/A	N/A
Nukhailan Winter 2012	1.96 (0.21)	0.27	0.27 (0.08)	0.29 (0.03)

Activity pattern

Summer

Winter

Distribution maps

Summary
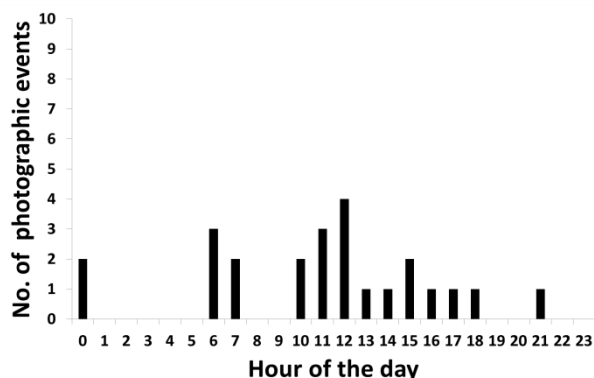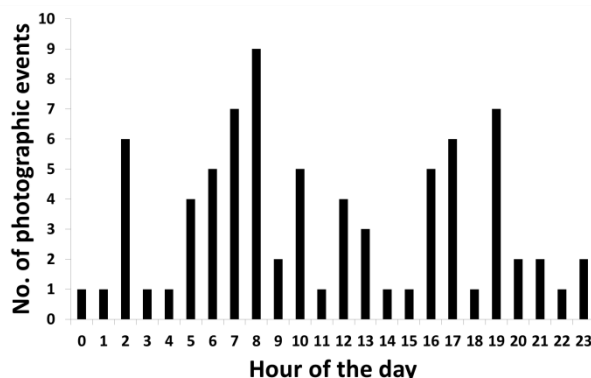
Summer
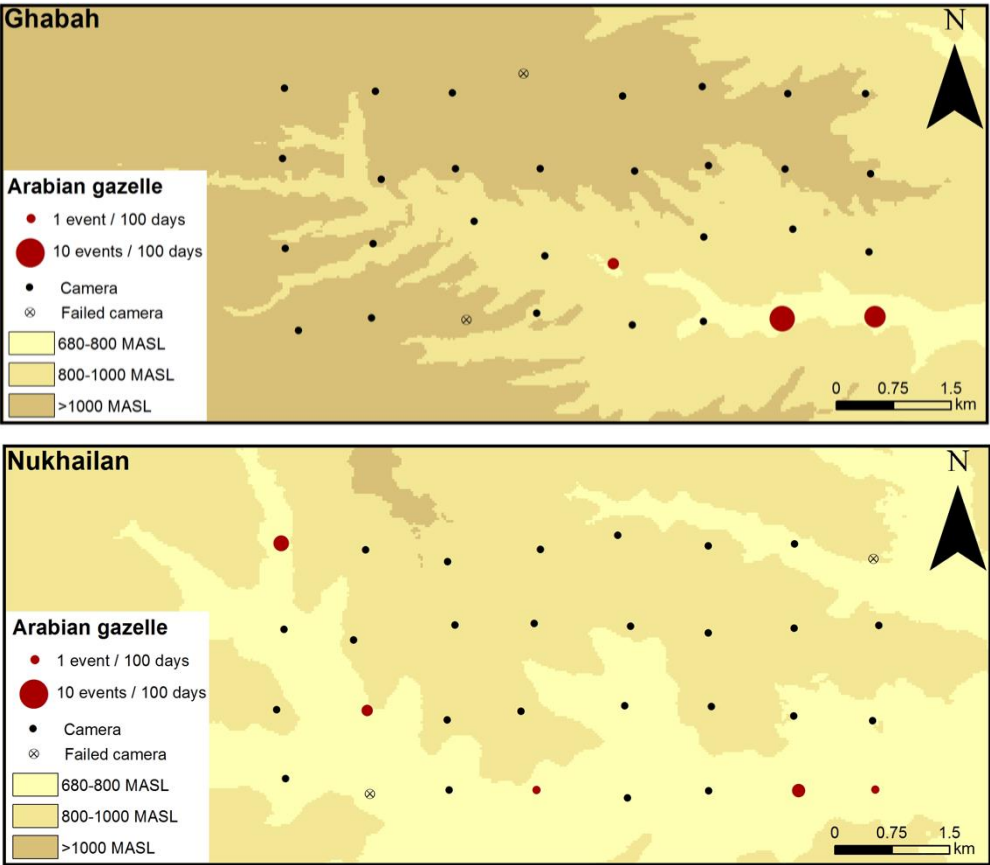
Winter
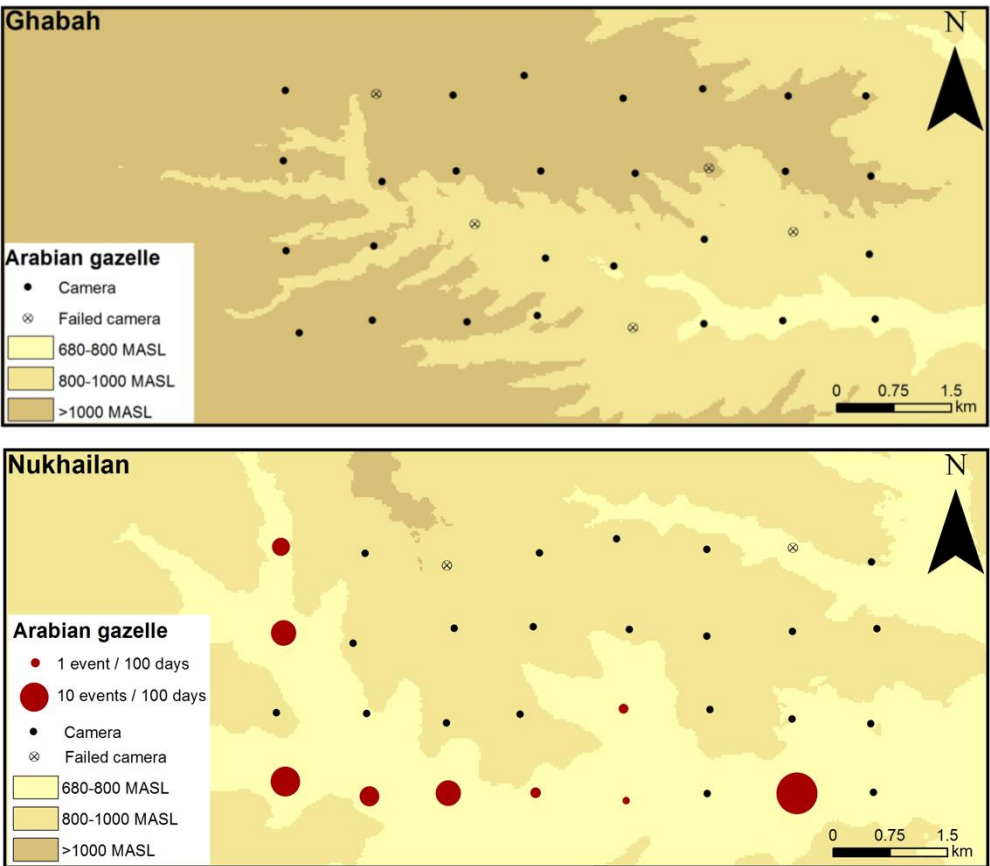
3) ARABIAN WOLF (*Canis lupus arabs*)

Species notes
- 14 events from the Ghabah camera grids but recorded only one once in Nukhailan over both seasons.
- Timing of camera-trap events suggests a mainly crepuscular / nocturnal activity pattern possibly related to the activity of rodents and cape hare, but the data are few.
- All sightings were of single adults; Arabian wolf do not usually live in large packs.
- Observed carrying large piece of meat and probably lactating on 06/05/2012, suggesting possible active den site with cubs.

Global conservation status:
Least Concern (Mech & Boitani, 2010)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	6	11	33
Ghabah Winter 2013	27	3	3	9
Nukhailan Summer 2013	30	0	0	0
Nukhailan Winter 2012	30	1	1	3

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0.30 (0.11)	0.2	N/A	N/A
Ghabah Winter 2013	0.11 (0.06)	0.1	N/A	N/A
Nukhailan Summer 2013	0	0	N/A	N/A
Nukhailan Winter 2012	0.03 (0.03)	0.03	N/A	N/A

Activity pattern
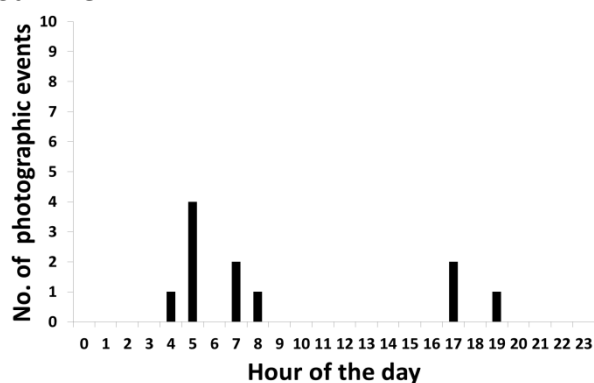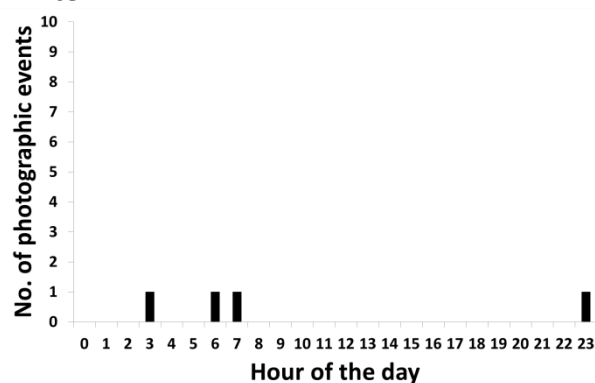
Summer

Winter

Distribution maps
Summer
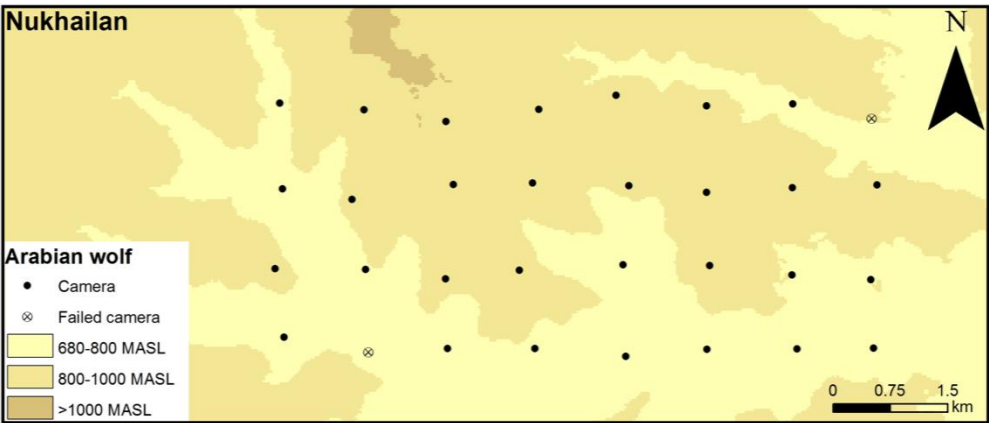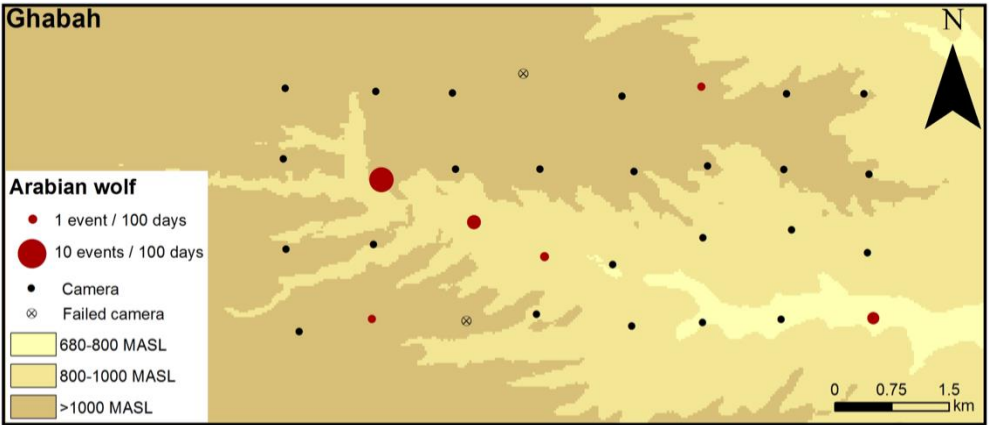
Winter

4) BLANFORD'S FOX (*Vulpes cana*)

Species notes
- Only known at the Ibex Reserve from camera trap records, representing an 800 km range extension.
- Timing of camera-trap events indicates a strictly nocturnal activity pattern.
- Most frequently recorded in Ghabah in winter with twice as many records than in the summer. Only one encounter was in Nukhailan. [However, there were a number of images where it was not possible to reliably identify fox species – see species account 7].
- During the summer, two out of three sites in Ghabah where the fox was detected were on the wadi bed. This changed in winter where it was only detected on slopes and plateaus.
- Blanford's fox is believed to den in pairs in winter and singly in summer (Geffen & Peters 2013); which is a possible explanation for the increased winter trapping rate.

Global conservation status:
Least Concern (Hoffman & Sillero-Zubiri, 2015)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	3	6	18
Ghabah Winter 2013	27	3	11	33
Nukhailan Summer 2013	30	1	1	3
Nukhailan Winter 2012	30	0	0	0

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0.19 (0.08)	0.1	N/A	N/A
Ghabah Winter 2013	0.35 (0.12)	0.1	0.12 (0.07)	0.13 (0.05)
Nukhailan Summer 2013	0.03 (0.03)	0.03	N/A	N/A
Nukhailan Winter 2012	0	0	N/A	N/A

Activity pattern
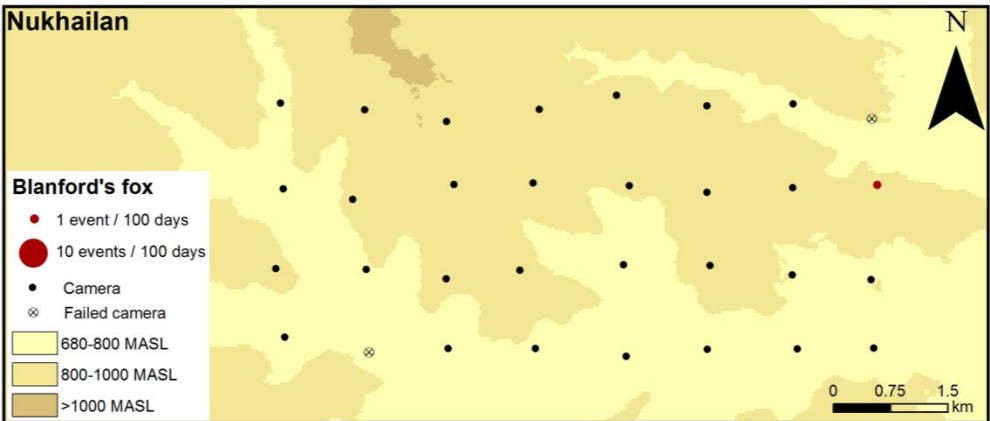
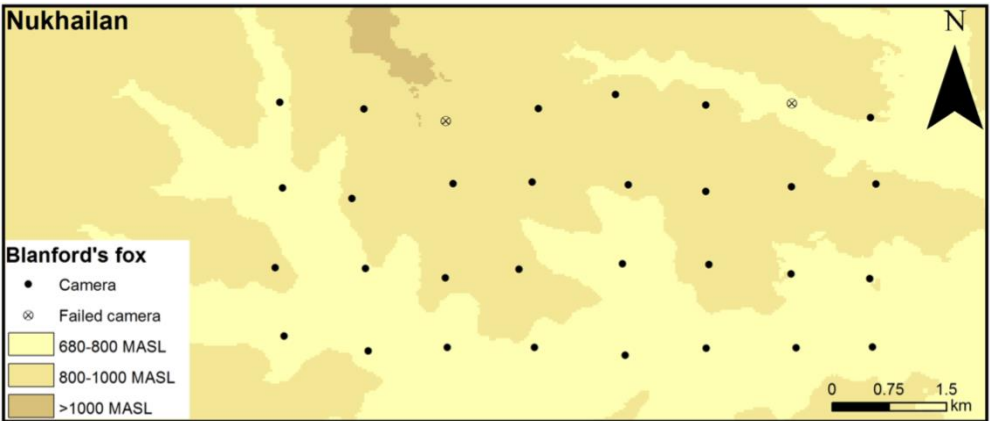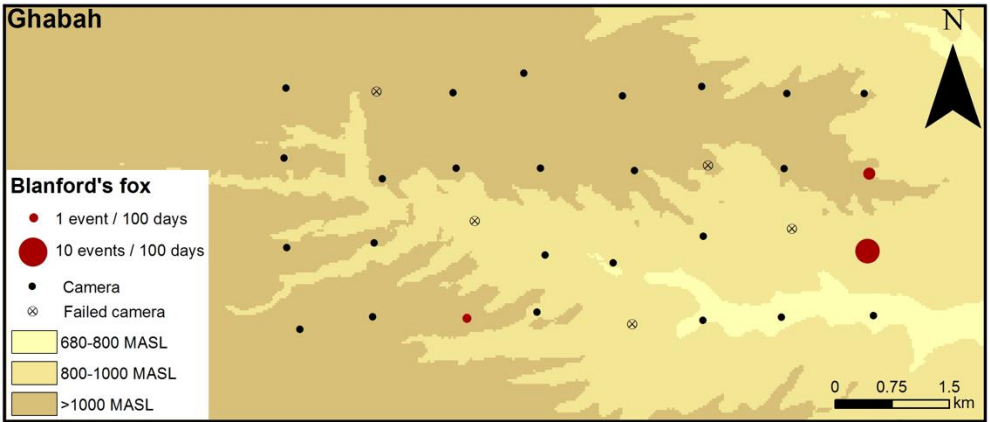**Summer**

Winter

Distribution maps

Summary
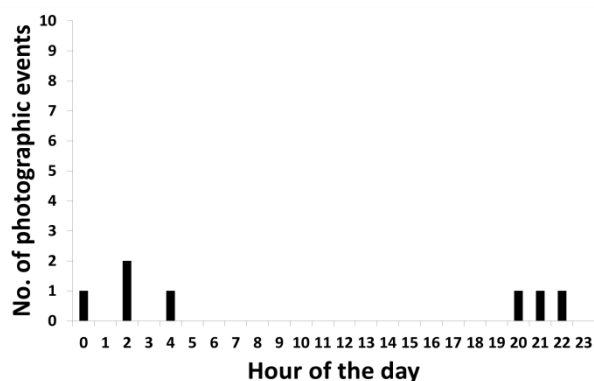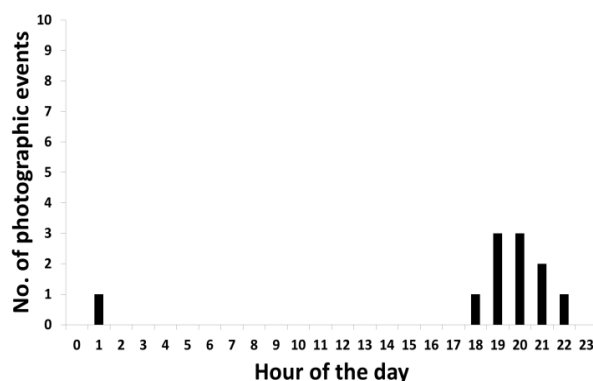
Summer

Winter

5) RÜPPELL'S FOX (*Vulpes rueppellii*)

Species notes
- It was only possible to confirm presence of Ruppell's fox in two events across both sites and seasons (see notes in species accounts-7 on uncertainties of fox identification in central Arabia).
- Known to be active during the day in the winter, the two daytime observations in the summer are unusual for this species.
- Reported to occur in lower densities when Red fox and other carnivores are present in relatively higher numbers (Yom-Tov & Mendelssohn, 1988; Mallon & Budd, 2011).

Global conservation status:
Least Concern (Mallon et al., 2015)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	0	0	0
Ghabah Winter 2013	27	0	0	0
Nukhailan Summer 2013	30	2	2	4
Nukhailan Winter 2012	30	0	0	0

Trapping rates, occupancy and detectability

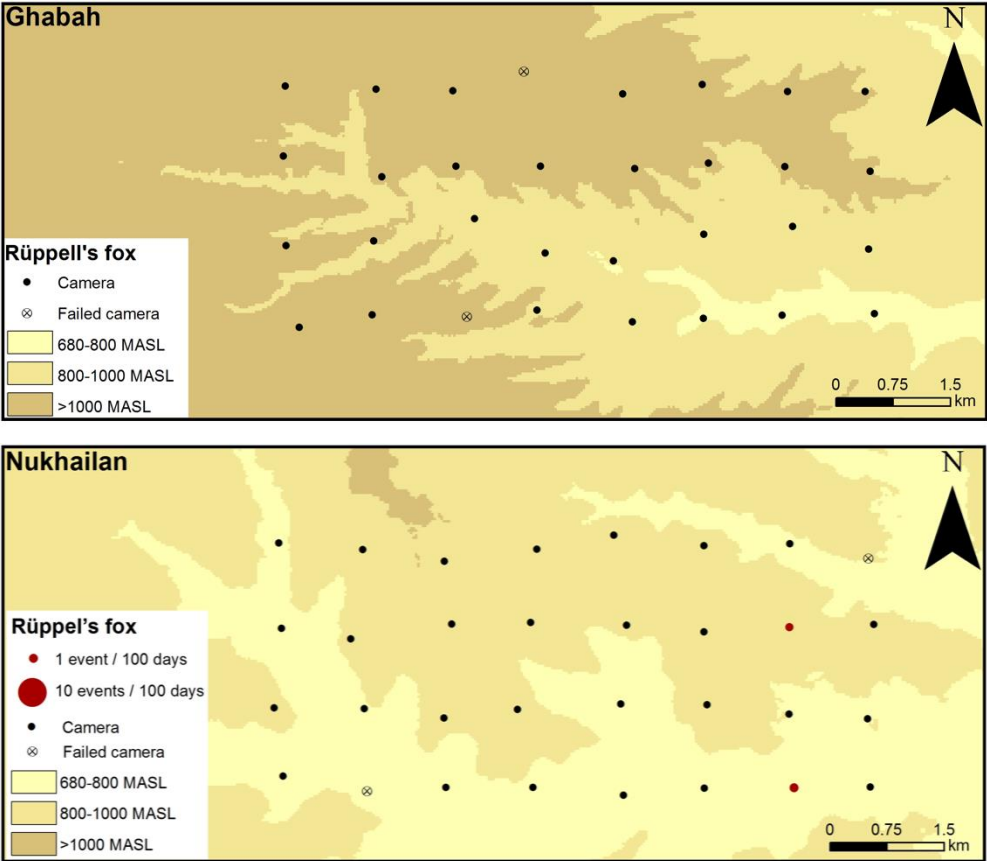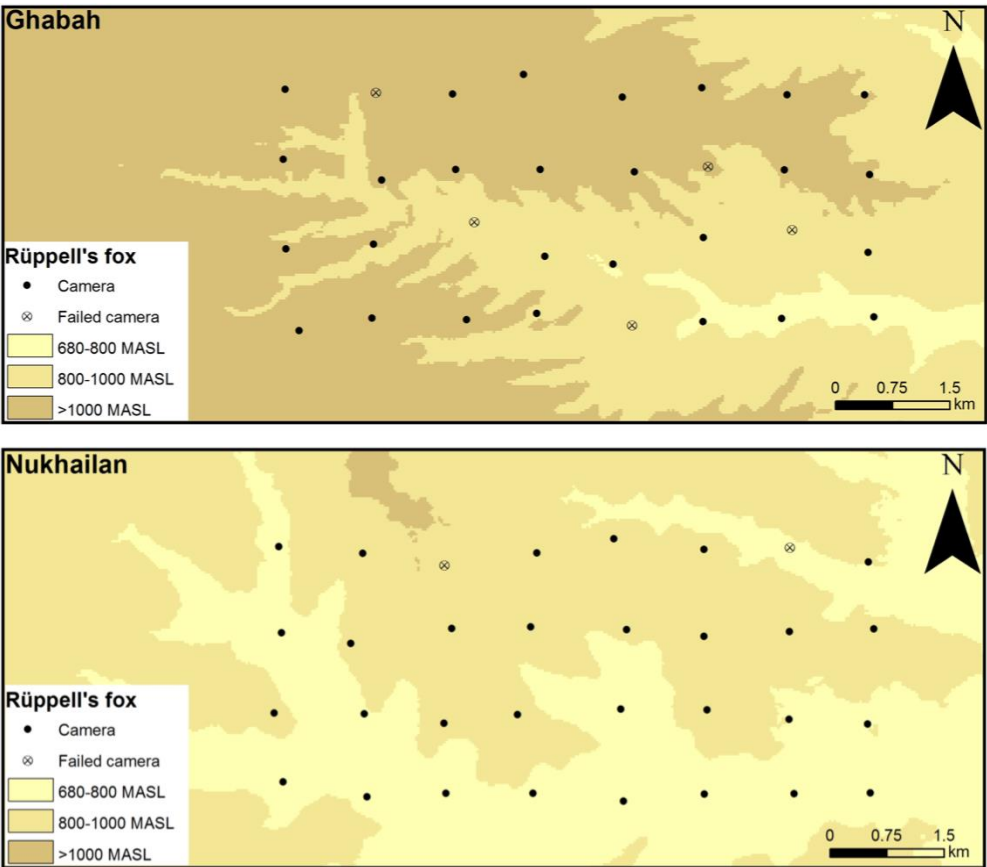| Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0	0	N/A	N/A
Ghabah Winter 2013	0	0	N/A	N/A
Nukhailan Summer 2013	0.06 (0.04)	0.03	N/A	N/A
Nukhailan Winter 2012	0	0	N/A	N/A

Activity pattern
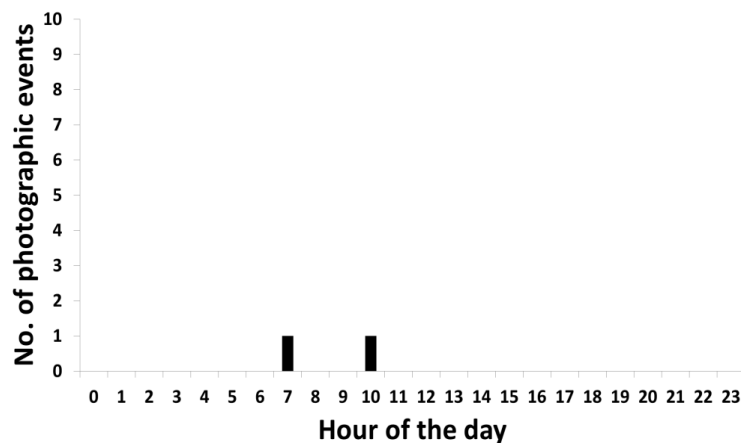
Summer

Distribution maps
Summer

Winter

6) ARABIAN RED FOX (*Vulpes vulpes arabica*)

Species notes
- The most commonly recorded carnivore in the reserve.
- Recorded most frequently in the summer in Nukhailan (where livestock grazing occurs), mostly in a smaller wadi bed to the north of the main wadi bed.
-
- In the winter, camera-trap observations were more dispersed on the plateaus, slopes and in the wadi beds of both sites.
- Mainly nocturnally active.

Global conservation status:
Least Concern (Hoffman & Sillero-Zubiri, 2016)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	8	38	171
Ghabah Winter 2013	27	10	39	129
Nukhailan Summer 2013	30	8	79	321
Nukhailan Winter 2012	30	10	24	75

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	1.04 (0.24)	0.27	0.31 (0.10)	0.10 (0.02)
Ghabah Winter 2013	1.33 (0.26)	0.37	0.39 (0.10)	0.14 (0.03)
Nukhailan Summer 2013	2.07 (0.27)	0.27	0.27 (0.08)	0.17 (0.03)
Nukhailan Winter 2012	0.61 (0.13)	0.3	0.35 (0.10)	0.08 (0.02)

Activity pattern
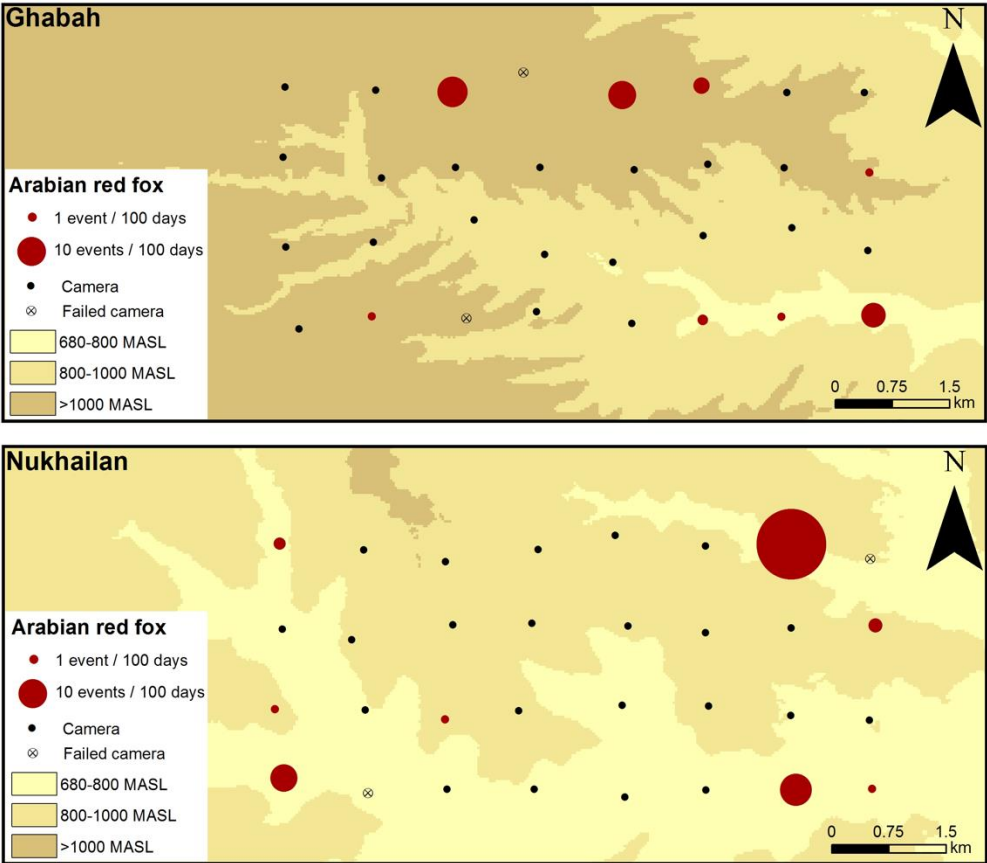
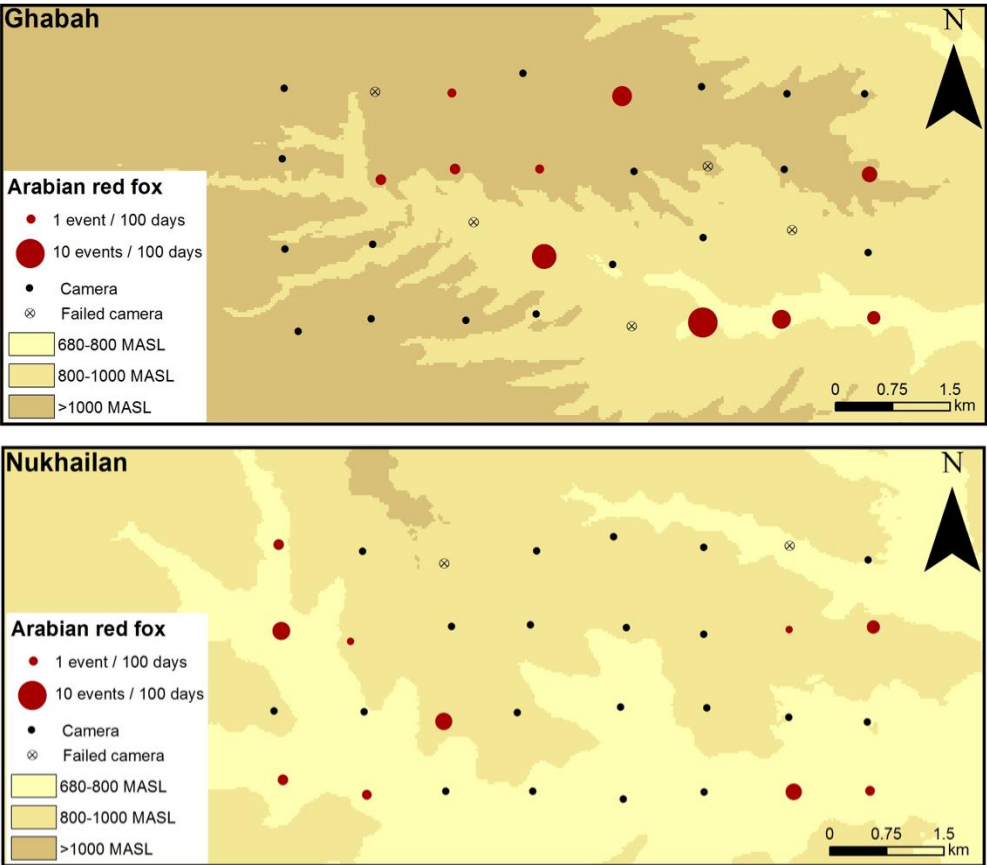**Summer**

Winter

Distribution maps

Summary
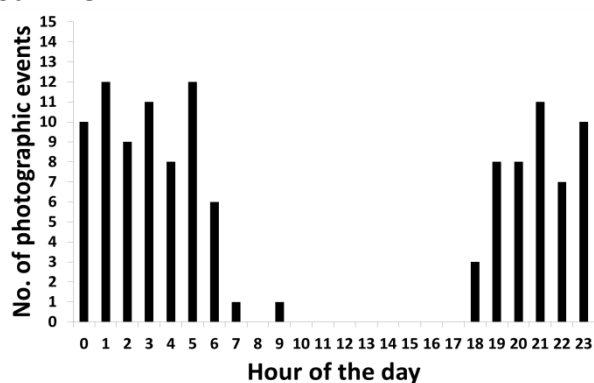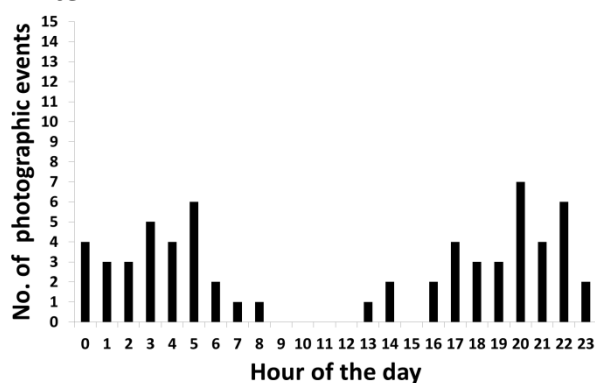
Summer

Winter

7) FOX SPECIES (*Vulpes sp.*)

Species notes
- Fox identification in central Arabia is complicated by immense gross variation in appearance of individuals between hot summer and cold winter season, resulting in a naturally wide range of pelage density, colour and pattern. On top of this many of the more reliable features such as body proportion, blackish back to the ears and a black throat (adult red fox), or a more pronounced dark spot beneath each eye (Rüppell's fox) can easily be distorted and invisible under infra-red illumination. This results in many images which could not be reliable identified to species (see photo).
- All *Vulpes* species are included in this analysis.

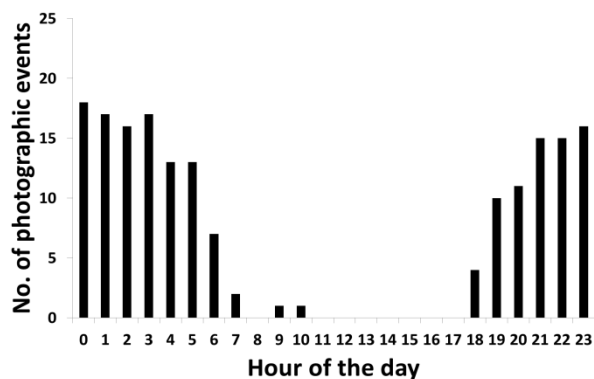**Global conservation status:**
Not Applicable

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	14	65	290
Ghabah Winter 2013	27	15	65	222
Nukhailan Summer 2013	30	16	110	440
Nukhailan Winter 2012	30	12	37	117

Trapping rates, occupancy and detectability

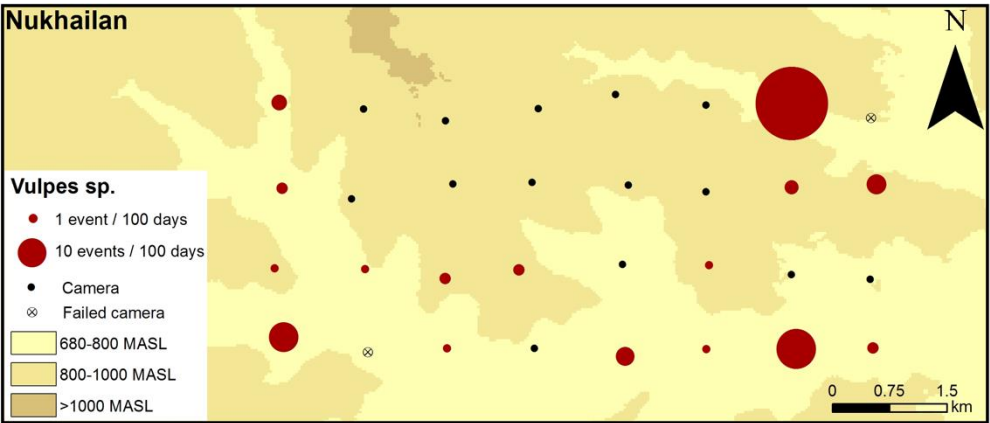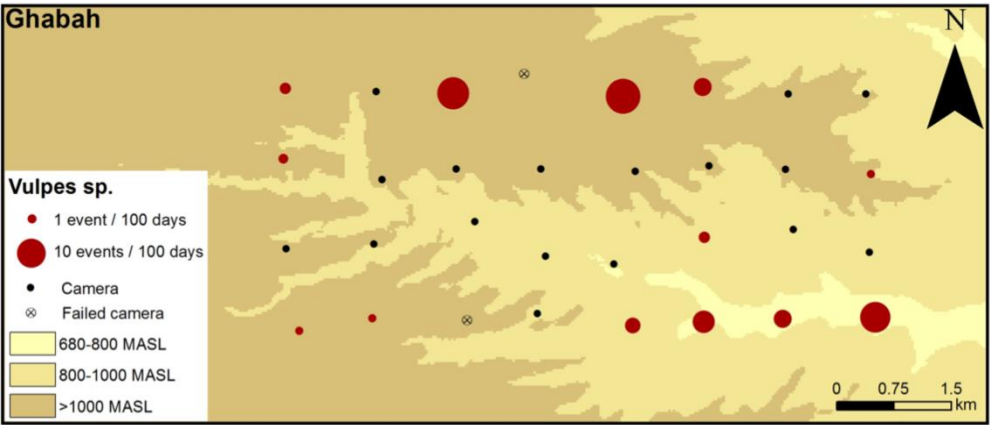| Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	1.90 (0.31)	0.40	0.42 (0.09)	0.13 (0.02)
Ghabah Winter 2013	2.14 (0.32)	0.56	0.57 (0.10)	0.15 (0.02)
Nukhailan Summer 2013	2.93 (0.33)	0.53	0.55 (0.09)	0.16 (0.02)
Nukhailan Winter 2012	0.95 (0.16)	0.37	0.39 (0.09)	0.12 (0.02)

Activity pattern

Summer

Winter

Distribution maps

Summer

Ghabah

Vulpes sp.
- 1 event / 100 days
- 10 events / 100 days
- Camera
- ⊗ Failed camera
- 680-800 MASL
- 800-1000 MASL
- >1000 MASL

0   0.75   1.5 km

Nukhailan

Vulpes sp.
- 1 event / 100 days
- 10 events / 100 days
- Camera
- ⊗ Failed camera
- 680-800 MASL
- 800-1000 MASL
- >1000 MASL

0   0.75   1.5 km

Winter

Ghabah

Vulpes sp.
- 1 event / 100 days
- 10 events / 100 days
- Camera
- ⊗ Failed camera
- 680-800 MASL
- 800-1000 MASL
- >1000 MASL

0   0.75   1.5 km

Nukhailan

Vulpes sp.
- 1 event / 100 days
- 10 events / 100 days
- Camera
- ⊗ Failed camera
- 680-800 MASL
- 800-1000 MASL
- >1000 MASL

0   0.75   1.5 km

8) WILD CAT (*FELIS SILVESTRIS*)

Species notes
- Only three encounters over both sites in winter only.
- Recorded only at night and dawn.
- The number of observations could be greater as presence of domestic cats (image on the right) and quality of infrared images meant some had to be classified as Felis sp. due to uncertainty.
- Camera-trapping has not provided any direct evidence of introgression between wild and domestic cat, but the presence of both within the reserve suggests it likely this has happened.
- The distance from the wild cat sites to the nearest domestic cat detection was 2.3 km.

Global conservation status:
Least Concern (Yamaguchi et al., 2015)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	2	2	15
Ghabah Winter 2013	27	0	0	0
Nukhailan Summer 2013	30	1	1	12
Nukhailan Winter 2012	30	0	0	0

Trapping rates, occupancy and detectability

| Survey | Trapping rate / 100 days (SE) | Occupancy | | |
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0.07 (0.05)	0.07	N/A	N/A
Ghabah Winter 2013	0	0	N/A	N/A
Nukhailan Summer 2013	0.03 (0.03)	0.03	N/A	N/A
Nukhailan Winter 2012	0	0	N/A	N/A

Activity pattern
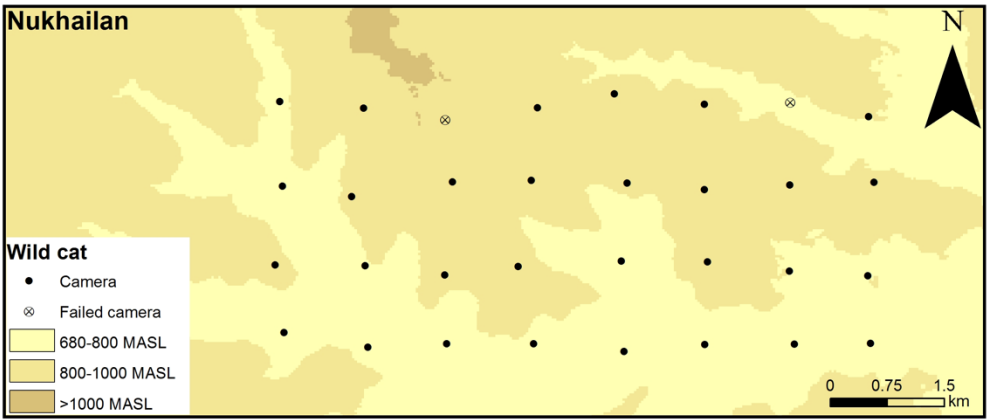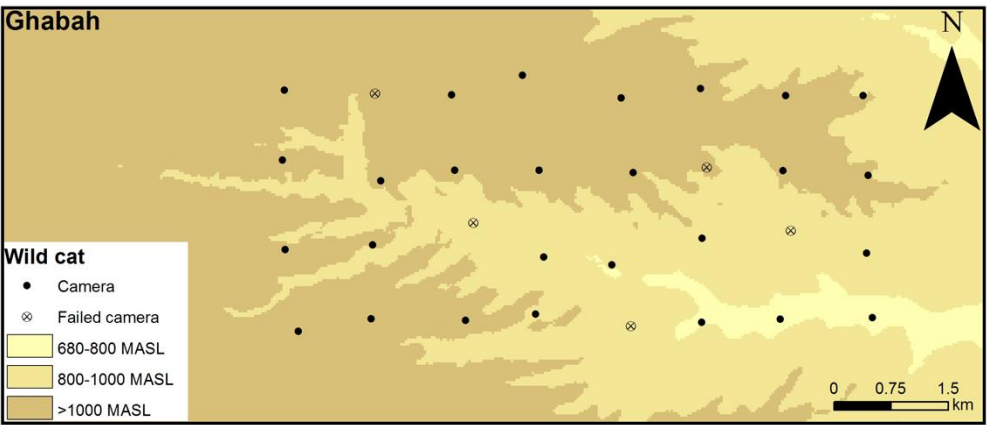
Summer

Distribution maps

Summary
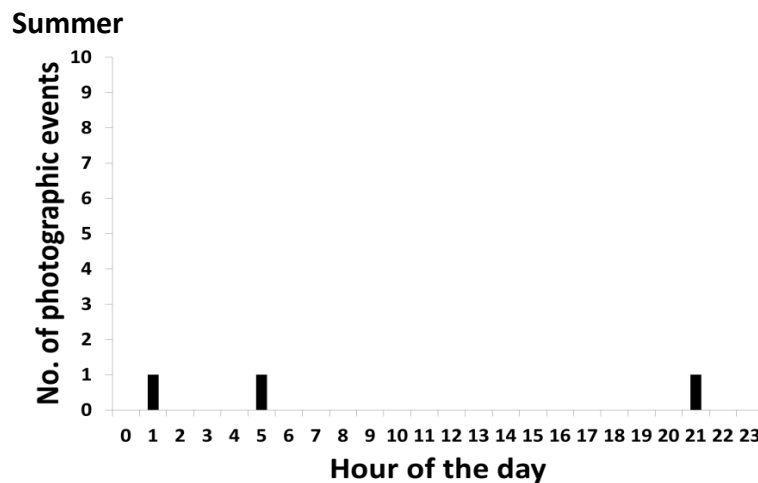
Summer
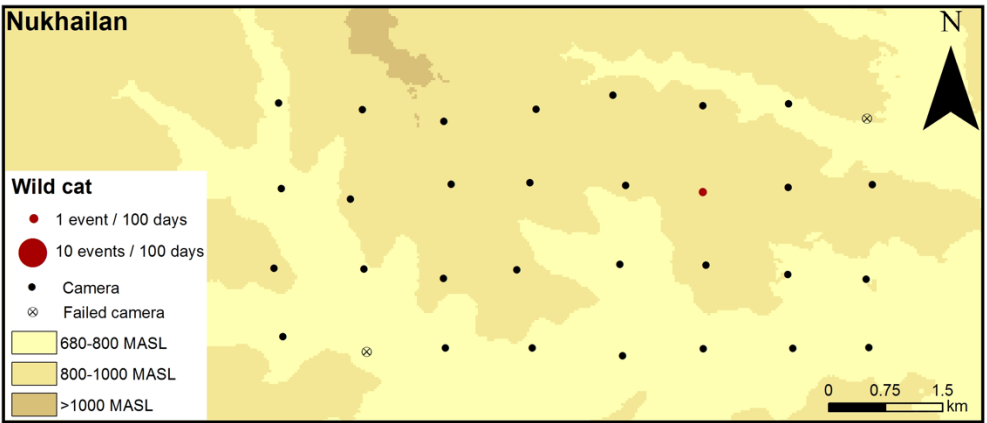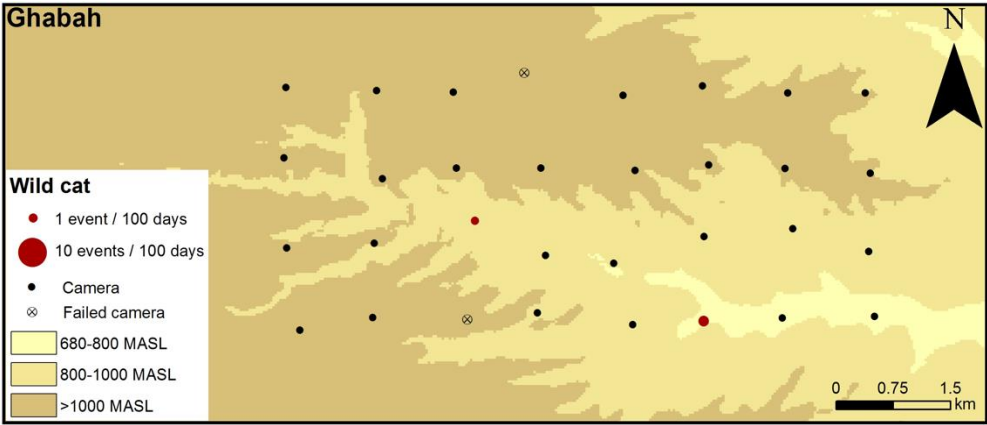
Winter

9) CAPE HARE (*Lepus capensis*)

Species notes
- The second most frequently recorded mammal within the Ibex Reserve, with a total of 369 events compared to 1161 Nubian ibex events and 274 Vulpes sp. events.
- Timing of camera-trap encounters indicate a nocturnal activity pattern apart from one event which was captured in the afternoon.
- Despite having a high number of observations, they were unevenly distributed in Ghabah, displaying a preference for the plateau area of the habitat which is grazed by camels in both seasons with camels recorded much more in winter.
- In Nukhailan, they were observed mostly in the wadi beds, which are heavily grazed by camels throughout the year.

Global conservation status:
Least Concern (Drew et al., 2008)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	6	166	912
Ghabah Winter 2013	27	4	27	114
Nukhailan Summer 2013	30	11	44	163
Nukhailan Winter 2012	30	11	132	465

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	4.87 (0.38)	0.17	0.17 (0.07)	0.44 (0.05)
Ghabah Winter 2013	0.96 (0.20)	0.15	0.15 (0.07)	0.21 (0.04)
Nukhailan Summer 2013	1.22 (0.21)	0.37	0.39 (0.09)	0.13 (0.02)
Nukhailan Winter 2012	3.26 (0.28)	0.37	0.37 (0.09)	0.30 (0.03)

Activity pattern
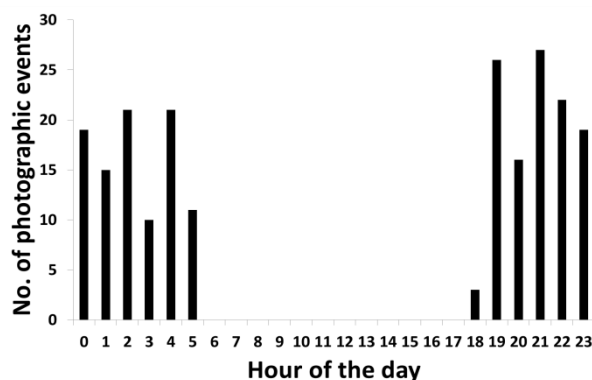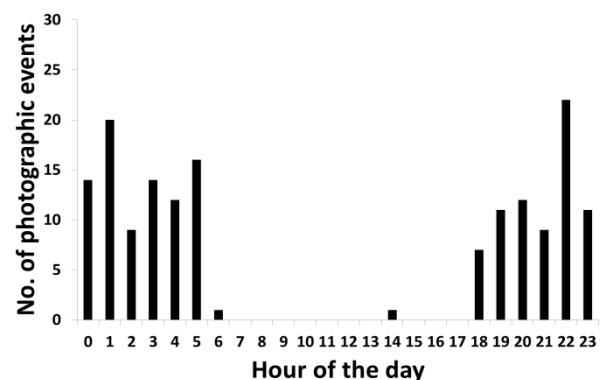
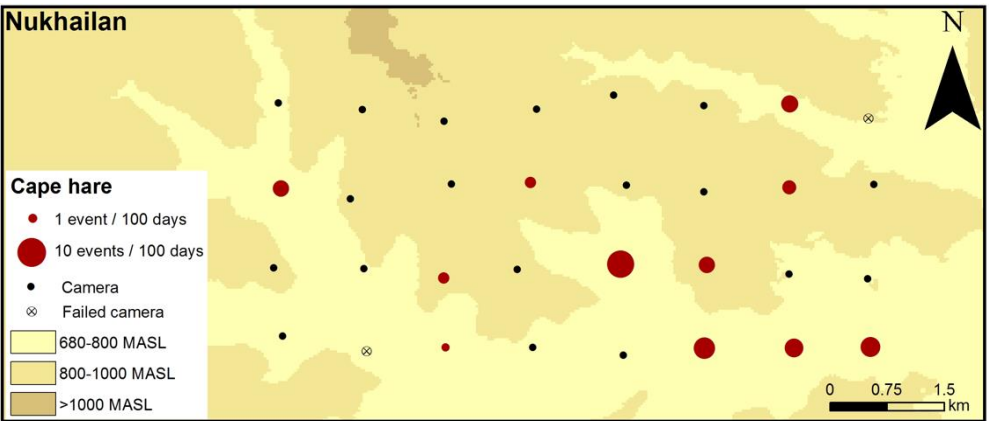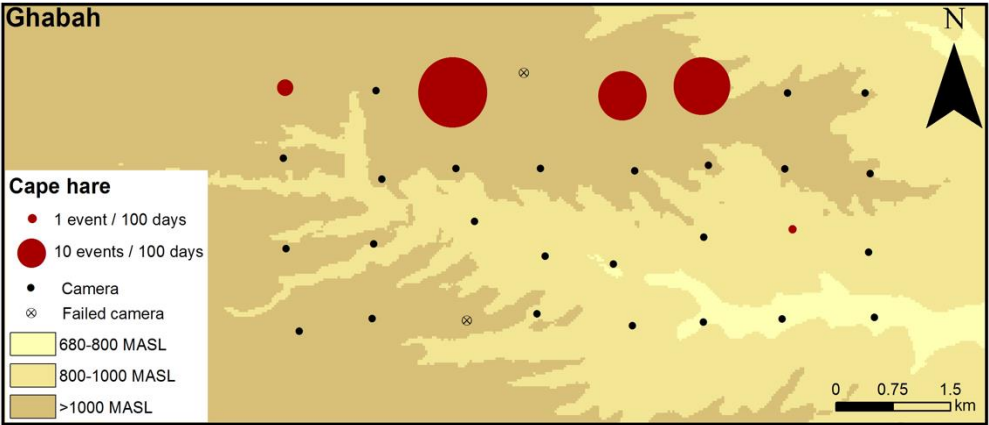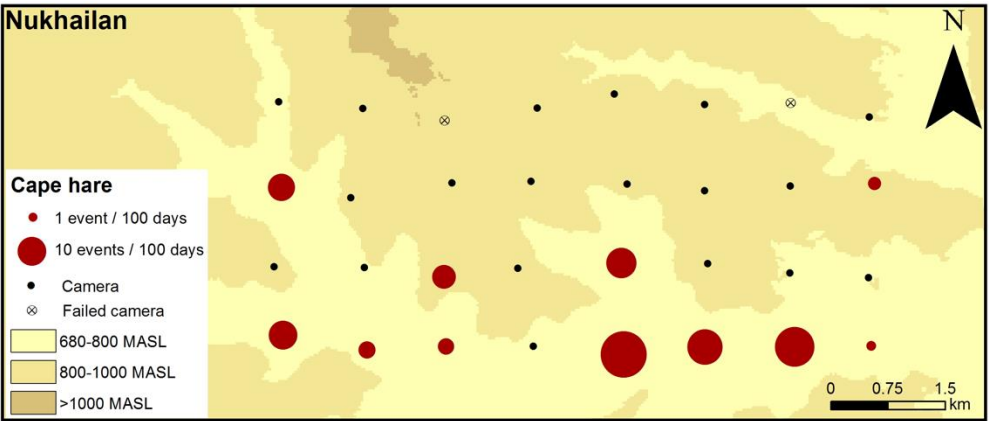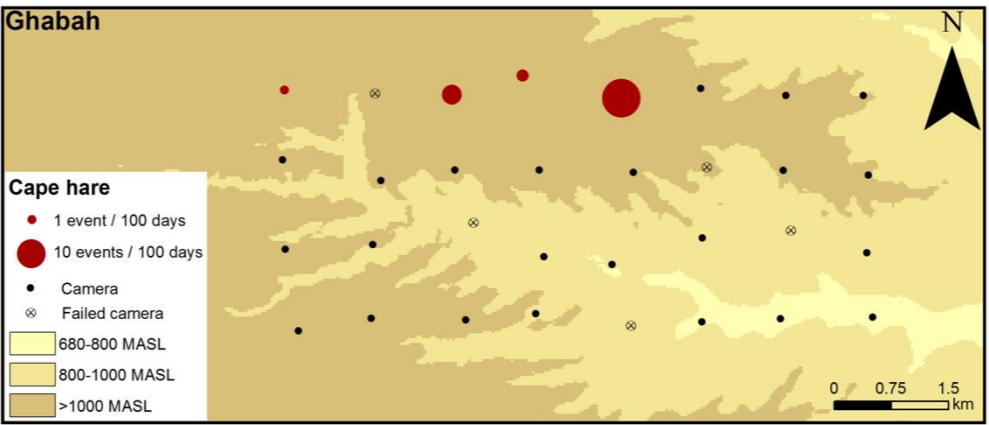**Summer**

Winter

Distribution maps

Summer

Winter

10)   ROCK HYRAX (*Procavia capensis*)

Species notes
- Recorded more frequently in Ghabah perhaps relating to the greater availability of Acacia trees close to broken scree slopes in Ghabah compared to Nukhailan.
- Frequently encountered in groups, sometimes with multiple members climbing trees to forage or use as a vantage point.
- Ibex photographed feeding beneath trees containing foraging hyrax.
- Timing of events show a diurnal activity pattern.
- Timing of events in the summer show a noticeable increase in activity around sunrise and much less activity during the hottest part of the day.

Global conservation status:
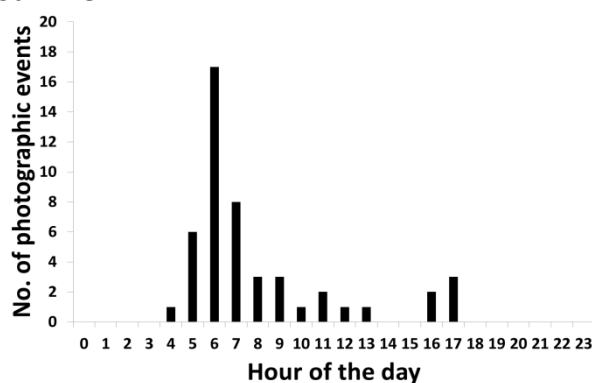Least Concern (Butynski et al., 2015)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	9	46	245
Ghabah Winter 2013	27	5	28	180
Nukhailan Summer 2013	30	2	2	9
Nukhailan Winter 2012	30	4	16	75

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	1.41 (0.21)	0.3	0.31 (0.09)	0.16 (0.03)
Ghabah Winter 2013	1.01 (0.23)	0.19	0.19 (0.08)	0.19 (0.04)
Nukhailan Summer 2013	0.05 (0.04)	0.03	N/A	N/A
Nukhailan Winter 2012	0.40 (0.10)	0.13	0.14 (0.07)	0.11 (0.03)

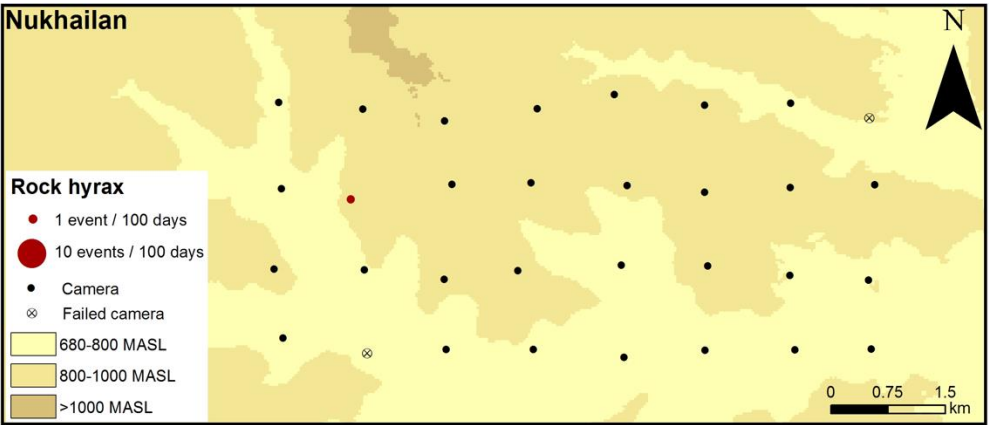## Activity pattern
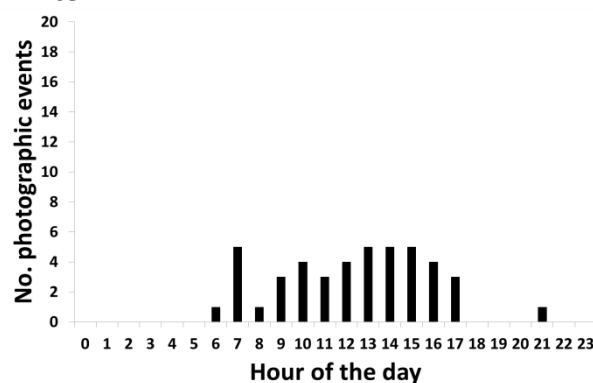
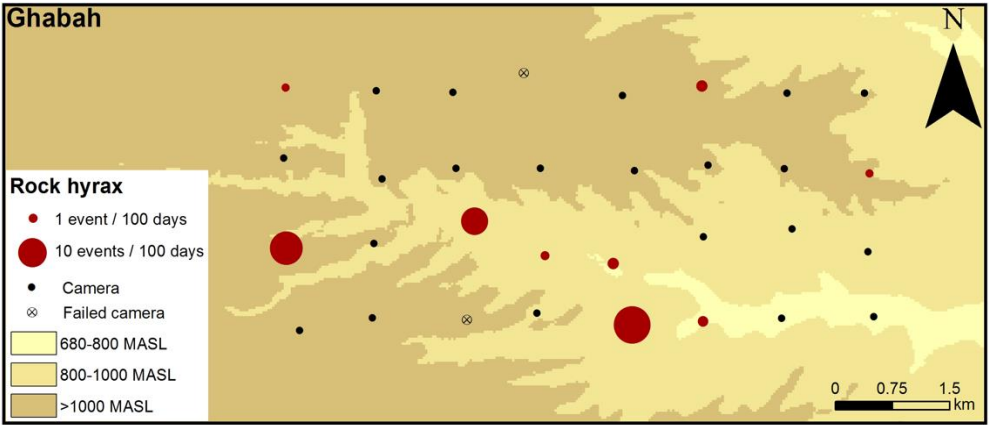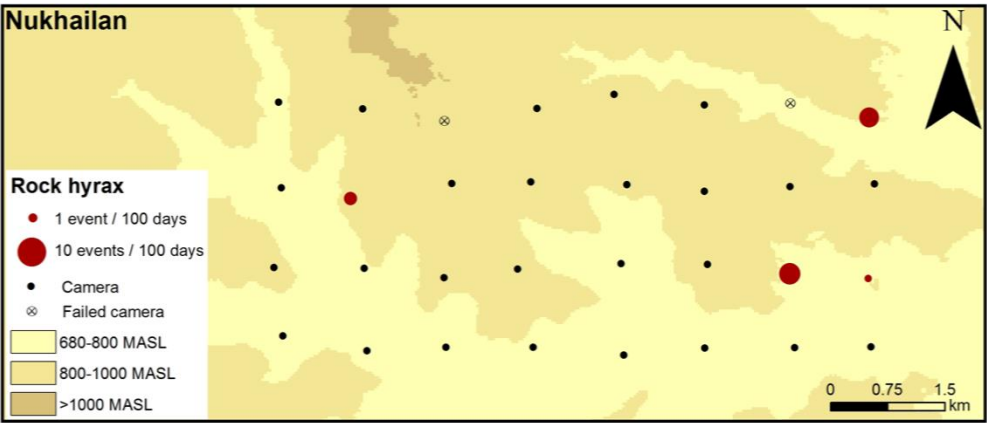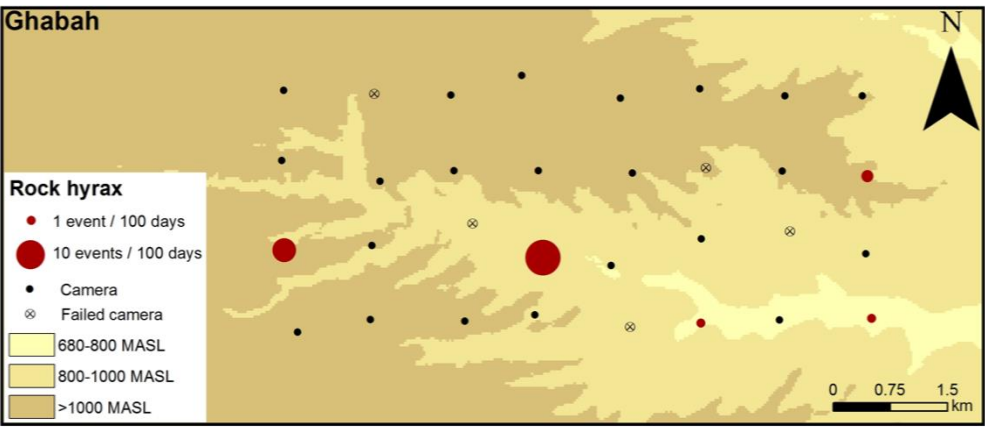**Summer**

Winter

Distribution maps
Summer

Winter

11)   DESERT HEDGEHOG (*Paraechinus aethiopicus*)

Species notes
- Recorded at both sites with very few encounters mostly in the summer in Nukhailan.
- Being a primarily solitary mammal, repeated events at the same camera-trap in Nukhailan are likely to be of the same individual.
- Activity pattern was strictly nocturnal, as expected for the species.

Global conservation status:
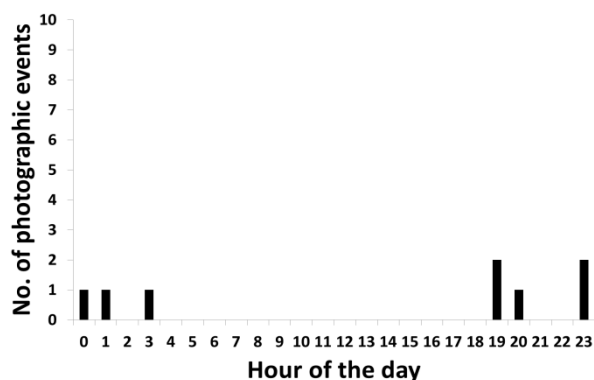Least Concern (Hutterer, 2016)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	1	1	3
Ghabah Winter 2013	27	1	1	3
Nukhailan Summer 2013	30	3	7	21
Nukhailan Winter 2012	30	1	1	3

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0.03 (0.03)	0.03	N/A	N/A
Ghabah Winter 2013	0.04 (0.04)	0.04	N/A	N/A
Nukhailan Summer 2013	0.21 (0.08)	0.1	N/A	N/A
Nukhailan Winter 2012	0.02 (0.02)	0.03	N/A	N/A

Activity pattern

Summer

Winter

Distribution maps

Summary
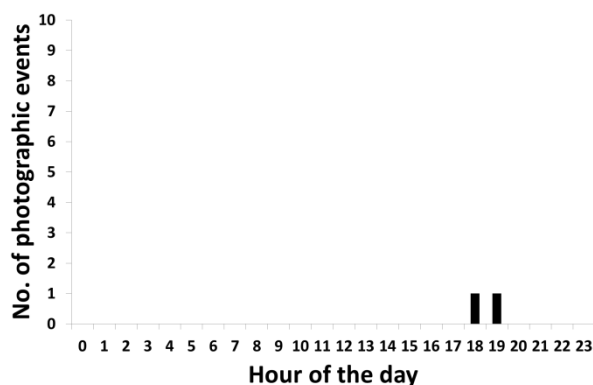
Summer
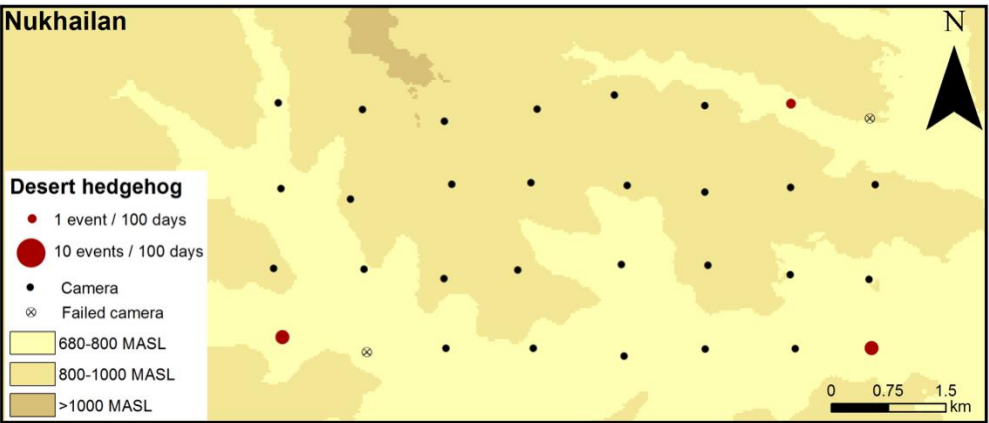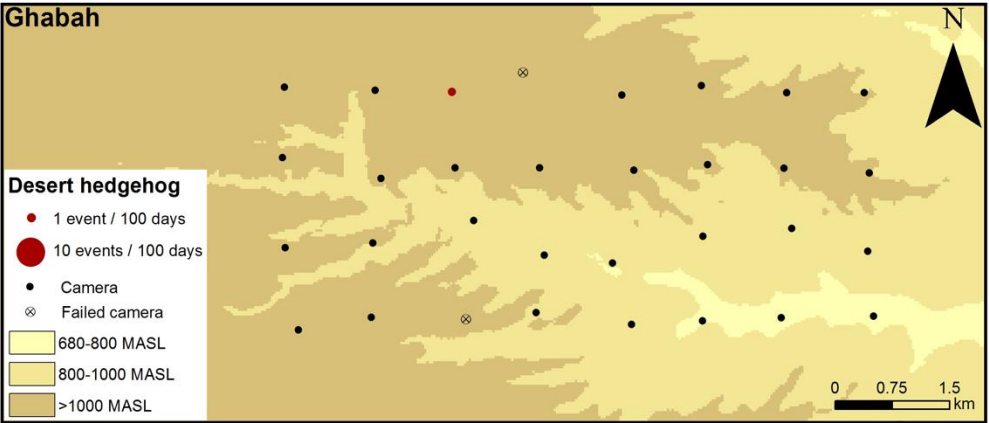
Winter

12) BUSHY-TAILED JIRD (*Sekeetamys calurus*)

Species notes
- First records from the Ibex Reserve, providing evidence for a minor southward range extension from the isolated population known from around Riyadh (Schlitter et al., 2008).
- Recorded by camera-traps at elevations of 763-951 m, marking a substantial altitudinal range extension compared to current IUCN Red List records which give the upper elevation limit as 600 m.
-
- Strictly nocturnal with no events recorded during the day.
- Only recorded at Nukhailan.

Global conservation status:
Least Concern (Schlitter et al., 2008)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	0	0	0
Ghabah Winter 2013	27	0	0	0
Nukhailan Summer 2013	30	5	10	57
Nukhailan Winter 2012	30	1	2	6

Trapping rates, occupancy and detectability

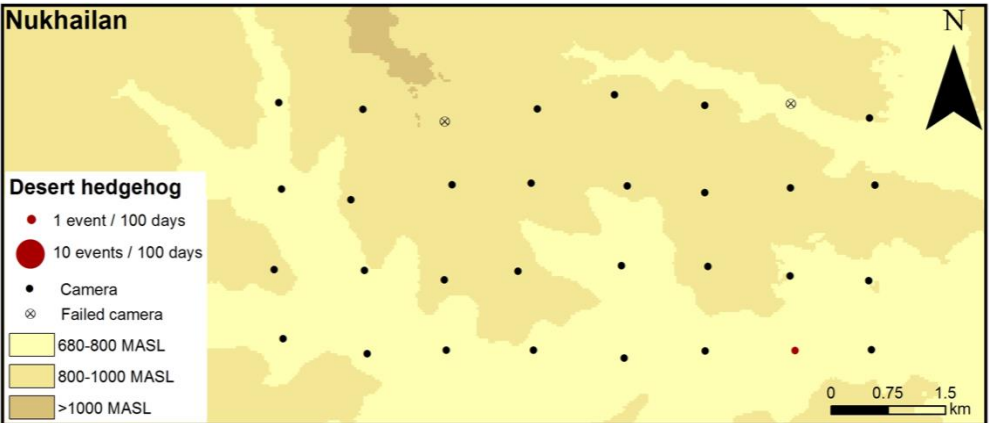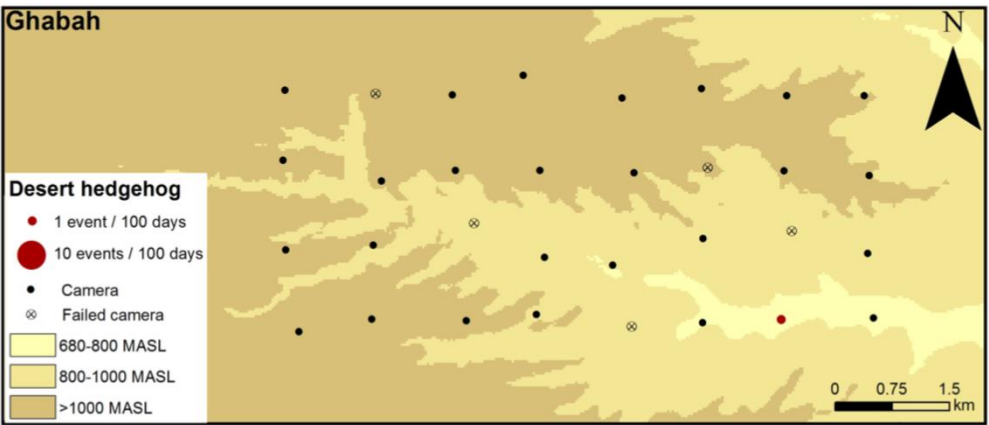| Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0	0	N/A	N/A
Ghabah Winter 2013	0	0	N/A	N/A
Nukhailan Summer 2013	0.28 (0.10)	0.13	N/A	N/A
Nukhailan Winter 2012	0.06 (0.04)	0.03	N/A	N/A

Activity pattern
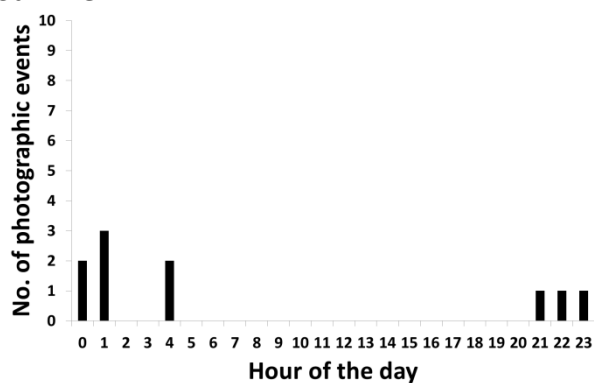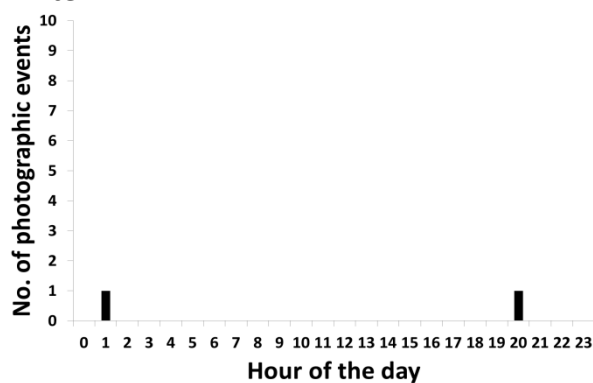
Summer

Winter

Distribution maps
Summer
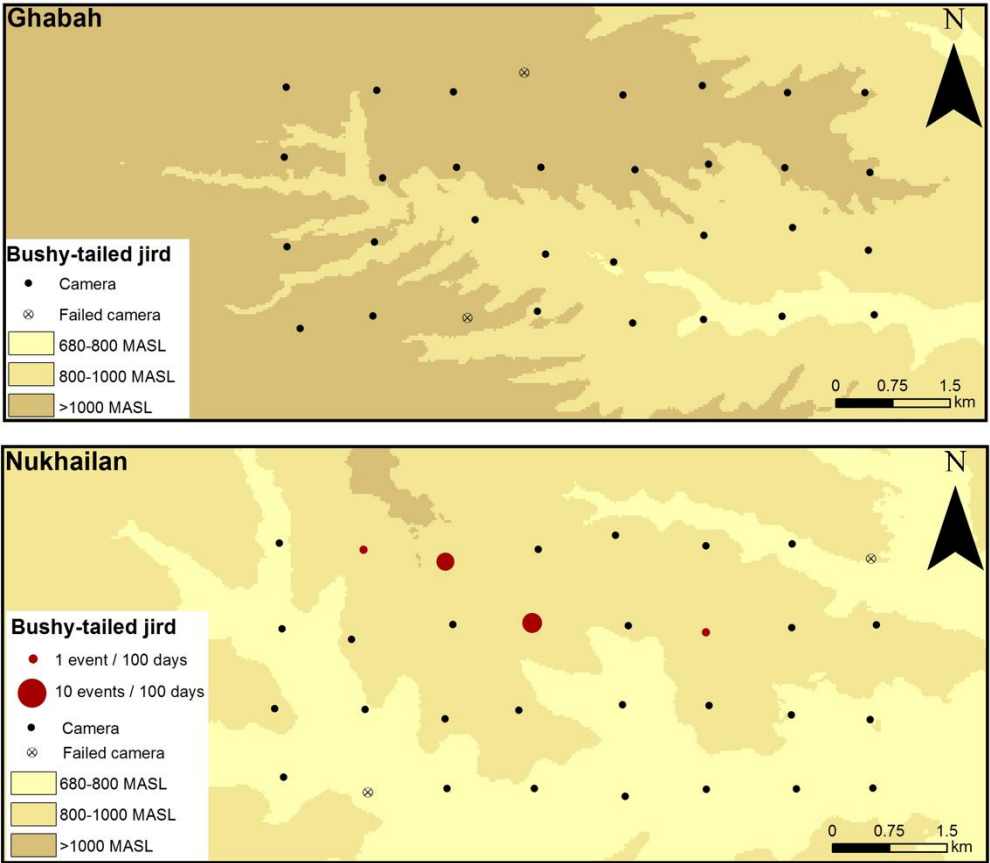
Winter
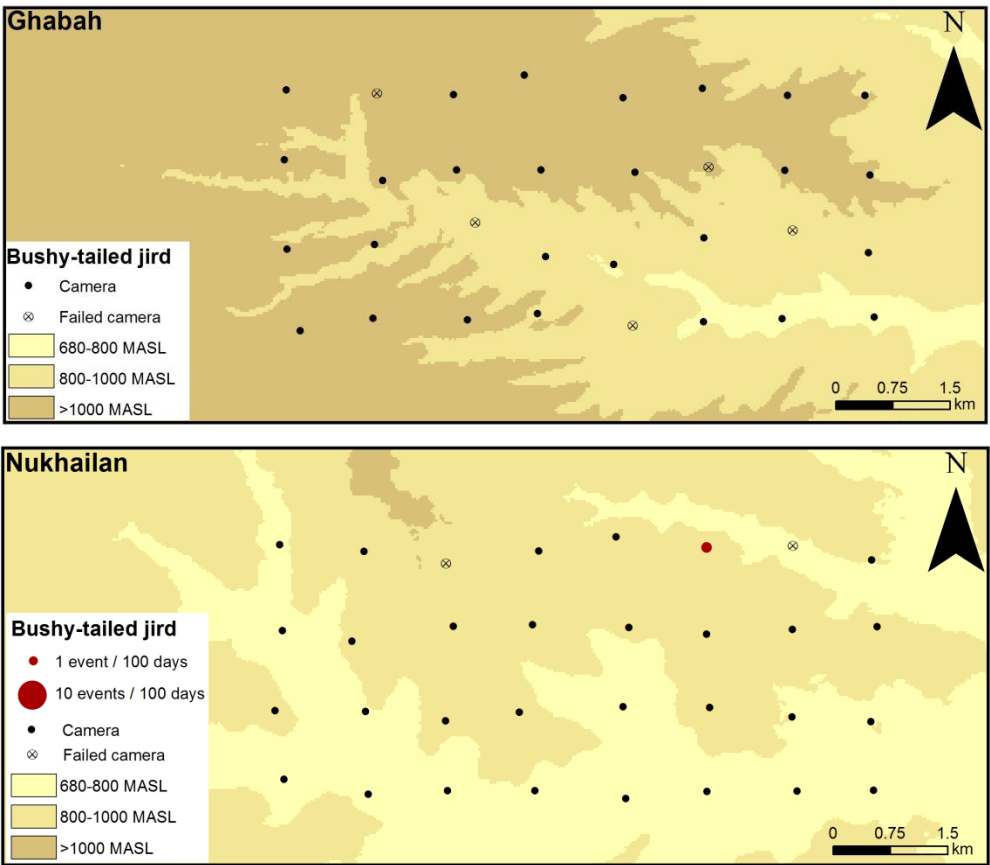
13)   ARABIAN SPINY MOUSE *(Acomys dimidiatus)*

Species notes

- Only three events recorded; all within the Nukhailan at the same camera-trap in the different seasons.
- Adults weigh approximately 90 g so may not be consistently triggered by cameras.
- Two of the events occurred at dawn and the other at night; however with so few detection events a reliable activity pattern cannot be established.
- Species identification primarily based on known distribution of *A. dimidiatus,* but possibility that these records represent a range extension of Golden Spiny mouse *A. russatus* could be born in mind in future research in the reserve.

Global conservation status:
Least Concern (Amr et al., 2008)

Camera trap survey results

| Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	0	0	0
Ghabah Winter 2013	27	0	0	0
Nukhailan Summer 2013	30	1	1	1
Nukhailan Winter 2012	30	1	2	6

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0	0	N/A	N/A
Ghabah Winter 2013	0	0	N/A	N/A
Nukhailan Summer 2013	0.03 (0.03)	0.03	N/A	N/A
Nukhailan Winter 2012	0.06 (0.04)	0.03	N/A	N/A

Activity pattern

Summer

Winter

Distribution maps

Summary

Summer

Winter

14)   RODENT SPECIES (*Murid sp.*)

Species notes
- It was difficult to confirm identity of most small desert mammals especially in infra-red images (gerbils and mice; <0.5 kg and largely nocturnal).
- Murids had their highest trapping rate and occupancy in Nukhailan during the summer.

Global conservation status:
Not Applicable

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	2	10	45
Ghabah Winter 2013	27	2	3	9
Nukhailan Summer 2013	30	13	34	132
Nukhailan Winter 2012	30	4	9	30

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0.33 (0.10)	0.07	N/A	N/A
Ghabah Winter 2013	0.11 (0.07)	0.07	N/A	N/A
Nukhailan Summer 2013	0.96 (0.22)	0.43	N/A	N/A
Nukhailan Winter 2012	0.24 (0.08)	0.2	N/A	N/A

Activity pattern
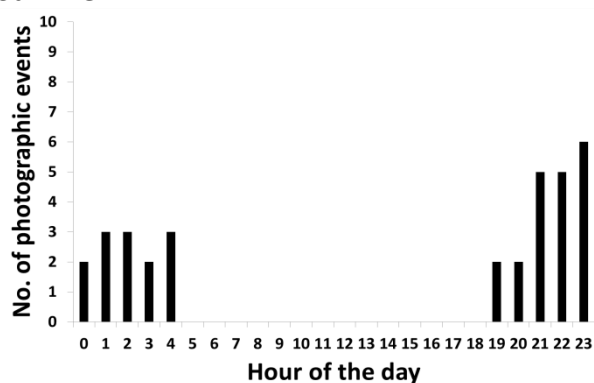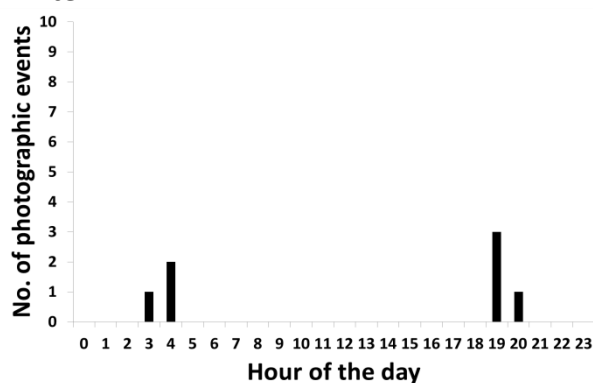
Summer

Winter

Distribution maps

Summer
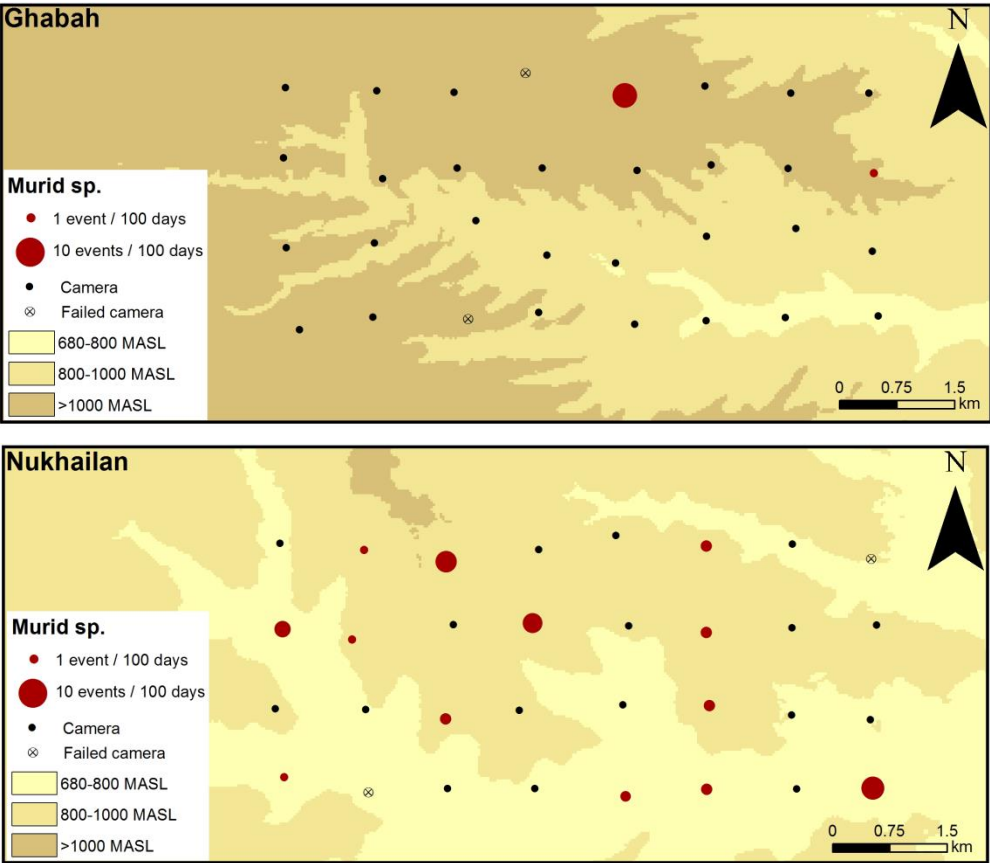
Winter
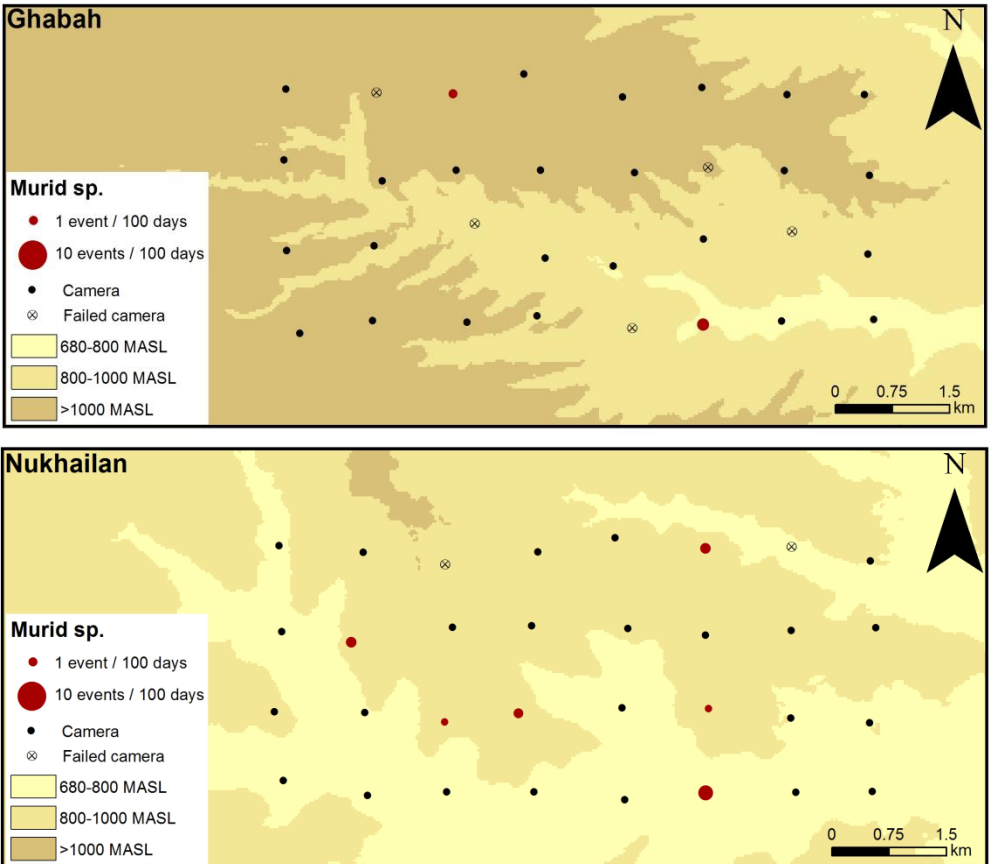
15)   DROMEDARY CAMEL (*Camelus dromedarius*)
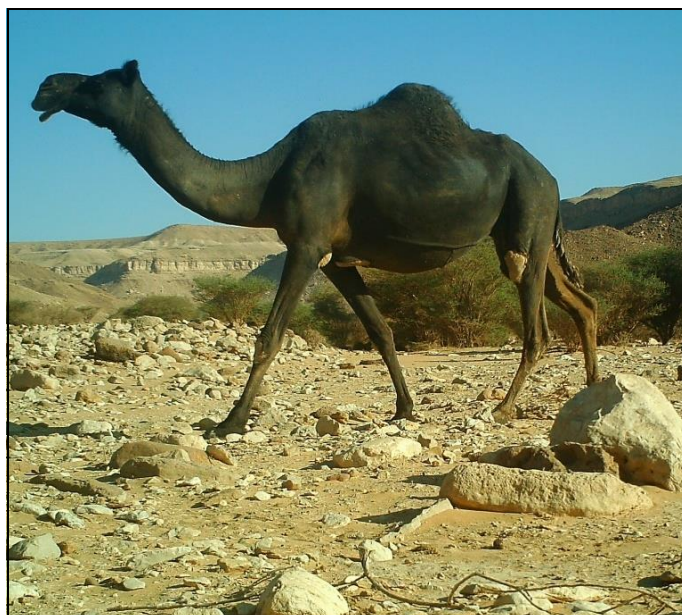
Species notes

- Present in both camera grids and seasons.
- Most frequently recorded in Nukhailan which is to be expected as a controlled grazing area.
- Results also indicate 37% of the surveyed area was used by camels in winter.
- No encounters in the wadi bed of Ghabah only on the plateau indicating the fence is working to exclude camels at this site.
- Active throughout the day with increased activity around dawn and dusk (in winter), but a small number of events at night were recorded.
- The capturing of images at night indicates that camels are being kept in the reserve at night, which is against the law.

Global conservation status:
Not Applicable

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	2	8	39
Ghabah Winter 2013	27	5	37	330
Nukhailan Summer 2013	30	5	42	265
Nukhailan Winter 2012	30	11	143	996

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0.16 (0.08)	0.07	N/A	N/A
Ghabah Winter 2013	1.39 (0.32)	0.19	0.19 (0.08)	0.23 (0.04)
Nukhailan Summer 2013	1.16 (0.22)	0.17	0.17 (0.07)	0.24 (0.04)
Nukhailan Winter 2012	3.54 (0.36)	0.37	0.37 (0.09)	0.29 (0.03)

Activity pattern

Summer

Winter

Distribution maps

Summary

Summer

Ghabah

Camel
- 1 event / 100 days
- 10 events / 100 days
- Camera
- Failed camera
- 680-800 MASL
- 800-1000 MASL
- >1000 MASL

Nukhailan

Camel
- 1 event / 100 days
- 10 events / 100 days
- Camera
- Failed camera
- 680-800 MASL
- 800-1000 MASL
- >1000 MASL

Winter

Ghabah

Camel
- 1 event / 100 days
- 10 events / 100 days
- Camera
- Failed camera
- 680-800 MASL
- 800-1000 MASL
- >1000 MASL

Nukhailan

Camel
- 1 event / 100 days
- 10 events / 100 days
- Camera
- Failed camera
- 680-800 MASL
- 800-1000 MASL
- >1000 MASL

16)   DONKEY (*Equus asinus*)

Species notes
- Like other livestock, donkeys were not recorded in Ghabah.
- Detected most frequently in the wadi bed, with very few events recorded on the plateaus or slopes of Nukhailan.
-

Global conservation status:
Not Applicable

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	0	0	0
Ghabah Winter 2013	27	0	0	0
Nukhailan Summer 2013	30	8	49	345
Nukhailan Winter 2012	30	13	69	396

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0	0	N/A	N/A
Ghabah Winter 2013	0	0	N/A	N/A
Nukhailan Summer 2013	1.42 (0.23)	0.23	0.24 (0.08)	0.19 (0.03)
Nukhailan Winter 2012	1.69 (0.21)	0.43	0.45 (0.10)	0.14 (0.02)

Activity pattern
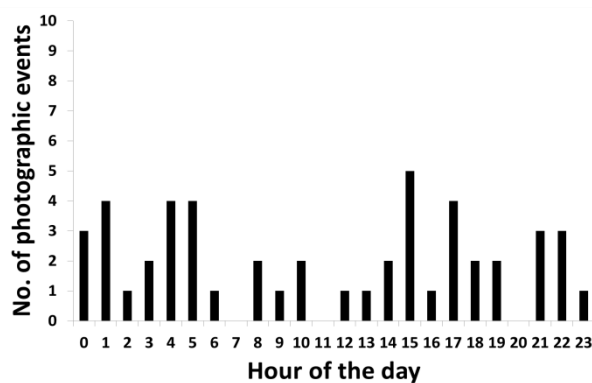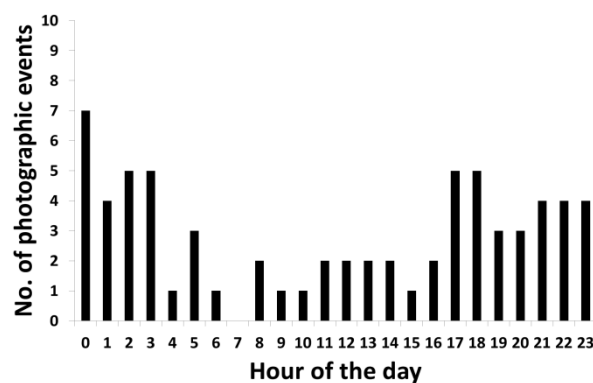
Summer

Winter

Distribution maps
Summer

Winter

17)   SHEEP & GOAT

Species notes
- The species were classified as shoat, with both goat and sheep often herded together by the Bedouin (Lancaster & Lancaster, 1999).
- Mixed flocks of sheep and goats were recorded in Nukhailan only, mainly in large groups of approximately twenty in size. Encounter rate 50% less in winter compared to summer.

Global conservation status:
Not Applicable

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	0	0	0
Ghabah Winter 2013	27	0	0	0
Nukhailan Summer 2013	30	4	34	652
Nukhailan Winter 2012	30	3	18	312

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0	0	N/A	N/A
Ghabah Winter 2013	0	0	N/A	N/A
Nukhailan Summer 2013	0.91 (0.17)	0.13	0.13 (0.06)	0.22 (0.05)
Nukhailan Winter 2012	0.45 (0.11)	0.10	0.10 (0.06)	0.21 (0.05)

Activity pattern
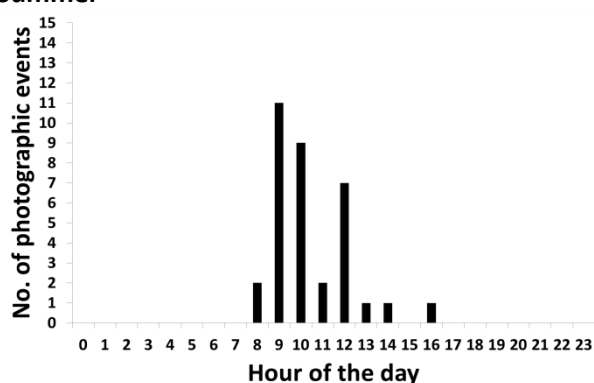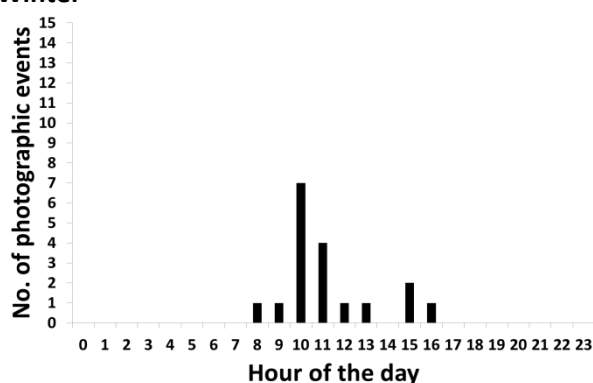
Summer

Winter

Distribution maps
Summer
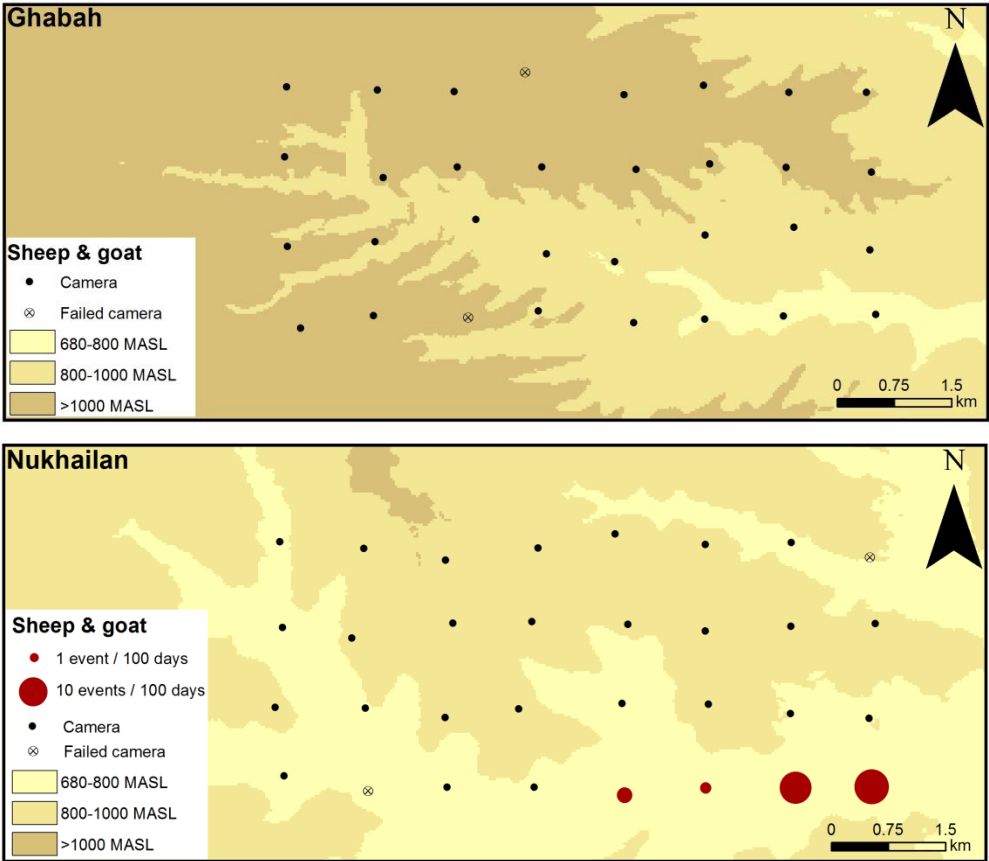
Winter
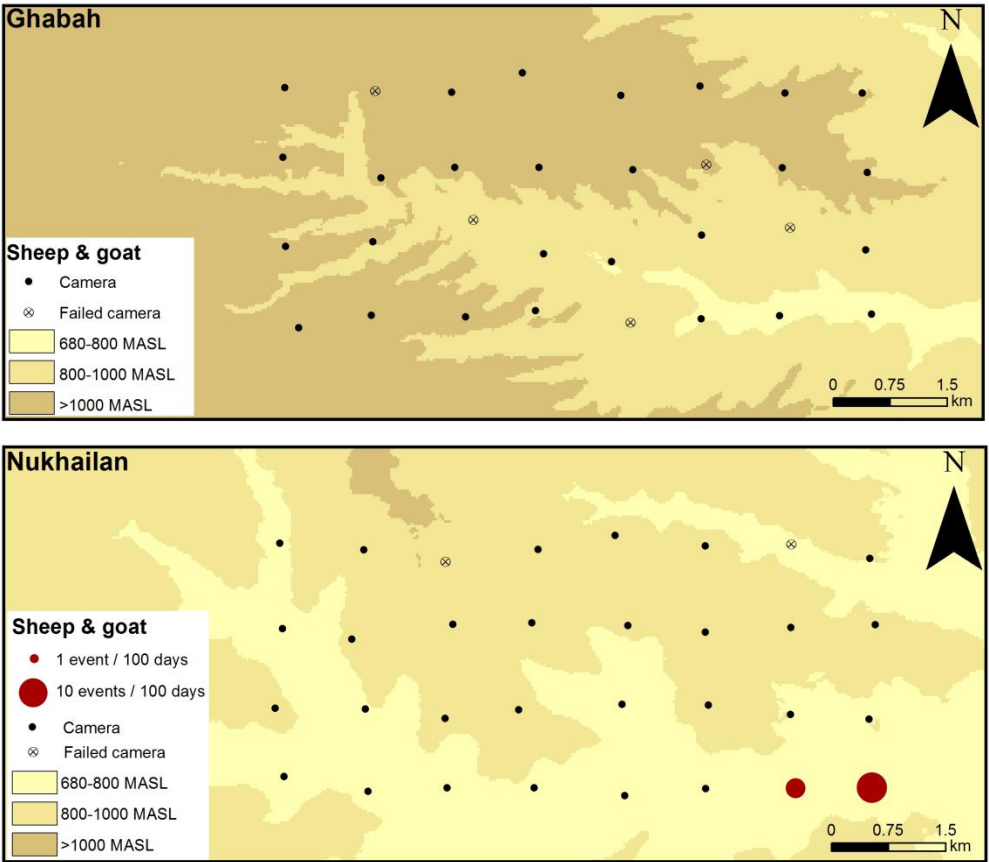
18)   HONEY BADGER (*Mellivora capensis*)

Species notes
- An image of this species in the Ibex Reserve was obtained by an off-grid camera-trap set opportunistically by reserve rangers and is included here as the first confirmed record of honey badger for the reserve.

Global conservation status:
Least Concern (Doh Linh San et al., 2016)

Camera trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
Ghabah Summer 2012	30	0	0	0
Ghabah Winter 2013	27	0	0	0
Nukhailan Summer 2013	30	0	0	0
Nukhailan Winter 2012	30	0	0	0

Trapping rates, occupancy and detectability

Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
Ghabah Summer 2012	0	0	N/A	N/A
Ghabah Winter 2013	0	0	N/A	N/A
Nukhailan Summer 2013	0	0	N/A	N/A
Nukhailan Winter 2012	0	0	N/A	N/A

Activity pattern

A single night time record and low quality image.

5. Conclusions and recommendations

The Ibex Reserve is an important protected area for the conservation of the Nubian ibex and other desert adapted species in Saudi Arabia. It is also a multi-use reserve where camel and livestock grazing is allowed in certain areas. However, reduction of plant species diversity, biomass and therefore food for mammals as a result of overgrazing by domestic animals has been documented (Campbell 1996, Gallacher & Hill 2008, Wronski 2010, Al-Khamis 2012). This camera-trap study is the first detailed assessment on the status of medium-to-large mammals in two wadis in the reserve: one with camel exclusion barriers and the other where controlled grazing is allowed.

The study has confirmed that the Ibex Reserve continues to support a functioning community of desert adapted predators and herbivores. Eleven medium-to-large mammal species were recorded. Five medium-to-large mammal species expected in the study area according to available distribution maps and literature were not detected, but as the reserve is peripheral to the striped hyenas range and there hasn't been a local sighting recently it seems likely the striped hyaena has been extirpated from the reserve.

The reserve's flagship species, the Nubian ibex, was the most frequently encountered species. However, the species abundance as measured by two metrics, trapping rate and occupancy, was significantly higher in the camel exclusion zone of Ghabah. This is the region of highest altitude and is also furthest from the peripheral urban and agricultural developments around the reserve boundaries. Lower occupancy and trapping rates were recorded at Nukhailan where controlled camel grazing is allowed and which is at lower altitude and closer to the reserve boundary. Standardised monthly transect surveys carried out in eleven wadis across the reserve by park management since 2005 have shown an overall decline in Ibex sighting rates (number of Ibex per km surveyed) (Barichievy et al., *in prep)*. Camera-trap surveys in these areas would be useful to confirm the trends.

Patterns of ibex distribution changed seasonally in Ghabah, congregating in the wadi bed during summer and dispersing to the plateaus and slopes in the winter. This is most likely due to the floor of the wadi providing more food than the sparse shrubs and annuals on the plateau, along with reduced exposure to high temperatures and easier access to water during the summer months. In contrast, the ibex were virtually absent from the main wadi bed in Nukhailan in both seasons and were largely restricted to the slopes and plateaus and in the smaller wadi bed to the north where camels were not detected. The use of steep slopes has been documented as a primary response by the species when continuously disturbed or threatened (Hochamn & Kotler 2006). Detailed occupancy analysis of camera-trap data reported in a separate publication has shown environment variables: altitude, habitat and slope, and disturbance (camel presence/absence) to significantly affect ibex distribution.

Other notable findings from the survey included:

1. The reserve still retains a population of the reintroduced Arabian gazelle with most records from the wadi bed in Nukhailan. There were also significantly more detections in winter when camels were also encountered more frequently. It is likely that the higher temperatures during the summer season leads to a general reduction in activity as a key water and energy saving mechanism, which could account for the reduced detections during the summer compared to the winter. The reintroduction of the species was started in Ghabah with more animals released there and population numbers were at one time much higher in Ghabah (Dunham 1997, 2001), but now appear to have collapsed. They have persisted better in Nukhailan. The exact reasons for this remain unknown.

2. First images of the Arabian wolf in the reserve. Previous evidence was limited to tracks and prey kills reported by Wronski & Macasero (2008).

3. The Arabian red fox was the most abundant predator species within the reserve and was most frequently encountered in Nukhailan during the summer. The higher relative abundance in Nukhailan compared to Ghabah is most likely due to the higher human activity within this part of the reserve, given the species is an opportunistic omnivore (Macdonald et al., 1999).

4. Confirmation of range extension of bushy-tailed jird south from the isolated population known from around Riyadh and an increase of the upper elevation limit from 600 to 951 meters. Previously only known from a single isolated record in central Saudi Arabia (Schlitter et al., 2008).

5. The study has shown that camera-trapping can be a useful tool for long-term monitoring of mammals in the reserve. Conventional methods such as distance sampling are often not suitable for obtaining reliable population estimates for desert mammals given their low numbers and combination of wide ranging patterns, nocturnal and solitary behaviour.

6. References

Al-Khamis, H.H., Al-Hemaid, F.M., & Ibrahim, A.S.S. (2012) Diversity of perennial plants at Ibex Reserve in Saudi Arabia. *The Journal of Animal and Plant Sciences*, *22*, pp.484-492.

Alkon, P.U., Harding, L., Jdeidi, T., Masseti, M., Nader, I., de Smet, K., Cuzin, F., & Saltz, D. (2008) *Capra nubiana*. The IUCN Red List of Threatened Species 2008: e.T3796A10084254.

AL-Shaya, M., El Hag, E., & Muneer, S.E. (2007) The role of people's knowledge and attitudes in conservation of wildlife in the natural reservations: a case study of the Ibex Reservation in AL-Riyadh Region, Saudi Arabia. *Saudi Journal of Biological Sciences*, *14*(1), pp.123-135.

Amin, R., Andanje, S. A., Ogwonka, B., Ali, A. H., Bowkett, A. E., Omar, M., & Wacher, T. (2014) The northern coastal forests of Kenya are nationally and globally important for the conservation of Aders' duiker Cephalophus adersi and other antelope species. *Biodiversity and Conservation*, 1-18.

Amin, R., Bowkett, A. E., & Wacher, T. (2015) The use of camera-traps to monitor forest antelope species. Chapter 11 in Bro-Jørgensen J, Mallon D (editors) Antelope conservation in the 21st century: from diagnosis to action. Conservation Science and Practice Series. Oxford: Wiley-Blackwell.

Amin R., Davey K., Fitzmaurice A., Stokes, H., Bruce, T., & Wacher, T. (2016) ZSL Camera Trap Data Analysis Tool: User Manual Version 1.0. Pages 1 – 143.

Amr, Z., Shenbrot, G., & Molur, S. (2008) *Acomys dimidiatus*. The IUCN Red List of Threatened Species 2008: e.T136471A4296336.

Butynski, T., Hoeck, H., Koren, L., & de Jong, Y.A. (2015) *Procavia capensis*. The IUCN Red List of Threatened Species 2015: e.T41766A21285876.

Campbell, J.P. (1996) The effects of camels on forage for Mountain gazelles and Nubian Ibex in Saudi Arabia (Doctoral dissertation, UNIVERSITY OF MINNESOTA).

Child, G., & J. Grainger. (1990) A system plan for protected areas for wildlife conservation and sustainable rural development in Saudi Arabia. NCWCD, Riyahd and IUCN, Gland. 335 pp.

Davies, J., Poulsen, L., Schulte-Herbrüggen, B., Mackinnon, K., Crawhall, N., Henwood, W.D., Dudley, N., Smith, J., & Gudka, M. (2012) Conserving Dryland Biodiversity. xii +84p

Do Linh San, E., Begg, C., Begg, K., & Abramov, A.V. (2016) *Mellivora capensis*. The IUCN Red List of Threatened Species 2016: e.T41629A45210107.

Dunham, K. M. (1997) Population growth of mountain gazelles Gazella gazella reintroduced to central Arabia. *Biological Conservation*, *81*(3), 205-214.

Dunham, K. M. (2001) Status of a reintroduced population of mountain gazelles Gazella gazella in central Arabia: management lessons from an aridland reintroduction. *Oryx*, *35*(02), 111-118.

Durant, S.M., Pettorelli, N., Bashir, S., Woodroffe, R., Wacher, T., De Ornellas, P., Ransom, C., Abáigar, T., Abdelgadir, M., El Alqamy, H., & Beddiaf, M. (2012) Forgotten biodiversity in desert ecosystems. *Science*, *336*(6087), pp.1379-1380.

Durant, S.M., Wacher, T., Bashir, S., Woodroffe, R., Ornellas, P., Ransom, C., Newby, J., Abáigar, T., Abdelgadir, M., El Alqamy, H., & Baillie, J. (2014) Fiddling in biodiversity hotspots while deserts burn? Collapse of the Sahara's megafauna. *Diversity and Distributions*, *20*(1), pp.114-122.

Efford, M.G., & Dawson, D.K. (2012) Occupancy in continuous habitat. *Ecosphere*, *3*(4), pp.1-15.

Gallacher, D.J., & Hill, J.P. (2008) Effects of camel grazing on density and species diversity of seedling emergence in the Dubai (UAE) inland desert. *Journal of arid environments*, *72*(5), pp.853-860.

Geffen, E., & Peters, G. (2013) *Vulpes cana* Blanford's Fox. In: J. Kingdon and M. Hoffmann (eds), *Mammals of Africa. Volume 5. Carnivores, Pangolins, Equids and Rhinoceroses*, pp. 60-62. Bloomsbury, London.

Gompper, M.E., Kays, R.W., Ray, J.C., Lapoint, S.D., Bogan, D.A., & Cryan, J.R. (2006) A comparison of noninvasive techniques to survey carnivore communities in northeastern North America. *Wildlife Society Bulletin*, *34*(4), pp.1142-1151.

Hochman, V., & Kotler, B.P. (2007) Patch use, apprehension, and vigilance behavior of Nubian Ibex under perceived risk of predation. *Behavioral Ecology*, *18*(2),pp.368-374.

Hoffmann, M., & Sillero-Zubiri, C. (2015) *Vulpes cana*. The IUCN Red List of Threatened Species 2015: e.T23050A48075169.

Hoffmann, M., & Sillero-Zubiri, C.(2016) *Vulpes vulpes*. The IUCN Red List of Threatened Species 2016: e.T23062A46190249.

Huggel, A. (2012) Exiv2 software tool. http://www.exiv2.org/index.html Accessed 16 May 2012.

Hutterer, R. (2016) *Paraechinus aethiopicus*. The IUCN Red List of Threatened Species 2016: e.T40606A22326233.

IUCN (2016) *The IUCN Red List of Threatened Species. Version 2016-2*. <http://www.iucnredlist.org>. Downloaded on 06 July 2016.

Kelly, M.J. (2008) Design, evaluate, refine: camera trap studies for elusive species. *Animal Conservation*, *11*(3), pp.182-184.

IUCN SSC Antelope Specialist Group. (2008) *Gazella arabica*. The IUCN Red List of Threatened Species 2008: e.T8981A12946441.

Lancaster, W., & Lancaster, F. (1999) *People, land and water in the Arab Middle East: environments and landscapes in the Bilad ash-Sham* (Vol. 2). Taylor & Francis.

Lyra-Jorge, M.C., Ciocheti, G., Pivello, V.R., & Meirelles, S.T. (2008) Comparing methods for sampling large-and medium-sized mammals: camera traps and track plots. *European Journal of Wildlife Research*, *54*(4), pp.739-744.

Macdonald, D.W., Courtenay, O., Forbes, S., & Mathews, F. (1999) The red fox (Vulpes vulpes) in Saudi Arabia: loose-knit groupings in the absence of territoriality. *Journal of Zoology*, *249*(04), pp.383-391.

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L., & Hines, J. E. (2006) Occupancy estimation and modelling. Elsevier, Amsterdam.

Mallon, D., & Budd, K. (2011) Regional Red List Status of Carnivores in the Arabian Peninsula. IUCN and Environment and Protected Areas Authority, Cambridge, UK; Gland, Switzerland; and Sharjah, UAE.

Mallon, D., Murdoch, J.D., & Wacher, T. (2015) *Vulpes rueppellii*. The IUCN Red List of Threatened Species 2015: e.T23053A46197483.

McCallum, J. (2013) Changing use of camera traps in mammalian field research: habitats, taxa and study types. *Mammal Review*, *43*(3), pp.196-206.

Mech, L.D., & Boitani, L. (IUCN SSC Wolf Specialist Group). (2010) *Canis lupus*. The IUCN Red List of Threatened Species 2010: e.T3746A10049204.

Millennium Ecosystem Assessment., (2005) Ecosystems and Human Well-Being: Synthesis (Island Press, Washington, DC).

Roberts, N.J. (2011) Investigation into survey techniques of large mammals: surveyor competence and camera-trapping vs. transect-sampling.*Bioscience Horizons*, *4*(1), pp.40-49.

Robinson, E.R. (2008) Climatic Data of the Ibex Reserve 1991- 2008. Annual Report 2008. King Khalid Wildlife Research Centre, Thumamah, Saudi Arabia.

Schlitter, D., Shenbrot, G., Amr, Z. & Kock, D. (2008) *Sekeetamys calurus*. The IUCN Red List of Threatened Species 2008: e.T20089A9145058.

Silveira, L., Jacomo, A.T., & Diniz-Filho, J.A.F. (2003) Camera trap, line transect census and track surveys: a comparative evaluation. *Biological Conservation*, *114*(3), pp.351-355.

Tobler, M. W., Carrillo-Percastegui, S. E., Leite Pitman, R., Mares, R., & Powell, G. (2008) An evaluation of camera traps for inventorying large-and medium-sized terrestrial rainforest mammals. *Animal Conservation*, *11*(3), 169-178

Wronski, T., & Macasero, W. (2008) Evidence for the persistence of Arabian Wolf (Canis lupus pallipes) in the Ibex Reserve, Saudi Arabia and its preferred prey species. *Zoology in the Middle East*, *45*(1), pp.11-18.

Wronski, T. (2010) Factors affecting population dynamics of re-introduced mountain gazelles (Gazella gazella) in the Ibex Reserve, central Saudi Arabia. *Journal of arid environments*, *74*(11), pp.1427-1434.

Wronski, T., Sandouka, M.A., & Butynski, T.M. (2011) Twenty years conservation and monitoring of re-introduced Mountain Gazelle in the Ibex Reserve, Saudi Arabia. *Global re-introduction perspectives*, pp.175-179.

Yamaguchi, N., Kitchener, A., Driscoll, C., & Nussberger, B. (2015) *Felis silvestris*. The IUCN Red List of Threatened Species 2015: e.T60354712A50652361.

Yom-Tov, Y., & Mendelssohn, H. (1988) Changes in the distribution and abundance of vertebrates in Israel during the 20th century. In: Y. Yom-Tov & E. Tchernov (eds), *The zoogeography of Israel*, pp. 515-547. Dr. W. Junk Publishers, The Netherlands.

Annex I: Bird and reptile species

Twenty bird species and five reptile species were also photographed in the camera trap arrays in Ghabah and Nukhailan within the Ibex Reserve. These are listed below.

Family	Species	Common name	GS	GW	NS	NW	IUCN status
Alaudidae	*Ammomanes deserti*	Desert lark	Y	Y	Y	Y	LC
Columbidae	*Columba livia*	Rock dove	-	Y	Y	-	LC
Columbidae	*Streptopelia decaocto*	Eurasian collared dove	Y	Y	Y	Y	LC
Columbidae	*Streptopelia senegalensis*	Laughing dove	-	-	-	Y	LC
Corvidae	*Corvus ruficollis*	Brown-necked raven	-	Y	-	-	LC
Emberizidae	*Emberiza striolata*	Strioalted bunting	-	Y	Y	Y	LC
Falconidae	*Falco tinnunculus*	Common kestrel	-	-	-	Y	LC
Laniidae	*Lanius meridionalis*	Southern Grey Shrike	-	-	Y	-	?
Meropidae	*Merops orientalis*	Green bee-eater	Y	-	-	-	LC
Muscicapidae	*Oenanthe leucopyga*	White-crowned wheatear	Y	Y	Y	Y	LC
Muscicapidae	*Oenanthe melanura*	Blackstart	Y	Y	Y	Y	LC
Muscicapidae	*Oenanthe oenanthe*	Northern wheatear	-	-	Y	-	LC
Passeridae	*Passer hispaniolensis*	Spanish sparrow	Y	Y	Y	Y	LC
Phasianidae	*Ammoperdix heyi*	Sand partridge	Y	Y	Y	Y	LC
Phylloscopidae	*Phylloscopus collybita*	Common chiffchaff	-	Y	-	-	LC
Pycnonotidae	*Pycnonotus xanthopygos*	White-spectacled bulbul	-	Y	Y	Y	LC
Scotocercidae	*Scotocerca inquieta*	Streaked Scrub-warbler	-	Y	-	-	LC
Strigidae	*Bubo ascalaphus*	Pharaoh eagle owl	Y	Y	-	Y	LC
Turdoides	*Turdoides squamiceps*	Arabian babbler	Y	Y	Y	Y	LC
Upupidae	*Upupa epops*	Hoopoe	Y	-	Y	Y	LC

Reptilia	Species	Common name	GS	GW	NS	NW	IUCN status
Agamidae	*Agamidae sp.*	Agamid lizard	Y	Y	Y	-	?
Agamidae	*Pseudotrapelus sinaitus*	Sinai agama	-	Y	-	-	?
Agamidae	*Uromastyx aegyptia*	Egyptian spiny-tailed lizard	Y	Y	-	-	VU
Phrynosomatidae	*Uma sp.*	Fringe-toed lizard	-	-	Y	-	?
Varanidae	*Varanus griseus*	Grey monitor	-	-	Y	Y	?

GS: Ghabah summer survey; GW: Ghabah winter survey

NS: Nukhailan summer survey; NW: Nukhailan winter survey

IUCN Red List categories: LC: Least Concern, VU: Vulnerable,? = Not assessed