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Seasonal Dynamics of Herd Structure of Re-introduced Arabian Oryx in the Dubai Desert Conservation Reserve, United Arabian Emirates

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Declaration

I hereby declare that I have done this thesis entitled “Seasonal Dynamics of Herd Structure of Re-introduced Arabian Oryx in the Dubai Desert Conservation Reserve, United Arabian Emirates” independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 13.05.2020

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Sofiia Pyshnieva

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Abstract

Arabian oryx is the biggest antelope of the Arabian Peninsula. In 1972 population of oryx became extinct in the wild, but was successfully brought back to its original habitat with the help of re-introduction program already in 1980s. Current research aimed to study seasonal dynamics in herd structure and activity pattern of semi-wild population of Arabian oryx on one of the sites of re-introduction in the United Arab Emirates - Dubai Desert Conservation Reserve (225 km^2). Records from camera trap station and rangers` reports were analysed to reveal seasonal changes in herd composition within and between years - 2011 and 2019. Time pattern of records, amount of independent events, age-sex structure of herds, group size, density and abundance estimation were compared throughout these two years. Moreover, these parameters were compared within and between natural and improved areas (with water and feed supplies).

Results confirmed that there was a seasonal shift in activity pattern within and between studied years. In 2011 activity pattern revealed that Arabian oryx were active half of the day and were mostly crepuscular animals. In 2019 at artificially improved location the activity budget was much wider and following another distribution, i.e. with several daily peaks. Camera trap records analysis revealed, that there has been seasonal variation in detection rate of animals and their density, moreover some areas were more preferred by animals than the others. According to direct regular counts, abundance tended to increase during the year from winter to summer season. It was shown, that random encounter model (REM) is promising tool to use in fenced reserves with sufficient resource capacity to study species density. Comparison of advantages and disadvantages of different approaches in data collection resulted in the list of suggestions to improve research agenda of the DDCR. Obtained results might serve as a valid baseline for management team to apprehend potential issues in oryx population dynamics and improve current survey practises. Consistent research on seasonal dynamics of re-introduced Arabian oryx population in the range-limited facilities remain to be essential for assessing the success of wildlife conservation efforts, as well as applying this knowledge to ecologically similar antelope species in semi-arid and arid habitat.

Key words: Arabian oryx, Oryx leucoryx, seasonal dynamics, population dynamics, herd structure, camera trapping, random encounter model.

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List of the abbreviations used in the thesis

CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora

CT – Camera trap(s)

CTD – Camera trap days

DDCR – Dubai Desert Conservation reserve

FTA – Faculty of tropical AgriSciences

IUCN – International Union for Conservation of Nature

UAE – United Arab Emirates

UNESCO - United Nations Educational, Scientific and Cultural Organisation

WWF – World Wildlife Foundation

1. Introduction

In the modern world wildlife is experiencing the deep multifactorial stress: loss of habitat, excessive pressure and exploitation, high abundance of invasive species, imbalance of the trophic chain, chemical pollution and climate change effects. According to the latest report of World Wildlife Foundation, near 60% of the species of living organisms have disappeared from the planet in last 40 years (WWF International 2016). Biodiversity plays crucial role in maintenance of ecosystems on local and global scale, it provides a variety of ecosystem services for human population and assure stable ecological development for the region. One of the most crucial parts of ecosystem is keystone species. According to Dictionary of Forestry and Wildlife Science a keystone species is an animal and plant species (or any other living organism in general) identified as species of conservation importance, without which an ecosystem would collapse or change drastically and will perform different ecological functions and services (Kailash Chandra Bebarta, 2011). Therefore, detailed research and cultivation of nature of these species in needed. Conservation initiatives are needed, as an effective way to prevent irreparable loss of key species.

Since the middle of the XXth century conservation approach started to be more complex and focused not on animal or keystone species individually, but on its interconnection with environment, its interaction with other species and member of social group; dependences on seasonal changes; influence of climate events and human disturbance on its natural behaviour (Primark 2000). Moreover, nowadays conservation strategy includes socio-economic factors related to people living in the same environment, thus sharing resources with the species. The International Union for Conservation of Nature (IUCN), established in 1948, promotes the idea of scientifically based species conservation in cooperation with local community and involving a wide variety of stakeholders. Such efficient strategy brings benefits to world biodiversity: more than 1,500 wildlife species were part of a program of restoration of lost biodiversity locally or globally in 2013 - 2019 (IUCN/SSC 2013).

Current research project is focusing on Arabian oryx (*Oryx leucoryx*) - the biggest antelope of the Middle East. Population of this magnificent animal vanished from original habitats of Arabian Peninsula in 1972 due to unsustainable trophy hunting and overhunting with the purpose of blood collection for traditional medical applications (Harding et al. 2007). Fortunately, due to effort of conservationist and government institutions the small herd of Arabian oryx was returned to the desert habitat in the end of the XXth century. This significant project of reintroduction was the first documented case when a species considered extinct in the wild would change the conservation status from "critically endangered" to "endangered" (General Secretariat for Conservation of Arabian Oryx 2010). Recently, populations of Arabian oryx with total amount of more than 12,000 animals have been recorded in the Jordan, Iraq, Kuwait, Oman, Palestine, Saudi Arabia, Syria, Yemen and United Arab Emirates (Lignereux et al. 2018). But only 9% of Arabian population is re-introduced into wild (Lignereux & AlKharusi 2011).

What is important to mention, definition of “successful conservation” varies in conservation theory. Definitely, it is more complex, than just an action to prevents the extinction of the species (Ehrlich & Sodhi 2010). In addition to this valuable outcome, Kent Redford and George B. Amato offered several criteria to specify the “true success” of species conservation: populations should be healthy and self-sustaining, genetically diverse and flexible to environmental changes (Redford et al., 2011). These indicators support the requirements of the IUCN guidance for species translocation and re-introduction: management should perform the monitoring of the demographic performance after the animals` release (population growth and spread; estimation of individual survival, reproduction rate, etc.) (IUCN/SSC 2013).

Current research on Arabian oryx population helped to collect data on two out of three criteria to support management team evaluation with scientific data. Therefore, research can be used to investigate how successful was the re-introduction program at one of the centres of re-introduction, what is the present condition of population and how to improve the management strategy to guarantee the future maintenance of semi-wild animals. Social composition of Arabian oryx herds, critical temperature regime of the desert, population trends and census methods of work with semi-wild ungulate population were under the research focus.

1.1. Population structure of ungulates

Artiodactyla is a wide group of mammals, which includes such familiar even-toed ungulates as pigs, sheep, goats, cows, deer, giraffes, camels, and antelopes. It is a very diverse group displaying a wide range of social behaviours and strategies, including solitary individuals or really gregarious animals forming groups from several individuals up to very large herds. Herd composition include various characteristics:

- sex composition – male, female;
- age group – new born, juvenile, sub-adult, adult;
- reproduction cycle stage – pregnant, not-pregnant;
- group size – small, medium, big, solitary animal.

Parameters in each of these categories give understanding of population ecology and provide data on prediction and modelling future.

1.1.1. Social organisation of ungulates

Population heterogeneity of ungulates and influence of certain ecological factors on it attract researchers and for a long time it stays under the continuous study. Visually it is possible to divide ungulates into two big groups: with and without sexual dimorphism (dimorphic and monomorphic species, respectively). Sexual dimorphism in ungulates is linked to social and habitat segregation. Visually males and females can vary in size, colour, presence of horns or special colour marks. Monomorphic species, on the other hand, have no or very little difference in body-size, colour or other visual expression between females and males. Relatively small number of ungulates is monomorphic: some antelopes from family Alcelaphinae, Hippotragini tribe - roan (*Hippotragus equinus*), sable *(Hippotragus niger*), and oryx, Kirk's dik-dik (*Madoqua kirkii*), the oribi (*Ourebia ourebi*) (Ruckstuhl & Neuhaus 2009), bit amount of gazelle species.

There are several types of social grouping among ungulates, recorded both for monomorphic and dimorphic species: bachelor herd, breeding herd with female(s) and calves, mixed group (Ruckstuhl & Neuhaus 2009). There are some species that prefer to live solitary. If animals form the herd, it has the species-specific rank structure inside. Moreover, gregarious species of ungulates tended to form a fission–fusion society, i.e. those where group size and composition can change with time duration and movement of the animals in space.

There is classic study on social organisation of African ungulates, conducted by professor Peter Jarman in 1973. He investigated how feeding style and food availability dictate limits to maximum number of animals in a group and its sex-age composition. Taking into account how selective the diet of the ungulate, he suggested, that it may influence the size of social unit and distinguished antelopes in particular into 5 social classes (Jarman 1974). To understand the general system in social composition of ungulates from arid and semi-arid climate zones we will briefly describe these classes. Class A includes solitary or paired animals, who feed selectively on certain part of the plant and this species are pre-dominantly browsers. They found to be territorial and have small body size. Typical species are animals from genus *Madoqua, Neotragus, Raphicerus, Dorcatragus*. Class B species form group up to 12 individuals (on average 3-6 individuals). The adult females are forming a mini-herd and this groups are unstable, while part of adult males are territorial. Antelopes of class B are selective in plants body part and can be both grazers or browsers. Gerenuk (*Litocranius walleri*), lesser kudu (*Tragelaphus imberbis*), bushbuck (*T. scriptus*) are in this class. Next, class C linked to larger antelopes, like nyala (*Tragelaphus angasii*greater) kudu (*T. strepsiceros*), impala (*Aepyceros melampus*), who feed on the wide range of grass and browse vegetation. They tend to organise groups of 10-60 individuals, even large if the area capacity supports it. Large groups are formed by females with offsprings. Males are territorial. During the breeding season the male, who is guarding the certain land patch is accompanying the female herd, which entered his "property", and has a mating privilege. Bachelor herds are formed from sub-adult males and those adults, who have no territory. Such herds as well are allowed to enter the territory of dominant male so far, as they do not compete for mating. Male can lose territory to a stronger male competitor. A lot of common in social organisation with class C has the class D: part of adult males holds solitary territories, subordinate males are grouped in bachelor herds, female groups are bigger in size and include offspring. However, these species can form super-herds, their aggregation is seasonal without fixed home range and linked to migration. Group size in class D species varies throughout the seasons and years and females are accompanied by youngsters up to 3 years, before separation will happen. This class includes *Alcelaphinae* subfamily species, feeding rather unselective for plant species, but selectively on plant parts. The last class E includes wide group of antelope (genus *Oryx,* genus *Syncerus,* genus *Taurotragus*). In the wild they reported to form groups up to hundreds and thousands in favourable condition, feeding on variety of vegetation, being not strictly selective browsers or grazers. Some of species express seasonal variation in group size, but overall changes are not big. This is the only class, where tendency to form mixed herds are common. Thus, several mature males are present within one herd; while part of the males are forming independent bachelor herds. Here the strong fission-fusion pattern is detected. Fission of the herd may happen in dry season or when recourses are limited, and fusion is following, when resources become plenty again (Jarman 1974).

Described classification became a solid basis for variety of further researches on social grouping and dynamics in ungulates. However, it is important to remember, that forest ungulates may express completely different herding tendency, as environmental conditions are different in non-arid zones. As example, there is monomorphic ungulates, who is medium-size, but prefer to follow solitary lifestyle for the whole life - Indonesian lowland anoa (*Bubalus depressicornis*).

Despite P. Jarman includes the oryx species into the class E, Estes favour that gemsbok could be more territorial and described as less nomadic (Estes 2012). Scimitar-horned oryx (*Oryx dammah*) recorded to be seldom solitary (Castelló 2016) and reported to form bachelor herds both in nature and in captivity (Gilbert & Woodfine 2004). Subspecies of East African oryx, Fringe-eared oryx *(Oryx callotis)*, was never reported to form bachelor herds in the wild, because, even if large areas are accessible, males express fighting, constant sparring or aggressive behaviour (Lee et al. 2013). The same problem was as well detected for some zoo-populations of Scimitar-horned oryx (Gilbert & Woodfine 2004). All oryx species males reported to be territorial, but with different percentage from total population. Females of all oryx species show stronger trend to gregariousness, what can be explained as a strategy to reduce predation risks to themselves and young calves, which may associate with their mothers for 2-3 years (Lee et al. 2013). That was constantly confirmed, that oryx are mostly found in mixed-sex groups (Strauss 2002; Gilbert & Woodfine 2004; Hetem et al. 2012; Lee et al. 2013). And this fact put them in the special position in comparing to other antelopes and makes oryx interesting object for ethology research (Ruckstuhl & Neuhaus 2009). Mixed herds can be led by an old female, but usually hierarchy headed by alpha bull (Kasiringua et al. 2019). Overall, there is limited data on oryx social composition in different habitat, especially continuous and in comparison of fenced-range and free-ranged subpopulations.

Social composition of herd influenced by sex and age of the individuals, thus their ratios are efficient indicators to assess population trends. There are several age classes to define inside Artiodactyla herd: adults (fully developed individuals, reached maturity, coloration and secondary sexual characteristics are well-developed); sub-adult (usually smaller in size than adults; individuals with not fully developed coloration or secondary sexual characteristics); juvenile (younger than 1-year-old; significantly smaller in size, dependent on parental care, milk-sucking); calf (neonatal individuals). Ungulates are precocial species, they gave birth to well-developed offspring, which in short period of time can join adult parent in daily life. Age ratios are used to calculate fecundity of the herd and survival rate of young in endangered species populations. Some researches, however, argue, that drastic changes in population sizes can go unnoticed if rely only on age ratio (Harris et al. 2008), because different mechanisms may result in the same trend in age ratios. Therefore, not only age and sex parameters should be taken into account in population research of Artiodactyla.

Another important parameter of the social environment of gregarious antelope species is a group size. We already described one approach in predicting the group size of the animal, based on the dietary preferences, offered by P. Jarman (Jarman 1974). But it will be useful to discover wide variety of group sizes among Artiodactyla more detailed and from the position of the habitat type. To illustrate, tropical forest species prefer live in small groups of 2-4 individuals (chinkara, *Gazella bennettii*). Sambar deer (*Rusa unicolor)* showed a tendency to form larger groups in open habitats, while they were often solitary inside forests (Bagchi et al. 2008). In woodlands and savannahs of Africa gemsbok herds recorded to reach up to 200 animals, while Arabian oryx in the sand desert live in groups of 10 or less, despite in former times herds up to 100 individuals were reported (Estes 2012). There are plenty of factors influencing the herd size: from social adaptation to habitat structure (Cunningham & Wronski 2011). It is known, that group size may increase following rainfall and improved grazing period; foraging behaviour are often positively related to the group size (Lange et al. 2008). Animals can fuse into group/herd for some part of the day/season (sleeping, migration) and split (fission) in another period — e.g. foraging in small groups during the day.

Population dynamics observed among years is a direct respond to environmental and social factors: availability of food resources, habitat quality, climatic events, disease and predators influence, anthropogenic activities (Gaillard et al. 1998). Current research in the Dubai Desert Conservation Reserve aimed to access the group changes of the Arabian oryx, thereby enrich understanding of species, reveal influence of natural and artificial factors in the life of ungulates in the re-introduction site.

1.1.2. Activity pattern dynamics

The rhythm of life of the wild animal is dynamic and manifold; day is full of activities and different behaviour. The time spent expressing certain type of behaviour is defined as the “activity level” of the individual and this is an essential component in understanding of the species functional ecology. Common name for natural processes happened with certain regularity over 24-hour time period is circadian rhythm. Circadian physiology of the animal linked to the time point of the day and special environmental characteristics. These rhythms are mostly affected by light and darkness and regulated by the central circadian rhythm generator. In the mammals it is located in hypothalamus, in particular - in suprachiasmatic nucleus (SCN). Light stimulus activate the reaction chain, involving photoreceptors in the retina, SCN, optic nerve and locomotor centres (Korf and von Gall 2013). That is how animals adjust their daily schedule and follow a certain activity pattern, expressing particular type of the behaviour. As circadian rhythms and behaviour have a tendency to replicate themselves from day to day, season to season, such repeated mode is forming the pattern, activity pattern. Ungulates activities and behaviour includes: walking, standing, foraging, mating, fleeing, fighting, defecation, rearing and communication and more. Some activities are strictly linked to the time of the day, some to the season, some to the triggers from the environment. Those, which linked to the season changes are forming seasonal dynamics and will be discussed later. Study of the activity pattern and factors, influencing its natural expression help to form understanding on ecosystem complexity and predict animal respond in changing conditions.

There are 4 type of animals, according to the chosen day-niche and activity pattern: diurnal (day-active), cathemeral (no time-of-day preference), nocturnal (night-active) and crepuscular (active at dawn and/or dusk). For example, plains zebra (*Equus quagga*) and sable antelope (*Hippotragus niger*) tend to be diurnal animals, while African buffalo (*Syncerus caffer*) maintained similar activity levels through the day and night (Owen-Smith & Goodall 2014). Moreover, depending of the species the shape of the activity waveform differs: some can be active in a single daily peak, others have two or more daily peaks, e.g. crepuscular animals. (Phillips et al. 2013) White-tailed deer (*Odocoileus virginianus)* activity curves have been reported as strongly bimodal (Webb et al. 2010). Scimitar-horned oryx is characterised by crepuscular activity patterns, what is typical for desert inhabitants, as such activity patterns help to minimise water loss (Gilbert & Woodfine 2004).

Intraspecific as well as interspecific competition plays important role in ungulate decision of lifestyle. For the ungulates several studies revealed, that peaks of their activity correspond to local predators activity peak (Tang et al. 2019). Wolves are known to influence movements of elk and white-tailed deer (van Beest *et al.*, 2013). One of the form of interspecific competition is human-wildlife interaction. It was mentioned, that presence of human next to animal habitat range or human activity focused on the animals can affect them as strong as environmental factors. It has been documented that human activities lead to an increase in the daily movement of the American bison (*Bison bison*). Red deer (*Cervus elaphus)* and the European roe deer (*Capreolus capreolus*) have increased level of vigilance behaviour if their home range is close to human settlements. In Ecuador in the areas where hunting culture is well-developed, the red brocket deer (*Mazama americana*) was recorded to increases its activity peaks during the night, probably to avoid hunters (Espinosa & Salvador 2017). East-African oryx (*O.beisa*), blackbuck *(Antilope cervicapra)* exhibit a polyphasic rhythm of life, i.e. animal can rest 4 to 6 times during a day (Walther 1978). Such studies boost the curiosity to explore activity pattern of ungulates with novel methods, technologies and reveal the fluctuation in natural behaviour of the species.

1.1.3. Seasonal activity as adaptation to the environment

While some behaviour can change throughout the 24-h cycle, other is being expressed by animals only in certain time of the year. The predictable fluctuation in activity pattern that repeats over a one-year period called seasonal dynamics. In the life of ungulates, these dynamics coincide with the seasons of year, when some environmental and biological processes are taking place. Environmental factors include: vegetation seasonal growth, length and intensity of the solar radiation, temperature fluctuation, moon phase, rainfall level, etc. Moreover, anthropogenic activity may influence the natural spin of life (Espinosa & Salvador 2017). All factors in combination influence and trigger biological and physiological mechanisms in animal body - hormone release, behavioural changes, vitamin accumulation, etc. It is recorded that in the temperate zone domestic sheep begin to breed in the early autumn and cease during the winter. Then after, in the spring the lambs are born when pastures are maximally available (Ortavant et al. 1988). The same pattern is recorded to be in population of the wild ungulate species. For instance, offspring of hartebeest (*Alcelaphus buselaphus*), topi (*Damaliscus lunatus jimela*), impala (*Aepyceros melampus)* are born at the year season (usually spring) when feed and nutritional support of the individual is guaranteed (Ogutu et al. 2014). Large desert ungulates also using this strategy (Davimes et al. 2017). Regarding the desert species, the temperature regime has the leading role in their seasonal flexibility. Large mammals tend to be inactive during the hottest part of the day, what assure optimal heat control of the body (Ward 2009). Arabian oryx (*Oryx leucoryx*) express a continuous 24-hour activity pattern with crepuscular peaks in cooler months (winter season), while the hot summer season they became predominantly nocturnal (Hetem et al. 2012; Davimes et al. 2017). Precisely in the range-limited protected areas the seasonal dynamics were poorly studied.

1.2. Arabian oryx – flagship species of the Arabian Peninsula

The focus species of current work was the Arabian oryx (*Oryx leucoryx*, Pallas, 1777). It is the largest species of antelope on the Arabian Peninsula. This animal is well known among local communities as a symbol of strength, resistance and beauty. In the beginning of 1970s, due to overexploitation, habitat loss and unsustainable trophy hunting population of Arabian oryx dramatically decreased. In 1972 the last wild living oryx was killed in Oman. Fortunately, already in 1950 conservationist predicting the dramatic decrease of the free ranging animals. And in 1962 WWF together with Preservation Society of London (Flora & Fauna International nowadays) launched the "Operation Oryx", which the goal of catching remained wild animals for captive breeding, study them and potentially - release in the wild. Fruitful results of captive breeding program across the globe allowed to change status of oryx population at UICN Red list from "Extinct from the wild" ("Very rare and believed to be decreasing in numbers" in 1965) to "Vulnerable" (2011). In 2019 species has stable population trend and status "Vulnerable" (IUCN & SSC Antelope Specialist Group 2017).

"Maha" is the local name of the Arabian oryx. Through the centuries, the image of the white desert antelope has inspired artists and explorers; the unique silhouette of a desert unicorn embodied in the form of emblems, logos, symbols of many centres of recreation, education and culture in the UAE. Even more, in 2006 Arabian oryx was a mascot of Asian Games – the second largest multi-sport event after the Olympic Games. Protection of the species from extinction became a priority of national level among different countries of Middle East. UAE, Saudi Arabia, Oman, Bahrain, Jordan, Syria, Yemen – are proud to support the populations in facilities of different management style and overall the population size is reaching almost 13,000 individuals in the Middle East (Lignereux et al. 2018).

1.2.1. Species profile

Arabian oryx is a grazing antelope, which lives in semi-desert and desert environment. It belongs to Family Bovidae, Subfamily Antilopinae (Gray, 1821), Tribe Hippotragini Sundevall, 1845. Together with other 5 species of oryxes *(O. dammah, O. gazelle, O. beisa, O. gallarum, O. b. callotis*) Arabian oryx (*O. leucoryx*) forms genus *Oryx* (Groves & Grubb 2011). Arabian oryx is the only non-African species of all, which was originally spread across the Arabian Peninsula.

Arabian oryx differs from rest of the antelopes by its bright coloration: in adult it is white on the body part with cream, beige to brown part on the moderately long legs and chest. Each individual has dark (brown, almost black) marking on the face. Calves have a cryptic coloration – from the first day calves are brown, sandy colour with further brightening and turning into white (Figure 4). Nowak provides description of the adult antelope as big, up to 153 to 235 cm in body length with tail length is 45-90 cm and shoulder height of 90-140 cm (Nowak 1999). Among all species in the genus, Arabian oryx is not the biggest, but within its home range on the peninsula it is the largest antelope, which can reach up to 120 kg. Both sexes have long horn, from 60 cm up to 150 cm long. Skull and teeth much smaller than in any other oryx species. As well horns are shorter and slender (Castelló 2016). Sexual differences in not significant in oryx species, it’s typical monomorphic species: body mass in female is below 15% or often less (Ruckstuhl & Neuhaus 2009) and the horns of females are usually thinner and longer than males` one (Nowak 1999). Arabian oryx are consider to be the slowest runner in the genus *Oryx*, perhaps due to adaptations to sandy substrates, but it still can reach speeds of up to 60 km/h. Their usual gait is a walk or a slow canter.

In the wild nature oryx can live up to 21 year, while in captivity the longevity of life is increasing to 23 years (Kock et al. 2018). Average maturity age is about 2 years and female can produce 1 calf per year after 250 days (8 month) gestation period. Females are self-isolated from the herd for the first weeks after calf birth. Calves join the herd after 15-45 days and stop weaning after 4-5 month (Lignereux et al. 2018).

The Arabian oryx is a xerocole animal, i.e. adapted to desert living condition (Davimes et al. 2017). There are two major strategies to deal with extremes of temperature in the arid regions: evaders and endurers. Evaders avoid the heat by shifting the activity pattern to the colder period of the day, endurers can tolerate the hot temperatures (Ward 2009). Arabian oryx is a typical endurer. It has special physiological adaptation to harsh environment. Animal can lose excessive body heat by sweating or rising body temperature higher than the air, what allows to radiate heat to the environment. The brain cells are protected from damaging by higher temperatures by cooling blood returning system in the nasal passages: it absorbs heat from arterial blood and blood with already lower temperatures is reaching the brain. Ostrowski reported, that a mean daily body temperature variation of Arabian oryx can reach 4.1 ± 1.7˚C during the summer season and a variation of 1.5 ± 0.6 ˚C during winter months (Ostrowski et al. 2006). Oryx have a lower minimal fasting metabolic rate than many other Artiodactyla (Williams et al. 2001). Moreover, during water restriction, oryxs' kidney might diminish in size, animal might increase urine osmotic concentration and reduced its volume by about 40% (Ostrowski et al. 2006).

"Housing & Husbandry Guidelines for Arabian Oryx" mentioned D.R.M. Stewart as the first researcher studied the species in the wild nature prior to its extinction (Kock et al. 2018). His records of the wild diet of Arabian oryx include grass *Stipagrostis plumose* and *Lasiurus hirsutes* both from family *Poaceae*. The most common plant species nowadays for managed population, recommended by guideline, are: legume Alfalfa (*Medicago sativa)*, Bermuda grass (*Cynodon dactylon*), Orchard grass (*Dactylis glomerata*), Rhodes grass (*Chloris gayana*), Timothy grass (*Phleum pratense*). During personal observation it was noticed, that animals are focusing as well on fruits from date palms (*Phoenix dactylifera).* Oryx is independent from water source, as they can satisfy water requirements from plant-based diet; in wild nature they consume water infrequently, but drink freely if water is available (Kock et al. 2018).

Arabian oryx is gregarious species. They form all variations of social grouping: solitary individuals (young males, females giving birth, old male); harem herds; mixed herds; bachelor herds. Herds usually contain equal ratio of males and females (Vie, 1996). Usually herd is moving in the direction dictated by alpha male. Behaviour of the antelope depend on sex: males established territories which they marked and defend, males tend to express aggressive, defending behaviour; while female can express it in rare occasions.

Activity pattern have been reported to undergo seasonal switching: during summer season oryx follow nocturnal or crepuscular activity; during the winter - diurnal activity

(Davimes et al. 2017). When temperature rise to the maximal degrees, oryx is seeking shelter in the shadow, under the tree or bushes or dig shallow depressions in sand to rest (Davimes 2018). In addition, it was recorded that oryx in Saudi Arabia have inter- and intra-seasonal variations in the temporal budgeting (Davimes et al. 2018).

Arabian oryx could serve as a marker and indicator of maintenance of sustainable desert ecosystem. Taking to consideration that species was almost extinct from the planet, detailed research on semi-wild reintroduced population would enrich data pool. Information could be useful for conservation purpose for other oryx species, as part of them listed in the IUCN Red List as vulnerable or endangered. Current research collected data on seasonal changes in density, herd composition and activity pattern of Arabian oryx.

1.2.2. Results of successful re-introduction program

The Arabian oryx originally occurred in Jordan, Syria, Iraq, Israel and biggest part of the Arabian Peninsula (Greth & Schwede 1993). In the middle of the XXth century wild population of antelope decreased dramatically. In 1950s oryx had disappeared from the north (Iraq, Kuwait). In 1960s oryx population was restricted to central and southern part of Oman and in 1972 the last wild Arabian oryx was killed there, in the Sultanate of Oman. Fortunately, the Phoenix Zoo (Phoenix, Arizona, USA) already in 1962 started the first captive-breeding program ‘World Herd’ to save the population of Arabian desert unicorn (Spalton 1993). Starting with only 9 animals, the Phoenix Zoo has had over 200 successful births from the beginning of project.

In 1975 animal became listed in CITES Appendix I, means only in exceptional circumstances the trade of specimens of these species (alive, dead, parts of the body) was allowed (Harding et al. 2007). Such decision assured legal regulation of horn trade and illegal hunting across original habitat and the globe. In January 1982 eight individuals were released back in the desert in Oman (Spalton 1993). This first release gave a start of an active re-introduction operations which is taking place till now. According to the IUCN Guidelines, re-introduction aims to re-establish a sustainable population of the focal species within its indigenous range (IUCN/SSC 2013). Already in 1990 the number of Arabian oryx had increased to over 1300 individuals, including 112 captive bred and already released back to the wild. In 1993 year already more than 2,000 individuals were in world captive population (Greth & Schwede 1993). In 2007 there were five reintroduced populations within big natural habitat areas: Oman (Arabian Oryx Sanctuary, 27,500 km2); Saudi Arabia (Mahazat as-Sayd Reserve, 2,244 km2, and Uruq Bani Ma'arid Reserve, 12,500 km2); and Israel (Northern Arava and Negev Desert) (Harding et al. 2007). General Secretariat for the Conservation of the Arabian Oryx during Disease Survey recorded 9706 individuals in 2013 in captive breeding facilities only in seven countries of Arabian world. This number increased to 12,879 individuals in 2015, with the biggest collection in UAE (10,205 animals) (Lignereux et al. 2018). Globally over 6,000–7,000 individuals are being held in captivity. These populations are living in the variety of fenced reserves, natural parks and subject of different levels of management. Most of them are provided with supplementary food and water, veterinary care and management plan includes habitat enhancement and manipulation with social structure and breeding. (Kock et al. 2018). Nowadays, the "global wild herd" is around 1,220 (ca 850 mature individuals) (IUCN 2017).

In the Dubai Desert Conservation Reserve (UAE) Arabian oryx antelopes were re-introduced starting from the 1999. The re-introduction at this site had two phases: in 1999 -2003 the first small herd was released into the Al Maha Reserve (at that moment only 27 km^2 area was dedicated to nature protection); and starting from 2003 re-introduction program had been started at the Dubai Desert Conservation Reserve (225 km^2). The main wildlife manager of the DDCR, Greg Simkins, is mentioning, that already in 2008 approximately 270 Arabian oryx had occurred within the area, of which approximately 50 individuals were independent of supplementary feed or artificial shelters (Husam 2006). In 2019 the population of DDCR Arabian oryx substantially increased (Lignereux et al. 2018) and on summer 2019 reached around 740 individuals.

Despite inspirational data on survival rates and the stable population trend of Arabian oryx, it should not be taken as the only indicators of the success of re-introduction program. Preserving natural oryx behaviour, natural social interaction, migration pattern and genetic diversity of the herd – all these characteristics must be explored more. Scattered studies on wild and captive oryx population in Saudi Arabia and United Arab Emirates support the idea of scientific necessity of continuous study of this beautiful animal.

1.3. Camera trapping technique in wildlife conservation

Camera trapping method commonly dedicated to a wide range of equipment and ecological applications. According to the specialist of Royal Geographical Society: "…the principle behind camera trapping is beautiful in its simplicity…" - and it is hard to disagree (van Berkel 2014). Researcher is setting up one or several remotely-triggered camera(s) – camera traps (CT) - in an area of interest and camera activates/triggered every time, when animal is passing by, and records an image or video. According to research goal and species characteristics number of cameras, duration of record and other parameters are specified. The first camera trap research with wildlife conservation purpose was conducted in the 1990s and focused on the tiger (*Panthera tigris)* (Trolliet et al. 2014). Tendency and focus on big vertebrates remain stable till nowadays. For the period 2008-2013 CT studies were mainly focused on the fauna with approximate rate more than 90% focused on mammal species, overlapping with birds' studies (11.9%) and a few studies included reptiles and amphibians (ca 2%). While flora was presented only in 0.74% of analyse (Burton et al. 2015). There are several guidelines and books published on CTs utility in wildlife conservation and monitoring; number of software developed for image archivation, data analyses and statistic calculation (van Berkel 2014).

CT are being used to assess wildlife distribution and diversity (Abi-Said & Amr 2012), abundance of animals (Trolliet et al. 2014), behaviour, community structure, daily activities (Sanusi et al. 2013), species interactions, reproductive success and community dynamics (O Connell et al. 2011; Burton et al. 2015). CT method is owing such popularity to several factors: it minimally disturbs wildlife, what make it perfect for observation of the natural behaviour; CT allow long-term remote monitoring, what perceptibly lower the human work hours and cost of work in the field; video mode allows researchers to record interesting material on the animal behaviour; digital results are easy to analyze, combine and share.

Despite high interest and increasing trend in usage of CT, methodology and survey design of CT research are not 100% excellent. To conduct accurate and scientifically valuable CT survey there are plenty rules and recommendations, what should be followed (Trolliet et al. 2014; van Berkel 2014; Burton et al. 2015). Study focused on ungulates require special design of CT survey. To record and analyse activity pattern of the freely moving animals, camera traps sites should be located, where signs of mammals were recorded (Sanusi et al. 2013). If studied animal is high (> 1 m) camera should be located on certain distance from the surface, fixed to the natural object or firm tripod, pole. The same pole will prevent camera shake, fix camera at the right angle above the chosen area.

Of course, the researcher must consider the state of the environment and habitat. Some publications mention, that open habitats lack obvious animals trails or places animals likely to visit, what can reduce chances to spot wildlife activity. Nevertheless, if survey is organized on the sites, well-known for animal visits, this nuance is not influential (van Berkel 2014). More crucial - specific temperature regime of desert, which can affect technical equipment. As well strong winds and sandy storms on the open desert planes can intervene in continuous work of CT. To avoid data loss, camera traps sites should be checked at least every 30 days (Srbek-Araujo et al. 2013). In case, when study area consists of two different habitat types and the cameras are only operational in one, the results of one cannot be extrapolated to the other.

To collect record for all hours of day, camera should have an active night mode: incandescent flash or infrared light. First is allowing to take colourful pictures, while it activates photo shooting with a bright white flash; however, such method can scare animal and lower the attendance of the site. Second mode – IR light – is more popular, as it allows to record animal in black and white images with red light of the LEDs, which is slightly visible for ungulates and is not affecting behaviour. Trolliet recommends to use a camera with a “no-glow” infrared flash (Trolliet et al. 2014).

The size of the trapping area depends on home range of the animal. To ensure sufficient output of animals records, trapping area should be four times bigger, however this parameter usually is limited by capacity of the research team and project (Sollmann 2018). Trapping effort – the duration of the CT shooting - depends on 1) density of ungulates on the study area; 2) chosen location of CT (often visited by animals or not); 3) goal of the research (study on seasonal changes require certain duration – chosen season of the year). Generally, 40-60 days is taken as the maximum period/season to collect data on medium- or large-size mammals (van Berkel 2014). Choice of trigger speed - the time delay after trigger necessary for the camera to start record an image of an animal – depends on the regular speed of animal movement. In work with Artiodactyla the fast reactive trigger (0.5 - 1.0 sec) is the best option. Ungulates can move in herd, when the time of passing the group in front of the camera is relatively slow; however, if the animal is moving alone the slow trigger speed (1.0 sec <) can reduce a chance to spot the animal.

1.3.1. Density estimation using camera trap records

Population abundance – the total amount of animals per site - is commonly used parameter to study the state of populations. However, population density - number of animals per unit of area - can be a more meaningful metric from the management position, as it will correspond environmental conditions and changes of the area. Camera trapping technique is particularly suitable for study of abundance and density of populations (O Connell et al. 2011). A lot of field guides and books are describing the method of density estimation, dividing it according to the type of the animal it focused on: individually recognizable or not recognizable. Big cats, elands, kudu, zebras, orcas are forming the first category and density estimation is based on the capture-recapture method (CR) or spatial capture-recapture (SCR) models (Ancrenaz et al. 2012; Burton et al. 2015). We will focus on the second category of animals: whose colorization, body anatomy and visual appearance do not (or rarely) provide a chance to recognize animals as individuals.

The first mentioning of the abundance model for not-identified species was dated 2003 year, when J.A. Royle and J. D. Nichols presented their model, worked with the software programs PRESENCE and MARK (Royle JA & Nichols 2003). Five years later, J. Marcus Rowcliffe and his team published the work on density estimation without individual recognition of the animals using random encounter model (REM) and gave a new perspective of camera trap data treatment (Rowcliffe et al. 2008). The experimental model was focused on two species of ungulates among others taxa of animals, i.e. Chinese water deer (*Hydropotes inermis*) and Reeve's muntjac (*Muntiacus reevesi*). It provided promising technique to use particular method on other ungulates. This model is able to estimate individual and group densities of non-identifiable species, based on the trapping rate (number of species records per 100 camera trap days), species movement speed and two camera trap parameters - angle and depth of detection zone. There are several assumptions, reported by the Rowcliffe and the team, crucial in REM application: population should be considered as closed (i.e. has no migration, death or birth during the research duration); camera traps should be placed randomly with respect to animal movement and finally, animals fit in ecological pattern type, which is possible to describe with this model. Technique found a big support from scientific community, however, it is recommended to apply other technique of density and abundance estimation in addition to this model. This method has been tested in a wild forest ungulate Harvey's duiker (*Cephalophus harveyi)* by Rovero and Marshall (2009), European pine marten (*Martes martes*) (Manzo et al. 2012) and lion (*Panthera leo*) in Tanzania (Cusack et al. 2015b).

Basically, research includes several steps: random set up of sufficient number of camera traps; estimating the animal speed (v); recording the depth and the angle of the camera detection zone (r and θ). Important to extract images from day time of the timeline. From the collected photos and analyse of CT data it is possible to extract detection or trapping rate, what is needed for calculation (y/t), equal to the number of CT images with animal per unit of time. The formulas are derived mathematically and explained in the original article (Rowcliffe et al. 2008). Obtained data are combined in the equation 1.

$$D = \frac{y}{t} \frac{\pi}{vr(2+0)} \quad \text{(eqn 1)}$$

For gregarious species one modification in the formula is needed. Obtained density [D] from the first equation is focused on the solitary individual species. The group density [Dg] can be calculated by multiplying [D] on the average group number of individuals in a herd. As the technique is novel, the degree of over- or underestimation remains unclear, especially in different taxa group. Thus, further field tests of the approach persistent study and combination with other field methods are needed (Manzo et al. 2012).

2. Aims of the Thesis

The main goal of the research was to identify the population dynamics of Arabian oryx *(Oryx leucoryx)* at the Dubai Desert Conservation Reserve (DDCR) over a selected time in relation to seasons and management approach and measures (i.e. mobile feeding and water points).

According to available data from the DDCR archive and personal observation, several focuses of interest are underlined for the research. Density parameters, activity pattern and herd structure were compared in relationship with:

- Chosen timeframe: 2011 year VS 2019 year;
- Seasonal variety: summer months VS winter months;
- Management practices, i.e. artificially improved (feeding points, present of water) VS natural environment;
- Method of observation, i.e. direct observation by rangers VS camera trap record.

There were several objectives in the frame of the research:

- To identify the density changes of re-introduced semi-wild population of Arabian oryx on the area of DDCR by treating available data from DDCR archive (images from camera traps, “Biosphere Expedition” reports; personal observation reports).
- To gain better understanding of the herd structure and activity patterns using the data from camera traps in artificial settings, namely at feeding and water points.
- Gain understanding of population dynamics through years by comparing continuous data from 2011 year with other years with random camera trap distribution and by comparing population trends with discrete data from 2019 and different type of environment.

3. Methods

3.1. Study area

Dubai Desert Conservation Reserve is located in the east/north-eastern part of the United Arab Emirates (UAE). Established in 1999 at first as the small Al Maha Desert Resort & Spa with conservation territory, already in 2003 the area was transformed into the Dubai Desert Conservation Reserve (DDCR). Recently, in 2018 year the Desert Research Centre was established with the goal of boosting the scientific exploration of the region and active scientific and research support of wildlife conservation programs, taking place in the Middle East. The total area of DDCR is 225 square kilometres, what equals to 4.7% of Dubai's total land area. Reserve is located in UTM 40N zone (EPSG:32640 - WGS 84) (24º 49.5'N; 55º 40.5'E), on the edge of Sharjah emirate at an elevation of 180–260 m a.s.l. (El-Keblawy et al. 2009) (Figure 1). The DDCR is mainly

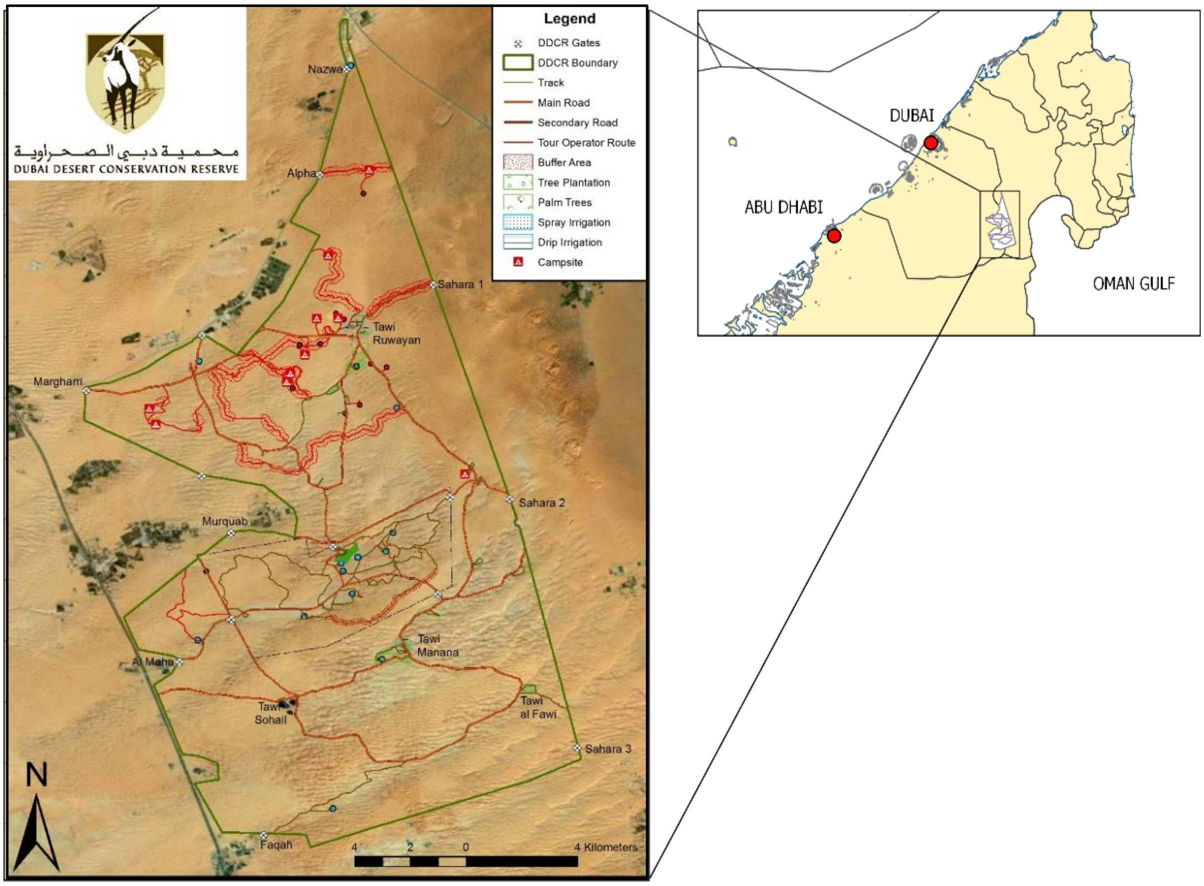

Figure 1. Dubai Desert Conservation Reserve (DDCR) (UAE). Detailed map of the reserve was kindly provided by DDCR managers` team.

a desert area with vast sandy barchans, gravel plains and rocky terrains in the northern part. According to Köppen-Geiger climate classification nature reserve is located at BWh climate zone: main climate is arid (B); precipitation is desert like (W), temperature – hot arid (h). Average annual precipitation is below 100 mm with a wet season from November to April (average monthly rainfall of 21 mm, relative humidity around 60%) and a dry season from May to October (average monthly rainfall of 8.6 mm, relative humidity around 35%). Climate characterized by pleasantly mild winters and extremely hot and sunny summers. Annual mean of monthly temperature, according to IBM Global High-Resolution Atmospheric Forecasting System, varies from 17°C - 20°C (January) to 38°C - 42°C (August). The substrate at the reserve is diverse: sand, gravel, alluvial clays.

A big variety of desert plants survive extreme desert conditions in DDCR: from wildflowers to bushfires and different trees. Typical flora of the reserve consists of shrubs and trees. Among trees - ghaf tree (*Prosopis cineraria*), umbrella acacia (*Acacia tortilis).* Next to the main gaits and human settlements the date palms (*Phoenix dactylifera*) were planted and still present, but originally there were not part of the native flora. Among tall shrubs in the DDCR lana (*Haloxylon salicornicum)* and *Leptadenia pyrotechica* occur, *Calotropis procera* and *Calligonum comosum* are the most abundant (Gallacher & Hill 2006). Fauna of the DDCR includes variety of species of different taxa. Among big vertebrates the main number is given to Arabian gazelle (*Gazella arabica*), sand gazelle (*Gazella subgutturosa marica*), red fox (*Vulpes vulpes*), cape hair (*Lepus capensis*), Gordon wildcat *(Felis silvestris gordoni*). Several cases of feral cats and dogs` occurrence were reported in the nature reserve.

The entire DDCR perimeter is fenced with 2 m high chain-link fencing what makes the area open but range-limited for wildlife inhabitants. Nature reserve is divided (virtually) into 3 sectors: North (N), Central (C) and South (S). To make measurements and analysis more elegant and reveal is there any differences in spatial distribution of animals across those 3 sectors, they were taken as the basic division of the research area. Population of Arabian oryx in the DDCR consider to be artificially maintained (Gallacher 2015), it supported with the feed and water supplements on weekly basis since the establishment of the DDCR. According the management plan, feeding stations are dislocated every six weeks to prevent overgrazing damage for native vegetation and reduce risk of disease outbreak. Nature reserve serves as a popular ecotourism location, with Al Maha resort centre in the middle of the reserve. Moreover, annually in winter season DDCR host a “Biosphere Expedition” – educational and green tourism activity, focused on implementing selected ground surveys on flora and fauna of the reserve. Presence of human settlements, green vegetation and architecture landscape forms with water – all these indeed attract animals, but in general Arabian oryx prefer to avoid humans. Thus, in the aim of this research it was decided to analyse only the influence of feeding stations and waterholes outside of the resort area. In 2011 nature reserve had 25 artificially improved sites across three sectors, while in 2019 there were 30 sites (Figure 2).

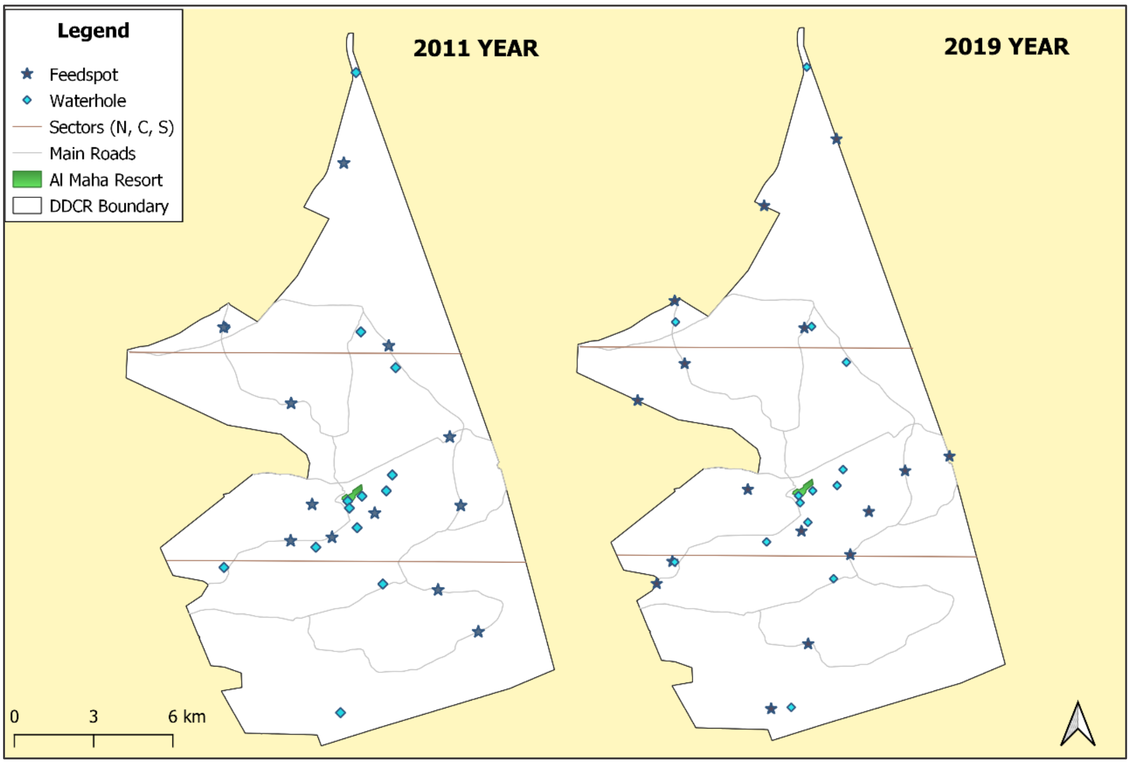

Figure 2. Distribution of the improved sites (waterholes, feeding stations) across DDCR in 2011 and 2019 years

3.2. Data collection

Data were collected using a set of camera traps, personal observations, rangers’ field reports and notes of management team of the DDCR. Taking into consideration the specific arid climate condition, two main seasons were distinguished on the territory of the nature reserve: 1) winter - December, January, February months - characterized as a period of year with the lowest average temperature (21°C - 22°C) and highest precipitation; 2) summer – June, July, August, September months - is a period of the highest average temperature (35°C - 36°C) and minimum of precipitation. Data from 2011 year and winter 2019 was available from the archives of DDCR and was kindly provided by managers` team. Data from summer 2019 was collected by author during the field work in July - August 2019.

3.2.1. Camera trapping survey design

In 2011 ten cameras were randomly located across the DDCR area. Camera trap sites of 2011 year were considered to be non-attractive for Arabian oryx (Figure 3), as the closest waterhole was approximate 500 m away. In 2019 eighteen cameras were set up both in the natural and improved locations around three zones of the nature reserve. In winter 2019 twelve cameras were monitoring area next to the water points; in summer - six of them were relocated to replicate the distribution of cameras of 2011 summer season, rest of the cameras continued to work on the same location (Figure 3). Selection of the sufficient camera for an analyses was based on the trapping rate (>50%).

The species of interest was not possible to identify individually, thus non-paired cameras (one-camera survey method) design was applied in both seasons in both years. Cameras were facing North direction to avoid direct sun light from East and West side, which can distract trigger mechanism and eliminate qualitative results. Camera trap sites were located away from the roads at least on 100 m. The distance between two closest cameras was more than 4 km to prevent the double count of moving animals. GPS-coordinates of each CT site were noted into GPS-navigator and field journal. Installation of camera traps in 2011 and winter 2019 was done by management team of the reserve, while in summer 2019 cameras were set up by DDCR managers in cooperation with master student of Czech University of Life Sciences Prague. Cameras were located 0.75 – 1 m above the surface, fixed to the metal pole. Each site was visited several times per month to check camera settings and working condition and remove natural object, which may have occurred in front of the camera detector.

In 2011 survey year, cameras were operating during the whole year - from December 2010 till December 2011. Only data from summer and winter months were selected for the current research goals. In 2019 cameras were deployed for winter and summer season separately: from January till February and from July till September. The survey duration choice was based on recommendation, that for study of medium and large mammals, duration of 2-3 months camera traps is optimal (Ancrenaz et al. 2012).

In 2011 cameras of Bushnell (Trophy Cam) and Reconyx (RC60 Covert) brands were used. In 2019 Bushnell (Trophy Cam) and Reconyx (model RC60 Covert, HC500 Hyperfire) camera were in use. Bushnell had image resolution of 96 pixels/inch; Reconyx - resolution 72 pixels/inch. Night regime type for all cameras was no-glow IR flash. Cameras were programmed to be active 24-hours/day with a 2-minute interval between photos; cameras recorded one photo per trigger (in 2011) and three photos per trigger (in 2019). All cameras recorded the date, time and temperature of the air. The crucial parameters of the radius [r] and angle [θ] of detection zone were specified with the help of the official guidelines and description of camera setting in combination with visual observation of images from camera traps. For Bushnell Trophy Cam radius of detection was recorded to be up to 30 m with angle – up to 35.1°; Reconyx RC60 Covert – up to 15 m (11 m at night); Reconyx HC500 Hyperfire - 18 m (at night 15m) in 42° detection zone.

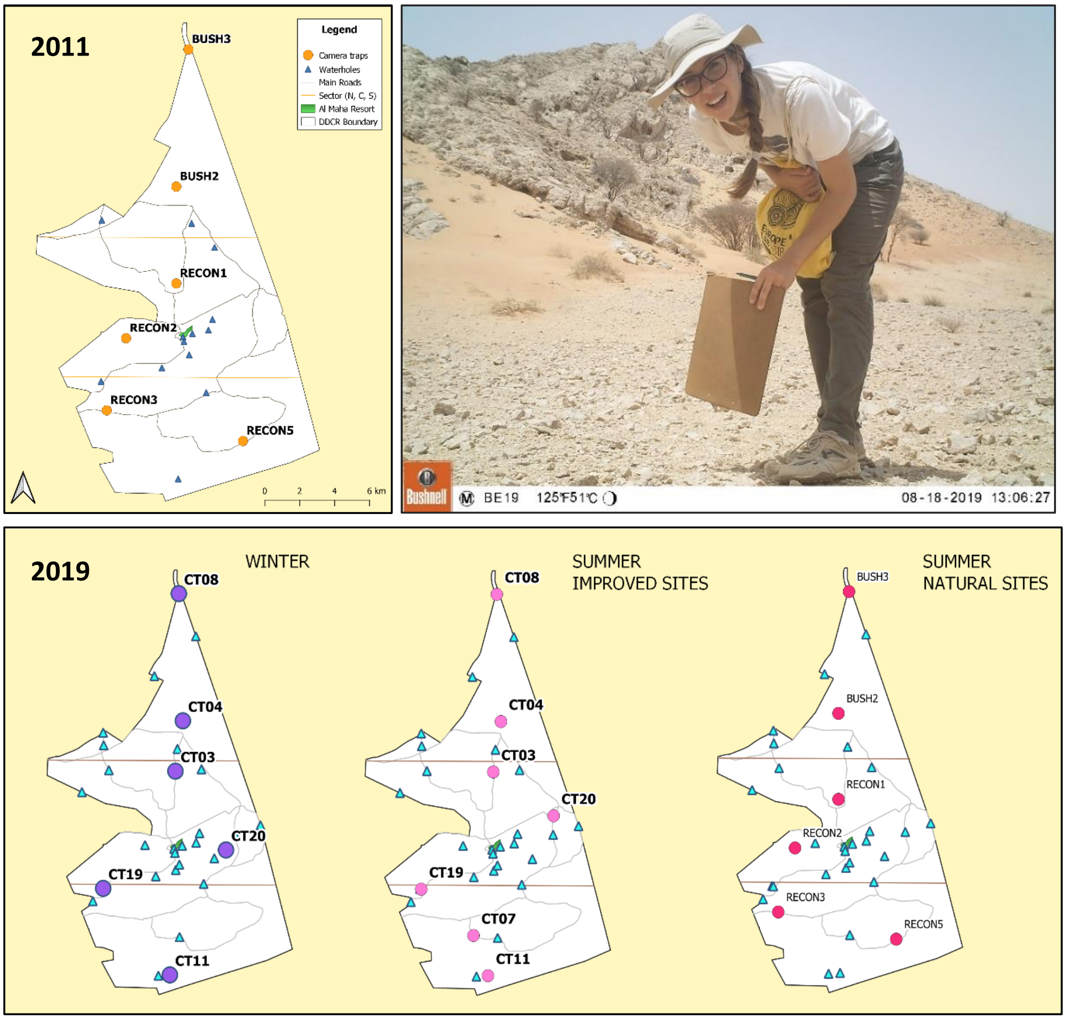

Figure 3. Distribution of selected for analyses CT across DDCR in 2011, 2019 year in different seasons and types of environment. Blue triangles indicate the artificial improvement of any kind. On the right top – author of the work, checking the readiness of CT.

3.2.2. Direct observation and monitoring

Direct observation of the Arabian oryx was done mainly at feeding stations and waterholes during summer field work of 2019. Weekly the group of rangers calculates the number of ungulates across the nature reserve via drive approach. As it was mentioned, DDCR territory is divided into 3 sectors: north, central and south. Due to managerial capacity there are two teams of field rangers (South and North team), who are making animal survey (counting session) during the feeding time once in a week (usually on Tuesday). One team consists of 2-3 persons. Calculation of animals are made manually with fixation in a field notebook. Rangers calculate number of all animals on each feeding stations and in between on the fixed route and make specification on the amount of the "adult" and "calf" per each group, individual recorded. Reports are saved in database in Excel format. Ground surveys of Oryx population were made traveling on accessible roads and tracks. Approximate distance route – 70-110 km of transects per visit for each team, 80 km on average. Average speed of vehicle - 30 km/h (with 40 km/h limitation within DDCR area). The same method was used in 2011 year, thus archive data from field report was in the same format as the 2019 data. Such technique is used as part of the regular survey, specifically regular complex total count of the animals at the reserve, where rangers try to counts every member of population. Distances between the animals are taken as a marker of group-composition, however on the attractive location this assumption is controversial, as it is not taking into the account ecological and behavioural background of the study species.

3.3. Data analyses

3.3.1. Camera trap data analyses

To process images from camera traps of different years "Camera trap data management and analysis package from Zoological Society of London" (ZSL CTAP) was used. It was invented by team of wildlife ecologists led by Dr. Rajan Amin to manage and process large volumes of image data efficiently (Amin et al. 2016). ZSL CTAP is providing scientists with a powerful tool to reveal daily and seasonal trapping rate, occupancy, activity patterns, population density estimation, species richness and much more (Amin, Davey and Wacher, 2016). Images of Arabian oryx were identified and organized for further analyses in the datasets, prepared by the software. Before inserting images into software the metadata for each photo per camera trap was extracted with the help of Picture Information Extractor (Version 7.10.11.29). This program provide output in an Excel table, where selected metadata parameters are listed for each of the photo from selected camera trap: date when photo was taken, GPS-coordinates, flash mode, ISO, zoom type, size, camera model, etc.

Before uploading data into the ZSL CTAP software several requirements were fulfilled. All images from camera trap were analysed manually. Four standard format data source files in Microsoft Excel were organized:

1) Description of camera locations (GPS coordinates) and habitat type description;

2) Individual camera trap configurations (settings for each camera);

3) Time management of each camera trap (setup, service and recovery history);

4) Image details for every photograph from each camera (number of animal individuals on the picture, their sex, age class (adult vs. calf) and type of activity were recoded).

During the pre-processing, images from camera traps were sorted into categories “wildlife”, “service”, “other”. Number of animals in each specific age-group was noted in the table, as well as performed behaviour (fighting, feeding, resting, looking in the camera, investigating, other). Images of variety of wildlife mammals (gazelles, foxes, hares) and birds (doves, owls, vultures) were obtained too, but were not important for consideration for the current research. All main camera trap characteristics were calculated only for Arabian oryx for each year and season individually: occupancy, sampling effort, sampling occasions, trapping rate, amount of wildlife events, occasion lengths. Naïve occupancy estimated as presence or absent of focus species on CT site - if the species is observed at least once (one wildlife event), it considers to be present in the study area. Based on the percentage of the occupied sites among total amount of deployed camera the naïve occupancy is calculated: 0 – not present, 1 – all study sites are occupied by focus species. Sampling effort was calculated by multiplying the total number of CT by the number of sampling days (survey duration). The trapping rate was calculated by dividing the number of records by the sampling effort. The result was multiplied by 100 to scale capture rate for 100 camera trap days (100 CTD). By default, only cameras, operated at least 50% of time were taken for further calculation. A threshold of 60 minutes was used to distinguish independent photographic events. Moreover, trapping rate and amount of wildlife events were calculated both for 24-hour day and only day time

(04:00 - 18:00). Sampling occasions (survey occasions) is a probability of detection a focus-species, it is based on amount of repeated visits of oryx to every CT study site (Ancrenaz et al. 2012). The idea was to check if CT will detect animals in some locations more often than another in relation to the season. Occasion lengths (the day period estimated to have at least one records of the animals) was calculated for each camera in both years. To visualise outputs from CT records several maps were created in the QGIS - open-source cross-platform desktop geographic information system (QGIS 3.8 Zanzibar). All photos and images, used in graphic elements were taken from DDCR archive or personal collection of the author.

3.3.2. Animal census and herd composition

As data on herd composition and animal census were collected with the help of two methods (direct observation and camera trap records), the analyses were separated for each of the dataset. For camera trap records several age groups were divided for oryx individuals, which were visually identified one from another. The age classification according to the horn size and body coloration was offered by DDCR managers team, based on classic method of herd age classification: calves (new-born and juvenile), yearlings (sub-adult) and adults (Kaji & Takahashi 2005). More detailed classification was needed to adjust data for the CTAP ZSL software (Figure 4). Adults – the largest animals in the herd; have white colorization of the body; contrast dark face mask near eyes; brown legs and long tail with furry dark ending; horns are long and can reach twice as size of the head. Sub-adult – smaller in body size than adults; body colour can be white with pale beige areas on the side of the belly or head; face mask is not fully developed. Calves - juvenile and new-born – have similar size, the smallest individuals in the herd, can be recorded while sucking the milk, have the brown fur, no horns at all (new-born) or horns are smaller than ears (juvenile). Photographed antelopes were classified into several sex-age classes: adult males, adult females, unknown adults, sub-adult male, sub-adult female, sub-adult unknown, juvenile and new-born individuals. Due to specificity of monomorphic ungulates the sex of the individuals was barely recognized from the records, that is why for the further analyses the ratio was composed only for age-groups adult - non-adult individuals.

The sex-age composition of the DDCR oryx population was analysed using a statistical package of RStudio (Version R-3.6.3 RStudio) (R Core Team, 2020).

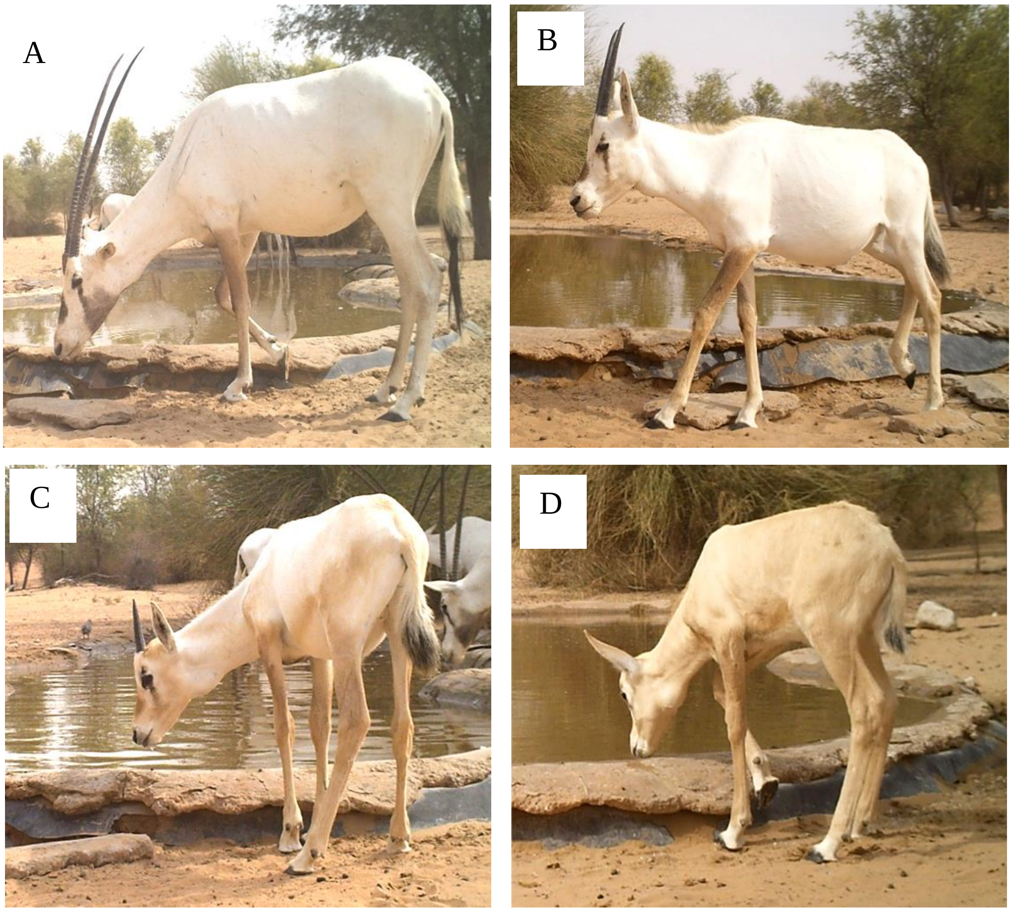

Figure 4. Age groups of Arabian oryx: A) adult; b) sub-adult; C) juvenile; D) new born.

Normality of data distribution was checked with Shapiro-Wilk normality test. For each variable (average size group, adult and non-adult animals recorded) range and mean was found. Seasonal variables were independent, thus for revealing significance in mean differences the Wilcoxon Rank Sum Test or Welch's t-test were used for not normally distributed and normally distributed data accordingly. The Wilcoxon test (other names - unpaired Wilcoxon rank sum test or the Mann-Whitney U test) deals with continuous or ordinal data and measure equality of means in two independent samples. It is based on the ranking of the observations of the combined sample (Ruxton 2006; Du Prel et al. 2010). Welch's t-test is an adaptation of the Student's t-test for comparing the means of two independent groups when the sample size of groups is not equal. The null hypothesis (H_0) was that the mean value of certain parameter in summer season was equal to the mean of the same parameter in winter season. The alternative hypothesis claim, that there was a significant difference in the means between groups. The value of 0.05 as significance level was chosen to validate the results and confirm or reject the null hypothesis. Data on animal census and sex-age composition from rangers` protocols were available in DDCR archives. The sex classes were not noted for calculation, but the age classes were in a way – adult, non-adult, total amount of animals. To reveal significant difference in seasonal dynamics of herd composition statistical tools of RStudio similar to described above were used. Moreover, the total amount of animals had providing a raw estimation of population abundance, which we used later as a check-point for density and abundance estimation using camera traps records. Statistical analyses were as well performed in RStudio with already described procedure.

Group size estimation was the most controversial part of the analyses obtained from camera trap records and rangers reports. It was decided to work with both values – from CT records we took average amount of animals recorded on the one image, and from rangers` reports we calculated the average amount of animals met on the feeding station or during the drive on the route. To perform the statistical analyses on both parameters we used the Wilcoxon test (for non-normally distributed data) or Welch's test (for normally distributed data) in RStudio. As well we noted the maximum amount of the animals per image to enrich understanding of the herd composition and forming. Both datasets from 2011 and 2019 year were tested with Wilcoxon or Welch's two sample t-test based on normality of data distribution

3.3.3. Density estimation using camera trap records

Based on the selected CT design the estimation of the density was controversial, but it was decided to apply random encounter model technique to get the raw estimation, useful for a continuous research in the future. For density calculation only cameras with specific background were chosen: those which had sufficient amount of operational days during the winter and summer season of 2011, 2019 and only records from 04:00 till 18:00 were taken, as this period was consider to be a day time. The average speed of animal movement was taken as 2 km/h – walking speed (Tear et al. 1997). Based on described methodology of REM, individual and group density was calculated both for seasons in 2011 and 2019. Group density was calculated twice, according to the chosen approach: a) the group size of the animals was taken as the average amount of the animals registered at one CT site; b) the group size were based on rangers count report (direct observation). Our assumption was that there was a difference between seasons in density of Arabian oryx across DDCR, as seasonal environmental changes may influence the animal activity and distribution across the reserve. Moreover, it was important to explore is the group size is monotype across different sectors of DDCR. With the help of Wilcoxon and Welch testing the significance between means in individual and group density was tested. Abundance was calculated by multiplying the group density by total DDCR area.

The density estimation for the improved locations was not possible to do 100% unbiased, according to the REM methodology “attractive” sites should be excluded from the calculation, as attractive artificial facilities influenced the frequency of animals visits and as consequence – trapping rate. According to the original techniques, density calculation through CT records valid only for randomly set up cameras at non-baited sites. Nevertheless, we decided to calculated the density with specification, that it will have overestimated numbers and can serve as maximum point to compare results with.

Some papers refer to trapping rate and it connection to density and population size estimation as a relative abundance index (Ancrenaz et al. 2012). To reveal the interdependence between trapping rate and calculated density it was decided to apply linear regression test, which is known, as the best tool to measures the statistical association between continuous variables (one response variable and one explanatory variables).

3.3.4. Activity pattern estimation

The activity patterns of Arabian oryx in the DDCR were analysed using a statistical package for circular statistics, the ORIANA package (Kovach 2011). The dependent variable for all tests was the time of animals’ activity recorded by camera traps.

We explored the diurnal activity pattern of Arabian oryx in 2011 and 2019, each year separately, and then we tested the difference in activity pattern of Arabian oryx between seasons, i.e. winter and summer. To describe the diurnal activity pattern, we calculated the basic circular statistics, i.e. mean vector (μ) and the circular standard deviation (CSD). Then, we used the Rayleigh´s Uniformity Test (Fisher 1993) to calculate if the data (μ±CSD) uniformly distributed (i.e., when the test is significant the data is clumped around a certain date or time). This test is based on the length and direction of the mean vector, and may be not significant when species have a bimodal circadian activity. Hence, we also calculated for the daily activity the Rao´s Spacing Test (Mardia & Jupp 2000; Landler et al. 2018), which is based on the uniformity in the spacing between adjacent points. If any of these tests is significant we can conclude that the diurnal activity of the animals is not uniform.

To test if the diurnal activity pattern differs between winter and summer seasons, we applied the multi-sample Watson-Williams F-test in Oriana package, based on time as dependent variable and number of individuals on the picture. In addition, we calculate basic statistical parameters for each season, there were two hypotheses tested: 1**)** the Hotelling's Test - testing whether the whole population has a significant mean direction, and 2) the Moore's Modified Rayleigh Test - a non-parametric analogue of the Raleigh test that is based on weighting the mean angles with the rank order of the r values of each. The null hypothesis (H_0) is that the means of the population are uniformly distributed around the circle. A significant probability (significance level corresponds to 0.05) indicates that the data are not distributed uniformly and that they show evidence of a preferred direction.

Rose diagrams were used to visualise the animals' diurnal activity patterns.

4. Results

4.1. Wildlife events

Total amount of obtained camera trap images was 50,731. After selection of records linked to Arabian oryx ecology, results revealed that in 2011 in the natural type of environment camera traps recorded 157 independent photographic events during 898 camera trap operational days carried out in the winter and summer season. Table 1 shows, that sampling effort was 384 CT days during winter season and 514 CT days during summer 2011. There were 119 and 38 events in winter and summer respectively. Welch two sample t-test revealed no significant difference between seasons in the amount of independent events ($t = -1.77$, p-value=0.11). Important to mention, that the results of the camera CT07, located on the border of south-central sectors, was added to the amount of CT from south sector. It was one of the additional cameras located for the same duration with the rest camera traps as a backup. The Appendix 1 shows, that stationary cameras in the south sector during summer 2019 were not operational for the planned duration of time. It was decided to add results from backup camera CT07 to cameras from south sector (CT19, CT11).

In 2019 during winter and summer seasons six cameras were located in the area with water and feed supplies, so called “improved areas” and they consider to be “baited”. Four of them were performed well (operated at least 50% of whole duration) and were taken for analysis (Appendix 1). In total 817 independent events were recorded during 331 operational days with the overall number of Oryx images – 4426 photographs. There was a significant difference revealed in amount of wildlife events recorded between seasons (t=2.42, p-value=0.04). Sampling effort for CT from natural sites in summer 2019 was bigger than for improved sites - 166 CT days, even taking to consideration that the same amount of cameras was taken for an analysis as well in 2019 (four out of six installed). There are productivity and sampling records of each camera, which were working during winter/summer season in both years listed in the Appendix 1.

Naïve occupancy Arabian oryx was estimated for 2011 between 0.8 – 1.0, as one camera in summer had no registrations of oryx; while for improved locations in 2019 both season occupancy was 1.0 and for natural sites in summer – 0.83 (with condition that even 1 event was valid to prove the presence of animals in research area). Sampling occasions were estimated for each camera to reveal the seasonal pattern (Appendix 1). Occasion lengths for natural sites in 2011 during the summer was equal to 20 days, while in winter – only 4 (Table 1). At the same locations but in summer 2019 animals were recorded on average once in 18 days. For the improved locations monitored by CT in 2019 the length was the shortest – as animals were recorded to visit the waterhole every day during the survey time for both seasons. At camera trap sites, located close to waterholes (improved areas), animals were captured mostly expressing feeding behaviour or walking around the water source. At the natural sites, animals were mostly walking.

Table 1. Overview of the camera trap seasonal productivity* across DDCR in 2011, 2019.

Year	Season	Environment	N	Operational days	Wildlife photos	Wildlife events	Occurrence (days)	Part from the total duration (%)	Occasion lengths (day)
2011	Winter	Natural	6	384	392	119	15	26	4
2011	Summer	Natural	6	514	66	38	4	5	20
2019	Winter	Improved	6	188	2054	342	22	69	1
2019	Summer	Improved	4	143	1372	475	31	90	1
2019	Summer	Natural	4	166	20	9	2	6	18

**All results linked only to the CT records of Arabian oryx.*

4.2. Trapping rate

For obtaining result on trapping rate six cameras from winter and six from summer of 2011 were taken, while from 2019 year - six cameras from winter season and four cameras from summer season were taken (Appendix 1).

Trapping rate in connection to the season of the CT survey.

In 2011 year at the natural sites in winter it varied from 13 to 53 records/100 CTD; in summer from 1 to 24 records/100 CTD (Figure 5). Wilcoxon test revealed that there was a significant difference of average trapping rate value between seasons at natural sites in 2011 (W=2, p-value = 0.01): in winter there was more records than in summer (Table 2). In 2019 at the improved locations trapping rate was much higher (10x times higher) and with reverse pattern: there were more records in summer. It varied significantly (t=2.23, p-value = 0.057) from 40 to 423 images/100 CTD in winter and from 195 to 425 records/100 CTD in summer (Figure 5). Trapping rate variation across CT sites are shown on the map below (Figure 7).

Table 2. Trapping rate (records/ 100 CTD) from camera trap records in 2011, 2019 years.

Year	Season	Environment	N	Range	Mean	SD
2011	Winter	Natural	6	12.68 - 53.49	31.5	15.48
2011	Summer	Natural	5	1.15 - 23.91	8.45	9.32
2019	Winter	Improved	6	40 - 422.6	181.3	135.84
2019	Summer	Improved	4	195 - 425	353.7	107.31
2019	Summer	Natural	3	2.50 – 12.82	7.67	5.16

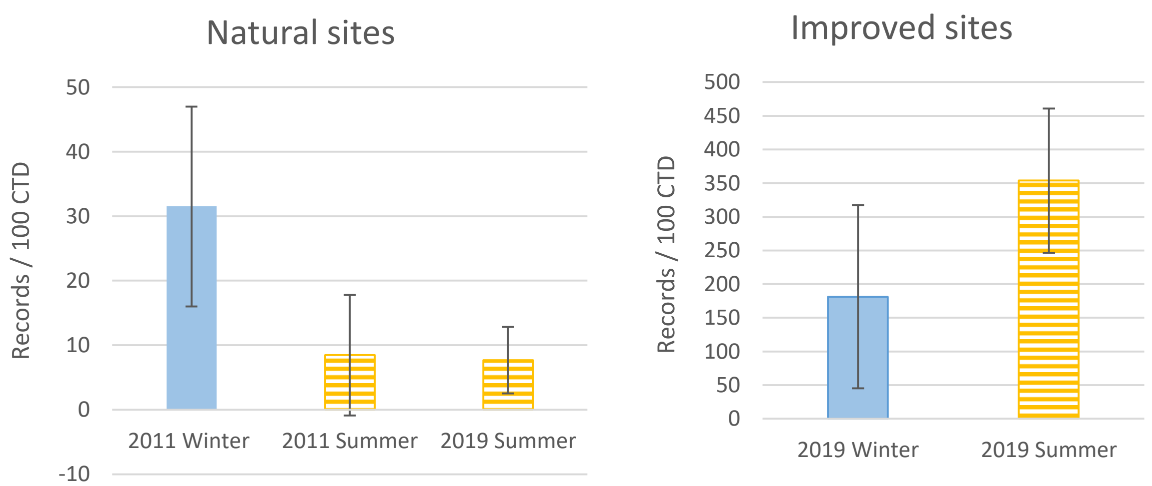

Figure 5. Camera trapping photographic rate recorded along study sites in the DDCR in the connection to the type of environment.

Trapping rate in connection to the sector of the CT survey.

To check hypothesis that sector-wise division and location of cameras can record differences in Arabian oryx distribution across the reserve, the trapping photographic rate was as well calculated for each sector (Table 3). Results visualised in the Figure 6. Simple calculation revealed, that indeed the frequency of animal's appearance in front of the camera vary from sector to sector. In natural sites in 2011 the biggest amount of records in 100 CTD were recorded in North part of the DDCR, both in winter and in summer, with maximum value in winter months. The pattern of 2019 looks reversed for both parameters – the biggest trapping rate recorded for South region for both season and in summer it's higher than in winter. As for natural sites in 2019 the records were diverse and the highest value recorded to be in central region, following not linear pattern.

Table 3. Trapping rate estimation (records/ 100 CTD) from camera trap records in 2011, 2019 years in respect to the DDCR sector

Year	Environment	Winter			Summer		
		North	**Central**	**South**	**North**	**Central**	**South**
2011	Natural	38.94	33.09	22.48	14.34	5.12	1.69
2019	Improved	85.63	148.39	309.78	403.68	195.00	412.50
2019	Natural	NA	NA	NA	7.69	12.82	2.50

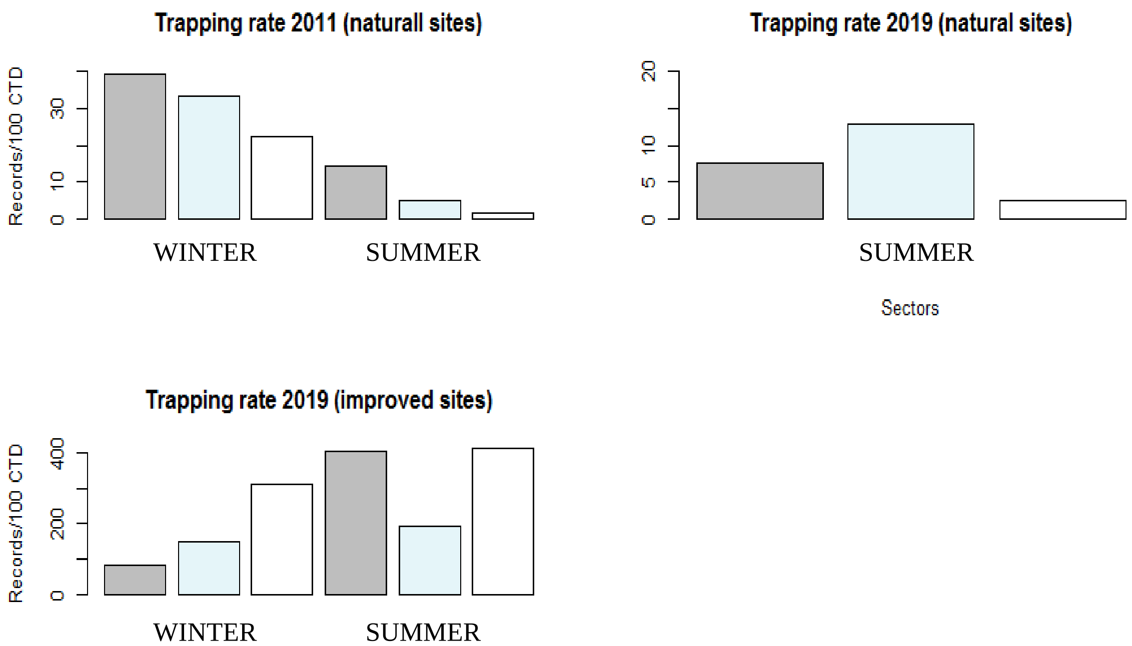

Figure 6. Trapping rate of Arabian oryx in connection to DDCR sector. Colour indicates the sector, where CT were deployed: grey – North, light blue – Central, white – South.

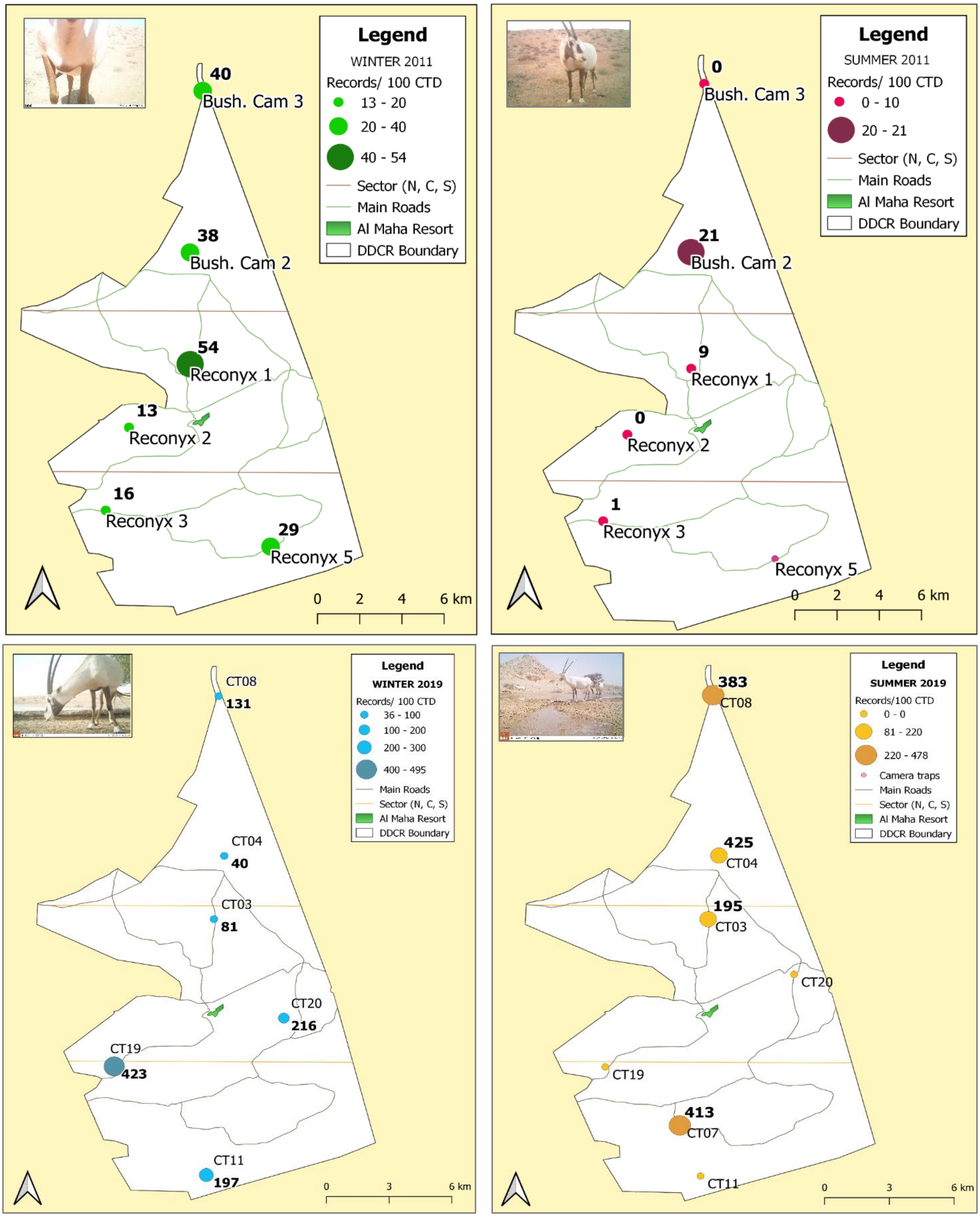

Figure 7. Trapping rate of Arabian oryx during winter and summer seasons in 2011 at natural locations and in 2019 at improved locations.

4.3. Herd composition

Herd composition parameters of Arabian oryx population were obtained from camera traps records. The adult age-group included records of male, female and unknown adult individuals; non-adult age-group included records of sub-adults, juvenile and new-born (with now sex specification). Overall numbers of adult and non-adult individuals, recorded on CT in winter and summer of 2011, 2019, are presented in the Table 4. The proportion of adult to non-adult individuals provided clear vision on the herd age composition throughout seasons and years. The revealed pattern of adult/non-adult ratio was not uniform from year to year (Figure 8). Analyses of camera traps showed in the Table 4. presents that in the winter 2011 92% of population were adult, while in summer this value dropped to 87%. The opposite situation was recorded in 2019 – in winter 89% of population were adults, while in summer this value increase to 93%. Camera trap survey showed that in 2011 the amount of the adult individuals recorded at natural site varied from 1 to 12 individuals/image in winter 2011 and from 1 to 4 individuals/image in summer 2011 (Table 5). The difference between the mean values was not significant ($W = 1857$, p-value = 0.573). The same outcome was for seasonal values of recorded adult individuals per image in 2019 ($W = 103578$, p-value = 0.3651). In 2011 on average there were 1.2 non-adult individuals at one CT image in winter and 1.8 non-adults/image in summer. We assumed, that if there was no significant difference between records of adult individuals, we will not find difference in non-adult records as well. Statistical testing proved our assumptions ($W = 28$, p-value = 0.8187). It is important to point out, that one season was standing apart from the general tendency: the average value of non-adult individuals recorded per image was smaller than adult number, but the records from summer 2011 are not following this pattern (Figure 8). Analysing precisely the age-group composition for small dataset from the natural environment of 2019 ($N=11$) we can mention, that all parameters had lower values than their analogues at improved sites 2019. For the natural sites in 2019 it was revealed significant difference in amount of adults per image ($W=4603.5$, p-value=0.0125) recorded by CT, but no difference in the amount of non-adult individuals ($W=84.5$, p-value=0.3831).

Table 4. Age-group composition of the Arabian oryx population in 2011, 2019 according to the camera trap records: number of adult and non-adult animals and its proportion from the total amount (%).

Age group	2011		2019	
	Winter	Summer	Winter	Summer
Adult individuals	187	47	895	1922
Non-adult individuals	16	7	108	177
Total	**203**	**54**	**1003**	**2099**
Proportion of adult (%)	92	87	89	92
Proportion of non-adult (%)	8	13	11	8

Table 5. Results of age-sex group estimation in Arabian oryx herds from camera traps data.

Year	Season	Environment	Adult individuals				Non-adult individuals			Number of animals per image		
			N	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
2011	Winter	Natural	120	1 -12	1.62	1.48	1 - 2	1.23	0.43	1 - 12	1.74	1.6
2011	Summer	Natural	36	1 - 4	1.38	0.77	1 - 4	1.75	1.5	1 - 7	1.5	1.2
2019	Winter	Improved	341	1 - 14	2.64	2.35	1 - 5	1.47	0.88	1 - 17	2.94	2.66
2019	Summer	Improved	477	1 - 19	2.9	2.81	1 - 3	1.43	0.55	1 - 19	2.98	2.97
2019	Summer	Natural	11	1 -3	1.27	0.64	1	1	NA	1 - 3	1.36	0,67

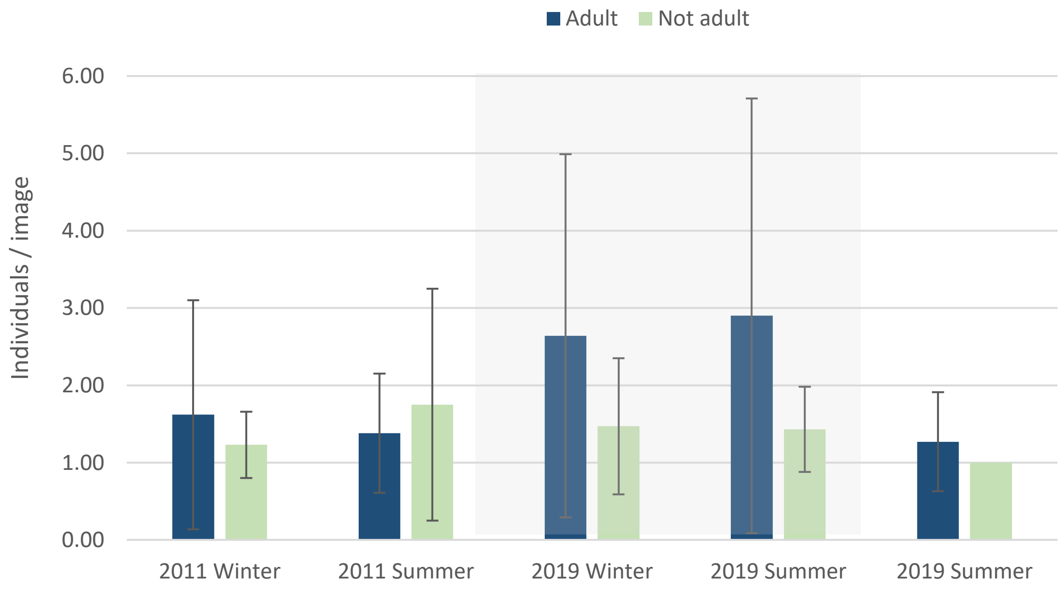

Figure 8. Average amount of individuals per image according to their age-group, based on records from camera traps in different habitats and years. Grey background indicates improved sites, white – natural sites.

4.4. Group size and density estimation

Group size

The average group size of Arabian oryx was obtained via two methods –from CT records and direct observation. Group size, recorded via camera traps, varied between the years and seasons. Such outcome was expected as CT sites where located in different types of environment and the population size had increased throughout the years. On average there were 1-2 animals presented on one image in 2011 and 3 animals in 2019 (Table 6). Group size was not significantly different between seasons both in 2011 ($t = -0.002$, p-value=0.99) and 2019 ($W = 76039$, p-value = 0.09683) (Table 6).

The field journals recorded the average number of animals for artificially improved location and on drive between them. In 2011 there were on average 19 to 22 individuals during winter and summer, and around 18 individuals to 20 respectively in 2019 (Table 6). Statistical analyses of data from direct observation revealed, that there was no significant difference in seasonal group size in 2011 (W=70, p-value=0.2362), but there was a significant difference between seasonal mean values in 2019 (W=0, p-value=6.233E-05). The maximum number of animals recorded at one image varied from 12 individuals in winter to 7 individuals in summer 2011; while in 2019 year at the improved locations cameras recorded maximum 17 animals per image in winter and 19 animals in summer (Figure 10). The frequency of occurrence of certain group number formation visualized in the Figure 10, the example of the camera trap image included into analyses for group calculation presented in the Figure 9.

Table 6. Average group size calculated during direct observation and through CT survey.

		Camera trap records				Rangers report			
Year	Season	N	Range	Mean	SD	N	Range	Mean	SD
2011	Winter	120	1- 12	1.7	1.6	12	1.2 - 73	19.4	19
2011	Summer	36	1 - 7	1.5	1.23	16	3.8 - 54	22.4	13.6
2019	Winter	341	1 - 17	2.9	2.6	9	17.1 - 18.6	18	0.4
2019	Summer	477	1-19	2.98	2.9	15	18.7 - 21.8	20	1.12
2019 (natural sites)	Summer	11	1 - 3	1.4	0.6	NA	NA	NA	NA

Figure 9. Camera images with records of Arabian oryx in different group composition: on the left - one animals; on the right - at minimum group of nineteen animals. Both images are taken during the summer season 2019 at improved location.

* *images taken from DDCR archive of camera trap records.*

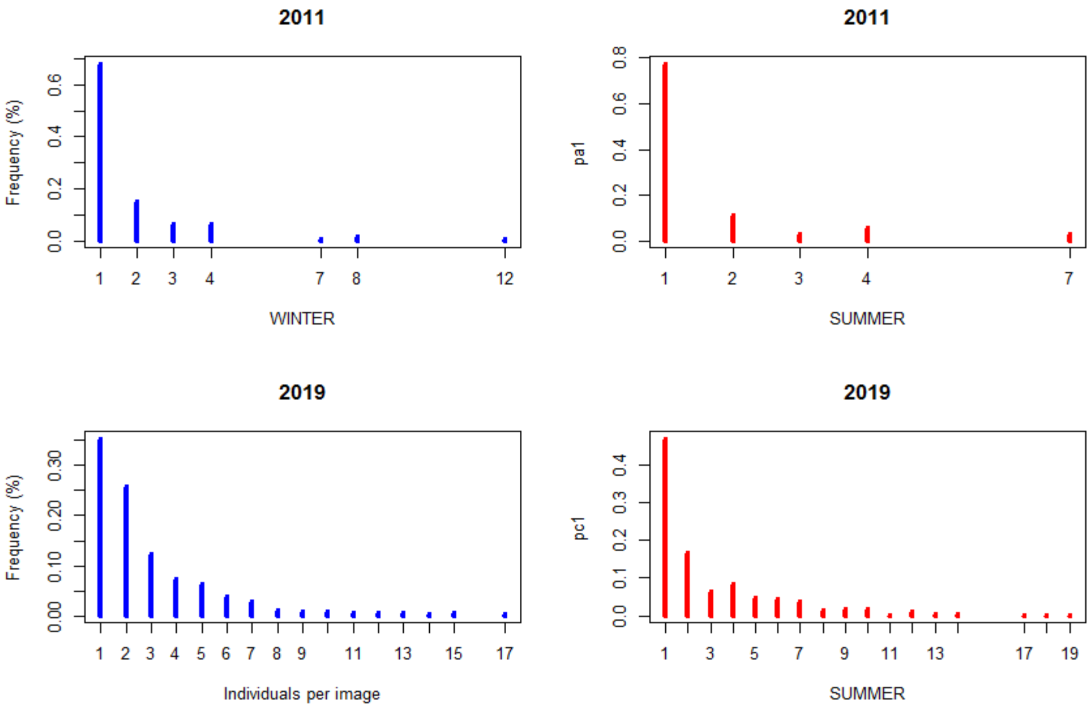

Figure 10. Frequency of certain group size records of the Arabian oryx, based on the amount of the animals recorded at one image from the CT in DDCR during 2011, 2019 years.

Density estimation in connection to season

Results for individual density estimation supported the idea, that animals will be distributed across DDCR area not homogenously (Figure 13). In 2011 year at natural sites the difference in seasonal individual density was significant (t = -2.3554, df = 7.6286, p-value = 0.04778), while for 2019 improved sites no significant difference was revealed (t = 1.4115, df = 7.2654, p-value = 0.1995). As it is visible from the table in Appendix 1. the calculation of the density and abundance for the natural sites of summer 2019 were not possible due to absent data from diurnal period. In the Appendix 2 calculation for each camera sites are shown. Group density, calculated with average group size recorded by CT, differ widely from group density, based on rangers' group count (Table 8, Figure 11). For group density of first type the difference between seasons in 2011 was significant (W=2, p-value=0.03): in winter it was much higher — 17 individuals/100 km2 against 4 individuals/100 km2 in summer. In 2019 on the improved locations group density varied in a range 36 - 495 individuals/100 km^2 in winter and 99-478 individuals/100 km^2 in summer (Table 8). Our hypothesis (Ha) was repeated, we expected a significant difference between the seasons. Testing showed that our assumption was wrong: there was no significant difference in group density. between seasons in 2019 on the artificial sites (W = 17, p-value = 0.3524).

Based on direct observations**,** the obtained group density was several times bigger that those, based on CT group size estimation. And it revealed no significant density changes within the years. In 2011 with the mean values of 206 and 77 individuals/100 km^2 for winter and summer accordingly, statistical test did not reveal significant difference (t = -2.0314, df = 7.0719, p-value = 0.08133) (Table 8). The same case for 2019 with not significant seasonal changes in group density (t = 1.6837, df = 6.775, p-value = 0.1375). The density fluctuation across the DDCR area is shown on the maps, where each camera trap station indicated with group density value (Figure 13).

The linear regression between trapping rate and group density was strong (r = 0.92) (t = 13.917, df = 16, p-value = 2.338e-10) and shown on the Figure 12.

Table 7. Individual density estimation from camera trap records from natural and improved sites in 2011, 2019 years. N – number of camera tested (sample size).

Year	Season	Environment	N	Range	Mean	SD
2011	Winter	Natural	6	4.3 - 16.0	10.8	5.4
2011	Summer	Natural	4	0.4 - 9.6	3.5	4.3
2019	Winter	Improved	6	12.3 - 132.3	54.2	46.7
2019	Summer	Improved	4	54.6 - 130.4	91.2	37.5
2019	Summer	Natural	1	3.9	NA	NA

Table 8. Group density (individuals/ 100 km2), calculated differently according to the selected average group size estimation (from CT records or rangers' count).

Year	Season	Environment	Camera trap records				Direct observation		
			N	Range	Mean	SD	Range	Mean	SD
2011	Winter	Natural	6	10.4 - 24.4	17	5.8	82 - 313	206	104.7
2011	Summer	Natural	4	4-14.3	4.7	6.5	9.4-210.2	76.5	94.5
2019	Winter	Improved	6	36 - 495	162	177.7	222 - 2382	975	841
2019	Summer	Improved	4	100 - 481	259	160	1093 - 2626	1869	808

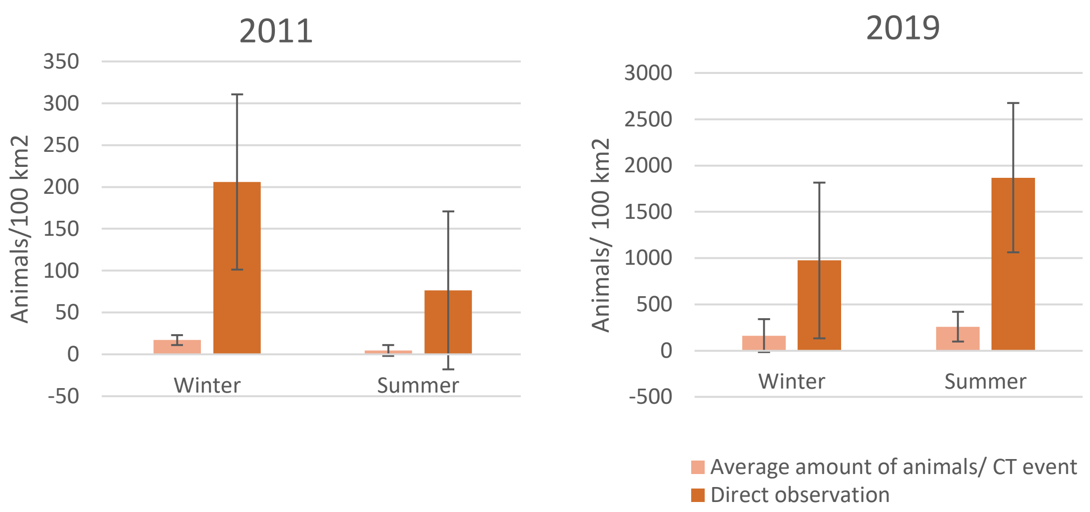

Figure 12. Group density estimation overview, based on different approaches in calculation group size: light orange – average number of animals recorded per image; dark orange - direct observation during counting sessions.

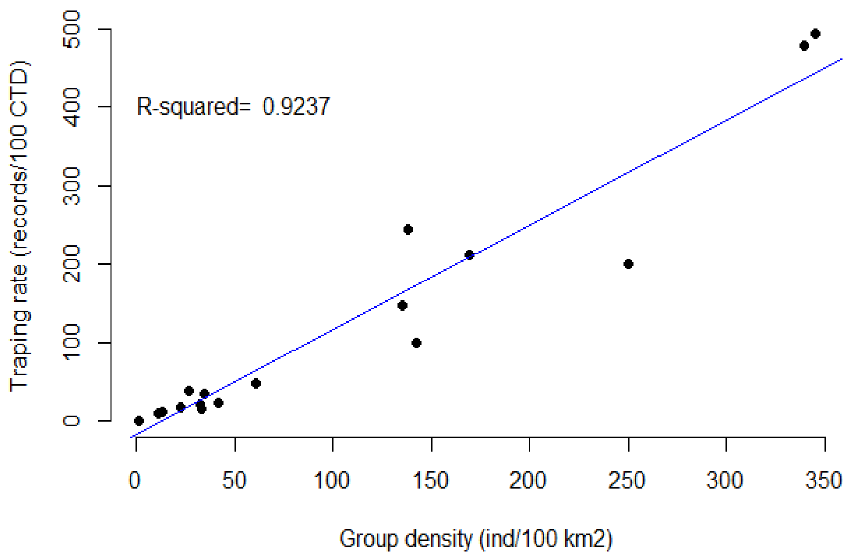

Figure 12. Correlation between density estimation and trapping rate of Arabian oryx in the DDCR throughout seasons in 2011, 2019 years.

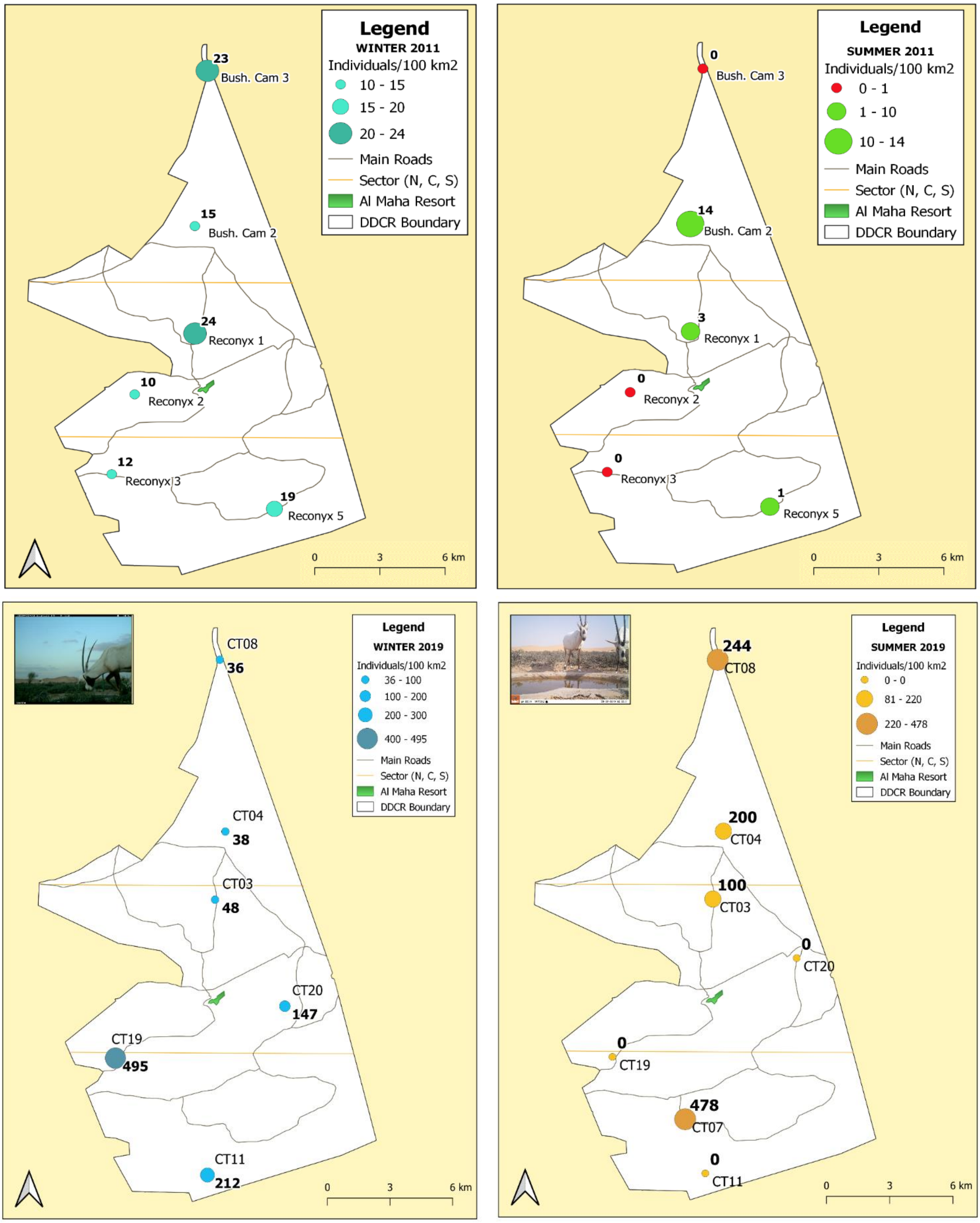

Figure 13. Group density estimation of Arabian oryx from camera trap records in 2011, 2019 year, from natural and improved sites respectively.

Population size

Rangers` field reports provide data to estimate population size of Arabian oryx within the nature reserve in 2011, 2019 years. In addition, it was decided to calculated abundance, based on the group density estimation based on CT records. For 2011 (natural sites) the abundance was estimated as 39 animals in winter and 9 animals in summer (Table 9). Only one camera trap covered all requirements to be included for density and abundance calculation. Nevertheless, it showed the population size of 11 animals for the whole reserve area, what can serve as starting point for future research. Certainly, such estimations far from the real numbers, provided by rangers' report. But underestimated results linked to observation from natural, not-improved location, while rangers report provided data on abundance from attractive locations. To explore REM technique and it capacity, it was decided to calculate abundance for improved sites in 2019 (Table 9). Indeed, this data gave overestimated results, but it was possible to compare it with rangers` field reports – both were linked to improved location. The field reports showed that in 2011 there were on average 269 animals in winter and 397 animals in summer, while in 2019 this value increased to 648 and 724 animals respectively. Abundance calculated from CT records, based on group size estimation obtained from images, for summer 2019 showed the smaller values of population size than rangers' reports, but with the same pattern – in summer there was more animals than in winter (Table 9).

Table 9. Abundance estimation based on different methods of data collection: density estimation from camera trap records (average group size as well) and from direct observations by rangers. Value calculated for the total area of the DDCR**.**

			Camera trap records				Rangers field reports			
Year	Season	Environment	N	Range	Mean	SD	N	Range	Mean	SD
2011	Winter	Natural	6	24 - 53	39	13.3	12	219 - 358	269	38.7
2011	Summer	Natural	4	1 - 32	9	13.3	16	314 - 490	397	49.4
2019	Winter	Improved	6	80 - 1119	367	401.7	9	614 - 669	648	16.8
2019	Summer	Improved	4	226 - 1081	586	362.4	15	673 - 784	724	40.1

4.5. Activity pattern

During the whole research period in 2011 the oryx were active only half of the day on average with the 2 visual peaks: one at night – around 01:00 and the second – around 11:00 (Figure 14). Activity were recorded between 01:00 and 13:00 with mean peak time of 07:50 (SD = 03:38 hours). The annual activity pattern in 2019 clearly showed that Arabian oryx was mostly active during the day time, but occasional activities were recorded throughout 24 hours. Circular statistic registered the slightly curves of activity at night (after sunset at 19:00 and till sunrise at 06:00) and the great amount of records at day time, starting from 06:00 till 19:00 (Figure 14).

Seasonal changes in activity pattern reported to be in ungulates, were recorded as well during our study (Figure 15). We reveal a significant difference between average time of peak in winter and summer in 2011, according to Watson-Williams F-tests (p-value = 1.56E-7) (Table 10). During winter season (December 2010 – February 2011) Arabian oryx was virtually inactive from 13:00 to 01:00; had the mean active time at 08:08. During summer season (June–August 2011), the activity pattern had the first peak at 01:00 and second at 06:00, while mean time was 04:30. During winter months of 2019 the oryx herds appeared intensively between 10:00 and 18:00 with the peaks at 11:00-12:00 and 17:00 (mean value of 13:56 hour). In the summer season most active registration were from 08:00 till 12:00 and from 16:00 till 20:00 (mean value of 14:08). We revealed a significant difference in seasonal activity pattern in 2019 (p-value = 6.10E-5) at the improved sites. As camera trap in 2011 were located at the natural sites mainly animals were captured during walking or resting activities. In the winter and summer of 2019 the camera trap sites were located at improved locations (facing waterhole), what influenced the type of the recorded activity: animals were feeding, resting, rarely fighting. In all seasons both years, small amount of images recorded investigation of the camera by animals or looking in the camera.

Table 10. Activity pattern recorded for Arabian oryx from CT records. CI – confidence interval.

	2011		**2019**	
	Natural sites		Improved sites	
	Winter	Summer	Winter	Summer
N	372	66	2053	1965
Mean	8:08	4:30	13:56	14:08
95% CI	7:33 – 8:41	3:12 – 6:20	13:29 – 14:24	13:24 – 14:52

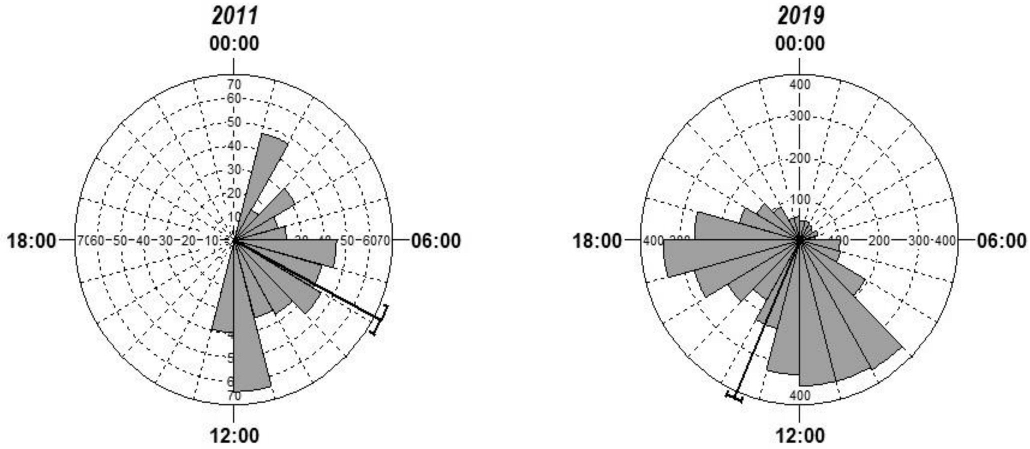

Figure 14. Annual activity pattern of Arabian oryx recorded by camera traps: in 2011 – at the natural sites; in 2019 – mixed.

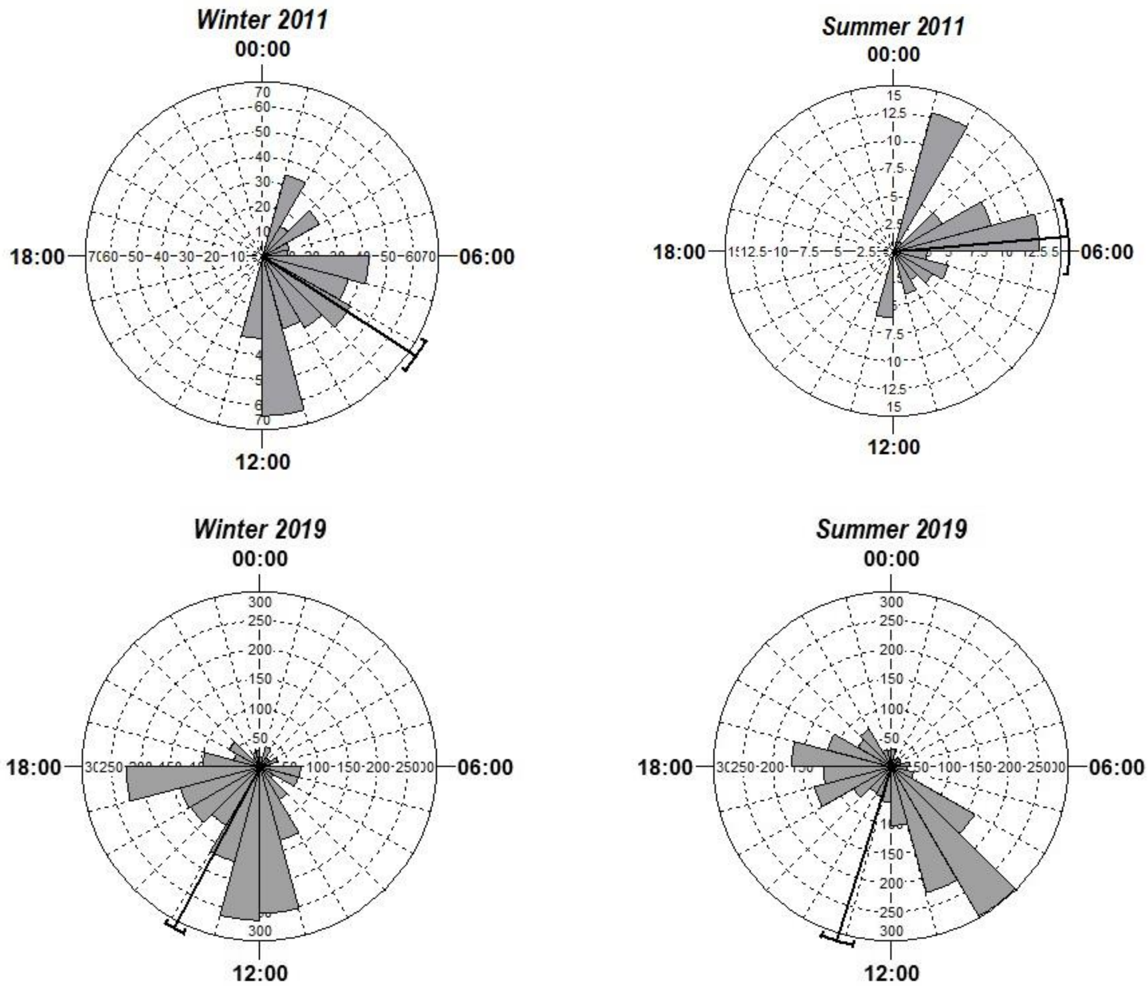

Figure 15. Seasonal activity pattern of Arabian oryx in the DDCR: in 2011 – at the natural sites; in winter 2019 – natural sites: in summer 2019 - mixed.

5. Discussion

In this study we covered several aspects of two main research questions: what are the seasonal changes in population dynamics of Arabian oryx population in the DDCR throughout the selected years and to what extent the camera trap technique is usable to study addressed research goals.

5.1. Camera trap research in the UAE

Generally speaking, camera trapping is still developing field of wildlife research in the Middle East region. Cole Burton and Nelson were reviewing amount of published articles involving CT method in 2008 – 2013 period and reported that majority of studies took place in Asia (28.6%) (Burton et al. 2015). It is relatively big percentage in comparison to Europe (8.1%). However, we should mention that Asia-region is including a vast geographical range and a lot of countries. More detailed focus on camera trap experience in the Middle East in particular gives an understanding, how poorly explored this area. The bright representation of current situation globally in the field of CT studies is the infographic of Oliver R. Wearn and Paul Glover-Kapfer (Wearn & Glover-Kapfer 2019). It provides a solid evidence of necessity of further development and support of camera trap studies in the Arabian Peninsula (Figure 16).

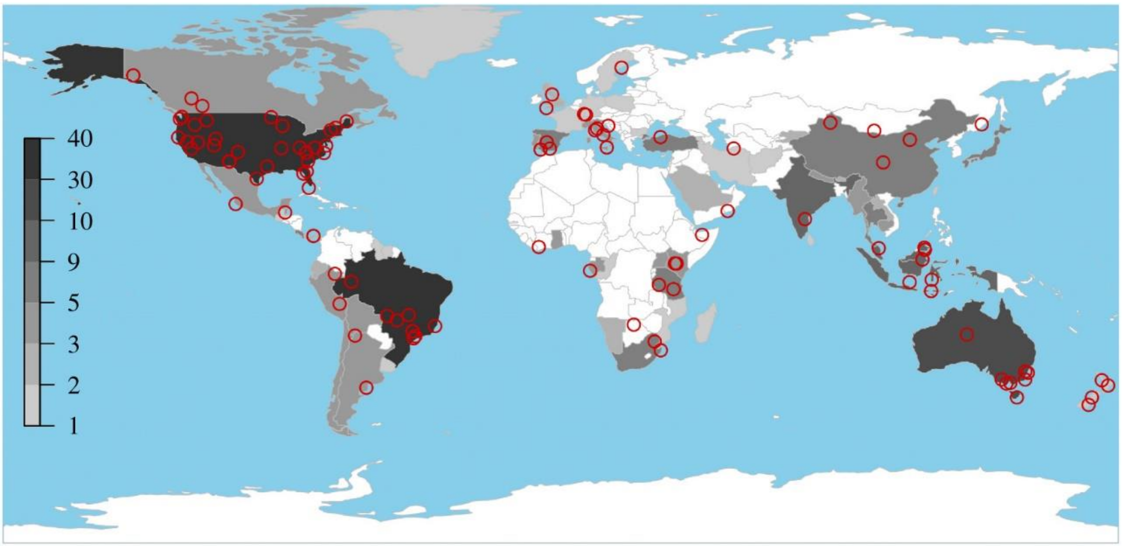

Figure 16. Overview map displays a measure of overall camera-trapping publishing output globally: based on the number of CT studies per country published between 2008 and 2014 (Burton et al 2015; Wearn & Glover-Kapfer 2019).

In support of conservationist and researchers, who are working in the Middle East with camera traps, there have been great results and intentions, happened with the help of remote records and each CT survey was definitely beneficial and crucial for wildlife conservation agenda. Making a research on how Arabian oryx was studied through the years, we may conclude that CT were not the first choice of tool to apply, predominantly CT are recommended to apply for cryptic carnivores' species. Active studies were done on Arabian leopard (*Panthera pardus nimr*) in Saudi Arabia and Oman (Jackson et al. 2011), Persian leopard (*Panthera pardus saxicolor*) and Asiatic cheetah (*Acinonyx jubatus venaticus*) in Iran (Hamidi et al. 2014; Farhadinia et al. 2017); Arabian sand cat (*Felis margarita harrisoni*) in the UAE (Ahmed et al. 2016); hyenas and fox species in Lebanon (Abi-Said & Amr 2012). Studies on species richness using CT were conducted in Turkey and only one species of ungulate was included in the report - roe deer (*Capreolus capreolus*) (Can & Togan 2009). Usage of the CT to study ungulates happened on rare occasion in Saudi Arabia: in 2015 the endemic Arabian tahr (*Arabitragus jayakari)* had been recorded in the Wadi Wurayah National park (Mohamed et al. 2015). In 2012 CT survey on the Arabian gazelle (*Gazella arabica*) from Wadi Tarj reserve confirmed that this still present and persistent in the region (Boug et al. 2012). Usually, oryx were studied with the help of non-invasive methods - GPS collars (Gallacher 2015), faecal samples (Al Jahdhami 2010) and invasive methods - direct observation (Heezik et al. 2003; Ruckstuhl & Neuhaus 2009), using radio-transmitters (Ostrowski et al. 2003), implants (Davimes et al. 2016)б caging oryx in the experimental facilities (Williams et al. 2001), collect blood samples (Cribiu et al. 1990).

In my opinion the CT survey can massively enrich understanding of Arabian oryx behaviour and ecology, as such non-invasive method of observation has a unique capacity to record natural scenes of oryx life. It seems like there were no published results from CT survey focused on Arabian oryx biology, however the "Biosphere Expedition", which takes place annually at the DDCR is including the CT method into monitoring of fauna. Undeniably, every analysed camera trap survey is enriching the local database and understanding of the species ecology, as well as improving the quality of the of conducted research. Hence, current project on population studies of Arabian oryx was useful from the position of exploring camera traps capacity, its potential in the fenced facilities and highlighted, that there is a great potential to record natural behaviour, activity pattern, even migration routes of desert antelope. As well as it specified CT survey details, essential for improving the CT use and practise in DDCR.

5.2. Seasonal changes in Arabian oryx population in DDCR

For deeper understanding of the results, we should consider than seasonal shift in activity pattern is the main cause of seasonal changes in density records on camera traps, herd composition and other parameters. In addition, obtained results should be put in a context of continuous development and transformation of the DDCR facilities: in the period from 2011 till 2019 several new infrastructure objects had appeared on the reserve territory. This possibly influenced a movement, distribution pattern and activity schedule of the reserve inhabitants. It is important to note the average time of sunrise and sunset in the summer season: 05:30 - 06:00 and 18:45-19:15 respectively. For winter season this time shifted to 06:30-07:00 and 17:40-18:00. To bring more context - Arabian oryx at the site of re-introduction is provided with feed supplement (hay and pellets) on weekly basis with fixed schedule (from 5:00 till 8:30).

First publications on the Arabian oryx daily activity patterns and its alteration were done since 1989 and are made constantly on the different oryx species around the globe in different types of habitat (Seddon & Ismail 2002; Ostrowski et al. 2006; Cusack et al. 2015a). Still it seems that there is scattered knowledge on antelopes in range-limited facilities of the UAE, only several studies could be used as reference for the current research. For instance, Joshua Davimes studied the movement dynamics of the species and demonstrated that oryx antelope has seasonal changes in 24-hour activity patterns (Davimes et al. 2017). Thus, we expected to gain similar results for 2011 and 2019 for natural locations, but at the same time we were open to possibility to detect other pattern for improved location, as Davimes` research had happened at the natural sites. It was important to take a look on activity shift with connection of habitat type, where the records were collected. Indeed, in not-improved natural habitat in 2011 a clear shift at seasonal level was recorded and animals were active only half of the day. In the contrast, in 2019 only shift in daily peaks was noticeable, while the amount of active hours increased to 24 hours and stayed the same during both seasons. Oryx expressed crepuscular activity during summer 2011 at natural sites and partly during summer 2019, what can be explained by typical endurer strategy to cope with extreme temperatures of the desert area. In the Waterberg National park (Namibia) daily activity pattern was studied for gemsbok and results revealed, that wild oryx tend to be night and morning drinkers (Kasiringua et al. 2017). Earlier, Hetem studied the seasonal changes in activity pattern in free-living Arabian oryx in the Saudi Arabian desert (Hetem et al. 2012) and reported that they were mostly nocturnal during hot summer season and were virtually inactive part of the day. Therefore, we expected the similar pattern for DDCR population and it was confirmed for Arabian oryx, recorded at natural sites in 2011**.** This could be explained again by coping strategy of body temperature regulation. Supporting previous study, diurnal activity of Arabian oryx in the DDCR was recorded within winter seasons 2011 and 2019, when temperature was the lowest. But changes were revealed for hot season 2019: several clear daily peaks were registered at improved sites in summer 2019, probably due to the water supplement and animals` habituation to free access to water during hot months. These results reaffirmed David Gallacher report, showed that collared Arabian oryx at DDCR sites in the summer months at the middle of the day were tend to spent part of the day close to water (Gallacher 2015). Our pattern was even stronger: animals in summer 2019 used the artificial waterholes on daily basis, as a place to feed, rest and interact with each other. We expected to see activity peaks around "feeding hours" – from 6:00 to 8:00, but such pattern was visible for 2011 year, not 2019. One of explanation would be, that animals after feeding did not seek water source, but only shade. Thus, animals were not going to the waterholes. From other side – traveling to and from feeding site could be detected by cameras, if we would set up more them frequent to grasp this migration. On this stage, we cannot be sure, that peaks in 2019 or 2011 were linked to feeding schedule. Additional monitoring is need to say is the same individuals are visiting water sites everyway or there are several herds, who are coming back to the waterhole with stable occasion length. Undoubtedly, for 2019 improved locations, animals were gathering and visiting site more often before the hottest hours of the day starts (first daily peaks in winter, summer 2019).

Significant changes happened in seasonal activity budget between years: while in 2011 animals were recorded on cameras only in half of the day, at the natural sites in 2019 records were happening every hour (occasion length was equal to 1 day). Possible driver of such behaviour was a free access to water and shade. But what is the complex of driving factors behind such shifting should be examined more. Studied Arabian oryx population is secure from natural predators, therefore such factor will not play a role. Yet it is still valid to include interspecies and intraspecies interactions which occur in the reserve. The connection of seasonal changes with photoperiod and alteration of temperatures, reported for other habitats (Ortavant et al. 1988; Webb et al. 2010; Cunningham & Wronski 2011), is definitely valid for DDCR area. In addition, as it was mentioned, feeding schedule and interaction with rangers` team should be taken into account.

Our results on activity pattern of Arabian oryx in DDCR enhance the understanding of how animals cope with temperature regime in the limited home range, within the fenced reserve. We saw, that of Arabian oryx in DDCR were reducing its activity during the day, when the temperature reaches its maximum, animals were staying in the shade during these hours, and the same pattern was reported to be in the re-introduced free-roaming population in Oman (Spalton 1993). That provides an evidence of natural behaviour in wild and semi-wild population. Davimes also suggested, that the adaptive responses of Arabian oryx in a limited-range, but harsh, close to original natural conditions, could help in work with true wild populations and in improving conservation efforts (Davimes et al. 2017).

Direct consequences of seasonal activity dynamics were variations in values of the occasion length, trapping rate and camera sites occupation between seasons and years. All camera trap-related parameters confirmed to be season-specific for 2011. Frequency of the wildlife occasions in summer of 2011 was much less than in winter, therefore the trapping rate in winter was much higher than in summer. The latter, again, links the strategy of coping with body core temperature regulation. In winter, the animals were more actively exploring an area and were caught on CT more frequently. For 2019 due to monitoring of artificially improved locations the pattern was vice versa: there were more detections of Arabian oryx in the summer and they happened on daily basis.

5.3. Sex-age identification using camera traps

Sex composition and age structure of ungulates herd reported to be closely related to ecological factors (Jarman 1974; Cunningham & Wronski 2011; Estes 2012). In the wild habitat influencing role play type of habitat, predator presence or food availability. In the fenced area, where animals provided with feed supply and there are no predators, influencing role is shifted to anthropogenic disturbance, habituation to artificial sites and intraspecies interactions. The knowledge on the herd dynamics in time and seasons at

DDCR site is limited. Previously, there was no research conducted on herd composition involving CT methodology, thus CT survey design should be invented form the scratch. The referring values and scale to compare our results were taken from studies, based on other methodology, but with focus on the similar research questions. Eventually, several solid conclusions were possible to formulate. Variety in recorded raw numbers of adult and non-adults between years can be explained by the growth of the population itself. In 2019 population size became three times bigger than in 2011; the proportion of the non-adult individuals from natural habitat in 2011 was higher in summer than in winter - all these indicate the successful breeding environment in the DDCR and tendency to natural population growth. At the same time such pattern was not revealed in records of 2019, probably due to unnatural conditions of study sites.

Overall, there are several limitations in using CT for sex indication of antelopes. In theory it is possible, but for trained researcher or only when animal is close to the camera from a certain angle (when its sexual organs are visible). Otherwise, the identification may be incorrect for monomorphic ungulate. In our case, the initial plan of identification herd composition precisely with female and male identification was possible only in half of the cases, that is why it was decided to reveal herd composition pattern only for age groups, reducing the sex parameter. Direct observation may be much more sufficient and accurate for sex-age study. Other point, non-adult individuals may be difficult to detect on the CT images, as within the distance of the 10 m due to the coloration of new-borns and juveniles, it's hard to distinguish the calf on the sandy background. Moreover, due to small size and position of the young individuals close to their parent, they were often covered by adults and probably stayed undetectable for camera. On the other hand, there were helpful outcomes, taken from night-records, as females with offspring were recorded at different sites at night and were probably not visiting the same site during the day (of visiting less frequent).

5.4. Attention to details in group size estimation

As well as sex-age group composition, it is well known, that the herd size is driven by ecological factors as season, food variability, human presence and reproductive season (Jarman 1974; Spalton 1993; Lee et al. 2013). In different habitat oryx recorded to have density from 2 to 300 individuals/100 km^2. Wilson in 1980 reported the group size for Chad population of Scimitar-horned oryx *(Oryx dammah)* from 10 to 30 individuals with mixed age-sex composition. Observations from Tunisia reported that *Oryx beisa* forms group from 2 to 30 individuals. At the same time, gemsbok in wild conditions tend to form herds up to 30 individuals, but following the rainfall, the group composition were increasing to 300 individuals (Kingdon et al. 2013). Somehow similar results were reported in the USA, where captive Scimitar-horned oryx are kept in Llano uplift region in Texas: group size there varied from 2 to 52 individuals, with the mean of 11 animals in the fenced area of 719 ha (7.2 km^2) (Robinson & Weckerly 2010). The reason why animals were forming herd of “natural size” believed to be the sufficient range area to express this natural pattern. Therefore, we took into account where exactly and how data was collected during our research in DDCR in 2011 and 2019 years.

For example, rangers calculated herd size within “baited” and on average their group size estimation was close to the analogue from wild populations, i.e. 19 - 22 individuals. We could say, that even in limited range area oryx tend to form group size as in wild condition, what serves as one of the indicators of wilderness. From one side, that could serve as evidence, that so far there is enough place/recourses for Arabian oryx population in the DDCR; from the other side, it is important not to be misled by this outcome that population habitat is perfectly balanced and do not need regulations. Using the CT approach of calculating average number of animals recorded at one image, we obtained the trend, showed that there were no seasonal changes in group size. When for direct observations, rangers recorded bigger group formation in summer 2019 than in winter. And this could be explained by increasing number of individuals in population in addition to tendency to gathered around water point at hot season.

Special interest from my side was the influence of human activity on animals and their response to it. There were particular studies, how human presence influences the group size of the ungulates (Brown et al. 2012; Howe et al. 2013; Lima et al. 2015). Bright example, for the mountain gazelle (*Gazella gazelle*) in Israel a negative relationship between group size and human disturbance was found: specifically, in open areas with low disturbance levels gazelles were in significantly bigger groups, than in open areas with high disturbance levels (Manor & Saltz 2003). Does this rule apply for big antelopes in environment with constant presence of human? From the observation for Arabian oryx in the DDCR it is hard to tell, particular methodology should be applied to study this question. Nevertheless, our research brought closer vision on group size variation within the year and can serve as a starting point to explore influence of other factors on this parameter.

The main question how to obtain group size from CT, adequate from ecological and behavioural perspective, remains open. Definitely, wildlife event and group composition estimation should be based on precise analyse of the images. In case of oryx in the DDCR in some cases it was possible to distinguish particular individuals: some animals were collared, some had specific horn shape of face mask, not repeated in other individuals. But even in without individual recognition, age and sex can be noted. However, such detailed work should be done by researcher, who has previous experience in sex-age or/and individual identification of Arabian oryx. Other option would be an adapted technique, described by Jarman for ground survey (Jarman 1974). The idea is in summing up the size of the groups in which individual found itself and dividing this sum by total amount of registered animals. For that we can note the frequency of certain group appearance, thus this approach should be doable without additional survey. Another option is conduct parallel survey on group size estimation, using faeces samples, direct observation or other technique, adequate for research plan. Though the CT records provided controversial information on natural group size of oryx, it increased understanding of the potential and limitations of CT method to study demographic variation of Arabian oryx.

Regarding the direct observation technique, used in the DDCR, several concerns should be listed. From my personal observations, during the drive to the feeding station, animals were waiting for the vehicle with alfalfa and pellets, and precisely knew the schedule of the constant feeding, what definitely marks changes in behaviour. It is unclear if the group, arriving to the feeding spot, is an independent herd and if it stays in the same composition after the feeding session. Separate study is needed to reveal how solitary individuals do behave in regards to feeding session - do they join the herd on the way to the point or remain excluded from the feed supplement? Moreover, there was probably some hierarchy and special priority in the access to the feeder what should be studied more as well. It is important to mention part of the animals who are not habituated for feeding schedule and may be missing from the total count, as they stay in parts of DDCR unreachable for rangers` observation.

The feeding behaviour of the Arabian oryx at DDCR and its strategy in dealing with human activity can be a complex independent study in the future. Our study showed that group size analysis can be performed by both methods, and each can complement the results of another technique.

5.5. Density and abundance estimation

The pilot test for density derivation from camera trapping rates can be graded as useful and beneficial. Estimation of population characteristics of Arabian oryx via camera trap just started take place on the continuous base and the search of the proper methods efficient in the DDCR condition is ongoing. The problematic moment with density study of the Arabian oryx, in general, is that it has no proper documentation on the original distribution and density before extinction in the wild in 1972. To provide the background for interpretation of our research results, we had to compare acquired estimation with other oryx species in Africa or re-introduction sites in the Middle East.

Regarding the other species in the genus *Oryx*. It was recorded that in Kalahari Desert the free-ranching gemsbok density is around 45-87 individuals/100 km^2. In 1977 in Namibia this value was 17 individuals/100 km^2 (Kingdon et al. 2013). But in the centres of distribution in Kenya (intensive management) density of Fringe-eared oryx was ten times higher – up to 120-140 per 1 km^2. For roan antelope, from the same family *Hippotraginae*, in wild African condition it density reaches 20-60 individuals/100 km^2 in Benin, 80-150 individuals/100 km^2 in Burkina Faso, but under intense management the value reach 2,000 individuals/100 km^2 (Kingdon et al. 2013). From this position big difference in obtained results between natural and improved location for Arabian oryx in DDCR in 2011 and 2019 looks adequate: as it also increased ten times.

Regarding the Arabian oryx itself, historically it was reported, that because of low resources availability, its density in the desert was low – 1.6 individuals/100 km^2. In 2009 oryx density in DDCR was estimated at 110 individuals/100 km^2 (Gallacher 2010). At that time the estimation was significantly higher than its estimation in the similar conditions in Saudi Arabia with 1.6-20 individuals/100 km^2. For free-roaming population of Arabian oryx in Oman density was reported to be around the same value - about 3.5 individuals/100 km^2 (Mésochina et al. 2003). Such low density was not expected to be found in DDCR sites, as it is not considered to be wild, and our expectations partially came true.

Individual and group density at not-attractive natural locations in 2011 were in range 1-16 individuals/100 km^2 and 2-25 individuals/100 km^2 respectively. For group density in 2011, with estimation of group size by camera traps, the final value varied from 7 to 17 individuals/100 km^2, what can stay in comparison with density estimation done by Mesochina and Gallacher. Both were significantly higher in winter than in summer, what can serve as evidence of higher movement rate in colder months and less active movement in hot season or bigger size of group, recorded for each season. To conclude, that changes in density were linked with changes in seasonal movement, we should take into account the parameters of the equation, used for density estimation. Two main parameters, which influence the outcome, were trapping rate and group size. In our case the group size was not significantly different within the years, but the trapping rate was – it varied significantly both in 2011 and 2019. More intensive walking, traveling across DDCR assured more records in the CT. This outcome confirms, that winter season is better for density and abundance estimation with the help of REM in the arid habitat. Important specification, that such strategy should be applied for natural sites. For improved location the trapping rate pattern was contrariwise. Animals were seeking shading and stay closer to water source for longer time, thus trapping rate was much higher in summer season. If we analyse group density of 2011, based on group size estimated by direct observation, value increased to 76-206 individuals/100 km^2 in 2011, repeatedly in winter higher than in summer. These values are close to estimations from centre with intensive management in Africa.

It was mentioned above, that the density calculation with REM technique for improved location were suggested to be calculated only to reveal the range of density and abundance parameters. They should not be taken as reference to compare it unbiased with not-improved sites. Classic random encounter model did not include camera traps from attractive/baited sites into density calculation. Clear that the obtained density was much higher. There were few limitations to consider the REM method unbiased: inefficient amount of the CT and complication in obtaining average group size. Markus Rowcliffe and his team suggested to install at least 20 CT, but for more accurate estimation - at least 40, especially when the photographic rate is diverse within the study site (Rowcliffe et al. 2008). The amount of CT in the frame of our research in 2011 was only 12 on 6 locations (six cameras per each season) and 18 CT in 2019 (six in winter, twelve in summer) at twelve locations. Explanation was that, it was important to us to replicate the CT survey design of 2011 to compare data. And the old design was not counting on REM technique. Thus, the compromise solution was found: replicate the 2011 camera trap design, plus - modern 2019 winter CT design and find the common ground to work with archive and modern data. I would like to indicate separately the calculation of the linear regression. It was driven by recommendation from scientific works focused on usage of photographic trapping rate as indicator of density and abundance of a focus species, i.e. relative abundance index (RAI). Indeed, there was a strong connection between density and trapping rate, but from biological point of view RAI estimation may be controversial (Rowcliffe & Carbone 2008), as it overlooks ecological characteristics of the species. For current research it was decided not to include RAI as a valid index for abundance estimation.

Calculated abundance from camera trap records provides not one, but a spectrum of values. But from the perspective of the management planning, population size estimation had raised awareness of possible overpopulation crisis, what might happen in near future. The direct observations reported of population size in 2011 around 270-400 animals, while the CT survey reveal only 9-40 individuals. Successful population growth over the year results in bigger population size in 2019 year: rangers counted on average 650 animals in winter, 720 animals in summer, while the CT from improved location recorded animals on average 370 animals in winter and 590 individuals in summer, but at maximum – more than 1,100 individuals at several improved locations. Though, this calculation in over-estimated modelling, it was beneficial from educational perspective to conduct and apply REM technique on different type on environment with different parameters to find the optimum conditions for its future applications. Detailed analyses of carrying capacity of the reserve is needed to make a conclusion, what density value is suitable, what is critical for the DDCR. Anna C. Treydte organised study on the optimal management strategy for the re-introduced population of Arabian oryx in Mahazat as-Sayd (Saudi Arabia), as well in the fenced facilities, but bigger that DDCR (2,244 km2). In her opinion, population will thrive if the part of the population (above 70% of carrying capacity level of Mahazat as-Sayd) will be removed. She suggested, that "extra" animals can be used as founder herds for other re-introduction sites or introduced to other managed populations to increase genetic diversity in subpopulations (Treydte et al. 2001). Additional research is needed to make any conclusion on population tendency in the DDCR to reveal the risk of overpopulation. Undoubtedly, one is clear at the moment, there is a stable growth in re-introduced Arabian oryx population in the DDCR.

5.6. Sector-wise focus on the activity pattern

Analysing the animal activity in the context of its distribution across the reserve, several distinctive patterns were perceived. Already in 2015 Gallacher mentioned, that some areas of the DDCR were less occupied by oryx antelope than others. For example, area from 0.5 to 1.5 km close to the reserve fence, i.e. edge territory, was visited by animals only occasionally at night (Gallacher 2015). Such avoidance reduces the available, already limited, home range of antelopes and can increase chances of accumulation of animals at certain location with potential degradation by overexploitation. Predicting such problem earlier, management team was implementing the strategy of shifting feeding stations every six weeks to a new location, to encourage animals to spread around all available reserve area. Nevertheless, the problem remains to be in 2015 and still in 2019. At the same study Gallacher assumed that fenced area would probably limit the natural migratory patterns, which oryx express in the wild, driven by the search of fresh vegetation. I would mention, that such micro-migration is probably already happening at the DDCR in the new form: not migration, but concentration of animals closer to the centres with infrastructure objects. Detailed research of the driven factor is needed – are animals in the need of shade, feed or other? Do animals aggregate themselves for a long time or CT survey revealed temporary state of natural dynamics?

Clearly, there was strong sector-division in animal appearance and recording them on cameras. And pattern got the seasonal shift in the not-natural locations of 2019, but remain the same in natural sites of 2011. If in the 2011 more records were linked to the north part of the DDCR, in 2019 at the same natural location, the central part of the reserve was more abundant. As for improved locations in 2019, – animals clearly appeared more often and in higher numbers in south and central part of the reserve. Referring to the work of Washington-Allen, it is important to predict animals` concentration and the risk of overgrazing on the area. The phenomena, known as piosphere appearance, describes the animal impact on the environment over time, when accumulation of some animals, for instance antelopes, can increased the soil erosion, vegetation cover deprivation and transformation of soil chemistry (Heezik et al. 2003; Washington-Allen et al. 2004). Piosphere analysis utilises the knowledge on land resources and on animal-resource interaction and can be used as indicators of land degradation (Washington-Allen et al. 2004). Constant monitoring of the area and grazing effect of ungulates on it always was at the working agenda of the DDCR Research centre team. Camera trap survey from this position can provide evidences of changes and can be a reflecting tool to prevent the situation.

Discussing the drivers of possible animal accumulation – what are they? In the wild, natural vegetation type and food dispersion are the main factors of animal dispersion (Jarman 1974). But in the areas, where human settlements are present, the anthropogenic disturbance reported to affect sensitive species of ungulates: such pattern was revealed in the Grand Teton National Park (USA) for elk (*Cervus elaphus*) and pronghorn (*Antilocapra americana*). At the same time, other ungulates reported to adapt to regular exposure of noise and become accustomed to non-lethal human activities (Brown et al. 2012). What plays the role in range-limited managed facilities in the arid habitat? From point of view of topography, the DDCR area may influence animals` behaviour and decision-making through several aspects: 1) presence of car on the passes, which might be used as well by animals as easy routs; 2) presence of infrastructure objects, which are providing shade, sometimes extra water/feed resources; 3) higher noise and light disturbance near resort centre; 4) presence of feeding and waterholes, organised for animals.

The north part of the reserve has the specific triangle shape and narrowing to the top. Referring to Gallacher (2015) observation, that oryx were not approaching the edge area frequent, we assumed, that the North sector looks like the one to have reduced area for antelope daily use. The top part of the North sector has an elevation and rocky hills, which are not typically used by antelopes for long time. As well the amount of waterholes in the north is less than in other sectors, at the same time – these waterholes are shifted to the north-central part of the sector. In the middle of the North sector once a year, the "Biosphere Expedition" camp is located. In the Central sector of the DDCR there are several big infrastructure objects – resort centre, staff accommodation, farms, where fields of alfalfa are planted, camel centre and dense net of roads. Each of the object provides extra benefits (shading, possible feed supply, exclusion from the herd for solitary individuals) and disturbance factors, described earlier as human-related, at the same time. And the general influence of this factor-complexes on animals is not possible to predict univocal. The South sector has the widest shape and minimal branching of the roads. The farms and waterholes are located on big distance from each other, what is comparable to North sector, but not to the Central one, where all elements are much compacted on the area. In this research it is important to have a retrospective of appearance of new objects and landscape elements in the DDCR. From this perspective, archive of data with camera trap images may have answers on composition and characteristics of artificial objects, if camera where located to observe them.

Arabian oryx are one of the few arid-zone ungulates able to maintain independence of water sources during summer. However, it was reported that Arabian oryx could take advantage of human presence: some individuals were using the waste water, digging up and chewing pipes, several animals had entering researches tents at research Camp in Mahazat as-Sayd protected area (Heezik et al. 2003). Besides, Hasen reported, that animals in areas, where contact with humans happen on regular basis, showed reduced flight response (Hansen & Aanes 2015) and such tendency could be valid for some individuals at the DDCR. From personal observation it was noticeable, that small ungulates were more frighten of human proximity than big antelopes: oryx tolerated human presence till the short distance. Several papers also suggest that vehicles following predictable paths (established roads) are perceived by animals as less threatening than those in unusual situations (Stankowich 2008; Lima et al. 2015). During the field trip at DDCR in 2019, animals were seen close to gates in date palms alley, close to pipes and using the roads as routes, variation of reaction was noticed for car approaching the individual or herd (from staying at the same place to escaping from the long distance). Apparently, the population of oryx became habituated to DDCR reality, but it is an individual (or collective) decision of the animal (or herd) how to interact with natural and improved component of landscape. Taking all this information into account, the interpretation of results sector-wise could be appealing for ethologists or behaviouralists.

5.7. Direct observation VS camera traps

Taken as a whole, there are several advantages and disadvantages in both methods, each of it needed to be improved and taking into consideration for particular goal of the research. Between two approaches in herd composition study it is difficult to give preference to one of the working methods. Camera traps performed excellent in diurnal activity estimation, recording animals in the remote areas, showing the distribution pattern. While the direct observation did provide the better abundance estimation, precise age-class herd calculation. Of course, the effort and costs linked to both methods should be taken into account. From the personal experience and based on the literature review, we could compare selected techniques for usability in DDCR as it follows in the Table 11.

Table 11. Comparison of the camera trap technique to the direct rangers` observation. Strengths and limitations of technique for population study of antelopes.

Characteristic	Strengths	Limitations
Duration of study	**CT.** Operates 24-hour for a long time period.	**Rangers.** Available only for a short period of the day. Limited duration of study.
Accuracy of monitoring	**CT.** Detect variety of age-sex groups. **Rangers.** Detect variety of age-sex animals with understanding of group composition. Higher chances to detect cryptic new-born or resting in bushes individuals.	**CT.** Missing hidden individuals. **Rangers.** Double-counting of the animals during round trip around the forest/bit area.
Invasiveness	**CT.** Non-invasive.	**Rangers.** Disturbance of the animals, animals` habituation to rangers` arrival and feeding schedule.
Monitoring bias	**CT.** Not biased.	**Rangers.** Could be biased.
Cost/efficiency ratio	**CT**. Variety of models and equipment.	**CT.** High cost. **Rangers.** Cost on human/hour work.
User-friendliness	**Rangers**. Easy method to educate workers. **CT.** Easy to learn.	**CT.** Require digital literacy
Additional information option	**CT.** Digital camera settings provide range of information for each particular image (temperature, time, moon phase, wind). **CT.** Have photo and video options.	**Rangers.** Time consuming to note all details about event. Provide average information on environmental parameters.
Context factor	**Rangers.** Can note specific abnormalities in behaviour, health condition of the antelope.	**CT.** Irrelevant to specific changes in herd composition, individual behaviour of animals.
Reusability	**CT**. Data and results are saved into database, archive. Possible to use for other studies, double-check results.	**Rangers.** Only results are saved in the archive, not possible to check details or accuracy of calculation.
Standardisation	**CT**. Standardisation of technique allow the long-term and seasonal comparison.	**Rangers.** Standardisation is present, but influenced by individual qualification to conduct a survey.
Degree of inclusiveness	**CT.** Provide information about animal presence and distribution at the remote areas; record solitary individuals.	**Rangers.** Work in particular sites of close proximity to official routes. Exclude animals from unreachable sites.

5.8. Contribution to management tool set

Coming back to classification of successful conservation plan, offered by K. Redford it is visible, that population of Arabian oryx at DDCR area considered to be between “lightly managed species” and “conservation dependent” (Redford et al. 2011). Thus, it should be supported by a number of strategic decisions by managers. Our results can serve as a valid information, enriching the database of the nature reserve and serving as an example and basis for improvement and future research studies. What can be taken from present work:

1) Results of sector-linked trapping rate may suggest the possible risk of piosphere appearance, linked to accumulation of the animals in one or another location. Therefore, continuous research on the movement dynamics of the herds and individuals is suggested.

2) Records from camera traps from natural sites in 2011 provide the estimation on occurrence of animals at certain site in natural condition. This can serve as a reference for ground survey in the future. While records from improved location in 2019 confirmed, that animals are using waterhole on daily basis.

3) Repeated CT survey on natural location in summer 2019 revealed similar trapping pattern and occasion length, as in 2011. These values might be stable wilderness indicators or at least indicators of behaviour constancy.

4) Camera trap shown to have usability in natural group size identification with certain training. Along with frequency of certain amount of individual occurrence, which serves as the essential part to group size estimation in some methods.

5) Group estimation from rangers` report revealed clear seasonality in 2019 year. This should be taken into account in further population studies.

6) Camera trap proved to be useful in density and abundance estimation with the certain preparation and particular CT survey design. REM technique, from our position, is suitable technique for DDCR, as reserve has technical capacity to organise it, sufficient knowledge to conduct research and analyse the data. For proper survey for density estimation without need of individual recognition of animals, camera traps should be located randomly, but with the respect to animal movement; detection zone of camera should be noted during the CT set up; CT should be checked more often than once in 2 weeks, as strong desert wind may shift the holding pole and camera. Winter season turned out to be better season to monitor density than summer.

7) CT survey on improved sites to study Arabian oryx population dynamics would benefit from improvement in methodology. Several methodological moments were reconsidered and adjustments were made: wildlife event should be defined as an ecological occasion with the respect to time scale (not only as time based period); sex and age identification is possible to do for researcher, after previous practising the sex-age oryx identification via direct observation; to include all types of group composition present in the study area it is recommended to include 24-hours records for analysis.

8) CT survey both on natural and improved location is excellent tool to study activity pattern.

9) Camera traps proved that range-limited population tends to keep seasonality in activity pattern within the year. Shown that Arabian oryx are not strictly diurnal or nocturnal, as they have several daily peaks and tendency to seasonal crepuscularity.

10) Response of animals to feeding schedule should be studied precisely. For that CT locations should be adjusted accordingly to reveal group dynamic before, during and after the feeding session.

11) In general, results from 2011 provide the excellent baseline and starting point to compare results from other years. Analyse of the camera trap records from past years provide constructive and important information on population development in timeline and can help to predict the future trend.

6. Conclusions

Current research is a valuable addition to the overall information about the range-limited population of Arabian oryx in the Middle East. From one side, it can serve as a baseline in comparing different stages of population development, as were worked with retrospective of 2011 and 2019 years. From another side, this might be a foundation and a template of continuous data analyses of DDCR archive materials. Camera traps records from more than 10 years were available for the work and even the small selected part, that we analysed, provides important details on oryx seasonal population dynamics. We could estimate density parameters, activity pattern and partly the herd structure (age-class composition). It was shown, that improved locations indeed attract animals so persuasive, that Arabian oryx, who in wild nature may not require water supply at all, in the reserve reality is visiting the waterholes on a daily basis. Linking the variation of trapping rate to the geographical location of the camera provided the certain vision on animal accumulation across the reserve and raised awareness about hazard of environment degradation in long-term perspective. Seasonal changes in trapping rate and as a result in density were year- and season-specific with different patterns in the sites with different types of habitat. Variation in activity pattern proved that so far Arabian oryx save the natural pattern of seasonal shifting within the year: in natural habitat oryx were more active in winter; while in habitat with artificial improvements antelopes tended to concentrate more frequent and for longer time during summer.

The original idea of comparing two methods of observing wildlife was transformed into identifying the advantages and disadvantages of each method in accordance with the purpose of the study team. Both methods proved to be equally important and even better in combinational usage for particular research purpose (group size, density estimation). Random encounter model technique was applied by research team for the first time to test the method suitability for DDCR reality. The conclusion from the trial test of REM application, that it has a great potential in usage for management purpose. During the analyses of available data, even more questions had occurred: how animals are affected by human activity; does distribution pattern have temporal or permanent character; how density variation among sectors can improve understanding of distribution pattern of antelope; will the population reach the critical maximum number and how to improve camera trap survey methodology to identify sex-composition and group size of the herd more precisely?

We strongly recommend to continue the investigation on the re-introduced population of Arabian oryx. Desert unicorn, who got extinct in the wild, antelope, who was brought back to the original habitat only with the huge conservation effort - this antelope is still have been unknown from a lot of perspectives. Current research was the pilot master thesis project of the Czech University of Life Sciences Prague and Dubai Desert Conservation Reserve. Importance of qualitative international cooperation is the crucial reason, why some re-introduction programs are successful. Therefore, further collaboration and joining force for a conservation effort promise to be useful and potential both for partner sides and Arabian oryx population.

References

Abi-Said M, Amr ZS. 2012. Camera trapping in assessing diversity of mammals in Jabal Moussa Biosphere Reserve, Lebanon. Vertebrate Zoology **62**:145–152.

Ahmed S, Al Zaabi R, Soorae P, Shah JN, Al Hammadi E, Pusey R, Al Dhaheri S. 2016. Rediscovering the Arabian sand cat (*Felis margarita harrisoni*) after a gap of 10 years using camera traps in the Western Region of Abu Dhabi, United Arab Emirates. European Journal of Wildlife Research **62**:627–631.

Al Jahdhami MH. 2010. Physiological monitoring of welfare for conservation of Arabian oryx, *Oryx leucoryx* [PhD. Thesis]. University of Exeter, Exeter.

Amin R, Davey K, Wacher T. 2017. ZSL Camera trap data management & analysis package - user guide. ZSL.

Ancrenaz M, Hearn AJ, Ross J, Sollmann R, Wilting A. 2012. Handbook for wildlife monitoring using camera-traps. J C Printer, Sabah, Malaysia.

Bagchi S, Prakash Goyal S, Shankar K. 2008. Social organisation and population structure of ungulates in a dry tropical forest in western India. Mammalia **72**:44–49.

Boug A, Islam MZ, Shehry A Al, Wronski T. 2012. Camera trapping confirms the persistence of Arabian gazelles, Gazella arabica, in the Asir mountains, Saudi arabia. Zoology in the Middle East **57**:3–10.

Brown CL, Hardy AR, Barber JR, Fristrup KM, Crooks KR, Angeloni LM. 2012. The effect of human activities and their associated noise on ungulate behavior. PLoS ONE **7**:38–40.

Burton AC, Neilson E, Moreira D, Ladle A, Steenweg R, Fisher JT, Bayne E, Boutin S. 2015. Wildlife camera trapping: A review and recommendations for linking surveys to ecological processes. Journal of Applied Ecology **52**:675–685.

Can ÖE, Togan I. 2009. Camera trapping of large mammals in Yenice Forest, Turkey: Local information versus camera traps. Oryx **43**:427–430.

Castelló JR. 2016. Bovids of the World: Antelopes, Gazelles, Cattle, Goats, Sheep, and Relatives. Princeton University Press, New Jersey, United States.

Cribiu EP, Asmondt JF, Durand V, Greth A, Anagariyah S. 1990. Robertsonian chromosome polymorphism in the Arabian oryx *(Oryx leucoryx)*. Cytogenetics and cell genetics **54**:161–163.

Cunningham PL, Wronski T. 2011. Seasonal changes in group size and composition of Arabian sand gazelle *Gazella subgutturosa marica* Thomas, 1897 during a period of drought in central western Saudi Arabia. Current Zoology **57**:36–42.

Cusack JJ, Dickman AJ, Rowcliffe JM, Carbone C, MacDonald DW, Coulson T. 2015a. Random vs Game Trail-Based Camera Trap Placement Strategy for Monitoring Terrestrial Mammal Communities. PLoS ONE **10(5)**:1.

Cusack JJ, Swanson A, Coulson T, Packer C, Carbone C, Dickman AJ, Kosmala M, Lintott C, Rowcliffe JM. 2015b. Applying a random encounter model to estimate lion density from camera traps in Serengeti National Park, Tanzania. Journal of Wildlife Management **79**:1014–1021.

Davimes GJ. 2018. Sleep in the Arabian oryx, *Oryx leucoryx* [PhD. Thesis]. University of the Witwatersrand, Johannesburg.

Davimes JG, Alagaili AN, Bertelsen MF, Mohammed OB, Hemingway J, Bennett NC, Manger PR, Gravett N. 2017. Temporal niche switching in Arabian oryx *(Oryx leucoryx)*: Seasonal plasticity of 24 h activity patterns in a large desert mammal. Physiology and Behavior **177**:148–154.

Davimes JG, Alagaili AN, Bhagwandin A, Bertelsen MF, Mohammed OB, Bennett NC, Manger PR, Gravett N. 2018. Seasonal variations in sleep of free-ranging Arabian oryx *(Oryx leucoryx)* under natural hyper-arid conditions. SleepJ **20**:1–16.

Davimes JG, Alagaili AN, Gravett N, Bertelsen MF, Mohammed OB, Ismail K, Bennett NC, Manger PR. 2016. Arabian Oryx *(Oryx leucoryx)* respond to increased ambient temperatures with a seasonal shift in the timing of their daily inactivity patterns. Journal of Biological Rhythms **31**:365–374.

Du Prel JB, Röhrig B, Hommel G, Blettner M. 2010. Choosing Statistical Tests. Dtsch Arztebl Int **107**:343–348.

Ehrlich PR, Sodhi NS. 2010. Conservation Biology for All. Oxford University Press Inc., New York, United States.

El-Keblawy A, Ksiksi T, El Alqamy H. 2009. Camel grazing affects species diversity and community structure in the deserts of the UAE. Journal of Arid Environments **73**:347–354.

Espinosa S, Salvador J. 2017. Hunters' landscape accessibility and daily activity of ungulates in Yasuní Biosphere Reserve, Ecuador. Therya **8**:45–52.

Estes RD. 2012. The behavior guide to African mammals. Including Hoofed Mammals, Carnivores, Primates. 20th Anniversary Edition. University of California Press, Berkeley.

Farhadinia MS, Hunter LTB, Jourabchian A, Hosseini-Zavarei F, Akbari H, Ziaie H, Schaller GB, Jowkar H. 2017. The critically endangered Asiatic cheetah *Acinonyx jubatus venaticus* in Iran: a review of recent distribution, and conservation status. Biodiversity and Conservation **26**:1027–1046.

Fisher NI. 1993. Statistical analysis of circular data. Cambridge University Press, Cambridge.

Gaillard JM, Festa-Bianchet M, Yoccoz NG. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. Trends in Ecology and Evolution **13**:58–63.

Gallacher D. 2015. Movement patterns of two Arabian Oryx *(Oryx leucoryx)* within a midsized reservation. Ecology, Environment and Conservation **21**:1175–1181.

Gallacher DJ, Hill JP. 2006. Effects of camel versus oryx and gazelle grazing on the plant ecology of the Dubai Desert Conservation Reserve. Pages 85-97 in Mohamed AMO, editors. Reclaiming the desert: towards a sustainable environment in arid lands - Proceedings of the 3rd UAE-Japan Symposium on Sustainable GCC Environment and Water Resources. Taylor & Francis Group, London.

General Secretariat for Conservation of Arabian Oryx EA. 2010. Arabin Oryx Biodiversity Strategy and Action Plan. Environment Agency, Abu Dhabi, UAE.

Gilbert T, Woodfine T. 2004. The Biology , Husbandry and Conservation of Scimitar-horned Oryx *(Oryx dammah)*. Marwell Preservation Trust, Winchester.

Greth A, Schwede G. 1993. The reintroduction programme for the Arabian oryx, *Oryx* *leucoryx,* in Saudi Arabia. International Zoo Yearbook **32**:73–80.

Groves C, Grubb P. 2011. Ungulate Taxonomy. Johns Hopkins University Press, Baltimor, Maryland.

Hamidi AK, Ghoddousi A, Soufi M, Ghadirian T, Jowkar H, Ashayeri S. 2014. Camera trap study of Persian leopard in Golestan National Park, Iran. CATnews. IUCN Cat Specialist Group **60**:5.

Hansen BB, Aanes R. 2015. Habituation to humans in a predator-free wild ungulate. Polar Biology **38:**145-151.

Harding LE, Abu-Eid OF, Hamidan N, Al Sha'lan A. 2007. Reintroduction of the Arabian oryx *Oryx leucoryx* in Jordan: war and redemption. Oryx **41**:478–487.

Harris NC, Kauffman MJ, Mills LS. 2008. Inferences about ungulate population dynamics derived from age ratios. Journal of Wildlife Management **72**:1143–1151.

Heezik Y Van, Ismail K, Seddon PJ. 2003. Shifting spatial distributions of Arabian oryx in relation to sporadic water provision and artificial shade. Oryx **37**:295–304.

Hetem RS, Strauss WM, Fick LG, Maloney SK, Meyer LCR, Shobrak M, Fuller A, Mitchell D. 2012. Activity re-assignment and microclimate selection of free-living Arabian oryx: Responses that could minimise the effects of climate change on homeostasis? Zoology **115**:411–416.

Howe M, Okello MM, Davis JM. 2013. Interspecific variation in the distribution of ungulates relative to human infrastructure surrounding Amboseli National Park. African Zoology **48**:159–166.

IUCN/SSC. 2013. Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland: IUCN Species Survival Commission. Page Ecologial Applications.

IUCN, SSC Antelope Specialist Group. 2017. *Oryx leucoryx*. The IUCN Red List of Threatened Species.

Jackson R, Islam MZ, Boug A, Shehri A Al. 2011. Camera Trapping Manual for the Arabian Leopard. National Wildlife Research Center, Taif, Saudi Arabia.

Jarman PJ. 1974. The social organisation of antelope in relation to their ecology. Behaviour **48**:215–267.

Kaji K, Takahashi H. 2005. Variation in the herd composition counts of sika deer. Population Ecology **47**:53–59.

Kasiringua E, Kopij G, Procheş Ş. 2017. Daily activity patterns of ungulates at water holes during the dry season in the Waterberg National Park, Namibia. Russian Journal of Theriology **16**:129–138.

Kasiringua E, Procheş Ş, Kopij G. 2019. Population structure of ungulates in Waterberg National Park , Namibia **53**:31–46.

Kingdon J, Happold D, Butynski T, Hoffmann M, Happold M., Kalina J. 2013. Mammals of Africa (Vol. I-VI.). Bloomsbury Publishing, London, United Kingdom.

Kock M, Burns K, Al Faqeer M, Chege S, Al Qargaz M, Lloyd C, Tutt C. 2018. Arabian oryx Housing & Husbandry Guidelines Version 1. Biological Conservation **1**:129.

Korf H-W, von Gall C. 2013. Circadian Physiology. Pages 1–33 in Pfaff DW, editors. Neuroscience in the 21st Century: From Basic to Clinical. Springer

Science+Bussiness Media, LLC.

Kovach WL. 2011. Oriana – Circular Statistics for Windows, version 4.

Landler L, Ruxton GD, Malkemper EP. 2018. Circular data in biology: advice for effectively implementing statistical procedures. Behavioral Ecology and Sociobiology **72**:128–138.

Lange H, Skarpe C, Rooke T, Inga B, Bateman PW. 2008. Foraging competition, vigilance and group size in two species of gregarious antelope. African Journal of Wildlife Research **38**:138–145.

Lee DN, Dolman RW, Leslie DM. 2013. *Oryx callotis* (Artiodactyla: Bovidae). Mammalian Species **897**:1–11.

Lignereux L, AlKharusi YH. 2011. Middle East Arabian Oryx disease survey 2011. Environmental Agency, Abu Dhabi, Unired Arab Emirates.

Lignereux L, Nessrine A, AlKharusi Y, Pesci ME. 2018. Middle East Arabian oryx disease survey. Environmental Agency, Abu Dhabi, Unired Arab Emirates.

Lima SL, Blackwell BF, DeVault TL, Fernández-Juricic E. 2015. Animal reactions to oncoming vehicles: a conceptual review. Biological reviews of the Cambridge Philosophical Society **90**:60–76.

Manor R, Saltz D. 2003. Impact of human nuisance disturbance on vigilance and group size of a social ungulate. Ecological society of America **13**:1830–1834.

Manzo E, Bartolommei P, Rowcliffe JM, Cozzolino R. 2012. Estimation of population density of European pine marten in central Italy using camera trapping. Acta Theriologica **57**:165–172.

Mardia K V., Jupp PE. 2000. Statistics of directional data. 2nd Edition. John Wiley & Sons, Chicester.

Mésochina P, Bedin E, Ostrowski S. 2003. Reintroducing antelopes into arid areas : lessons learnt from the oryx in Saudi Arabia. C. R. Biologies **326**:158–165.

Mohamed RZA, Soorae P. 2015. Camera trapping results from Jabel Hafit , Abu Dhabi , United Arab Emirates. Willdlife Middle East **7**:8237.

Nowak RM. 1999. Mammals of the world. Johns Hopkins University Press, Baltimore, Maryland.

O Connell A, Nichols J, Karanth U. 2011. Camera Traps in Animal Ecology. Springer, Tokyo, Japan.

Ogutu JO, Piepho HP, Dublin HT. 2014. Reproductive seasonality in African ungulates in relation to rainfall. Wildlife Research **41**:323–342.

Ortavant R, Bocquier F, Pelletier J, Ravault JP, Thimonier J, Volland-Nail P. 1988. Seasonality of reproduction in sheep and its control by photoperiod. Australian Journal of Biological Sciences **41**:69–86.

Ostrowski S, Williams JB, Ismael K. 2003. Heterothermy and the water economy of free-living Arabian oryx *(Oryx leucoryx)*. The Journal of Experimental Biology **206**:1471–1478.

Ostrowski S, Williams JB, Mésochina P, Sauerwein H. 2006. Physiological acclimation of a desert antelope, Arabian oryx *(Oryx leucoryx)*, to long-term food and water restriction. Journal of Comparative Physiology B: Biochemical, Systemic, and

Environmental Physiology **176**:191–201.

Owen-Smith N, Goodall V. 2014. Coping with savanna seasonality: Comparative daily activity patterns of African ungulates as revealed by GPS telemetry. Journal of Zoology **293**:181–191.

Phillips AJK, Fulcher BD, Robinson PA, Klerman EB. 2013. Mammalian rest/activity patterns explained by physiologically based modeling. PLoS Computational Biology **9**.

Primark RB. 2000. A Primer of Conservation Biology. Oxford University Press Inc, New York, United States.

QGIS Development Team (2020). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Redford KH et al. 2011. What does it mean to successfully conserve a (vertebrate) species? BioScience **61**:39–48.

Robinson SE, Weckerly FW. 2010. Grouping patterns and selection of forage by the Scimitar-horned oryx *(Oryx dammah)* in the Llano Uplift region of Texas. The Southwestern Naturalist **55**:510–516.

Rowcliffe JM, Carbone C. 2008. Surveys using camera traps: Are we looking to a brighter future? Animal Conservation **11**:185–186.

Rowcliffe JM, Field J, Turvey ST, Carbone C. 2008. Estimating animal density using camera traps without the need for individual recognition. Journal of Applied Ecology **45**:1228–1236.

Royle, J.A., Nichols JD. 2003. Estimating abundance from repeated presence – absence. Ecology **84**:777–790.

Ruckstuhl KE, Neuhaus P. 2009. Activity budgets and sociality in a monomorphic ungulate: the African oryx *(Oryx gazella)*. Canadian Journal of Zoology **87**:165–174.

Ruxton GD. 2006. The unequal variance t-test is an underused alternative to Student's t-test and the Mann-Whitney U test. Behavioral Ecology **17**:688–690.

Sanusi MAM, Shukor MA, Juliana WAW, Traeholt C. 2013. Activity pattern of selected ungulates at Krau Wildlife Reserve. AIP Conference Proceedings **1571**:325–330.

Seddon PJ, Ismail K. 2002. Influence of ambient temperature on diurnal activity of Arabian oryx: Implications for reintroduction site selection.

Husam EA. 2006. Reintroduction of Arabian oryx in Dubai Desert Conservation Reserve, Dubai, UAE. Reintroduction News **25**.

Sollmann R. 2018. A gentle introduction to camera-trap data analysis. African Journal of Ecology **56**:740–749.

Spalton A. 1993. A brief history of the reintroduction of the Arabian oryx *Oryx leucoryx* into Oman 1980–1992. International Zoo Yearbook **32**:81–90.

Srbek-Araujo AC, Chiarello AG, Horizonte B. 2013. Influence of camera-trap sampling design on mammal species capture rates and community structures in southeastern Brazil. Biota neotropica **13**.

Stankowich T. 2008. Ungulate flight responses to human disturbance: A review and meta-analysis. Biological Conservation **141**:2159–2173.

Strauss WM. 2002. Towards the effective management of the Arabian oryx *Oryx leucoryx* in the Kingdom of Saudi Arabia. European Journal of Wildlife Research **48**:7–16.

Tang X, Tang S, Li X, Menghe D, Bao W, Xiang C, Gao F, Bao W. 2019. A study of population size and activity patterns and their relationship to the prey species of the eurasian lynx using a camera trapping approach. Animals **9**.

Tear TH, Mosley JC, Ables ED. 1997. Landscape-scale foraging decisions by reintroduced Arabian oryx. The Journal of Wildlife Management **61**:1142–1154.

Treydte AC, Williams JB, Bedin E, Ostrowski S, Seddon PJ, Marschall EA, Waite TA, Ismail K. 2001. In search of the optimal management strategy for Arabian oryx. Animal Conservation **4**:239–249.

Trolliet F, Huynen M-C, Hambuckers A, Vermeulen C. 2014. Use of camera traps for wildlife studies. A review. Biotechnology, Agronomy and Society and Environment **18**:446–454.

Van Beest FM, Vander Wal E, Stronen A V., Brook RK. 2013. Factors driving variation in movement rate and seasonality of sympatric ungulates. Journal of Mammalogy **94**:691–701.

van Berkel T. 2014. Expedition Field Techniques: Camera Trapping for Wildlife Conservation. Royal Geographical Society, London, United Kingdom.

Walther FR. 1978. Behavioral observations on Oryx antelope *(Oryx beisa)* invading Serengeti National Park , Tanzania. Journal of Mammalogy **59**:243–260.

Ward D. 2009. The Biology of Desert. Oxford University Press Inc, New York, United States.

Washington-Allen RA, Van Niel TG, Ramsey RD, West NE. 2004. Remote sensing-based piosphere analysis. GIScience and Remote Sensing **41**:136–154.

Wearn OR, Glover-Kapfer P. 2019. Snap happy: camera traps are an effective sampling tool when compared to alternative methods. Royal Society Open Science **6**:181748.

Webb SL, Gee KL, Strickland BK, Demarais S, Deyoung RW. 2010. Measuring fine-scale white-tailed deer movements and environmental influences using GPS collars. International Journal of Ecology **2010**.

Williams JB, Ostrowski S, Bedin E, Ismail K. 2001. Seasonal variation in energy expenditure, water flux and food consumption of Arabian oryx Oryx leucoryx. Journal of Experimental Biology **204**:2301–2311.

WWF International. 2016. Living Planet Report 2016: Risk and resilience in a new era. WWF International, Gland, Switzerland.

Appendices

List of the Appendices:

1. Overview of camera trap records, linked to Arabian oryx activity in summer and winter seasons of 2011, 2019 in the DDCR.
2. Individual and group density estimation of Arabian oryx in the DDCR, based on different approaches in average group size calculation.

Appendix 1: Overview of camera trap records, linked to Arabian oryx activity in summer and winter seasons of 2011, 2019 in the DDCR.

Sector	Year	Season	Environment	Camera trap label	Days operational	Wildlife photos	Wildlife events	Wildlife events (diurnal)	Days with visits	Sampling occasions	Maximum group recorded	Average group size	TR (records/ 100 CTD)	TR (Diurnal) (records/100 CTD)
N	2011	Winter	Natural	BUSH2	52	37	9	8	8	7	1	1	37.50	33.33
N	2011	Winter	Natural	BUSH3	24	96	21	17	15	2	4	1.5	40.38	32.69
C	2011	Winter	Natural	Recon1	86	132	46	36	31	3	4	1.48	53.49	41.86
C	2011	Winter	Natural	Recon2	71	13	9	8	9	8	12	2.4	12.68	11.27
S	2011	Winter	Natural	Recon3	75	43	22	17	13	6	8	2.18	28.95	22.37
S	2011	Winter	Natural	Recon5	76	71	12	10	11	7	8	2.25	16.00	13.33
N	2011	Summer	Natural	BUSH2	24	32	22	19	12	7	4	1.5	23.91	20.65
N	2011	Summer	Natural	BUSH3	52	16	4	0*	4	23	7	4	4.76	0.00
C	2011	Summer	Natural	Recon1	86	14	9	8	7	13	1	1	10.23	9.09
C	2011	Summer	Natural	Recon2	71	0	0	0	0	0	0	0	0.00	0.00
S	2011	Summer	Natural	Recon3	76	3	1	1	1	90	1	1	1.15	1.15
S	2011	Summer	Natural	Recon5	75	1	2	1	2	44	2	1.5	2.22	1.11
N	2019	Winter	Improved	CT08	32	208	42	11	24	1	5	2.23	131.25	34.38
N	2019	Winter	Improved	CT04	30	46	12	8	11	3	15	3.08	40.00	26.67
C	2019	Winter	Improved	CT03	31	148	25	19	16	2	7	2.04	80.65	61.29
C	2019	Winter	Improved	CT20	31	244	67	42	28	1	7	2.34	216.13	135.48
S	2019	Winter	Improved	CT11	33	478	65	56	23	1	14	2.7	196.97	169.70
S	2019	Winter	Improved	CT19	31	930	131	107	28	1	17	3.74	422.58	345.16
N	2019	Summer	Improved	CT08	34	390	130	47	32	1	19	3.82	382.35	138.24
N	2019	Summer	Improved	CT04	24	268	102	60	22	1	6	1.73	425.00	250.00
C	2019	Summer	Improved	CT03	40	134	78	57	29	1	18	1.83	195.00	142.50
C	2019	Summer	Improved	CT20	5	201	40	35	5	1	12	5.25	800.00	700.00
S	2019	Summer	Improved	CT11	7	192	36	28	5	1	16	5.27	514.29	400.00
S/C	2019	Summer	Improved	CT19	4	181	42	31	4	1	28	6.61	1050.00	775.00
S	2019	Summer	Improved	CT07	40	580	165	136	40	1	13	3.67	412.50	340.00
N	2019	Summer	Natural	BUSH2	2	1	1	1	1	2	1	1	50.00	50.00
N	2019	Summer	Natural	BUSH3	39	5	3	0	3	13	3	1.6	7.69	0.00
C	2019	Summer	Natural	Recon1	39	9	5	4	5	8	2	1.2	12.82	10.26
C	2019	Summer	Natural	Recon2	6	2	1	1	1	6	1	1	16.67	16.67
S	2019	Summer	Natural	Recon3	40	3	1	0	1	40	2	2	2.50	0.00
S	2019	Summer	Natural	Recon5	40	0	0	0	0	0	0	1	0.00	0.00

**In red on the grey background indicated cameras, which were not included for analyses results, due to insufficient sampling effort or amount of diurnal records.*

Appendix 2: Individual and group density estimation of Arabian oryx in the DDCR, based on different approach in average group size calculation.

Year	Season	Camera	Environment	Individual density (ind/ 100 km^2)	Group density (ind/ 100 km^2)	
					CT records	Direct observation
2011	Winter	BUSH2	Natural	15.4	15.4	293.1
2011	Winter	BUSH3	Natural	15.1	22.7	287.4
2011	Winter	Recon1	Natural	16.5	24.4	313.4
2011	Winter	Recon2	Natural	4.3	10.4	82.1
2011	Winter	Recon3	Natural	5.1	11.1	97.1
2011	Winter	Recon5	Natural	8.6	19.3	162.9
2011	Summer	BUSH2	Natural	9.6	14.3	210.2
2011	Summer	Recon1	Natural	3.5	3.5	76.7
2011	Summer	Recon3	Natural	0.4	0.4	9.7
2011	Summer	Recon5	Natural	0.4	0.6	9.4
2019	Winter	CT08	Improved	15.9	35.5	286.3
2019	Winter	CT04	Improved	12.3	38.0	222.1
2019	Winter	CT03	Improved	23.5	47.9	423.0
2019	Winter	CT20	Improved	62.7	146.7	1128.4
2019	Winter	CT11	Improved	78.5	212.0	1413.4
2019	Winter	CT19	Improved	132.3	494.9	2382.0
2019	Summer	CT08	Improved	62.6	239.1	1252.1
2019	Summer	CT04	Improved	125.3	216.8	2506.4
2019	Summer	CT03	Improved	54.6	100.0	1092.7
2019	Summer	CT07	Improved	131.3	481.9	2626.3