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RESEARCH ARTICLE

Long-Term Mortality Monitoring of Captive Sand Gazelles (*Gazella Marica*): Assessment and Recommendation

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Abstract

The major objective of captive breeding programs for threatened wildlife species is the production of animals for reintroduction and to maintain self-sustaining populations in captivity. One strategy to improve reintroduction success as a conservation tool, is to produce enough animals that have good prospects for survival in the wild. It is therefore imperative to increase the number of potential recruits by reducing mortalities within the captive population. This goal can be best achieved by implementing a good animal health and welfare management. Causes of mortality in captive sand gazelles (*Gazella marica*) held at King Khalid Wildlife Research Center (KKWRC) in Saudi Arabia were monitored from 1988 to 2012. For this purpose, the pathology and necropsy records of 1,938 mortalities recorded at KKWRC were reviewed and summarized. The largest number of deaths were due to trauma (n = 744, 36.1%), whereby, 291 cases were self-inflicted (15.0%), 210 were caused by predators (10.8%), and 243 cases could be attributed to mate aggression (12.5%). Malnutrition (n = 108, 5.6%) and birth-related causes, such as maternal neglect (n = 165, 8.5%), dystocia (n = 44, 2.3%) and stillbirth (n = 95, 4.9%) accounted for another 21.3% of all mortalities. Among the infectious diseases, respiratory infection was the major cause of mortality, accounting for 159 cases (8.2%) of recorded deaths. Respiratory infections were most prevalent during spring (March - May) suggesting seasonal or climatic effects. Other clinical causes of death included gastro-intestinal diseases (n = 31, 1.6%) and general infections (n = 146, 7.5%), such as that with *Pasteurella multocida*. Euthanasia due to disease management (n=74, 3.8%) such as *Brucella melitensis* and *Mycobacterium bovis* eradication were also important causes of mortality. The study discussed the significance of these findings to improve the captive management of sand gazelles in captivity and reports in detail on the first *Brucella melitensis* and *Pasteurella multicida* cases in this threatened desert ungulate.

Keywords: King Khalid Wildlife Research Center, Saudi Arabia, necropsy, trauma, infectious diseases, euthanasia, birth-related casualties.

Introduction

Historically, the Arabian sand gazelle (*Gazella marica*) occurred in the open habitats of the Arabian Peninsula, Iraq, Jordan and Syria [1]. In recent decades, numbers have dramatically decreased throughout the species range, particularly after World War II, when the construction of roads and the availability of off-road vehicles opened areas previously inaccessible to man. Competition with domestic life stock was another reason for the decline and the IUCN Red List classified the species therefore as 'Vulnerable' [2]. In Saudi Arabia, the population decrease was particularly accentuated, with a present-day population of only 1,000 to 1,100 individuals separated in two successfully reintroduced populations, i.e., Mahazat as-Sayd and Uruq Bani Ma'arid in the west and south of Saudi Arabia [2]. The historic population decline of sand gazelles and other wildlife in Saudi Arabia prompted the Saudi Wildlife Authority (SWA) in 1986, to initiate a sand gazelle re-introduction program and to establish a captive breeding population at King Khalid Wildlife Research Centre [3]. To prevent catastrophic, stochastic events and thus the loss of the entire captive stock, the collection was divided into two meta-populations, one in the Prince Mohammad Al-Sudairi Gazelle Breeding Centre in Qassim and the other one in the Thumamah National Park (TNP) near Riyadh.

The major objective of captive breeding programs for threatened wildlife species is the production of animals for reintroduction and to maintain self-sustaining populations in captivity. One strategy to improve reintroduction success as a conservation tool, is to produce enough animals that have good prospects for survival in the wild [2]. It is therefore imperative to increase the number of potential recruits by reducing mortalities within the captive population. This goal

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can be best achieved by implementing a good animal health and welfare management [4].

At KKWRC, such a health and welfare management program was introduced in 1988, resulting in a long-term monitoring of mortality causes among captive sand gazelles of different age. Beside diseases and parasitic infections, several other causes of mortality were recorded, including malnutrition, trauma (including stress-related mortalities), maternal neglect, dystocia and stillbirth, environmental (weather) conditions, and failed human-induced anaesthesia. In this study we compiled and summarized all causes of mortality of sand gazelles that occurred during a period of 23 years at KKWRC and discussed the results in the light of seasonality and the management regime prevailing at KKWRC until today.

Materials and Methods

Study site

King Khalid Wildlife Research Centre is located 70 km north of Riyadh in Saudi Arabia and was established in 1986, emerging from the private gazelle collection of King Khalid bin Abdulaziz Al Saud. The management of the collection was handed over to the Zoological Society of London to operate it on behalf of the National Commission for Wildlife Conservation and Development (now Saudi Wildlife Authority, SWA). The captive breeding scheme at KKWRC serves solely a conservation purposes [2], and consists of about 60 rectangular pens each with an area of 100 x 50 m. A double fence separates the enclosures to prevent nose-to-nose contact between adjacent groups. Additionally, draping fences between pens with shade netting reduce visual contact that would otherwise promote aggression between neighboring males. Trees, logs, and earth mounds provide protection for newborn gazelles from harsh weather conditions. Gazelles at KKWRC are fed *ad libitum* on dried, baled alfalfa (*Medicago sativa*) and 200–300 g Superlac concentrate (Arasco, Saudi Arabia) per animal and day. Superlac is an ideal food supplement (a combination of by-pass fat, yeast, organic zinc, niacin, and vitamins) to increase body condition, without the adverse effects of feeding more alfalfa [5, 6]. A metal shelter and several *Acacia* trees provide shade and protection from occasional rain. Each pen further contains a capture facility (or 'boma') facilitating easy capture and handling of gazelles for veterinary or management purposes. Pens either hold breeding groups or single sex groups, with each breeding group being composed of one male and 8–14 females. All animals included in this study received equal treatments (regular captures, vaccinations), food, water and mineral supply.

Data Collection

The average number of sand gazelles held at KKWRC from January 1988 to December 2012 was 471 ± 47 individuals [7]. Breeding pens were patrolled daily over a period of 23 years recording all mortalities that occurred within the last 24 hours. Individual identification number, date of birth and death, age, sex, weight at birth and death, and the pathologic diagnosis were recorded in the Animal Records and Keeping System (ARKS) developed by the International Species Information System (ISIS; [8]). Necropsy records of 1,938 perished sand gazelles were evaluated to determine the causes and frequency of mortalities at KKWRC (Table 1). The primary cause of death could be determined for 1,685 individuals, i.e., 86.9% of all perished sand gazelles. In 253 cases (13.1% of all mortalities) the cause of death could not be determined due to advanced putrefaction (Table 1). The records included 569 newborns (<15 days), 146 juveniles (16 days to 4 months), 91 sub-adults (4 months to 1 year) and 1,132 adults (>1 year). The age of deceased sand gazelles ranged from 0 to 5,840 days, with a mean mortality age of 879 days.

Table1. Causes of mortality recorded in for four age categories of captive sand gazelles, *Gazella marica* (n = 1,938), held at King Khalid Wildlife Research Center. Neonate: up to 15 days, juvenile: 16 days to four months, sub-adult: four months to one year, and adult: more than one year.

Cause of death	Sample size (n)	Neonates (n=569)	Juveniles (n=146)	Sub-adults (n=91)	Adults (n=1,132)
Weather condition	57	32	7	2	16
Failed anesthesia	4	1	0	0	3
Euthanasia – disease management	74	0	0	1	73
Euthanasia – neurologic	2	1	1	0	0
Euthanasia – old age	14	0	0	0	14
Malnutrition	108	25	13	7	63
Maternal neglect	165	150	15		0
Dystocia	44	0	0	0	44
Stillbirth	95	95	0	0	0
Genetic abnormalities	4	2	1	0	1
Respiratory infection	159	25	10	8	116
Urinary infection	31	0	0	0	31
Gastro-intestinal infection	31	13	8	3	7
Generalized infection	146	17	8	5	116
Trauma - mate aggression	243	24	12	8	199
Trauma - predation	210	73	6	5	126
Trauma - self-inflicted	291	17	31	49	194
Unknown (other causes)	259	94	34	3	123

Definitions of Casualties

Causes of death were subdivided into five categories, i.e., environmental (weather conditions), management-related (failed anesthesia or euthanasia), birth-related and genetic causes, infections and diseases, and trauma. Weather conditions were considered detrimental when temperatures were high and humidity extremely low (during the hot summer months) or during autumn and winter when humidity was high but temperature relatively low. Animals that were tested positive for tuberculosis or brucellosis were subsequently euthanised and summarized under 'euthanasia due to disease management'. In some cases, gazelles were euthanised due to neurological reasons or because of old age. In a few incidences, gazelles died due to an overdose of anesthetics. Birth-related mortalities included malnutrition or genetic abnormalities at birth, maternal neglect, and still birth. Mortalities, due to abnormal, slow, or difficult childbirth, usually caused by disordered or ineffective contractions of the uterus were considered reproductive dystocia. A fetus was considered 'stillborn' if pathologic examination revealed that the lungs had not been inflated and a full somatic development was not completed. In cases where gross *post-mortem* examination and complementary laboratory test results showed no obvious signs of bacteriological infection, or the cytological examinations were without pathological findings, juvenile mortalities were considered as 'maternal neglect'. The most common macroscopic abnormality during *post-mortem* investigations of neonates was the lack of milk in the gastro-intestinal tract. Instead, the presence of sand or other foreign material, indicated the presence of unsuccessful suckling behavior. Malnutrition was defined as the condition which develops when the animal is deprived of vitamins, minerals and other nutrients that are imperative to maintain healthy tissues and organ function.

Microbiological, cytological and histopathological examination were regularly carried out on samples collected from macroscopic lesions of all major organs, including heart, liver, lung, and the intestine, and allowed a classification into respiratory, urinary, or gastro-intestinal infections. If complementary laboratory studies did not allow for a distinct diagnosis, the cause of death was defined as a 'generalized infection'. Pathological micro-organisms were identified to species level using the standard API (analytical profile index) identification system. Trauma was diagnosed if the carcass showed obvious macroscopic or histopathological signs of trauma such as cervical dislocation, degenerative skeletal muscles or skin lesions. Causes for trauma were subdivided into 'caused by mate aggression', 'caused by predators' (i.e., migrant eagles like *Aquila nipalensis* and *A. heliacal*, wolves, *Canis lupus* or feral dogs) and 'self-inflicted' (e.g., collision with fences due to anxiety or stress). If no diagnosis was possible due to advanced putrefaction, the cause of death was considered "unknown".

Results

The major cause of mortality in sand gazelles at KKWRC was trauma (n = 744, 38.4% of all mortalities; Table 1). Trauma, specifically self-inflicted, was the primary cause of death in neonates and juveniles (n = 48, 6.7% of all neonate and juvenile causalities). In sub-adult (n = 62, 68.1% of all sub-adult casualties) and adult sand gazelles (n = 519, 45.8% of all sub-adult casualties), trauma was also the major cause for mortalities in the breeding center. In sub-adults most traumata were self-inflicted (subadults: n = 49, 79.0% of all juvenile traumata), while in adults mate aggression was the main cause (n = 199, 38.3% of all adult traumata). The occurrence of trauma showed a clear seasonal pattern, whereby males (n = 62, 39% of all male casualties) died predominantly from severe male mate aggression, especially during the peak of the rutting season (between October and November), while female mortalities were mostly associated with female mate aggression between March and April, i.e., during the calving season (n = 14, 38.9% of all adult female casualties). Trauma due to predator attacks was another common reason for casualties (n = 210, 28.2% of all trauma-related casualties), whereby neonates were most affected (n = 73, 12.8% of all neonate casualties).

Among infectious diseases, respiratory (n = 159, 43.3% of all infectious diseases), gastro-intestinal (n = 31, 8.4%) and urinary infections (n = 31, 8.4%) were most commonly diagnosed (Table 1). The urinary pathology observed in this study was often associated with chronic renal fibrosis. Generalized infections with general systemic symptoms accounted for 39.8% (n = 147) of all infections (Table 1). The average death age for infectious diseases, was 7.15 years, i.e., 2612 days.

Respiratory infections were most common among adult gazelle (n = 116, 10.2% of all adult casualties), whereby 91 cases were males, and 66 cases were females. Respiratory infections were strongly seasonal, with males showing increased mortality from October to December (n = 32, 35.2% of all respiratory infections) and from March to May (n = 28, 30.8% of all respiratory infections). For females, the calving season (March to April) was the period with the highest rate of mortality cases due to respiratory infection (n = 23, 21.8% of all respiratory infections). Thirty-seven of those cases were caused by *Arcanobacterium pyogenes* (Table 2), 46 cases were caused by *Fusobacterium necrophorum,* of which 31 individuals also had concurrent *Arcanobacterium pyogenes*. In 19 cases *Escherichia coli* was considered the cause of respiratory infection (11.9% of all respiratory infections) and *Streptococcus* sp. and *Staphylococcus aureus* were implicated in nine and seven individuals, respectively. In 11 cases (6.9% of all respiratory infections), *Proteus vulgaris* was identified as the cause of mortality. In 10.7% (n = 17 cases) of all cases of respiratory pathology, no bacterial growth was detected.

Table2. Cause of mortality due to respiratory infections (n = 159) recorded in captive sand gazelles, *Gazella marica,* held at King Khalid Wildlife Research Center.

Microorganism	Number of casualties	Percentage of casualties
Arcanobacterium pyogenes	37	23.3
Fusobacterium necrophorum/ Arcanobacterium pyogenes	31	19.5
Escherichia coli	19	11.9
Fusobacterium necrophorum	15	9.4
Proteus vulgaris	11	6.9
Streptococcus sp.	9	5.7
Staphylococcus aureus	7	4.4
Pseudomonas aeroginosa	5	3.1
Enterococcus faecalis	5	3.1
Serratia odorifera	3	1.9
Unknown	17	10.7

Another cause of death with pronounced seasonality were gastro-intestinal infections, which occurred mainly from March to May (n = 41, 38% of all gastro-intestinal casualties). In 28 cases of gastro-intestinal pathology (25.9% of all gastro-intestinal infections), *Escherichia coli* was identified as the primary cause of infection, while *Clostridium perfrigens* caused the death in 25 cases (23.1% of all gastro-intestinal infections) and *Streptococcus faecalis* in nine cases, (8.3% of all gastro-intestinal infections). Other gastro-intestinal infections accounted for only 50.9% of gastro-intestinal pathology and were summarized in Table 3. Coccidiosis was considered the most common protozoan parasitic cause of mortality, with nine confirmed cases (8.3% of all gastro-intestinal cases). *Haemonchus contortus* added an additional three cases to this category. The main cause of generalized infections was *Pasteurella multicida* (hemorrhagic septicemia, n = 37, 25.3% of all generalized infections). This was followed by pathology due to concurrent *Arcanobacterium pyogenes* and *Fusobacterium necrophorum* (n = 33, 22.6% of all generalized infections), as well as *Escherichia coli* (n = 11, 7.5% of all generalized infections). Other common causes of generalized infection were summarized in Table 4.

In neonates, the main cause of mortality was maternal neglect (n = 150, 26.4% of all neonate casualties). Other common causes of death in this age class were malnutrition with 108 cases (18.9%) and stillbirth with 95 cases (16.7% of all neonate deaths). Reproductive dystocia is rarely reported for wild ruminant species, but accounted for 44 mortalities, corresponding to 2.3% of all observed casualties.

Finally, euthanasia as a tool of disease management of tuberculosis (n = 37) and brucellosis (n = 36) accounted for 3.8% of all casualties, mainly in adult sand gazelles (see discussion) and 57 case (2.9% of all casualties) could be attributed to harsh weather condition (Table 1). However, a total of 259 cases (22.6% of all mortalities) could not be identified.

Table3. Cause of mortality due to gastro-intestinal infections (n = 108) recorded in captive sand gazelles, *Gazella marica,* held at King Khalid Wildlife Research Center.

Microorganism	Number of casualties	Percentage of casualties
Escherichia coli	28	25.9
Clostridium perfrigens	25	23.1
Coccidea	9	8.3
Streptococcus sp.	9	8.3
Enterococcus faecalis	7	6.5
Proteus mirabilis	5	4.6
Haemonchus contortus	3	2.8
Bacillus cereus	1	0.9
Pseudomonas aeroginosa	1	0.9
Staphylococcus aureus	2	1.9
Enterobacter sp.	2	1.9
Unknown	16	14.8

Table4. Cause of mortality due to generalized infection (n = 146) recorded in captive sand gazelles, *Gazella marica,* held at King Khalid Wildlife Research Center.

Microorganism	Number of deaths	Percentage of deaths
Arcanobacterium pyogenes and *Fusobacterium necrophorum*	33	22.6
Pasteurella multicida	37	25.3
Staphylococcus aureus	18	12.3
Arcanobacterium pyogenes	14	9.6
Escherichia coli	11	7.5
Fusobacterium necrophorum	8	5.5
Streptococcus sp.	2	1.4
Enterococcus faecalis	2	1.4
Clostridium sordellii	2	1.4
Pseudomonas aeroginosa	2	1.4
Unknown	17	11.6

Discussion and Management Recommendations

The first seven years (1988–1994) subsequent to the foundation of KKWRC, accounted for 42% of the total mortality considered in this study. During these first years the animals were kept in a large multi-species enclosure in which it was difficult to regularly conduct prophylaxis, captures or individual supervision of each animal. In addition, during the 1990/91 Gulf War, there was a significant reduction of staff working at KKWRC due to the close proximity to Thumamah's military air base. Consequently, many casualties of unknown cause occurred during this period, with 253 cases not being submitted for pathology investigation due to advance putrefaction. During this period, many self-inflicted trauma cases occurred, because individuals had to be caught several times a year for disease management. Moreover, experimental capture techniques designed to improve management, were introduced [3], resulting in increased disruption and stress for the animals. The year 1991 accounted therefore for the highest number of self-inflicted traumata in this study.

Likewise, in later years (i.e., after 1995), self-inflicted trauma was the most common cause for casualties and was clearly increasing with increasing age of the individual. Breeding pens at KKWRC are fenced by chain link, able to cause serious injuries and lesions if a frantic gazelle runs into it [5]. Interestingly, adult gazelles had distinctly more casualties by self-inflicted trauma than juveniles or sub-adults, although it would be expected that young, unexperienced animals are more likely to underestimate the limits of the breeding pen than experienced adults. It might be thus advantageous to stock breeding pens with females of different age, i.e., older, more skittish females with younger, calmer animals and hence reduce the likelihood of severe trauma. Trauma due to mate aggression was the second most observed trauma, mainly among adult individuals, but not higher if compared to Arabian gazelle (*Gazella arabica*) held in the same breeding center [7]. Since sand gazelles are seasonal breeders and males show strong territorial behavior during the mating season in autumn, males were more affected (n = 159) than females (n = 36). To reduce mate aggression among males, weaning of youngsters was brought forward from late October to late September, coinciding with annual routine health checks and vaccinations and thus reducing the time youngsters stay with their mothers and the breeding male. This simple management tool allowed sub-adult males to be removed from breeding pens and to transfer them to specific weaning pens well before the rutting season. Surplus males were transferred to a 5,000 m^2 single male pen, in which bachelor males had enough space to avoid intra-sexual conflict and thus the number of casualties could be reduced [5]. Moreover, the provision of hiding places and blinds allowed males to escape to relative safety from pen mates which further helped reducing casualties. Adult females, on the other hand, showed a mortality peak during spring, coinciding with the calving season, in which females are generally more protective of their young. Several rationales for agonistic interactions among females were discussed by [9] including horn length, experience of the females, and familiarity among pen mates. The authors found that keeping older, more experienced females that have formed well-established dominance hierarchies, can reduce mate aggression within female groups and can thus help to reduce trauma among females. Predators, such as eagles, wolves, or feral dogs, were also considered an important cause of trauma in adult sand gazelles (n = 126). KKWRC is located within the Thumamah Protected Area, an area that accommodates several Arabian wolves, but that also attracts feral dogs. Despite that KKWRC is protected by two lines of 2 to 3 m high fences, 78 casualties due to trauma related to wolve or dog attacks were recorded between 27th January and 7th February 2002 alone. To combat this serious cause of mortality, fences were patrolled daily and repaired as soon as a damage were detected. Moreover, feral dogs were selectively and humanely removed, using methods approved by the Saudi Wildlife Authority.

The overwhelming majority of neonatal mortalities were attributable to maternal neglect and malnutrition of the calf. Maternal neglect is fairly common in wild ruminants and is likely caused by a strained mother and/or inadequate weather conditions [10]. During summer months, inclement weather condition, especially in the center of the Arabian Peninsula can cause conditions which prevent calves from suckling or affect the parental care of the mother. To mitigate such adverse conditions, live trees were planted, and logs or boulders positioned to provide more shade in summer and better cover from cold winds in winter. Furthermore, the age of mothers at parturition was also taken into consideration, since primiparous, inexperienced females are more likely to show inadequate maternal behavior and old females tend to have a higher probability of showing clinical complication, which affected the level of milk production and the weight of calves at birth [10]. Females, more than 10 years old, were therefore isolated in specific non-breeding pens for better supervision and to avoid further pregnancies. Calves with less than 1.4 kg are more likely to be neglected [11]. As a standard procedure, all neonates were weighted and inspected shortly after birth, *a priori* to daily follow-up checks for the first 30 days after birth. These measures, allowed duly detection of neglected or undernourished calves and transferring them to a hand-rearing facility. Another major cause of mortality in newborn gazelles were predator attacks. The creation of shade and hiding places did therefore not only help to protect calves from harsh weather conditions but also from attacks by eagles and/or red foxes, *Vulpes vulpes* [5]. Neonate mortality associated with dystocia corresponded to 2.3% of all casualties. Compared to Arabian gazelles, *G. marica* fawns showed a lower mortality associated with dystocia [7], whereby the mean age of sand gazelle mothers with dystocia was 1,697 days. This could be explained, by the fact that sand gazelles generally have twins [12, 13], which could contribute to a higher number of dystocia cases than in a species producing only singletons.

Respiratory infections were relatively rare in sand gazelles, compared to those reported for Arabian gazelles [7]. In sand gazelles, the disease was either clinically inapparent or caused only moderate fever, tachypnea or slightly mucoid or mucopurulent nasal discharge with moderate to severe weight loss. At necropsy, lung lesions vary from irregular lobular foci of atelectasis or slightly consolidated purple-red foci in cranioventral regions to disseminated pyogranulomatous pneumonia, with abscessed lung tightly bound to the thoracic wall by fibrous adhesions. Respiratory pathology showed a clear seasonality in sand gazelles held at KKWRC, with autumn and spring being closely associated with the occurrence of respiratory infections. This is in line with observations on Arabian gazelles, that showed higher mortality rates due to respiratory infections when temperatures were low [7]. In autumn, when temperatures decrease, sand gazelles are in mating season with males showing strong territorial behavior, while spring is the calving season corresponding

to high humidity and highest mortality rates among females with respiratory infection. Both, mating and calving season represent a stressful time during which males and females need a lot of energy and resources, especially in a species that often produces twins. The increased rates of social stress during these periods, associated with the cooler and wetter weather conditions, can explain the increased rates of mortality. The provision of earth mounds and troughs in all breeding pens, provided better cover from extreme weather conditions and thus reduced respiratory infections. Cases of gastro-intestinal infections contributed 14.8% to the overall number of casualties at KKWRC and were mainly caused by viral pathogens. Studies on the prevalence of viral diseases such as, bovine adenovirus indicate that these pathogens are common within the KKWRC collection [14]. Moreover, in the past gastro-intestinal parasites also contributed to mortalities [7], however at present, regular parasitology screenings are carried out whenever appropriate and treatments are administered when levels of parasites are considered pathogenic. Another cause of mortalities commonly observed in this species were urinary infections, which accounted for 1.6% of the overall mortality. The mean age for this pathology (2,612 days) was like that reported for Arabian gazelles (2,904 days; [7]). The reasons behind these results have yet to be determined, but the high mineral level of the underground drinking water provided to the gazelles at KKWRC [15], together with the high annual mean temperatures (up to 50°C; [15]), might be related to the pathophysiology of urinary infections.

Generalized infections contributed 7.5% to the overall mortality in sand gazelles, a rate slightly higher than that reported for Arabian gazelles [7]. *Arcanobacterium pyogenes* and *Fusobacterium necrophorum* were the most frequently identified pathogens. Both organisms were found in the soil, food and water at KKWRC and, as such, are also part of the normal flora of the oral cavity of gazelles [14]. These two pathogens were the major cause of respiratory pathology when associated with increased stress levels, such as during the mating or calving season. Both organisms caused disease in immune compromised animals, especially during extreme climacteric conditions or because of trauma. For example, horn perforation of lung tissue invariably led to severe disseminated pyelogranulomatous pneumonia. Bacteria can be opportunistic invaders of pneumonic tissue but the isolation of an organism through culture does not necessary indicates a causal role. The presence of large numbers of bacteria in pure culture provides presumptive evidence of its importance in causing the pneumonic process. In some pneumonic cases there was pathological evidence of acidophilic intra-cytoplasm inclusion bodies in bronquioles epithelium together with generalized congestion and collapsed alveoli with a mixed inflammatory response consisting of macrophages, neutrophils and some syncytial cells. This bronchointerstital pneumonia, mixed neutrophilic and granulomatous, with syncytial cells and acidophilic intracytoplasmic inclusion bodies is often consistent with viral infections, plus secondary bacterial invasion. Although intracytoplasmic inclusion bodies tend to be present, they are rarely encountered in animals that died with obvious bacterial growth, since bacterial damage usually obscures possible earlier viral lesions or causes death after the stage at which inclusion bodies are detectable. Studies on the prevalence of certain viruses, such as bovine respiratory syncytial virus (BRSV) or Parainfluenza-3 virus, indicate that these pathogens are common within the KKWRC gazelle collection [16]. These results suggest that viral pathogens could be the cause of many of the respiratory disease primary lesions, which are then opportunistically colonized by bacterial pathogens. Given that BRSV and parainfluenza-3 virus are known to cause occasional mortality in ruminants [17], it seems likely that 11.8 % of the respiratory infections with no bacterial growth, could be attributed to viral pathogens. These findings suggest that the most suitable management tool to combat these respiratory viruses would be the introduction of long-term vaccination protocols.

During the first years of KKWRC, euthanasia was applied as a tool to control *Mycobacterium bovis* outbreaks, accounting for the majority of mortalities during that time. Tuberculosis occurs frequently in sheep, goats, camels and cattle and is the main cause of tuberculosis among the domestic livestock species of Saudi Arabia [18]. Due to a stringent euthanasia protocol, tuberculosis could be eradicated from the breeding program, so that the last tuberculosis case was euthanised in August 1996. The year 2011 accounted for the highest number of euthanasia cases due to brucellosis. *Brucella melitensis* positive animals were presented with classical clinical symptoms and diagnosed using a combination of polymerase chain reaction and serological tests [19]. *Brucella melitensis* occurs frequently in sheep, goats, camels and cattle and is the major cause of ovine, caprine and human brucellosis in Saudi Arabia [18]. Ovine and caprine brucellosis eradication campaigns were implemented in the vicinity of KKWRC and PMSGBC, but a relatively high seroprevalence (33%) was still present around PMSGBC by October 2012 [19, 20]. Since 2015, PMSGBC is surrounded by a sanitary buffer zone and the risk of direct transmission from infected livestock to captive sand gazelles was minimized. It was speculated that brown-necked raven (*Corvus ruficollis*) and red foxes may have disseminated the infectious agent to the captive gazelle population, possibly picking up *Brucella* organisms by feeding on placentas or aborted fetuses of recently delivered livestock calves, subsequently contaminating the drinking troughs of both breeding centers. However, the role of these species as local reservoirs or disseminators of *Brucella* to sand gazelles has yet to be confirmed. The last *Brucella melitensis* case was euthanised in January 2013, and the collection was considered free of brucellosis in January 2014. [20].

Pasteurella multocida, i.e., hemorrhagic septicemia, was clinically suspected to be involved in fatal cases of cattle on the Arabian Peninsula [21]. Pasteurellosis in gazelles is often

acute and rarely occurs during dry periods. A serological survey of wild ruminants in Saudi Arabia revealed a relatively high number of *Pasteurella multocida* seropositive animals [22]. The rareness of clinical manifestations makes it likely that this bacterium is carried freely by many wild ruminants and causes diseases only when animals are stressed [22]. In KKWRC, an outbreak with 37 casualties due to hemorrhagic septicemia was registered in January 2005, shortly after a strong rain fall. The most obvious macroscopic lesion was a fulminating fibrinous lobar pneumonia. It is important to vaccinate gazelles against this disease, particularly before putative stressful conditions. A commercial vaccine, against hemorrhagic septicemia is currently used at the KKWRC to combat this generalized infection.

Several species of *Staphylococcus* were identified in healthy gazelles, with *S. scuiri* most frequently isolated [15]. *Staphylococcus aureus,* a common organism found in the skin flora and nasal passages of gazelles, and which is typically associated with a wide range of pathologies [23, 24], was not identified among these *Staphylococcus* species. In Arabian gazelles, *S. aureus* was identified as an important pathogen with an overall mortality that was similar to that found in this study [7]. Another generalized infection observed in sand gazelles was *Clostridium perfrigens,* which was associated with several mortalities observed in *G. arabica* [7]. This organism was a significant cause of gastro-intestinal pathology in sand gazelles (n = 25, 23.1%) and is considered a major pathogen in unvaccinated herds. In KKWRC, *Clostridium perfrigens* vaccinations are part of the annual standard prophylaxis since 1993. Finally, *Escherichia coli* is an organism that was an important pathogen associated with gastro-intestinal pathology in Arabian gazelles [7]. In the present study, 25.9% of all casualties due to gastro-intestinal pathology were caused by this bacterium. All cases were associated with hemorrhagic enteritis of the distal segments of the small intestine.

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