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Research article

Trends in the use of cooling stations for addax, ostrich, Dorcas gazelle and scimitar-horned oryx at Sharjah Safari

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Abstract

Zoo enclosure design should consider the social, behavioural and physical needs of animal inhabitants. These enclosures should provide microclimates which allow animals the freedom to behaviourally thermoregulate, especially in environments that experience extreme weather conditions. For desert-dwelling species, it is important that opportunities for cooling, through wetting of the body or entering shade, are provided. This study investigated the use of cooling stations in the Sahel enclosure at Sharjah Safari by four African species: Dorcas gazelle *Gazella dorcas*, North African ostrich *Struthio camelus camelus*, addax *Addax nasomaculatus* and scimitar-horned oryx *Oryx dammah*. To better understand cooling station use, the environmental temperature, relative humidity and solar radiation (cal/cm2) as per the local weather station were investigated. Cooling station use was recorded with a series of camera traps, with species presence recorded hourly, from 06:00 until 18:00 daily. Overall, all species used the cooling stations, and solar radiation was the best predictor of cooling station use, though temperature was also a significant predictor for cooling station use by addax and scimitar-horned oryx. Dorcas gazelles rarely used the cooling stations, despite the fact that they were the most abundant species in the enclosure, and there were no significant predictors of station use for this species. Ostriches used cooling stations regularly, and they showed no preference for a specific station, whereas scimitar-horned oryx showed a preference for station 2. This study demonstrates that the need for cooling stations may differ considerably, even between desert-adapted species, and so careful consideration must be given to cooling station provision and species suitability for outdoor housing in arid zoo environments. Further studies using larger sample sizes and wider numbers of species may aid in developing the evidence for cooling station use further.

Introduction

By the year 2100, global temperatures are projected to increase by over 2 degrees Celsius, resulting in dangerously hot regions, particularly around the equator (Vargas Zeppetello et al. 2022). In the face of climate change, it is becoming increasingly important that animal heating and cooling is integrated into zoo and aquarium enclosure design (Wark et al. 2020). Zoo enclosures have many stakeholders, including visitors and caregivers, though animal suitability should be prioritised during the design process (Crawford 2012). Naturalistic enclosures, here defined as exhibits that aim to mimic the natural floral and structural environment of the species, have a variety of benefits which include educational value for biodiversity conservation (Yilmaz and Alpak 2019) and species-specific conservation (Lukas and Ross 2015) whilst allowing animals to express natural behaviours (Bryan et al. 2017). Even though naturalistic enclosures can provide all the above-mentioned benefits, these environments can provide sources of stress that may be considered inappropriate for animals in human care (Fábregas et al. 2012). For example, wild environments, especially deserts, are subject to extreme temperatures which stress an animal's ability to maintain homeostasis. Subjecting animals to these extreme conditions may not be welfare-appropriate.

Heat stress, defined as the physiological and behavioural strain experienced by animals due to elevated environmental temperature, humidity, and solar radiation, is a significant concern for animal welfare (Silanikove 2000; Ward 2013; Yan et al. 2017). The adverse effects of heat stress on animals are well-documented: these effects include impaired growth rate, reduced appetite and activity, and dehydration (Hahn 1999; Sohail et al. 2010; Belhadj Slimen et al. 2015). Heat stress can also reduce reproductive performance, impact fertility, reduce embryo survival, and inhibit milk production (Collier et al. 1982). Additionally, warmer and more humid environments create favourable conditions for disease-causing agents, particularly invertebrate vectors, thereby increasing the susceptibility of animals to diseases, which could further impact welfare (Silanikove 2000). Climate change exacerbates these challenges, exposing novel areas to extreme heat and impacting food availability, which further heightens the risk of disease (Rojas-Downing et al. 2017). From a management and husbandry perspective, these impacts collectively could increase veterinary bills, reduce welfare, and ultimately jeopardise the viability of breeding programmes.

Naturalistic enclosures offer numerous benefits by raising public awareness of conservation, enabling animals to express natural behaviours, and ultimately supporting conservation efforts (Yilmaz and Alpak 2019; Lukas and Ross 2015; Bryan et al. 2017). However, these enclosures are not always reflective of the natural environment of the species being housed, or may not provide opportunities for behavioural thermoregulation (Fábregas et al. 2012). In birds and mammals, thermoregulation is the maintenance of a stable core temperature, through balancing of internal heat production with heat loss through morphological, physiological, and behavioural strategies (Wark et al. 2014; Ward 2013). Heat loss strategies include behavioural thermoregulation such as movement to shaded areas, where ambient temperatures are lower (Adah et al. 2023), and immersion in water, where heat dissipates more effectively.

Morphological adaptations such as body size, shape, coat colour, and pelage thickness play a critical role in thermoregulation. Larger animals have a lower surface area-to-volume ratio, which reduces the rate of heat gain but also slows heat loss: properties that are useful in colder climates (Blank and Yaoming 2022). As such, mammal species tend to be larger in body size in colder climates; a concept known as Bergmann's rule (He et al. 2025). The colour and density of an animal's coat also significantly affect heat absorption and loss. For instance, ungulates in warmer climates tend to have lighter and thinner pelage, facilitating greater heat dissipation (Hofmeyr 1985). Similarly, the light-coloured coats of desert-adapted species, like the Arabian oryx *Oryx leucoryx*, help reflect solar radiation, thereby reducing heat absorption (Owen-Smith 1998). Dark-coloured coats result in rapid absorption of heat, so tend to be rare in desert-dwelling species.

Physiological cooling strategies are used by ungulates, with sweating and panting serving as methods for evaporative cooling (Blank and Yaoming 2022). However, these strategies come with challenges, particularly in arid environments where water conservation is critical. For example, cattle *Bos taurus* primarily rely on sweating, while sheep *Ovis aries* are more dependent on panting to dissipate heat (Kadzere et al. 2002). Additionally, many ungulates have evolved selective brain cooling mechanisms, where blood cooled by evaporation in the nasal passages is directed to the brain, preventing brain hyperthermia even when the rest of the body is overheated (Mitchell et al. 2002; Strauss et al. 2017). Arid-adapted species, such as the Dorcas gazelle *Gazella dorcas*, further conserve water by reducing faecal moisture and urine output during drought conditions (Wacher et al. 1997; Cain et al. 2006). Many bird species, especially ratites, tend to rely on respiratory evaporative heat loss as a cooling mechanism (Maloney 2008).

There are additional welfare considerations for animals that are kept in climates beyond their physiological and morphological limits (Morgan and Tromborg 2007). In such environments, animals often rely on behavioural thermoregulation strategies, including reducing activity during extreme heat, seeking cooler microclimates for rest, orienting their bodies to minimise heat exposure, and engaging in behaviours, such as wallowing (Ward 2013; Blank and Yaoming 2022). To support these strategies, enclosures should be designed to provide thermal gradients, such as heating points and shaded or water-cooled areas, enabling animals to regulate their body temperature effectively (Fábregas et al. 2012). This, in turn, affords animals choice and control over their environment and reduces heat-related welfare risks, such as heat exhaustion (Wark et al. 2020).

This study aimed to investigate the use of artificial cooling stations installed in the Sahel enclosure at Sharjah Safari; a naturalistic enclosure designed to replicate the Sahel biogeographical region of Africa. Artificial cooling stations were installed in the enclosure to provide the animals with some relief from the extreme summer weather conditions in the area, where temperatures may reach 50°C (Komuscu 2017). The study monitored the behaviour of four species during the late summer, correlating the use of cooling stations with environmental conditions, such as relative humidity, solar radiation, and temperature, to assess the use of these stations by enclosure inhabitants.

Materials and methods

Area and cooling stations

This study took place at the Sahel enclosure at Sharjah Safari, United Arab Emirates, Sharjah. The enclosure is approximately 64.6 ha in size (Figure 1). In addition to natural sources of vegetation shade (trees, shrubs and grasses) in the enclosure, four artificial cooling stations were installed to increase enclosure shade availability and to provide a cooling microclimate area to support animal welfare during the hot summer months. Each cooling station was constructed from two shade canvases connected to six wooden support poles (approximately 4m high), and two water sprinklers connected to the support poles which sprayed water daily from 12:00 to 15:00 (Figure 2). The water sprinklers wet the soil under and around the shaded area and have also triggered grass to grow in the area, both of which further cool down the ground temperature. The shade structures were well-established in the exhibit before the study commenced.

At the time of data collection, four African species were kept in the Sahel enclosure, namely the Dorcas gazelle *Gazella dorcas*, North African ostrich *Struthio camelus camelus*, addax *Addax nasomaculatus* and scimitar-horned oryx *Oryx dammah* (Table 1).

Data collection

The initial plan for this project was to capture data during the hottest months in the United Arab Emirates (July and August). One wide-lens camera trap (Reconyx Hyperfire 1 HC600, with a built-in thermometer) was placed per location, at a distance of 20-30m from the structure. Unfortunately, the camera traps were unable to function in extreme summer conditions, so data collection took place between 7-16 September 2023. The camera traps were set late afternoon on the 6 September 2023, and the batteries and memory cards were checked periodically to ensure they were working properly. The installation, removal and check-ups were during the late afternoons when there were no Because the camera trap thermometers were less reliable and subject to extreme variation, alternative measurements of environmental variables were sought.

Approximately 1km away from the furthest cooling station, a Rainbird weather station was used to identify the environmental variables of relative humidity (%) and solar radiation (cal/cm²) for each hour of the study. While temperature information was

Figure 1. Sahel exhibit at Sharjah Safari, image taken from Google Earth. Cooling stations are shown as red squares.

also available from the Rainbird weather station, the temperature outputs was collected from each camera trap, as it was more reflective of climatic conditions around each cooling station. Sharjah Safari is closed to the public during the summer months (June to late September), so there was no effect of visitor presence on animal cooling station use.

For each of the four cooling stations, the species and the number of individuals were recorded along with the temperature

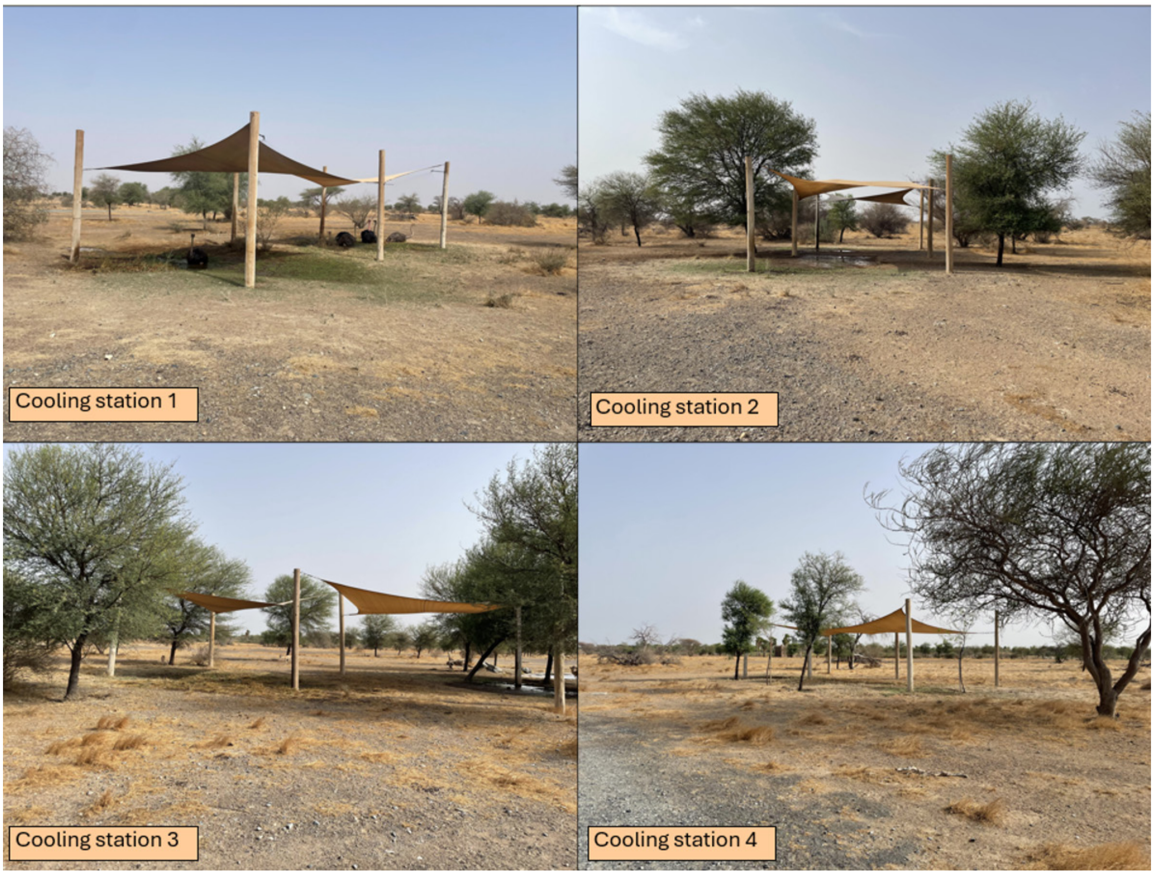

Figure 2. The four cooling stations investigated in this study.

at the beginning of the hour. A fixed time sampling method was used for data collection with one-hour intervals starting at 06:00 until 18:00 to determine the daytime use of the cooling stations. Permission was sought to conduct the study from the Operations and Animal Manager, and the project was deemed not to require full ethical review as no manipulation of animals or data collection from people was required.

Data analysis

All data were recorded using Microsoft Excel™ 2016, and statistical analysis was performed using Minitab version 21. First, data on animal presence at cooling stations, and temperature, humidity and solar radiation data were tested for normality using the Kolmogorov-Smirnov test. As data were found to be non-normal, non-parametric tests were used. A series of Spearman's correlations were run to identify the relationships between ambient temperature, humidity and solar radiation.

For animal presence data at cooling stations, Poisson regressions were run for each species, with temperature, humidity and solar radiation inputted as predictors. These models employed a forward-stepwise approach, so that predictors that did not improve the models were not included in the analysis. This also reduced the risk of model overfitting. For all models, Variance Inflation Factors (VIF) between predictors were consulted, to ensure that none of the VIFs exceeded a value of 5.

Results

Environmental conditions

The mean environmental temperature (based on weather station data) was 37.25oC, (range 27.86-43.49oC), and humidity was 33.33%, (range 13.90-70.30%), whereas solar radiation varied, depending on time of day (mean 37.81 cal/cm^2, range 0-71.56 cal/cm^2) (Figure 3 and 4). Spearman's correlations identified a significant, strong positive correlation between temperature and humidity (r=0.860, P<0.001), a significant, strong, positive correlation between temperature and solar radiation (r=0.660, P<0.001), and a strong, negative correlation between humidity and solar radiation (r=-0.743, P<0.001) (Figure 3.

Table 1. Number of species in the Sahel exhibit at the time of data collection

Species	Number of individuals in enclosure male: female: undetermined (total)
Dorcas gazelle *Gazella dorcas*	25:46:8 (79)
Addax *Addax nasomaculatus*	6:8:3 (17)
Scimitar-horned oryx *Oryx dammah*	4:8:2 (14)
Ostrich *Struthio camelus camelus*	1:2.: (3)

Animal presence in cooling stations

The Poisson regressions on animal presence at cooling stations demonstrated that increased solar radiation was a significant predictor of presence at cooling stations for ostrich (R^2=0.3497, P<0.001), addax (R^2=0.4602, P<0.001) and scimitar-horned oryx (R^2=0.7443, P<0.001) (Table 2, Figure 4). Increased temperature was a significant predictor of cooling station use for addax (P<0.001) and scimitar-horned oryx (P=0.002). There were no significant predictors of cooling station use for the Dorcas gazelle (R^2=0.054, P=0.101).

To visually demonstrate the proportional differences in cooling station use between the four species, a bar chart was developed (Figure 5). Despite having the largest population sizes, Dorcas gazelles (79 individuals) and addax (17 individuals) were observed less frequently than other species at cooling stations. Scimitar-horned oryx (14 individuals) used the cooling stations more frequently, but showed a potential preference for cooling station 2, whereas the ostrich (3 individuals) used all stations frequently.

Discussion

This study demonstrates that solar radiation was the best predictor of use of cooling stations by three of the four species housed in

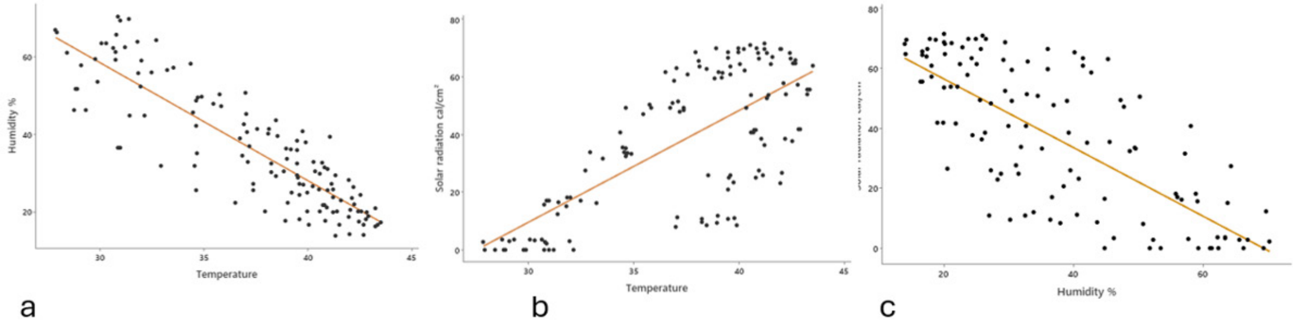

Figure 3. Correlations between the ambient temperature, relative humidity and solar radiation in the Sharjah Safari during the study period. a) correlation between temperature and relative humidity, b) correlation between temperature and solar radiation, and c) correlation between humidity and solar radiation

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Table 2. Outputs of stepwise Poisson regressions of animal presence under cooling stations. * indicates a statically significant result (P<0.05).

Species	R^2 %	Predictor	DF	Z	SE Coefficient	P
Ostrich	34.97	Constant	1	-6.30	0.249	<0.001*
		Solar radiation	1	8.54	0.037	<0.001*
Addax	46.02	Constant	2	-5.20	1.26	<0.001*
		Temperature	1	4.01	0.034	<0.001*
		Solar radiation	1	5.76	0.005	<0.001*
Scimitar-horned oryx	74.43	Constant	3	-3.85	1.290	<0.001*
		Temperature	1	3.15	0.028	0.002*
		Humidity	1	1.61	0.007	0.107
		Solar radiation	1	14.23	0.004	<0.001*
Dorcas gazelle	5.40	Constant	1	-3.81	0.568	0.101
		Solar radiation	1	-1.64	0.019	0.101

the Sahel enclosure at Sharjah safari. Solar radiation was a better predictor than either temperature or humidity, both of which have been used in previous zoo research studies to investigate behaviour and space use. In geographical locations that face great exposure, this suggests that solar radiation is an interesting avenue for future research. It is clearly important that cooling stations are provided, even for species that would naturally exist in hot environments. As climate change effects advance, the need for share in exhibit design will become increasingly important.

Solar radiation, temperature and humidity

Historically, the design of zoo enclosures and enclosures was centred around the needs of visitors, with animals and keepers considered more peripherally (Hosey et al. 2013). It is now recognised, however, that enclosures must be developed with animal welfare at the forefront of design strategies (IUDZG/CBSG IUCN/SSC 1993). Naturalistic enclosures play a critical role in achieving these goals, improving animal welfare by providing essential elements such as shade, shelter, perching, climbing

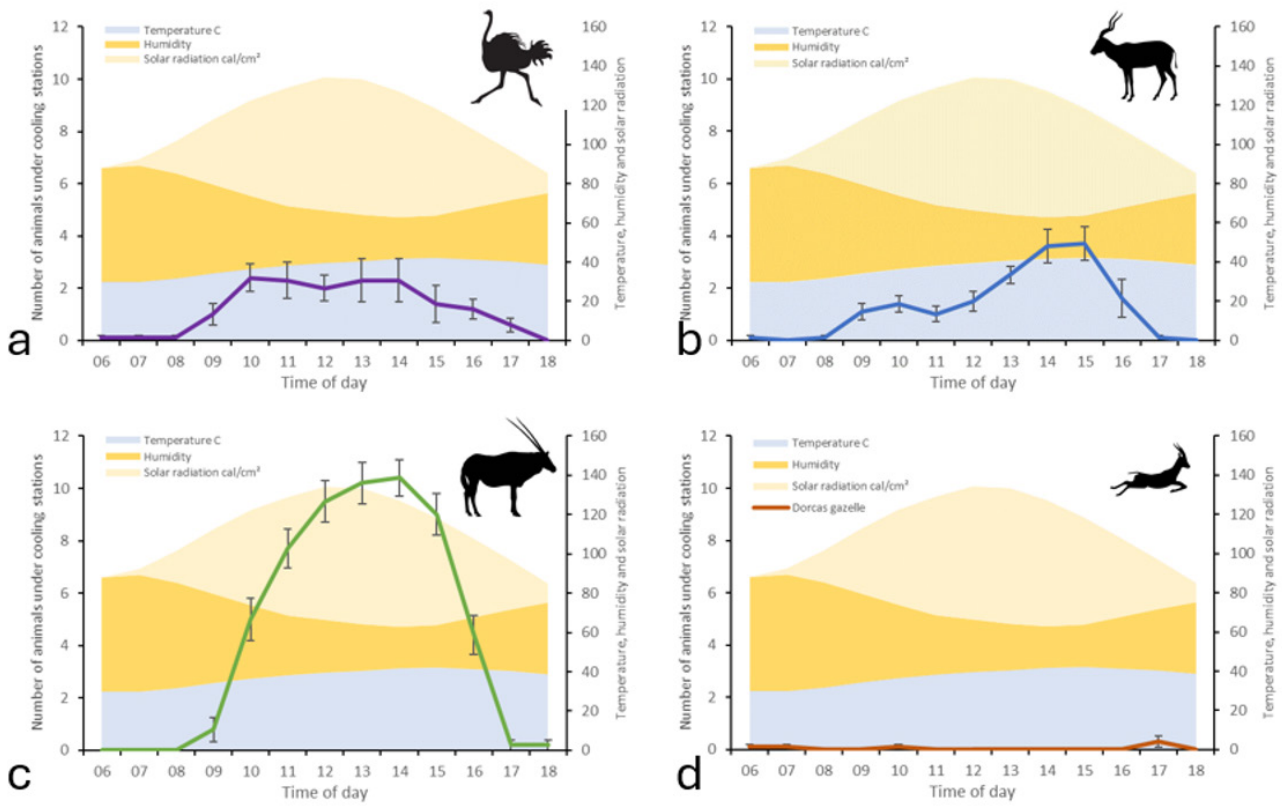

Figure 4. The relationship between temperature, relative humidity and solar radiation and presence at cooling stations (±std error) for animals in the Sahel safari exhibit at Sharjah Safari. a) ostrich, b) addax, c) scimitar-horned oryx and d) Dorcas gazelle.

opportunities, and supplementary food sources. Additionally, these enclosures enhance the visitor experience through landscape immersion (Hosey et al. 2013). Nevertheless, as Fábregas et al. (2012) highlight that, even if enclosures seem well-suited, all factors—including microclimates—must be considered to fully meet the animals' needs. Thermal biology is deeply embedded in zoo reptile and amphibian keeping, but it has been considered to be more peripheral in traditional ungulate husbandry (Arena and Warwick 2023). Environmental factors such as light, noise, and human presence also significantly affect animal welfare (Wark et al. 2020), highlighting the importance of microclimate provision in enclosure design (Crawford 2012).

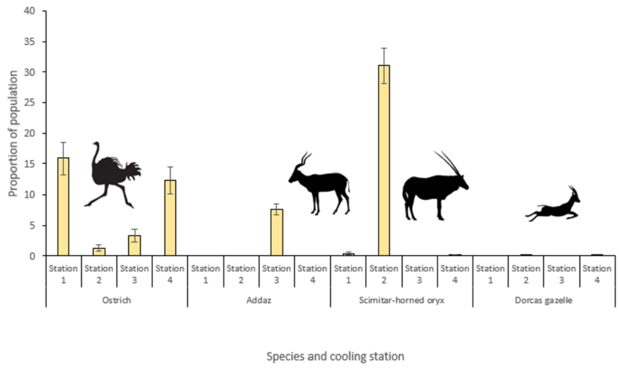

Figure 5. Bar chart demonstrating the mean proportion of each species' population found at each cooling station (±std error).

This study explored the use of artificial microclimates, specifically cooling stations, under varying environmental conditions. Across the Sahel enclosure, all species utilized the cooling stations, though usage of individual cooling stations varied considerably between species. Both ostrich and scimitar-horned oryx used the cooling stations most frequently, while addax were seen at stations less often, and Dorcas gazelles were rarely seen. With the exception of Dorcas gazelle, increased solar radiation predicted higher cooling station use, while higher temperatures were significant predictors of cooling station use only for addax and scimitar-horned oryx. These findings suggest that species react differently to environmental variables, even when they share the same conditions.

The role of the skin in evaporative cooling is well documented (Cain et al. 2022), with studies showing that the skin temperature of ungulates exposed to solar radiation is up to 6.4°C higher than those in shaded areas (Parker and Robbins 2018). Not only do the addition of shade structures reduce skin temperature. However, a study by Langman et al. (2003) found that shade structures reduce the heat in the enclosure of African elephants *Loxodonta* spp. by reducing the ambient temperature as well as shortwave and longwave radiation. In the current study, the cooling stations provided shade from the sun, moisture from the water sprinklers and wet substrate and grass. All factors which were intended to cool the environment and provide a microclimate. A related study on Sichuan takin *Budorcas taxicolor tibetana* also showed increased shade use in summer, though it highlighted temperature threshold differences between individuals (Wark et al. 2020), illustrating species and individual variability in microclimate use.

The increased use of cooling stations between 10:00 and 16:00 during summer aligns with established daily activity patterns in addax, Arabian oryx *Oryx leucoryx*: a close relative of the scimitar-horned oryx, Dorcas gazelles and ostriches (Davimes et al. 2016; Abáigar et al. 2018; Seri et al. 2018; Jenssen 2023). Shade-seeking behaviour and the use of microclimates during midday when the temperature is higher is a common behavioural response for a variety of ungulates including sable *Hippotragus niger*, African buffalo *Syncerus caffer*, zebra *Equus* spp., springbok *Antidorcas marsupialis*, and Dorcas gazelle (Owen-Smith and Goodall 2014; Bigalke 1972). In the hot summer months, most animals are more active during early morning and late afternoon, with some animals like Dorcas gazelles and gemsbok *Oryx gazella* switching to nocturnal activity during the hottest months, with little activity during the day (Blank and Yaoming 2022). The decreased use of the cooling stations during the early morning and late afternoon hours correlates with these natural activity patterns and are likely to be a direct result of both temperature and solar radiation. Addax were recorded using the cooling station less frequently, however the addax were anecdotally known to regularly move in close proximity to one of the cooling stations.

The relatively low use of cooling stations by the Dorcas gazelles, despite their larger population in the enclosure, was unexpected. This behaviour could be attributed to several factors, including their smaller group sizes, making it easier for them to find adequate resting areas without requiring cooling stations. Additionally, Dorcas gazelles may be better physiologically adapted to extreme heat, with mechanisms such as increased respiratory rates, reduced faecal and urinary output, and concentrated urine, in combination with smaller body size (Yom-Tov et al. 1995). This smaller size results in a high surface area-to-volume ratio and slender limbs, also facilitates heat dissipation (Blank and Yaoming 2022). Social factors may also play a role; Dorcas gazelles form small, flexible social groups, allowing them to adjust their social grouping to make best use of existing shade features in their environment (Walther et al. 1983). The smaller body size might allow these gazelles to make use of smaller, natural shade structures in the enclosure, such as small shrubs, that would not be effective for other, larger species.

Conversely, scimitar-horned oryx and ostriches used the cooling stations most frequently. Scimitar-horned oryx, although well adapted to arid environments (Gilbert and Woodfine 2004), may have sought out the cooling stations due to their daily activity patterns (Davimes et al. 2016). This species has a stronger social bond compared to Dorcas gazelles and can generally be made up of 10-30 animals of either harems, bachelor groups or mixed groups and occasionally sedentary males. Females tend to form stronger social bonds amongst each other and with their offspring (Gilbert and Woodfine 2004). In this study,scimitar-horned oryx made use of one cooling station (station 2) and rarely frequented the other areas. The oryx social behaviour likely contributes to their increased presence and high density at one cooling station, given the larger group size and likely lower movement between sites. Ostriches, while less social than scimitar-horned oryx, sometimes form groups of flocks for small periods and may even aggregate in high numbers at times (Bertram 2014). However, at the time of study only three ostrich inhabited the exhibit, and so these three animals could not aggregate in a large group. Ostrich made use of all cooling stations (though station 1 and 4 were used most frequently), which suggests greater movement around the exhibit, and subsequent use of all cooling stations. During resting periods, ostrich were sometimes observed to aggregate under cooling stations, which may aid in vigilance during these periods.

Body size and Bergmann's rule may partially explain the increased use of the cooling stations by the scimitar-horned oryx and the ostrich (Cain et al. 2006). Furthermore, larger animals

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generally rely more on cutaneous evaporation compared to smaller animals which tend to rely mostly on respiratory evaporation (Cain et al. 2006). Ambient temperature, solar radiation, core body temperature and skin temperature all influence the regulation of cutaneous evaporation (Parker and Robbins 2018) and thus would make sense for the scimitar-horned oryx to seek out cooler and shaded environments to conserve water. Ostriches are similarly well-adapted to arid environments using their respiratory systems, as they don't have sweat glands, but rather use their feathers by flattening and erecting to regulate their body temperature (Schmidt-Nielsen et al. 1969). The camera traps also showed on multiple occasions these birds completely soaked from the water sprinklers. Although their feathers reduce heat gain through solar radiation (Bertram 2014), it appears that ostriches actively seek out the cooling stations during times of high solar radiation. Ostriches were also the only species that made use of all four of the cooling stations in the enclosure.

In behavioural studies conducted in captive environments, temperature is frequently the primary environmental variable examined. However, solar radiation may be a more relevant factor to consider when assessing its impact on animal behaviour. While temperature fluctuations, wind, and humidity also play a role in influencing behaviour, direct solar radiation introduces an additional stressor that affects physiological processes, feeding patterns, and thermoregulation. For example, a study by Tucker et al. (2008) on Friesian-Holstein dairy cattle *Bos taurus* demonstrated that during periods of intense solar radiation, these animals sought shade that provided optimal protection, resulting in lower body temperatures. Moreover, animals exposed to high heat often reduce their food intake to decrease metabolic heat production. In the livestock industry, feeding schedules are typically adjusted to early morning or late afternoon during summer months to minimize the heat load associated with peak solar radiation (Sevi et al. 2001). This practice could be effectively adapted for zoo animals, particularly those in outdoor enclosures in hot climates, to mitigate the effects of excessive solar radiation.

Limitations and future research

The study period was relatively short, limiting the observation of temperature fluctuations, as daytime temperatures consistently remained above 25°C. Extending the study over a longer period would allow for a better understanding of how temperature and other factors, such as humidity, influence the use of microclimates. This is especially important, as currently no conclusions can be drawn on the effects of solar radiation when ambient temperatures are relatively cool.

At current, individual animals were not identifiable, and so conclusions on individual animal preference for specific locations and cooling stations is not available. New tools, such as RFID readers, may be useful in identifying animal cooling station use, as animal presence could be automatically logged if individual animals enter the area (Kim et al. 2009) This would also allow space-use data to be tracked over the full 24-hour period, whilst also improving the quality of the data from presence-absence to duration data on visits to cooling stations. Future studies should also incorporate additional environmental measurements—such as solar radiation, humidity, ground temperature, and wind speed—at each cooling station to determine their effectiveness. Techniques like infrared thermal imaging, used in studies of zoo animals such as elephant, takin, zebra, koala *Phascolarctos cinereus*, and rhinoceros (Narayan et al. 2019; Hilsberg-Merz 2015), could further enhance our understanding of how microclimates affect body temperature in zoo animals. Additionally, investigating the effects of body size and population density across different species would provide more comprehensive insights into cooling station use.

Conclusions

This study highlights the potential for utilisation of thermal gradients provided by artificial means. A strong relationship was identified between cooling station use and solar radiation in the addax, scimitar-horned oryx, and ostriches, emphasising the necessity of creating microclimates in enclosures. Larger animals, such as scimitar-horned oryx and ostrich, appeared to benefit the most, though all species used the cooling stations. By contrast, Dorcas gazelles appeared to use the cooling stations relatively infrequently. The highest use of cooling stations occurred when solar radiation peaked, reinforcing the importance of offering diverse thermal environments to ensure animal welfare, particularly in hot climates.

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References

Abáigar T., Cano M., Ensenyat C. (2018) Time allocation and patterns of activity of the dorcas gazelle (*Gazella dorcas*) in a sahelian habitat. *Mammal Research* 63: 73–82.

Adah A.S., Ayo J.O., Adah D.A. (2023) Unique physiological and behavioural adaptive features of the one-humped camel (*Camelus dromedarius*) to arid environments. *Journal of Applied Veterinary Sciences* 8(1): 57-64.

Bertram B.C.B. (2014) *The ostrich communal nesting system*. Princeton University Press.

Bigalke R.C. (1972) Observations on the behaviour and feeding habits of the springbok, *Antidorcas marsupialis*. *Zoologica Africana* 7(1): 333-359.

Blank D., Yaoming L. (2022) Antelope adaptations to counteract overheating and water deficit in arid environments. *Journal of Arid Land* 14(10): 1069-1085.

Bryan K., Bremner-Harrison S., Price E., Wormell D. (2017) The impact of exhibit type on behaviour of caged and free-ranging tamarins. *Applied Animal Behaviour Science* 193: 77-86. https://doi.org/10.1016/j.applanim.2017.03.013

Cain J.W., Krausman P.R., Rosenstock S.S., Turner J.C. (2006) Mechanisms of Thermoregulation and Water Balance in Desert Ungulates. *Wildlife Society Bulletin* 34(3): 570-581.

Collier R.J., Beede D.K., Thatcher W.W., Israel L.A., Wilcox C.J. (1982) Influences of Environment and Its Modification on Dairy Animal Health and Production. *Journal of Dairy Science* 65(11): 2213-2227

Crawford E. (2012) An Elephant Never Forgets … The Right Microclimate: Thermal Comfort and Microclimatic Design of Asian Elephant Zoo Enclosures; Master's Thesis. University of Guelph, Guelph, Ontario, Canada.

Davimes J.G., Alagaili A.N., Alagaili A.N., Gravett N., Bertelsen M.F., Mohammed O.B., Ismail K., Bennett N.C., Manger P.R. (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(4): 365-374. https://doi.org/10.1177/0748730416645729

Fábregas M., Guillén-Salazar F., Garcés-Narro C. (2012) Do Naturalistic Enclosures Provide Suitable Environments for Zoo Animals? *Zoo Biology* 31: 362–373.

Gilbert T., Woodfine, T. (2004) The biology, husbandry and conservation of scimitar-horned oryx (*Oryx dammah*). Winchester: United Kingdom: Marwell Preservation Trust.

Hahn G.L. (1999) Dynamic responses of cattle to thermal heat loads. *Journal of Animal Science* 77(2): 10–20.

Hilsberg-Merz, S. (2015). Infrared thermography in zoo and wild animals. In *Fowler's Zoo and Wild Animal Medicine, volume 8.* Elsevier.

Hofmeyr M.D. (1985) Thermal properties of the pelages of selected African ungulates. *African Zoology* 20(4): 179–189.

Hosey G., Melfi V., Pankhurst S. (2013) *Zoo animals: behaviour, management, and welfare*. Oxford University Press Oxford.

IUDZG/CBSG (IUCN/SSC) (1993) Executive Summary, of The World Zoo Conservation, The Role of the Zoos and Aquaria of the World in Global Conservation. Chicago Zoological Society. https://portals.iucn.org/library/sites/library/files/documents/1993-033_Ex_Sum.pdf

Jenssen I.C.Ø. (2023) Behaviour of animals in a mixed-species African savannah zoo exhibit related to expansion of the enclosure, visitor numbers and weather effects - Master's Thesis. Norwegian University of Life Sciences. https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/3077706

Kadzere C.T., Murphy M.R., Silanikove N., Maltz E. (2002) Heat stress in lactating dairy cows: A review. *Livestock Production Science* 77(1): 59-91.

Kim S.H., Kim D.H., Park H.D. (2009) A tracking service of animal situation using RFID, GPS, and sensor. *The Journal of the Institute of Internet, Broadcasting and Communication* 9(5): 79-84.

Komuscu A.U. (2017) Long-term mean monthly temperatures trends of the United Arab Emirates. *International Journal of Global Warming* 11(1): 1-22.

Langman V.A., Rowe M., Forthman D., Langman N., Black J., Walker T. (2003) Quantifying Shade Using a Standard Environment. *Zoo Biology* 22: 253-260.

Lukas K.E., Ross, S.R. (2015) Naturalistic exhibits may be more effective than traditional exhibits at improving zoo-visitor attitudes toward African apes. *Anthrozoös* 27(3): 435-455.

Mitchell D., Fuller A., Meyer L.C.R., Maloney S.K. (2002) Brain temperature and arterial blood pressure in free-ranging antelope in their natural environment. *Nature* 419(6909): 607-609.

Morgan K.N, Tromborg C.T. (2007) Sources of stress in captivity. *Applied Animal Behaviour Science* 102(3-4): 262-302. https://doi.org/10.1016/j.applanim.2006.05.032.

Narayan E., Perakis A., Meikle W. (2019) Using thermal imaging to monitor body temperature of koalas (*Phascolarctos cinereus*) in a zoo setting. *Animals* 9(12): 1094.

Owen-Smith N. (1998) *Megaherbivores: The influence of very large body size on ecology*. Cambridge University Press.

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(3): 181-191.

Parker K.L., Robbins C.T. (2018) *Thermoregulation in ungulates*. In Bioenergetics of Wild Herbivores. Taylor & Francis Group.

Rojas-Downing M.M., Nejadhashemi A.P., Harrigan T., Woznicki S.A. (2017) Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management* 16:145-163

Ruckstuhl K.E., Neuhaus P. (2009) Activity budgets and sociality in a monomorphic ungulate: The African Oryx (*Oryx gazella). Canadian Journal of Zoology* 87(2): 165-174.

Seri H., Chammem M., Ferreira L.M., Kechnebou M., Khorchani T., Silva, S.R. (2018) Effects of seasonal variation, group size and sex on the activity budget and diet composition of the addax antelope. *African Journal of Range & Forage Science* 35(2): 89–100.

Slimen I.B., Najar T., Ghram A., Abdrrabba M. (2016) Heat stress effects on livestock: molecular, cellular and metabolic aspects, a review. *Journal of Animal Physiology and Animal Nutrition* 100(3):401-12. doi: 10.1111/jpn.12379. Epub 2015 Aug 6. PMID: 26250521.

Sohail M.U., Ahmad I., Yousaf M.S., Ashraf K., Zaneb H., Aleem M., Rehman H. (2010) Alleviation of cyclic heat stress in broilers by dietary supplementation of mannan-oligosaccharide and Lactobacillus-based probiotic: Dynamics of cortisol, thyroid hormones, cholesterol, C-reactive protein, and humoral immunity. *Poultry Science* 89: 1934-1938. 10.3382/ps.2010-00751.

Schmidt-Nielsen K., Kanwisher J., Lasiewski R.C., Cohn JE., Bretz, W.L. (1969) Temperature regulation and respiration in the ostrich. *The Condor* 71(4): 341–352.

Sevi A., Annicchiarico G., Albenzio, M., Taibi L. (2001) Effects of solar radiation and feeding time on behavior, immune response, and production of lactating ewes under high ambient temperature. *Journal of Dairy Science* 84(3): 629–640

Strauss W.M., Heten R.S., Mitchell D., Maloney S.K., O'Brien H.D., Meyer L.C.R., Fuller A. (2017) Body water conservation through selective brain cooling by the carotid rete: a physiological feature for surviving climate change? *Conservation Physiology* 5:1-15. doi: 10.1093/conphys/cow078. PMID: 29383253; PMCID: PMC5778374.

Tucker C.B., Rogers A.R., Schütz K.E. (2008) Effect of solar radiation on dairy cattle behaviour, use of shade and body temperature in a pasture-based system. *Applied Animal Behaviour Science* 109(2-4): 141-154

Vargas Zeppetello L R., Raftery, A.E., Battisti, D.S. (2022) Probabilistic projections of increased heat stress driven by climate change. *Communications Earth & Environment* 3(1): 183.

Wacher T., Attum O., Robinson E. (1997) Social structure and group dynamics in the Dorcas gazelle (*Gazella dorcas*). *Journal of Arid Environments* 35(2): 291–303.

Wark J.D., Kuhar C.W., Lukas, K.E. (2014) Behavioral thermoregulation in a group of zoo-housed colobus monkeys (*Colobus guereza*). *Zoo Biology* 33: 257–266.

Wark J.D., Wierzal, N.K., Cronin K.A. (2020) Mapping shade availability and use in zoo environments: a tool for evaluating thermal comfort. *Animals* 10(7): 1189. https://doi.org/10.3390/ani10071189

Yan X., Qing-shi M., Jie G., Xiang-fang T., Hong-fu Z. (2017) Effects of relative humidity on animal health and welfare. *Journal of Integrative Agriculture* 16(8): 1653–1658.

Yilmaz S., Alpak E.M. (2019) Visitor experiences in naturalistic zoo exhibits. *Fresenius Environmental Bulletin* 28(1): 44-52.

Yom-Tov Y., Mendelssohn H., Groves C.V. (1995) *Gazella dorcas. Mammalian Species* 491: 1–6.