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Dama gazelle population structure, distribution and interactions in socio-ecological system of the Takolokouzet massif, Aïr Ténéré National Nature Reserve, Niger

DISSERTATION THESIS

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Declaration

I, Abdoul Razack Moussa Zabeirou, hereby declare that I have completed this thesis entitled independently, except for the jointly authored publications that are included. In the case of such publications, my specific contributions have been clearly stated at the start of the relevant publication chapter. Furthermore, I confirm that proper acknowledgement has been provided within this thesis for any references made to the works of others. I also ensure that this work has not been, nor is it currently submitted, for any other degree, to this or any other university. All information sources have been quoted and acknowledged by means of complete references.

In Niamey, January 13, 2026

Abdoul Razack Moussa Zabeirou

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Abstract

Arid and semi-arid ecosystems are among the most challenging environments on Earth, characterized by extreme climatic conditions, limited water availability, and sparse vegetation. Despite these constraints, they support highly specialized fauna, including desert antelopes and gazelles, which are increasingly threatened by habitat fragmentation, resource scarcity, and growing human pressures. The dama gazelle (*Nanger dama*), one of the largest and most endangered gazelles worldwide, has undergone a dramatic decline in both population size and geographic range over the past century and is now listed as Critically Endangered. The Aïr and Ténéré National Nature Reserve in Niger harbors one of the last confirmed wild populations, restricted to remote and environmentally extreme areas such as the Takolokouzet massif.

This thesis assesses the status, spatial ecology, species interactions, and socio-ecological context of this relict population to inform evidence-based conservation strategies. Between 2017 and 2024, the study combined camera trapping, direct observations, spatial analyses, remote sensing, and community-based surveys. Relative abundance and distribution were assessed using the Kilometric Index of Abundance (KIA) and camera trap rates (CTR), while demographic structure, activity patterns, and spatial occupancy were analyzed in relation to environmental and anthropogenic drivers. Semi-structured interviews in surrounding communities explored local knowledge, perceptions, and attitudes toward wildlife.

Results indicate that the dama gazelle population in the Takolokouzet massif is tiny and spatially fragmented, persisting mainly in isolated refuges characterized by low human disturbance, specific topographic features, and particular vegetation conditions. KIA values and camera trap detections suggest a slight positive trend over time, although adults dominate the population and recruitment remains low. Comparative analyses with dorcas gazelle and Barbary sheep show that coexistence in this hyper-arid ecosystem is facilitated by niche partitioning across temporal, spatial, and behavioral axes, with the dama gazelle displaying marked sensitivity to heat and human disturbance.

Social surveys reveal strong links between ecological occurrence and social salience, with the dama gazelle standing out as a species of high cultural importance and widespread local awareness of its decline. Conservation relevance emerges most clearly where ecological vulnerability intersects with positive social value, highlighting opportunities for community-supported conservation.

Overall, this thesis demonstrates that effective conservation of the dama gazelle requires adaptive strategies integrating long-term scientific monitoring,

protection of key refuge, and active engagement of local communities. Beyond the focal species, the findings provide broader insights into the conservation of threatened Sahel-Saharan and Arabian desert ungulates facing similar ecological and socio-economic challenges.

Keywords

:

Dama gazelle, arid ecosystems, Conservation ; Ecology, Camera Trap ; species coexistence ; Community perceptions ; desert ungulates

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List of Abbreviations

ATNNR – Aïr and Ténéré National Nature Reserve
AZA – Association of Zoos and Aquariums
CBD – Convention on Biological Diversity
CITES – Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS – Convention on the Conservation of Migratory Species of Wild Animals
CNEDD – Conseil National de l’Environnement pour un Développement Durable (Niger)
CTAP – Camera Trap Analysis Package
DCFAP – Direction de la Conservation de la Faune et des Aires Protégées (Chad)
DFCPR – Direction de la Faune, de la Chasse, des Parcs et Réserves (Niger)
EAZA – European Association of Zoos and Aquaria
GIS – Geographic Information System
GPS – Global Positioning System
IPCC – Intergovernmental Panel on Climate Change
IUCN – International Union for Conservation of Nature
IUCN SSC ASG – IUCN Species Survival Commission Antelope Specialist Group
KIA – Kilometric Index of Abundance
MSAVI – Modified Soil Adjusted Vegetation Index
NGO – Non-Governmental Organisation
PAMU – Protected Area Management Unit
RZSS – Royal Zoological Society of Scotland
SAF – Second Ark Foundation
SCF – Sahara Conservation Fund
SMART – Spatial Monitoring and Reporting Tool
SSIG – Sahelo-Saharan Interest Group
UNCCD – United Nations Convention to Combat Desertification
UNEP – United Nations Environment Programme
UNESCO – United Nations Educational, Scientific and Cultural Organization

CHAPTER 1

1 Introduction

1.1 General introduction

Arid zones, encompassing dry subhumid, semi-arid, arid, and hyper-arid areas, cover 47% of the Earth's surface (Gaur & Squires 2017). The biodiversity within these regions is pivotal in the global fight against poverty, climate change, and desertification (Davies et al. 2012). Despite their importance, these ecosystems are increasingly threatened by factors such as rapid demographic changes, urbanization, agricultural expansion, land use alterations, weakened governance, and invasive species (Davies et al. 2012). Biodiversity is being eroded globally at unprecedented rates, primarily due to habitat loss, climate change, and other anthropogenic pressures (Pimm, 2008). The loss of species and ecosystems threatens the resilience of ecological networks and the services they provide to humanity. In arid regions such as the Sahara, Arabian, Gobi, and Kalahari deserts, antelopes are iconic mammals known for their remarkable adaptability to extreme temperatures and scarce water resources. Despite these adaptations, many largest terrestrial herbivores species are increasingly threatened by habitat loss, fragmentation, and human expansion for agriculture, urbanization, and resource extraction (Ripple et al., 2015). Additionally, climate change exacerbates environmental stress through shifts in precipitation patterns and increased droughts, further limiting natural resources. Hunting and poaching, as well as competition from domestic livestock, have further intensified pressure on these species, highlighting the need for robust conservation efforts (Ripple et al., 2015). Preserving antelope populations is crucial not only for biodiversity conservation but also for maintaining the ecological balance within arid landscapes, which reflects the overall health of these ecosystems (East 1988, 1989, 1990).

Amidst the antelope species, the dama gazelle (*Nanger dama*) exemplifies the urgent conservation challenges faced in arid regions. Once widespread across the Sahel, the dama gazelle's range has diminished to merely 0.65% of its historical expanse, primarily due to excessive hunting (Durant et al. 2014). As a species classified as '*Critically Endangered*' by the International Union for Conservation of Nature (IUCN, 2016), it is also listed in Appendix I of the Convention on International Trade in Endangered Species (CITES) and the Convention on the Conservation of Migratory Species (CMS) (IUCN SSC Antelope Specialist Group, 2020). This species is

threatened by habitat loss due to human encroachment, the effects of climate change, and poaching, exacerbated by competition with livestock for dwindling resources. In response to these threats, comprehensive conservation strategies have been implemented. These measures have been implemented globally by governments, conservation NGOs and international agencies through the establishment of protected areas, the enforcement of anti-poaching measures, and captive breeding and reintroduction programmes (Bruner et al., 2001; IUCN, 2016; Lindsey et al., 2018). In addition, the involvement of local communities through community-based natural resource management and sustainable land-use practices has been shown to improve conservation outcomes while supporting rural livelihoods (Berkes, 2004).

The conservation of the dama gazelle reflects broader ecological and socio-economic challenges in arid regions. Across the Sahara and Sahel, the decline of this species mirrors wider processes affecting dryland ecosystems, including increasing human pressure, pastoral expansion, habitat degradation, and climate variability. As a large herbivore occupying the Sahara and Sahel habitats, the dama gazelle is particularly sensitive to these environmental and socio-economic transformations.

By analysing population structure, group dynamics, species interactions, and habitat use, alongside local ecological knowledge from surrounding communities, this research aims to provide a more comprehensive understanding of the ecological drivers and conservation constraints affecting the dama gazelle in arid environments. Such knowledge is essential for evidence-based conservation planning and management.

The findings of this study can guide decision-makers in designing targeted interventions, such as identifying key habitats for protection, informing anti-poaching strategies, and improving habitat restoration efforts. In this way, the study contributes to practical conservation actions aimed at ensuring the long-term persistence of the dama gazelle in the Sahara and Sahel.

Although this research focuses on a specific population within a particular protected area, the ecological patterns identified such as population structure, group dynamics, habitat use, and interactions with human activities provide insights that may be applicable to other populations across the species' remaining range. These findings can therefore inform broader conservation strategies, including habitat management, monitoring protocols, and community-based conservation initiatives in arid ecosystems where similar ecological and socio-economic conditions prevail.

1.2 General Aim

The overarching aim of this dissertation is to assess the conservation status of the dama gazelle and to analyse its patterns of habitat use within the Takolokouzet massif in Niger.

1.2.1 Specific Objectives

To accomplish this, the study was structured around four specific objectives:

- To assess the population structure and social organisation of the dama gazelle population.
- To analyse the spatiotemporal activity patterns of dama gazelles and their interactions with other ungulates.
- To examine community knowledge and social dimensions relevant to dama gazelle conservation.
- To identify conservation challenges and propose management measures for the long-term persistence of the species.

1.3 Research Questions

The study addresses the following core questions:

- What are the current demographic structure and social organization of the population, and how do they compare with historical conditions?
- How do environmental factors and interactions with wild and domestic ungulates influence the spatial distribution and activity patterns of dama gazelles?
- How do local knowledge systems and resource-use practices shape human–gazelle interactions and conservation outcomes?
- What are the key ecological and anthropogenic constraints affecting the species, and which management actions could enhance its long-term persistence?

1.4 Chapters Overview

This thesis is structured into nine chapters. Chapters 1, 2, and 3 establish the general framework of the research, comprising the introduction, a comprehensive review of the relevant literature, and a detailed description of the methodological approaches employed. Together, these chapters provide the theoretical and analytical foundations of the study and articulate its overarching aims and objectives.

The core of the thesis is organized around three interconnected topics, each addressing complementary dimensions of the ecology, conservation status, and socio-environmental context of the critically endangered dama gazelle within the Aïr and Ténéré National Nature Reserve (ATNNR).

Chapter 4 presents the first topic, as research (Zabeirou et al. 2025), entitled “Status and social structure of the critically endangered dama gazelle (Nanger dama) in the Aïr & Ténéré National Nature Reserve, Niger.” Drawing on 15 field missions conducted between 2017 and 2023 in the Takolokouzet massif area, this study evaluates the species’ distribution and relative abundance using direct observations, indirect signs, and camera trap data. Kilometric Indices of Abundance indicate increasing trends over time, particularly for indirect evidence. Camera traps recorded an overall capture rate of 1.59 independent events per 100 trap-days. Demographic analyses based on direct sightings and 200 independent camera trap events show a population dominated by adults, with a mean group size of 2.95 individuals and calving occurring in two distinct seasons.

Chapter 5 contains the second topic, (Zabeirou et al. 2026, submitted to *Proceedings B journal*), titled “Sharing the space with dama gazelle: Spatiotemporal niche partitioning of desert ungulates in a hyper-arid mountain refuge.” This chapter models the spatial and temporal distribution of dama gazelle, dorcas gazelle, and Barbary sheep in the Takolokouzet massif, quantifies their spatial and temporal overlap with domestic livestock, and assesses the influence of human activities, particularly grazing pressure and transhumance routes, on these patterns. The findings underscore the dama gazelle’s ecological role as a sentinel and umbrella species within the Sahelo-Saharan ungulate assemblage and provide key insights for adaptive conservation planning in increasingly human-modified desert landscapes.

Chapter 6 presents the third topic, prepared as (Zabeirou et al. 2026, submitted to *Conservation Biology journal*), entitled “*Linking social and ecological salience of wildlife in the Aïr and Ténéré National Nature Reserve, Niger: implications for conservation of the critically endangered dama gazelle.*” This chapter investigates local ecological knowledge and community perceptions of wildlife, with particular emphasis on the dama gazelle.

Chapters 7, 8, and 9 synthesize the research findings, present the general discussion and main conclusions, and outline the implications of the study for the conservation and management of the dama gazelle. The thesis concludes with a complete list of references.

CHAPTER 2

2 Literature Review

2.1 Arid Zones, Desert Biomes and Ecosystems

2.1.1 *Definitions and global extent*

Aridity is primarily defined by climatic conditions, particularly low precipitation relative to potential evapotranspiration. Arid zones encompass hyper-arid, arid, semi-arid, and dry subhumid areas, collectively covering a substantial proportion of the Earth's terrestrial surface (Millennium Ecosystem Assessment, 2005; UNCCD, 2017). These environments are characterized by chronic water limitation, high climatic variability, and recurrent droughts, which strongly constrain biological productivity and ecosystem functioning. Within these drylands, deserts represent the most extreme environments, typically corresponding to hyper-arid and arid regions where annual precipitation is extremely low and vegetation cover is sparse (Laity, 2009; Ward, 2009).

Within these drylands, deserts represent the most extreme environments, and they occur in several distinct climatic and geographic forms across the globe.

2.1.2 *Desert types and characteristics*

Within drylands occur a diversity of ecosystems that collectively form the Deserts and Xeric Shrublands biome, one of the major terrestrial biomes identified in global biogeographic classifications (Olson et al., 2001 ; Dinerstein et al., 2017). This biome includes a mosaic of ecoregions defined by distinct assemblages of species, vegetation structure, and environmental conditions.

Major desert regions within this biome include:

- The Sahara and Arabian deserts (hot subtropical deserts)
- The Gobi and Central Asian deserts (cold continental deserts)
- The Namib and Atacama (coastal fog deserts)
- Polar deserts of the Arctic and Antarctic

Despite regional differences, these systems share key ecological features, including sparse vegetation cover, high temperature variability, nutrient-poor soils, and strong dependence on episodic rainfall events.

Table 2.1. Major desert types and their key environmental characteristics

Desert type	Main regions	Latitudinal distribution	Mean annual precipitation	Temperature characteristics	Key ecological features
Hot subtropical deserts	Sahara, Arabian, Kalahari, Australian deserts	~15–30° N and S	< 250 mm	Very high summer temperatures, large diurnal variation	Sparse vegetation, episodic rainfall, drought-adapted fauna
Cold continental deserts	Gobi, Central Asian deserts	~35–50° N	50–200 mm	Cold winters, warm summers, strong seasonal variation	Steppe-desert mosaics, cold-adapted flora and fauna
Coastal fog deserts	Namib, Atacama	Western continental margins ~15–30°	< 100 mm	Moderate temperatures due to ocean influence	Fog-dependent ecosystems, specialized vegetation
Polar deserts	Arctic and Antarctic regions	> 60° latitude	< 250 mm (mostly snow)	Extremely cold temperatures	Very sparse vegetation, limited terrestrial productivity

Sources: Olson et al., 2001; Ward, 2009; Laity, 2009; Dinerstein et al., 2017.

Given the ecological similarities, shared conservation challenges, and comparable assemblages of large herbivores, this thesis focuses primarily on the hot deserts of the Sahara, which host some of the last remaining populations of several critically endangered antelope species, including the dama gazelle. It also provides a brief overview of the Arabian Desert.

2.1.3 Biotic adaptations to aridity

In hot desert ecosystems, organisms exhibit convergent strategies to cope with extreme heat and chronic water scarcity (Singh & Sharma, 2025). These adaptations include physiological, behavioural, and morphological mechanisms that reduce water loss and allow survival under highly variable environmental conditions.

Physiological adaptations play a central role in water conservation. Many desert mammals can tolerate substantial body water loss and rely on metabolic water derived from fat catabolism. For example, desert antelopes such as the oryx can survive long periods without drinking free water, obtaining most of their water from vegetation and metabolic processes. In addition, desert animals often produce extremely dry faeces and highly concentrated urine, minimizing water loss during excretion (Doucey, 2005).

Behavioural adaptations also help organisms avoid extreme temperatures. Many species adopt nocturnal or crepuscular activity patterns to reduce exposure to daytime heat. Others seek refuge in burrows or shaded areas where temperatures remain considerably lower than at the surface. For instance, several desert rodents and insects use underground shelters that provide a more stable microclimate and reduce both thermal stress and dehydration (Doucey, 2005).

Morphological adaptations further enhance survival in arid environments. In animals, elongated limbs or specialized appendages facilitate locomotion in sandy substrates, while some insects possess structures adapted for burrowing rapidly into sand. In plants, morphological traits such as reduced leaf surfaces, spines, thick cuticles, and water-storage tissues help limit transpiration and increase drought resistance.

Thermoregulatory adaptations allow organisms to cope with extreme temperature fluctuations typical of desert environments. Many ectothermic animals regulate their body temperature behaviourally by adjusting their exposure to solar radiation. For example, reptiles may orient their bodies toward or away from the sun to regulate heat absorption. In mammals and birds, physiological mechanisms such as evaporative cooling or specialized vascular systems help maintain stable internal temperatures despite extreme external conditions (Doucey, 2005).

Refuge habitats and microclimates also play a crucial role in survival. Burrows, rock crevices, vegetation cover, or underground shelters provide important refuges where temperatures and humidity levels are more stable than at the surface. These microhabitats reduce both thermal stress and water loss, allowing organisms to survive extreme daytime conditions (Doucey, 2005).

Together, these physiological, behavioural, and morphological mechanisms enable vertebrates, invertebrates, and plants to persist in desert ecosystems characterized by extreme temperatures, scarce water resources, and highly variable environmental conditions.

2.2 Conservation status of antelopes in hot-desert ecosystems

2.2.1 Rationale for a Sahara–Arabia focus

Both regions share hot-desert climates, parallel ecological filters (scarce/unpredictable rainfall, thermal extremes), and analogous antelope assemblages. This facilitates like-for-like comparisons and the transfer of conservation insights between regions.

2.2.2 Antelopes of the Sahara

The Sahara Desert extends across North Africa from the Atlantic Ocean to the Red Sea and is typically defined by annual precipitation below approximately 150 mm, with the hyper-arid core receiving less than 50 mm per year (Le Houérou, 1997). South of this boundary lies the Sahel, a semi-arid transition zone characterized by annual rainfall between roughly 150 and 350 mm and dominated by Acacia savanna ecosystems (Olson et al., 2001; Dinerstein et al., 2017). These distinctions correspond to different biomes in global classifications, with the Sahara belonging to the Deserts and Xeric Shrublands biome and the Sahel to the Tropical and Subtropical Grasslands, Savannas and Shrublands biome. The native antelope guild includes:

- Dorcas gazelle (*Gazella dorcas*): Widely distributed across Saharan and sub-Saharan arid regions, occupying sandy and stony deserts as well as semi-arid steppes. Highly adapted to extreme heat and water scarcity, obtaining most moisture from forage. Populations have declined due to overhunting and habitat degradation.
- Slender-horned gazelle (*Gazella leptoceros*): Restricted mainly to hyper-arid sandy deserts of North Africa, particularly dune systems. Specialized for desert environments, with limited distribution south of the Tropic of Cancer (Beudels & Devillers, 2013).

- Cuvier's gazelle (*Gazella cuvieri*) is an antelope endemic to the mountainous regions of the Maghreb, adapted to rugged mountain landscapes and rocky arid habitats across North Africa (Cuzin, 2003 ; IUCN SSC Antelope Specialist Group, 2016).

- Red-fronted gazelle (*Eudorcas rufifrons*): Inhabits Sahelian and semi-arid savanna zones south of the Sahara, favoring open grasslands and shrublands with seasonal rainfall.

- Dama gazelle (*Nanger dama*): one of the most threatened desert antelopes, formerly widespread across the Sahelo-Saharan region but now restricted to a few fragmented populations (ASG, RZSS, SAF, 2024).

- Addax (*Addax nasomaculatus*): a highly desert-adapted antelope historically distributed across the Sahara, capable of surviving in extremely arid environments with minimal water intake (Newby et al., 2016)

- Scimitar-horned oryx (*Oryx dammah*): Formerly ranged across sub-desert steppes and northern Sahelian grasslands. Now extinct in the wild but reintroduced in parts of its former range (UNEP/CMS, 2006; Newby et al.,

2.2.3 Antelopes of the Arabian Peninsula

The Arabian Desert (Saudi Arabia, Oman, UAE, Yemen, Jordan, Iraq, Kuwait, Qatar, Bahrain) supports several desert antelopes with parallel adaptations:

- Arabian oryx (*Oryx leucoryx*): once widespread; extirpated then restored via captive breeding and reintroductions (Mallon et al., 2023).

- Arabian sand gazelle (*Gazella marica*): sandy/gravel plains; obtains most water from vegetation (Mallon & Kingswood, 2001).

- Mountain gazelle (*Gazella gazella*): occupies rocky escarpments and open desert along the Peninsula's western/southern margins (Mallon et al., 2023).

- The Arabian gazelle (*Gazella arabica*), declined and fragmented populations across the Arabian Peninsula due to illegal hunting for meat and live capture for pets and private collections, habitat loss through agricultural development (Mallon et al., 2023).

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2.2.4 Brief comparative context: Gobi and Kalahari

The Gobi (Mongolia–China) harbors Mongolian saiga (*Saiga tatarica mongolica*) and goitered gazelle (*Gazella subgutturosa*) in cold-desert/steppe mosaics

(Bannikov, 1954). The Kalahari (Botswana–Namibia–South Africa) supports gemsbok (*Oryx gazella*) and springbok (*Antidorcas marsupialis*) in semi-arid savannas (East et al., 1999). These systems illustrate contrasting climatic filters but are not the analytical focus of this thesis.

Table 2.2. IUCN Red List status and primary habitat of selected desert antelope and gazelle species from the Sahara and Arabian deserts

Species	IUCN Red List Status	Primary Habitat/Area
Sahara Desert		
Addax (<i>Addax nasomaculatus</i>)	Critically Endangered	Exclusively Sahara Desert (true desert specialist)
Dama Gazelle (<i>Nanger dama</i>)	Critically Endangered	Sahara & Sahel transition zones
Scimitar-horned Oryx (<i>Oryx dammah</i>)	Endangered	Formerly Sahara and Sahel
Cuvier's Gazelle (<i>Gazella cuvieri</i>)	Vulnerable	Maghreb mountains and arid rocky habitats (North Africa)
Dorcas Gazelle (<i>Gazella dorcas</i>)	Vulnerable	Widespread: Sahara Desert & Sahel fringe northern mediterranean
Red-Fronted Gazelle (<i>Eudorcas rufifrons</i>)	Vulnerable	Sahel belt, southern Sahara margin, Soudanais savanna.
Slender-horned Gazelle (<i>Gazella leptoceros</i>)	Endangered	Northern Sahara, sandy ergs of Libya, Egypt, Algeria, Tunisia
Arabian Desert		
Arabian Oryx (<i>Oryx leucoryx</i>)	Vulnerable	Arabian Peninsula deserts (reintroduced)

Sand Gazelle (<i>Gazella marica</i>)	Vulnerable	Sandy & gravel plains of Arabian Peninsula
Mountain Gazelle (<i>Gazella gazella</i>)	Vulnerable	Rocky escarpments and desert-steppe, western & southern Arabia
Arabian Gazelle (<i>Gazella arabica</i>)	Vulnerable	Arabian Peninsula (southern & central regions)

The conservation status of antelope species in the deserts showcases a spectrum of outcomes, from notable successes to critical challenges, underscoring the urgent need for tailored conservation strategies. While some species have seen population recovery due to focused conservation efforts, others remain at significant risk of extinction, demanding immediate action.

2.2.5 Key Antelopes of the Sahara and Arabian Deserts

Scimitar-horned oryx (*Oryx dammah*)

The scimitar-horned oryx faced more severe pressures in the Sahara, being declared *Extinct in the Wild* in the early 2000s by IUCN Red list. Overhunting, habitat degradation, and competition with livestock in fragmented desert ecosystems were the main drivers of its collapse (Newby et al., 2016). In the early mid-1980s, initial reintroduction efforts were undertaken in Tunisia, following in Senegal, and Morocco (Gilbert 2011). While these early initiatives laid important foundations, large-scale and well-coordinated reintroduction programs have since demonstrated greater success. In particular, reintroduction efforts in Chad have shown considerable promise. Beginning in 2016, captive-bred scimitar-horned oryx were released into the Ouadi Rimé–Ouadi Achim Wildlife Reserve (Chuven et al., 2018). By 2021, the population had increased to more than 140 mature individuals, with over 330 calves born in the wild, indicating successful establishment and reproduction (Mallon et al., 2023). The success of these initiatives depends not only on ecological suitability but also on sustained engagement with local pastoralist communities to reduce poaching and foster coexistence. This model highlights the importance of integrating rewilding, captive breeding, and community participation for long-term recovery.

Arabian oryx (*Oryx leucoryx*)

The Arabian oryx represents one of the most notable conservation successes, having recovered from extinction in the wild in the early 1970s through captive breeding and reintroduction programs. Declared Extinct in the Wild in 1972, captive-

bred individuals were first released in Oman's Jiddat Al Harasis in 1982 (Stanley Price, 1989), followed by reintroductions in Saudi Arabia, Israel, Jordan, and the United Arab Emirates (Islam et al., 2011). Early recovery efforts in Oman demonstrated the effectiveness of strong state-led conservation, although subsequent poaching, habitat degradation, and policy changes caused severe population declines. Today, the Al Wusta Wildlife Reserve maintains a managed population under stricter protection (Goraya et al., 2021), while regional cooperation has been crucial for the species' persistence across the Arabian Peninsula.

Addax (*Addax nasomaculatus*)

The addax classed as *Critically Endangered* species, with wild populations reduced to only a few dozen individuals scattered across isolated parts of the Sahara. Historically ranging from Morocco and Mauritania to Egypt and Sudan, its collapse was accelerated by unregulated hunting, oil exploration, and military disturbance. Today, the largest surviving group, fewer than 100 individuals, persists in the Tin Toumma desert of eastern Niger (Wacher et al., 2010a; T. Rabeil, pers. comm.).

Conservation responses have combined the protection of remnant populations with experimental reintroductions. In 2019, for example, 15 captive-born addax were translocated to Chad's Ouadi Rimé Ouadi Achim Reserve under a program coordinated by the Environment Agency Abu Dhabi (SCF; 2021). Together with ongoing reintroduction efforts in Morocco and Tunisia, and the current presence of addax within the Ennedi Cultural and Natural Reserve these initiatives illustrate both the urgency and the complexity of conserving a species that is now on the brink of extinction (DFCAP & DFCPR, 2017, African Parks, 2023). These efforts illustrate both the urgency and difficulty of conserving a species now hanging on at the edge of extinction.

Dama gazelle (*Nanger dama*)

The dama gazelle is another *Critically Endangered* species, facing persistent threats from hunting, habitat degradation, and competition with livestock. Historically widespread across Sahelian plains Saharan massifs (Aïr, Hoggar, Tibesti) and Atlantic Sahara, it is now reduced to only four fragmented populations, mainly in Niger and Chad.

Conservation efforts focus on key strongholds such as the Aïr-Ténéré National Nature Reserve and the Termit region in Niger, as well as western Chad. However, insecurity in areas like South Tamesna, Mali, complicates both survey efforts and effective protection (Lamarque et al., 2007; RZSS & IUCN Antelope Specialist Group, 2014). More details about the dama gazelle are introduced in Chapter 2.5. below.

2.3 Factors Contributing to Declines

Population declines of Sahelo-Saharan ungulates are not driven by a single factor, but rather by the cumulative and interacting effects of habitat degradation, climate variability, overhunting, and increasing competition with livestock. These pressures operate simultaneously within highly fragile socio-ecological systems

2.3.1 Habitat degradation and resource exploitation

Globally, land-use change remains a primary driver of biodiversity loss (IPBES, 2019). In the Sahara and Sahel, habitat degradation is less associated with intensive agriculture than in tropical systems, but instead linked to infrastructure expansion, extractive industries, and localized land conversion around permanent water sources.

Recent decades have seen rapid growth in gold mining, oil and gas exploration, and associated road networks across the Sahelo-Saharan belt (Brito et al., 2014; UNEP, 2022). These developments fragment previously continuous range lands and increase human accessibility to remote areas. Even limited infrastructure in desert ecosystems can have disproportionate ecological impacts because species such as the dama gazelle and addax depend on vast, low-disturbance landscapes.

Moreover, the expansion of off-road vehicles and firearms has facilitated access to previously inaccessible areas, increasing hunting pressure and wildlife disturbance (Newby et al., 2016). In highly open desert habitats, avoidance behaviour can result in effective habitat loss even without physical transformation.

2.3.2 Climate change and desertification

Climate change represents a major threat multiplier in arid ecosystems. The Sahel has experienced significant interannual rainfall variability and recurrent drought episodes over the past decades (IPCC, 2021). Rising temperatures and altered precipitation regimes intensify desertification processes and reduce primary productivity.

Dryland ecosystems operate close to ecological thresholds. When drought frequency increases, vegetation cover declines sharply, reducing both forage and thermal refuge for herbivores (Nwaogu et al., 2023). Although desert ungulates such as dorcas gazelle or slender-horned gazelle possess physiological adaptations to aridity, these adaptations evolved under historical climatic variability, not under rapidly accelerating climate change.

Importantly, climate effects interact with anthropogenic pressures: drought concentrates livestock and wildlife around remaining water points, intensifying competition and disease transmission.

2.3.3 Hunting and poaching

For large Sahelo-Saharan antelopes, overhunting has historically been the principal driver of collapse (Newby, 2016; Ripple et al., 2016). Traditional subsistence hunting, once relatively limited in impact, shifted dramatically during the 20th century with the introduction of firearms and motorized vehicles.

The bubal hartebeest became extinct in North Africa in the early 20th century, illustrating the vulnerability of large ungulates to unregulated hunting. Later, populations of scimitar-horned oryx and addax declined catastrophically due to commercial meat hunting and recreational expeditions.

Today, motorbikes and all-terrain vehicles allow poachers to pursue wildlife across vast distances, even inside nominally protected areas (SCF, 2022). In open desert landscapes, this technological advantage leaves little refuge for large-bodied species.

2.3.4 Competition with livestock

Livestock numbers in the Sahel have increased substantially over the past four decades, driven by demographic growth and economic demand (FAO, 2020). The drilling of permanent wells has reduced seasonal grazing refuges, enabling year-round occupation of previously marginal areas (Beudels-Jamar et al., 2005).

This sedentarization alters historical patterns of spatial separation between livestock and wildlife. Overgrazing reduces forage quality and availability, while frequent human presence increases disturbance. For highly sensitive species such as the dama gazelle and addax, chronic disturbance may lead to avoidance of otherwise suitable habitats.

In addition, spatial overlap facilitates pathogen transmission between domestic and wild ungulates, representing an emerging but understudied threat in desert systems.

2.4 Strategies for Addressing Declines

2.4.1 Habitat protection and surveillance

The establishment and effective management of protected areas are fundamental to species conservation. Aichi Target 11 of the Convention on Biological Diversity (CBD, 2020) calls for at least 17% of terrestrial and inland waters to be safeguarded under well-managed protected areas. Tools such as remote sensing, ranger patrols, and SMART monitoring have significantly improved surveillance effectiveness (Watson et al., 2014). In the Sahara, large reserves such as the Aïr–Ténéré (Niger) or the Ouadi Rimé–Ouadi Achim (Chad) are crucial strongholds for remnant populations of addax, dama gazelle, and scimitar-horned oryx.

2.4.2 Community awareness and engagement

Long-term conservation success in arid and semi-arid ecosystems depends fundamentally on local stewardship and sustained community engagement. In regions where protected areas overlap with pastoral and agro-pastoral livelihoods, conservation outcomes are closely linked to local perceptions, resource access, and governance arrangements.

Community-based conservation (CBC) emerged as a response to the limitations of strictly protectionist approaches, promoting participatory management and shared responsibility for natural resources (Western & Wright, 1994; Berkes, 2004). The underlying rationale is that when local communities derive tangible and equitable benefits from wildlife conservation, incentives for poaching and habitat degradation are reduced.

In the broader human–wildlife conflict literature, participatory approaches have been shown to improve tolerance toward wildlife, particularly when combined with education, livelihood diversification, and benefit-sharing mechanisms (Treves & Karanth, 2003; Brooks et al., 2012). For example, locally recruited eco-guard networks, community surveillance systems, and revenue-sharing schemes from tourism or conservation projects have contributed to reduced illegal hunting and increased reporting of wildlife presence in several African contexts.

However, empirical assessments indicate that the effectiveness of CBC initiatives varies considerably. Success depends on governance quality, transparency in benefit distribution, institutional legitimacy, and alignment with existing socio-economic systems (Dressler et al., 2010). In dryland regions such as the Sahara and the Sahel, where livelihoods are highly climate-sensitive and mobility is central to pastoral systems, conservation initiatives must be carefully designed to avoid restricting access to critical resources such as water and grazing areas.

In this context, community awareness programs that integrate environmental education, participatory monitoring, and locally adapted incentive structures are

particularly relevant. Rather than viewing local populations solely as sources of pressure, contemporary conservation frameworks increasingly recognize them as key partners in safeguarding desert biodiversity.

2.4.3 Research and monitoring

Scientific research and long-term monitoring are fundamental for informing effective conservation strategies, particularly for rare and threatened species in remote ecosystems. Advances in wildlife monitoring technologies have greatly improved the ability to collect reliable data on species distribution, abundance, behaviour, and movements. Camera traps, for instance, are widely used to monitor wildlife populations and activity patterns in a non-invasive manner (O’Connell et al., 2011; Burton et al., 2015). Similarly, satellite telemetry has become an important tool for understanding spatial ecology, migration routes, and habitat use of large mammals in arid landscapes (Hebblewhite & Haydon, 2010).

In recent years, unmanned aerial vehicles (drones) have also been increasingly employed to survey wildlife populations, particularly in remote or difficult-to-access environments (Linchant et al., 2015 ; De la Lata Quiroga, 2023). Furthermore, advances in artificial intelligence and automated image recognition now allow faster and more accurate processing of large volumes of camera-trap data, significantly reducing analysis time and survey costs (Kays et al., 2020).

In addition to technological advances, the involvement of local communities has become increasingly recognized as a crucial component of wildlife monitoring and conservation programmes. Community-based monitoring can improve data collection across large landscapes while strengthening local stewardship and increasing support for conservation initiatives (Danielsen et al., 2009). Local ecological knowledge can provide valuable insights into species presence, seasonal movements, and threats that may not always be captured through conventional scientific surveys. Integrating scientific monitoring with participatory approaches therefore contributes to more effective and socially inclusive conservation strategies

2.4.4 Ex situ conservation and captive breeding

Ex situ breeding has played an important complementary role in wildlife conservation in response to severe population declines across species’ former ranges. In such contexts, the protection of remaining centres of diversity alone is often insufficient, requiring the adoption of integrated “One Plan” approaches that combine captive breeding, habitat restoration, and reintroduction efforts (Byers et

al., 2013). Coordinated breeding programmes led by zoological institutions particularly through international associations such as the European Association of Zoos and Aquaria (EAZA) and the Association of Zoos and Aquariums (AZA) have maintained genetically managed captive populations that function as insurance against extinction. These programmes rely on studbooks, regulated transfers between institutions, and standardized husbandry protocols to preserve genetic diversity and demographic stability (Al Ain et al., 2019).

In addition to public zoological institutions, private breeding initiatives, notably in Texas (USA) and the United Arab Emirates, maintain substantial dama gazelle populations under semi-natural conditions (Mungall, 2018). When effectively integrated into international management frameworks, these privately managed herds can make significant contributions to population reinforcement and reintroduction efforts. Such approaches have already been successfully applied in the case of the scimitar-horned oryx and the Arabian oryx, both of which were reintroduced using animals originating from coordinated zoo and private captive populations (Price, 1989 ; Mallon et al., 2023). Despite ongoing challenges, intensively managed captive populations of Sahelo-Saharan ungulates such as the addax, scimitar-horned oryx, and dama gazelle remain sufficiently large, genetically diverse, and demographically robust to serve as viable sources for the reintroduction and augmentation of wild populations (Newby, 2016).

2.4.5 *Translocations and reintroductions*

Translocations and reintroductions have become essential tools for restoring populations of species that have disappeared from the wild or persist only in small, fragmented populations. These conservation interventions aim to re-establish viable populations within their historical ranges or reinforce existing ones. The International Union for Conservation of Nature (IUCN) emphasizes that successful conservation translocations require careful planning, including feasibility assessments, genetic considerations, habitat suitability, and long-term post-release monitoring (Soorae, 2018). Over recent decades, these approaches have been increasingly applied worldwide across a wide range of taxa, demonstrating their growing importance as a conservation strategy. The compilation of global case studies in *Global Reintroduction Perspectives* highlights hundreds of reintroduction and translocation programmes implemented across different regions and species, illustrating both the potential and the challenges associated with restoring threatened wildlife populations.

Several flagship examples illustrate the potential of such interventions in large desert ungulates.

The Arabian oryx (*Oryx leucoryx*), declared extinct in the wild in the early 1970s, represents one of the most celebrated conservation successes. Through coordinated captive breeding programmes, strong governmental support, and strict anti-poaching measures, the species was successfully reintroduced into several countries including Oman, Saudi Arabia, and the United Arab Emirates (Stanley Price, 1989).

Similarly, the scimitar-horned oryx (*Oryx dammah*), declared extinct in the wild by the early 2000s, benefited from early ex situ conservation initiatives. By the mid-1980s, when the species had already disappeared from most of its former range, the first reintroductions were initiated in Tunisia with releases into fenced enclosures in Bou Hedma National Park, Sidi Toui National Park, Oued Dekouk Nature Reserve, and Dghoumes National Park. Parallel conservation initiatives were undertaken in Morocco's Souss-Massa region and in Senegal's Guembeul Reserve (Gilbert, 2011). These early efforts laid the foundation for subsequent restoration programmes. Since 2016, reintroductions in the Ouadi Rimé–Ouadi Achim Reserve in Chad have led to the establishment of a free-ranging population now exceeding 500 individuals. This remarkable conservation success reflects long-term strategic planning, strong governmental commitment, collaboration between NGOs and scientists, and the active involvement of local pastoral communities (Newby et al., 2016 ; Mallon et al., 2023).

Reintroduction programmes for the dama gazelle (*Nanger dama*) were initiated through early conservation efforts in Senegal, Tunisia, and Morocco (Abáigar et al., 2018). More recently, in 2020, Sahara Conservation conducted a capture and translocation operation involving dama gazelles from the Manga region of Chad to the Ouadi Rimé–Ouadi Achim Reserve. This intervention aimed to strengthen the genetic pool and enhance the long-term viability of the existing wild population.

Similar genetic reinforcement strategies have been successfully implemented in other threatened species. For example, the translocation of Texas pumas into the Florida panther population significantly increased genetic diversity and improved population growth (Pimm et al., 2006). Likewise, translocations have been widely used to augment genetic diversity and restore populations of bighorn sheep across North America (Hogg et al., 2006). Comparable conservation interventions have also been applied in species such as the golden lion tamarin, where translocations were used to reinforce small isolated populations and increase genetic variability (Kierulff et al., 2012).

Large desert ungulates play an important ecological role in arid ecosystems, where they contribute to vegetation dynamics, seed dispersal, and trophic

interactions. However, many of these species have experienced dramatic population declines due to habitat degradation, overhunting, and increasing human pressure across the Sahara and Arabian deserts. Among them, the dama gazelle (*Nanger dama*) is one of the most threatened antelope species in the region and is currently classified as Critically Endangered. Once widely distributed across the Sahel and Saharan regions, the species has undergone a severe range contraction and now persists only in a few isolated populations.

Because of its ecological characteristics, historical distribution, and current conservation status, the dama gazelle represents a valuable model for understanding the ecological and socio-environmental processes affecting large desert ungulates. Studying this species provides insights into habitat use, spatial dynamics, and human–wildlife interactions in arid landscapes, which are key factors shaping the persistence of large herbivores in desert ecosystems.

Focusing on the dama gazelle therefore provides a unique lens through which to explore the ecological, spatial, and socio-environmental processes affecting large ungulates across the Sahara and Arabian deserts. The following section presents an overview of the species' ecology, distribution, and conservation history, forming the biological foundation for the present research.

2.5 The Dama Gazelle (*Nanger dama*): Ecology, Distribution and Conservation Status

Within this ecological and biogeographical context, the dama gazelle emerges as one of the most emblematic and threatened species of the Sahelo-Saharan desert ecosystems.

Its distribution, ecology, and conservation status reflect the broader dynamics that characterize these arid landscapes where extreme climatic conditions, habitat fragmentation, and increasing human pressures converge to shape the survival of desert-adapted ungulate species.

2.5.1 Description

The dama gazelle is one of the most emblematic yet critically endangered antelopes of the Sahelo-Saharan region. The former distributional area of *Gazella dama* extended from the Sudan through the southern part of the Sahara into the desert of Senegal and to the western coastal strip as well as into the south of Morocco (Mar Cano Perez 1984), it now survives only in a few isolated populations in Niger and Chad (ASG, RZSS, SAF, 2024) with no recent confirmed information

available on the current status of the species in Mali. As such, it has become one of a symbol of the ecological collapse of desert ecosystems and of the resilience of conservation efforts in some of the harshest environments on Earth.

Morphologically, the dama gazelle is readily identifiable by its large stature and is considered the largest of all gazelle species. The species has a head–body length ranging from 95 to 165 cm, a tail length of 26–35 cm, and a shoulder height of 90–120 cm). Body mass varies considerably across populations. In captive mhorh gazelles, average body weights of approximately 65 kg for males and 60 kg for females have been reported (Barbosa & Espeso, 2005), whereas eastern dama gazelles originating from Chad and raised in captivity in Texas averaged 55.8 kg in males and 40.9 kg in females (Mungall, 2018, Schreiber, 2022). It is characterized by long, slender legs, an elongated neck, and a distinctive reddish-brown and white pelage. The proportion of brown to white varies across its range: western populations tend to display darker coats, with brown covering most of the back and hindquarters, whereas eastern forms are much paler, sometimes with brown restricted primarily to the neck (Cano, 1984).

In his detailed description of the central dama gazelle (*N. d. dama*), identified two diagnostic coat characteristics: (1) a relatively broad, though variable, haunch stripe and (2) its vertical extension down the posterior aspect of the hind leg. This configuration distinguishes the central form from *N. d. mhorh*, in which the reddish coloration typically covers most of the haunch without a clearly delimited vertical extension. It also differentiates it from the eastern form (*N. d. ruficollis*, often referred to as “addra”), in which this vertical extension is usually reduced or absent (Cano, 1991).

Importantly, these two pattern elements originate from different regions of the coat and may fade or vary independently, particularly in eastern populations (Mungall, 2018). Their partial independence supports their treatment as separate morphological characters when evaluating geographic variation within *Nanger dama*.

Regardless of subspecies or geographic origin, the ventral area is consistently white, and unlike many other gazelles, the dama gazelle lacks a dark lateral stripe separating the dorsal and ventral zones (Le Berre, 1990). The white rump patch forms a tapered wedge extending onto the croup, a diagnostic characteristic of the genus *Nanger*, which also includes *Nanger grantii* and *Nanger soemmerringii*. Although this rump pattern is shared among members of the genus, it is particularly pronounced in *N. dama*, contributing to its distinctive morphology. The tail is short and predominantly white, ending in a sparse tuft of hair (Mallon & Kingswood, 2001). Newborn calves exhibit a fawn-coloured coat that gradually fades with age.

Most individuals also present a distinct white patch on the lower part of the neck (RZSS & IUCN Antelope Specialist Group, 2014). Both sexes bear horns, but those of males are notably thicker. The horns, relatively short (about 25 cm), ringed, and shaped in a backward-inclined S-curve, are among the species' most recognizable features.

2.5.2 Taxonomy and Subspecies

The taxonomic status of the different forms of the dama gazelle has long been debated. Bennett (1833), in his original description of the mhorra gazelle, suggested that *mhorra*, *dama*, and *ruficollis* might represent subspecies rather than distinct species if additional specimens were discovered in the regions between their distributions. Later, Sclater and Thomas (1897–1898) described *mhorra*, the central dama gazelle, and the red-necked gazelle (*addra*) as separate species, while acknowledging that the scarcity of available specimens limited reliable comparisons. They noted that more extensive material could eventually demonstrate that these forms were closely related and might represent subspecies of a single species.

Three subspecies have traditionally been recognized: *N. d. mhorra* in the west (now extinct in the wild but maintained in European, North African, and Arabian breeding programmes), *N. d. dama* in central Niger and Mali, and *N. d. ruficollis* in Chad and Sudan (Cano, 1984).

However, genetic analyses have revealed weak phylogeographic structure and do not support the division of the dama gazelle into three distinct subspecies. Consequently, it has been recommended that *Nanger dama* be treated as a monotypic species without subspecific divisions (Senn et al., 2016). Although this view is increasingly accepted, the intraspecific taxonomic arrangement of the dama gazelle remains debated. Observed morphological variation may be selectively neutral, resulting from genetic drift, or alternatively reflect adaptive differentiation along environmental gradients.

Within the genus *Nanger*, the dama gazelle is closely related to *Nanger grantii* and *Nanger soemmerringii*, which primarily inhabit semi-arid savanna and dry grassland ecosystems in East Africa (Kingdon, 2011; Bärmann et al., 2013). Phylogenetic analyses confirm that *Nanger* forms a distinct evolutionary lineage within the subfamily Antilopinae (Hassanin et al., 2012).

Although these species share key morphological traits, including elongated limbs and comparable horn structure, *N. dama* is the only member of the genus fully adapted to the hyper-arid Saharo-Saharan environment. Its ecological niche is therefore more comparable to that of desert-adapted Hippotraginae, such as the

addax (*Addax nasomaculatus*) or the scimitar-horned oryx (*Oryx dammah*), despite their greater phylogenetic distance.

Early morphological analyses proposed a directional evolutionary gradient within the genus *Nanger*, with *N. grantii* considered the least derived form, followed by *N. soemmerringii*, and *N. dama* representing the most evolutionarily derived species (Cano Pérez, 1991). This interpretation was based on comparative traits including body size, horn morphology, pelage contrast, and feeding ecology. In particular, the larger body size, reduced horn length, increased coat contrast, and enhanced browsing capacity of *N. dama* were interpreted as adaptive responses to increasingly arid environments along a southeast–northwest ecological gradient.

However, modern molecular phylogenetic analyses do not fully support a simple linear evolutionary progression within the genus (Bärmann et al., 2013; Hassanin et al., 2012). Instead, divergence patterns appear to reflect geographic isolation and ecological specialization rather than hierarchical evolutionary advancement. The extreme desert adaptation of the dama gazelle may therefore represent ecological convergence and local adaptation rather than a terminal evolutionary stage.

Taken together, these perspectives illustrate the dynamic and evolving nature of taxonomic interpretation within African Antilopinae and highlight the importance of integrating morphological, ecological, and molecular evidence when assessing species boundaries and evolutionary history.

2.5.3 Ecology and Behaviour

The ecology of the dama gazelle remains poorly documented, but available observations indicate that it is a mixed feeder with a strong browsing tendency. Most of its diet consists of tree and shrub foliage, whose tissues provide both nutrients and metabolic water. To a lesser extent, it also consumes non-graminoid herbs (Bonotte, 1958; Dragesco-Joffé, 1993; Mallon & Kingswood, 2001; Giazzi, 1996). In the Sahel during the dry season, it feeds on the leaves, flowers and pods of *Vachellia* species (*V. raddiana*, *V. ehrenbergiana*, *V. tortilis*), as well as on *Faidherbia albida*, *Balanites aegyptiaca*, *Boscia senegalensis*, *Maerua crassifolia*, and other woody plants. It also browses the abundant shrubs *Capparis decidua*, *Leptadenia pyrotechnica* and *Salvadora persica* (Grettenberger & Newby, 1986; Giazzi, 1996). Historical observations from Moroccan wadis indicate that dama gazelles feed mainly on the leaves of *Acacia seyal*, and to a lesser extent on those of *Maerua* spp. and *Ziziphus* spp. (Morales-Agacino, 1949; Valverde, 1957, Segura & Moreno, 2024). Grasses are eaten selectively and only during the rainy season and early dry season, after which their nutritional value declines markedly (Scholte, 2013). At the onset of

the rains, temporarily abundant high-quality herbs such as *Tribulus terrestris* may be taken.

Adapted to extreme arid conditions, the dama gazelle obtains most of its water from plants, including the desert gourd *Citrullus colocynthis*, *Leptadenia hastata* often cited as an important moisture source (Dragesco-Joffé, 1993). However, field data on its water requirements and drinking behaviour remain scarce.

Its movements are largely nomadic and driven by the ephemeral availability of green vegetation. The species inhabits open plains, wadis and low mountain slopes with sparse vegetation and shows activity peaks in early morning and late afternoon. Social groups are typically small—2 to 10 individuals, occasionally larger during the wet season (Grettenberger & Newby, 1986; Le Berre, 1990). Although naturally mobile, the dama gazelle's ability to track seasonal resources has become increasingly constrained by the fragmentation of suitable habitat and the expansion of pastoral activities across key valleys.

2.5.4 Distribution and Population Trends

Historically, the dama gazelle was widely distributed across the Sahelo-Saharan region, ranging from Mauritania and Senegal in the west to Sudan in the east. Its distribution extended across a broad belt approximately 200–300 km south of the central Sahara, reaching the Atlantic Sahara, the Anti-Atlas Mountains of Morocco, and several major Saharan massifs including the Hoggar, Tassili, Aïr, Adrar des Ifoghas, and Tibesti (Scholte, 2013; RZSS & IUCN Antelope Specialist Group, 2014).

Historical accounts also suggest gradual geographic variation in coat coloration across this wide range. Early observations reported that individuals tended to become progressively lighter in colour from west to east toward Lake Chad, suggesting clinal variation rather than sharply defined subspecies boundaries. Such patterns may partly explain differing interpretations of subspecific limits. For example, Drüwa (1985) recognised only two subspecies *Gazella dama mhorri* in the western Sahel and *Gazella dama dama* in the central and eastern Sahel while later classifications proposed additional subdivisions. The present restriction of *mhorri* to remnant populations at the far western edge of the species' historical range may also have influenced subsequent interpretations of subspecies boundaries (Groves & Grubb, 2011).

Today, the dama gazelle is classified as Critically Endangered, with the global wild population estimated at approximately 100–200 individuals, possibly fewer than 100 mature adults, placing the species at imminent risk of extinction (Mallon, 2019). Remaining wild populations persist in a few fragmented locations: two in

Niger (the Aïr and Ténéré National Nature Reserve and the Termit Massif, formerly part of the Termit and Tin-Toumma Reserve), and one in Chad (Ouadi Rimé–Ouadi Achim Wildlife Reserve). Additional reports indicate the possible persistence of a small population in the Manga region of Chad, although reliable data remain limited (IUCN, 2020; ASG, RZSS & SAF, 2024; Fig. 2.1). The presence of the species in Mali has not been confirmed since 2007.

In contrast, approximately 2,900 individuals are currently maintained in ex situ populations under coordinated breeding programmes managed by the Association of Zoos and Aquariums (AZA) and the European Association of Zoos and Aquaria (EAZA). These programmes maintain detailed pedigree records and genetic management strategies aimed at preserving genetic diversity. However, international veterinary and sanitary regulations, particularly in Europe and the United States, continue to restrict the transfer of animals from African populations, complicating efforts to integrate wild and captive management strategies (ASG, RZSS & SAF, 2024).

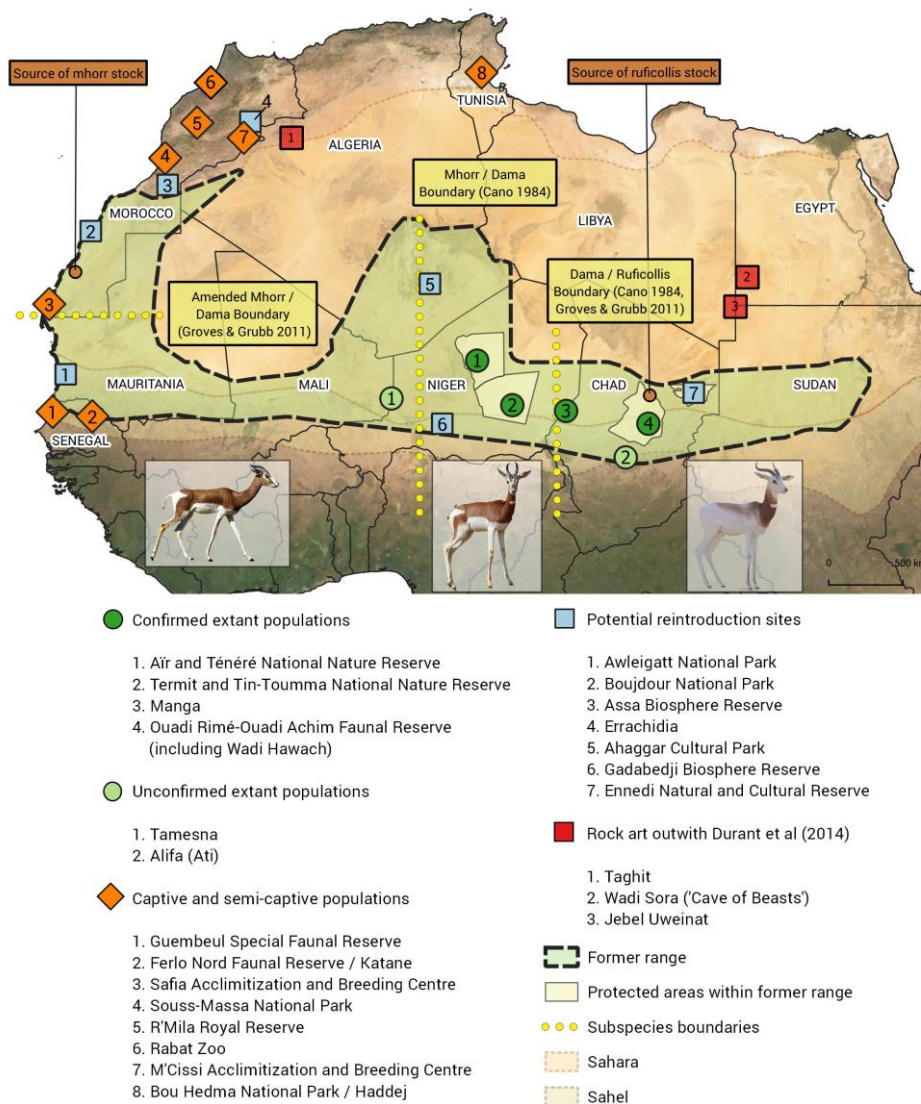


Figure 2.1 Key sites for the dama gazelle have been mapped based on historical range and recent survey data (after Durant et al., 2014), illustrating both former broad distribution and current focal areas for conservation planning. The origin of the mhor captive stock includes two locations, El Hagounia and Tichla–Bir Ganduz (Abáigar, 2018), which are important for ex situ genetic resources (Dama Gazelle Conservation Strategy 2019–2028).

2.5.5 Conservation Efforts and Regional Initiatives

Since the 1980s, Niger and Chad have remained the only countries preserving wild dama gazelles, supported by strong international partnerships. The 2019–2028 Global Conservation Strategy for the Dama Gazelle, coordinated by the Al Ain Zoo

and IUCN-ASG sets regional priorities for monitoring, habitat management and community engagement (Al Ain zoo et al. 2019). In parallel, a joint Regional Action Plan 2018–2022 for addax and dama gazelles in Niger and Chad seeks to harmonize field protection, research and awareness campaigns (DFCAP & DFCPR, 2017).

Within Niger, the species is fully protected under Law No. 98-07 on Wildlife Protection (1998). Conservation is now implemented through collaborative efforts among national authorities, the Sahara Conservation Fund, local communities and partner NGOs using tools such as SMART patrolling and environmental education. However, persistent funding shortages, insecurity and limited national capacity still constrain field implementation (RZSS & IUCN 2014).

2.5.6 Significance for the Present Study

The dama gazelle is considered a flagship species of the desert ecosystems in the Aïr and Ténéré region. Its rarity and striking appearance have contributed to its recognition as a flagship species for Saharan biodiversity, helping to raise awareness and attract conservation attention to desert ecosystems and the protection of threatened Sahel–Saharan wildlife (Mallon & Kingswood, 2001; IUCN SSC Antelope Specialist Group, 2016).. Its persistence in the Takolokouzet massif provides a unique opportunity to study how the species adapts to its environment, survives in small populations, and interacts with other wildlife. Building on earlier surveys (Grettenberger & Newby, 1986) and recent monitoring (Rabeil et al., 2014; Zabeirou, 2023), this research evaluates the species' current status, habitat use, and human–wildlife interactions, guiding conservation actions.

CHAPTER 3

3 General methodology

3.1 Conceptual Framework and General Approach

The methodological framework is based on an ecosystemic and interdisciplinary perspective, linking the biological dynamics of the dama gazelle to environmental conditions and anthropogenic pressures influencing its survival. The research follows a logical sequence of steps observation, quantification, comparison, and interpretation and is structured around three main components:

1. **Socio-biology**, focused on estimating population structure, abundance, and group composition.
2. **Ecological (spatio-temporal)**: focused on analyzing the habitat use and distribution patterns of the dama gazelle in relation to both interspecific (wild and domestic ungulates) and human–wildlife interactions, as well as key environmental variables influencing its occurrence.
3. **Socio-ecological (human dimensions)**: focusing on community perceptions, traditional practices, and local ecological knowledge concerning wildlife, particularly the dama gazelle and its conservation context.

These components correspond to the three core scientific papers of the thesis, all relying on a shared methodological foundation.

3.2 Study Area

The study was conducted in the Aïr and Ténéré National Nature Reserve (ATNNR), located in northern Niger between 17°–20° N and 8°–10° E. Covering approximately 77,000 km², the reserve represents the largest protected area in Niger and one of the largest protected areas in Africa (Figure 3.1).

Within the reserve, the Takolokouzet massif, covering approximately 3,167 km², is located around 18°18' N and 9°30' E in the Aïr Mountains in the central part of the reserve. This area constitutes the main study site due to the persistence of a small relict population of dama gazelles (*Nanger dama*).

The landscape is characterized by a rugged topography composed of rocky valleys, plateaus, and plains. Unlike most mountainous massifs of the Aïr, the Takolokouzet massif is dominated by a broad tabular relief and appears more as an extensive plateau than a typical mountain massif. This geomorphological

configuration creates relatively open landscapes that are favorable to the movements and visibility of dama gazelles.

The climate is hyper-arid to arid, with annual rainfall ranging from 50 to 200 mm, and temperatures frequently exceeding 45 °C during the hot season.

Vegetation is dominated by xerophytic species such as *Vachellia raddiana*, *Vachellia tortilis*, *Vachellia ehrenbergiana*, *Maerua crassifolia*, and *Balanites aegyptiaca*. These plant communities provide essential forage and shelter for dama gazelles and other Saharan fauna, including dorcas gazelles (*Gazella dorcas*), Barbary sheep (*Ammotragus lervia*), and several species of raptors and carnivores.

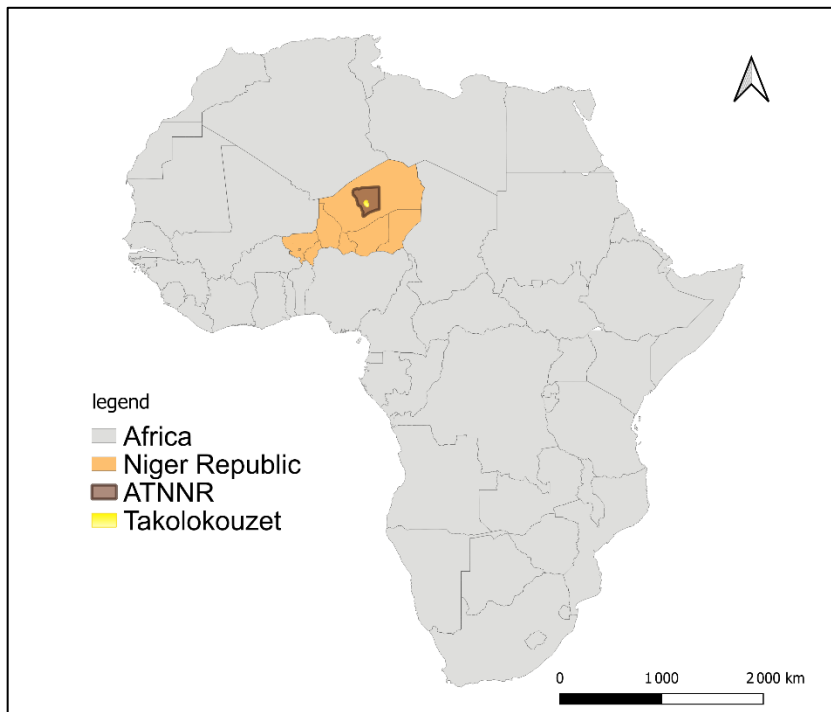


Figure 3.1. Geographic location of the Republic of Niger in Africa, the Air and Ténéré National Nature Reserve (ATNNR) in northern Niger, and the Takolokouzet massif showing the main study area..

3.3 Data Sources and Types

Multiple complementary data sources were used to capture the ecological and socio-environmental dimensions of the study and are summarized in Table 3.1.

Table 3.1. Summary of data types, sources, study periods, and objectives used for the analysis of dama gazelle population structure, distribution, habitat characteristics, and socio-ecological context.

Data type	Source / Tool	Period	Objective
Direct observations	Field missions (Sahara Conservation)	2017–2023	Visual counts, social structure, age/sex ratios
Camera-trap data	Standardized grids following Amin et al. (2014)	2017–2024	Distribution, group composition, activity patterns
Environmental data	MSAVI, WorldClim, Arcgis pro	1980–2023	Spatial variation and vegetation parameters
Socio-economic data	Community interviews and surveys	2022–2023	Perceptions, knowledge threats, resource use practices

3.4 Data Collection Methods

3.4.1 Direct Observations

Field observations were conducted on foot along pre-defined transects across valleys and grazing zones (Figure 3.2). For each sighting, GPS coordinates, group size and composition (males, females, juveniles), behaviour, and environmental context were systematically recorded. The Kilometric Index of Abundance (KIA) was calculated to estimate the number of individuals or groups observed per kilometre surveyed.



Figure 3.2. Field activities in the Takolokouzet massif, including dama gazelle surveys and camera trap deployment, accessed by camel.

3.4.2 Camera-Trap Monitoring

Camera-trap surveys were conducted during two periods: January 2017–March 2020 and May 2022–February 2024. A network of 12 to 31 camera traps (Reconyx, Bushnell, and Browning) was deployed following a standardized 2×2 km grid (Amin et al., 2014). Cameras were placed along wadis, valleys, and wildlife paths, mounted at 40–50 cm above ground (Figure 3.3).

During the first period, cameras were rotated between sites to increase spatial coverage, whereas during the second period they were installed at largely permanent locations. Images were processed using the Camera Trap Analysis Package (CTAP) in R (Amin et al., 2016). Independent detection events were used to calculate the Camera-Trap Rate (CTR) as a relative index of occurrence (O'Brien et al., 2003; Burton et al., 2015).



Figure 3.3 Camera trap deployed on *Vachellia ehrenbergiana* in a valley at the Takolokouzet massif.

3.4.3 *Spatial and Environmental Analyses*

Species occurrence and habitat use were analysed using occupancy models that account for imperfect detection, implemented in the spOccupancy package in R (Doser et al., 2022). Environmental predictors included vegetation productivity (MSAVI), topographic variables, and climatic factors (precipitation and temperature) derived from global remote-sensing datasets. All spatial analyses were conducted in a GIS environment to identify potential habitat and areas of high occurrence probability.

3.4.4 *Community Surveys*

Semi-structured interviews were conducted in 15 villages surrounding the reserve to document local knowledge of the dama gazelle and perceived threats, including grazing pressure, hunting, drought, and mining activities (Figure 3.4). Survey responses were analysed thematically and complemented by quantitative analyses, including logistic regression and salience indices, using SPSS and R.



Figure 3.4. Collection of local ecological knowledge from local communities.

3.4.5 Reference to Detailed Methodologies

Detailed descriptions of field protocols, analytical procedures, and statistical models are provided in the corresponding chapters in this thesis.

3.5 Data Analysis Methods

3.5.1 Abundance and Structure Estimation

Abundance indices (KIA and CTR) were computed for each survey period and compared across sites.

Demographic structure was established based on age and sex classification, and ratios (sex-ratio, age-ratio) were compared with historical data to assess population trends.

3.5.2 Spatial Analyses

Occurrence data were integrated into QGIS and ArcGIS to generate maps of gazelle distribution and intensity of occurrence. Correlation analyses between

occurrence points and environmental variables (vegetation, altitude) were performed to identify preferred habitats.

3.5.3 Statistical Analyses

All statistical analyses were carried out in R.were applied to test the influence of covariates such as camera model, season, and time of day on detection probability. Comparative tests were used to assess spatial and temporal differences in detection rates.

3.5.4 Qualitative Analyses

Interview data were transcribed, coded, and grouped into thematic categories such as perceptions, threats, and practices. A logistic regression analysis was then performed using IBM SPSS Statistics to examine relationships between key variables. This analysis helped identify the consistency between ecological findings and community perspectives, providing valuable insights to guide participatory management and conservation strategies.

3.6 Methodological Integration Across Papers

Each paper of the thesis is grounded in this unified methodological framework, addressing complementary questions as shown in Table 3.2:

Table 3.1.Summary of chapters (research papers), thematic focus, and key methods applied in this study.

Topic	Main theme	Key methods
Topic 1	Status and Social Structure	Direct observations, Cameras trap CTR, KIA, demographic ratios
Topic 2	Spatial and temporal distribution and environmental variables	Camera trap, GIS, MSAVI, spatial modelling
Topic 3	Community perceptions and knowledge	Semi-structured interviews, qualitative coding

Together, these approaches provide a comprehensive and cross-disciplinary perspective on the status and conservation needs of the dama gazelle in the ATNNR.

3.7 Methodological Limitations and Biases

Fieldwork in the desert environment presented several challenges: extreme temperatures, limited accessibility, logistical constraints, and low detection rates due to the rarity of the species.

Potential biases related to camera performance or uneven sampling effort were minimized through standardized protocols, multiple survey repetitions, and strict criteria for data independence. Despite these constraints, the integration of multiple methods and temporal replications strengthens the reliability and robustness of the results.

3.8 Chapter Summary

This chapter outlined the overall methodological framework underpinning the thesis. By combining standardized field protocols, spatial analyses, and community-based approaches, this research provides a holistic and scientifically robust assessment of the current status of the dama gazelle in the Aïr and Ténéré Reserve. The following chapters will present the results derived from these methods and discuss their implications for the conservation of the species and its habitat.

CHAPTER 4



This chapter is a literal copy of the published article

Adopted from Zabeirou, A. R. M., Rabeil, T., Barrios, V., Wachter, T., Newby, J., Mallon, D., ... & Brandlová, K. (2025). Status and social structure of the critically endangered dama gazelle (Nanger dama) in the Aïr & Ténéré National Nature Reserve, Niger. *Global Ecology and Conservation*, e03976.

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A. R. M. Zabeirou: Conceptualization, data curation, formal analysis, visualization, funding acquisition, writing – original draft, writing – review & editing.

T. Rabeil: Conceptualization, writing – review & editing.

V. Barrios: Resources, project administration, funding acquisition, writing – review & editing.

T. Wachter: Validation, writing – review & editing.

J. Newby: Supervision, resources, funding acquisition, writing – review & editing.

D. Mallon: Validation, writing – review & editing.

4 Status and social structure of the critically endangered dama gazelle (*Nanger dama*) in the Aïr & Ténéré National Nature Reserve, Niger

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Abstract

The dama gazelle (*Nanger dama* (Pallas, 1766)) is one of the largest of all gazelles, and also one of the world's most endangered antelopes listed as Critically Endangered on the IUCN Red List. Today, only a few small and highly scattered populations persist, mainly in Niger and Chad. This study provides recent insights into the population status, structure, and phenotypic diversity of dama gazelles in the Aïr & Ténéré National Nature Reserve (ATNNR), focusing in Takolokouzet massif, and based on 15 field missions conducted between 2017 and 2023.

Distribution and relative abundance were assessed using direct observations, indirect signs, and camera traps. The Kilometric Index of Abundance (KIA) averaged 0.058 for direct observations and 0.16 for indirect observations, showing a positive trend over time, particularly for indirect evidence. Camera trap data revealed an overall capture rate (CTR) of 1.59 independent events per 100 trap-days, with increased detection during recent targeted efforts.

Demographic analysis was based on 39 direct sightings (84 individuals) and 200 independent camera trap events (244 individuals). Solitary individuals were primarily adults, representing 83% of camera trap records and less than half of direct sightings. Group sizes were from 2-7 (direct) and 2-4 (camera traps), with an overall mean of 2.95 individuals. Adults were dominant in both datasets, while juveniles and subadults comprised less than 20% of individuals. Calving was observed in two distinct seasonal periods. Phenotypic diversity in the dama gazelle population at ATNNR was marked by traits associated with different coat patterns. The *N. d. dama* phenotype was the most common (73%), with smaller proportions exhibiting distinct variations (18% and 9%). This suggests a phenotypically mixed population, but caution is needed as subspecies differentiation remains debated. The variation may represent a spectrum rather than distinct subspecies.

Our results highlight the importance and fragility of a small, little-known population of dama gazelle in the Takolokouzet massif. The consistently low proportion of young individuals highlights concerns about recruitment. Our findings justify urgent conservation measures focused on securing refuges, reducing disturbance, sustaining monitoring, and protecting breeding females during calving peaks, while ecological drivers will be examined in future work.

Keywords

antelope conservation, camera trap, population structure, phenotypic variation, Africa

4.1 Introduction

The large mammal and bird fauna of the Sahara, along with the bordering sub-desert and Sahelian grasslands, ranks among the most threatened on the planet. Many species across this vast Sahelo-Saharan region of Northern Africa are classified as threatened by the IUCN Red List of Threatened Species (Baillie et al., 2004). Large ungulates are of particular concern, including five species of gazelles, namely dorcas gazelle (*Gazella dorcas*), slender-horned gazelle (*Gazella leptoceros*), Cuvier's gazelle (*Gazella cuvieri*), red-fronted gazelle (*Eudorcas rufifrons*), and dama gazelle (*Nanger dama*), as well as two large antelopes, the addax (*Addax nasomaculatus*) and the scimitar-horned oryx (*Oryx dammah*) (UNEP/CMS, 2006).

Among these, the dama gazelle belongs to the largest gazelles and is one of the three most endangered antelope species globally. It is listed as "Critically Endangered" on the IUCN Red List (IUCN SSC Antelope Specialist Group, 2016), and in Appendix I of both the CITES and CMS conventions, underscoring the urgency of its conservation (CITES, 2021). Historically, dama gazelles were widely distributed across the Sahel, western Sahara, and the lower valleys of the Sahara Mountain ranges, and assigned to three geographically and morphologically distinct subspecies. The mhorraz gazelle (*N. d. mhorraz*) originated from the western part of the Sahara and North Africa, the nominate subspecies (*N. d. dama*) occurred across central parts of the Sahara and Sahel with strongholds in Niger, and the addra gazelle (*N. d. ruficollis*) originated from the eastern part of the Sahara in Chad and Sudan. These subspecies differ in colour, being darker in the west and losing the brown on the back and hindlegs towards the eastern parts of their distribution range. Already in 1833, Edward Bennett, in describing the mhorraz gazelle for science, suggested that "mhorraz, dama, and ruficollis might well be subspecies rather than species provided that more individuals would be identified in the regions between" (Bennet, 1833, p. 13), which was also confirmed by Cano Pérez (1991). Subspecies differentiation within the dama gazelle has been questioned by recent genetic studies, which show no clear correlation between genetic structure and the traditionally recognized subspecies across the Sahara and Sahel. Mitochondrial DNA analyses, in particular, revealed a lack of correspondence between genetic structure and the geographic or subspecies boundaries of the putative *mhorraz*, *dama*, and *ruficollis* populations (Senn et al., 2014a, b). The key finding thus far is the absence of a clear genetic distinction corresponding to geographic regions or subspecies, highlighting the complex nature of subspecies classification in this species. Certainly, during the past century, the dama gazelle populations have suffered a dramatic decline due to habitat

fragmentation, poaching, competition with livestock, prolonged droughts, and regional insecurity (Devillers et al., 2005; Rabeil et al., 2008). As of 2024, Niger and Chad remain the last strongholds for wild dama gazelles (ASG, RZSS, SAF, 2024). Currently, only a maximum of five small, highly fragmented populations remain in the wild, with estimates suggesting fewer than 200 mature individuals, though more conservative assessments place the actual number between 100 and 150. There are four confirmed populations, two in Niger and two in Chad, with another tiny fragment possibly remaining in Mali, though the last confirmed sighting there dates to 2005–2006 (ASG, RZSS, SAF, 2024). In Niger, dama gazelles are legally protected, but their numbers continue to decline. The two remaining populations are now confined to mountain refuges within the Air and Ténéré National Nature Reserve (ATNNR) and the Termit and Tin-Toumma National Nature Reserve (TTNNR). Although mountains are not the gazelle's preferred environment, they have become vital refuges due to historical habitat loss, in contrast to the vast grasslands that were once their primary habitat 50 years ago, as they offer some shelter from human disturbance and poaching. However, conservation efforts are severely hindered by limited financial resources and regional instability, making field monitoring and protection increasingly difficult (Sahara Conservation, 2022).

In the ATNNR, the dama gazelle had not been recorded since 2002, leading to widespread concerns that the species had become locally extinct. It was not until 2014, during a field mission led by Sahara Conservation and funded by UNESCO, that its presence was reconfirmed in the Takolokouzet massif, where a group of eleven individuals was observed (Rabeil, 2014). In 2017, Sahara Conservation deployed camera traps in the area to further investigate and document this little-known and highly threatened population.

In 2022, Sahara Conservation benefited from an IUCN SOS project grant. This funding has been crucial for the conservation of the small population of dama gazelles in the ATNNR, enabling it to support a Protected Area Management Unit (PAMU) of ATNNR in organising monthly patrols of around ten days in 4 × 4 vehicles around the Takolokouzet massif. Additional activities included ecological monitoring of the massif, recruitment of community rangers, and implementation of local development initiatives. These interventions contributed significantly to reducing pressures on wildlife and natural resources (Sahara Conservation, 2022,2023, 2024).

This study provides an insight into the social structure of the dama gazelle population on the Takolokouzet massif in the ATNNR, Niger, covering the period from 2017 to 2023. Specific objectives were:

1. To describe recent relative abundance of the dama gazelle in the ATNNR-

2. To characterize basic demography of the spatially restricted dama gazelle population.
3. To examine morphological appearance (pelage pattern) of the dama gazelle population.

4.2 Methods

4.2.1 Study area

This study was conducted on the Takolokouzet massif (18° – 19°N, 8° – 9°E, Fig. 1), located in the Aïr & Ténéré National Nature Reserve (ATNNR). As one of Africa's largest protected areas, the ATNNR spans approximately 78,000 km². The Takolokouzet massif forms the eastern edge of the Aïr Massif and consists of a vast plateau with an average elevation of 1000 m above sea level (a.s.l.), reaching its highest peak at 1295 m in the west. The massif is geographically contiguous with the Ténéré Desert to the south, north, and east, creating a challenging yet ecologically significant habitat.

According to the Koppen climate classification, the region has a warm desert climate (BWh). Temperatures fluctuate significantly, with average highs reaching 41°C during the hot season of May and June. In contrast, in the coldest months of December and January the temperatures can drop below 9°C (WDI, 2020). Niger's climate is characterized by two primary seasons: a prolonged dry season from October to May and a short rainy season from June to September. Rainfall is highly variable, typically occurring in intense but infrequent events, delivering between 10 and 50 mm per occurrence, with an annual average of approximately 110 mm (CNEDD, 2000). The local Tuareg people recognize four seasonal phases: a cold dry season (November to March), a hot dry season (April to June), a rainy season (July to September), and a transitional season from mid-September to late October (Morel, 1985). This local classification was used in this study to contextualize ecological observations.

The region's landscapes include desert and West Saharan montane xeric woodlands (Olson et al., 2001). The reserve is sparsely vegetated with most of the plants concentrated along temporary watercourses, which support perennial grass and forb communities consisting primarily of *Panicum turgidum* and *Aerva javanica* with an overstorey dominated by *Vachellia spp.* and *Balanites aegyptiaca* (Grettenberger and Newby, 1986). The Takolokouzet massif hosts a diverse range of wildlife, including herbivores, predators, and other species adapted to the harsh desert environment. The region supports key ungulates such as the dorcas gazelle

and Barbary sheep (*Ammotragus lervia*), both of which rely on the scattered vegetation and seasonal water sources. Carnivorous species in the area include Rüppell's fox (*Vulpes rueppellii*), honey badger (*Mellivora capensis*), common genet (*Genetta genetta*), African wolf (*Canis lupaster*), and caracal (*Caracal caracal*), all of which are well-adapted to the arid conditions and fluctuating prey availability. The patas monkey (*Erythrocebus patas*) and other small mammals are also present, contributing to the ecological complexity of the massif (Zabeirou, 2022).

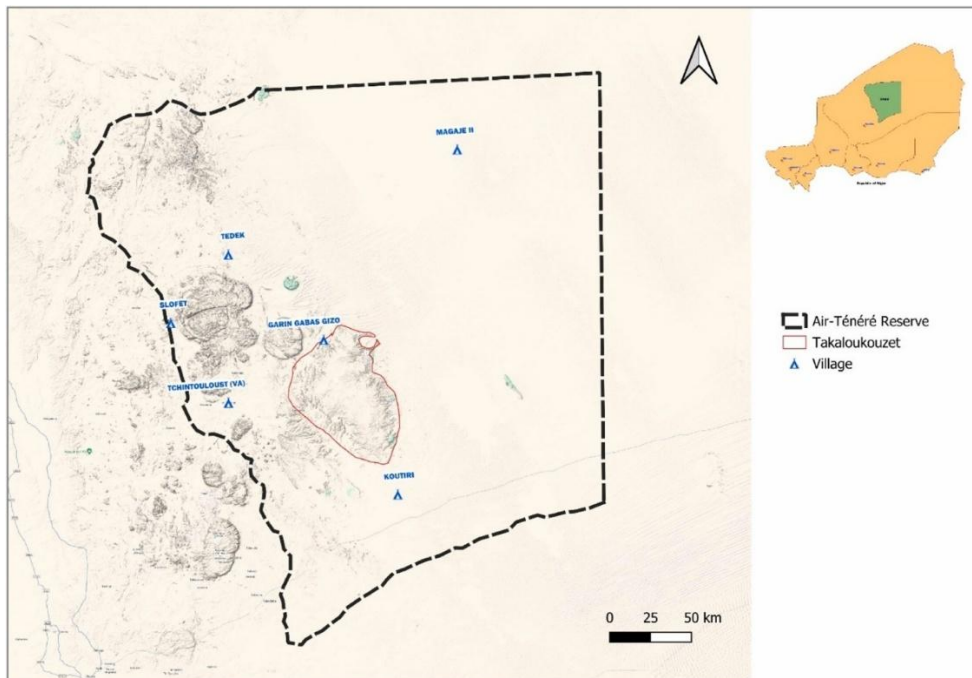


Figure 4.1. Map of the Air & Ténéré National Nature Reserve (ATNNR) and delimited area of the Takolokouzet massif in Niger.

4.2.2 *Data collection*

4.2.2.1 *Direct and indirect observations*

During 15 intermittent field visits to the reserve from January 2017 to November 2023, dama gazelle sightings were documented. The field team was typically composed of 3–7 people accompanied by 2–4 camels. Given the rugged terrain and logistical constraints, we did not conduct a systematic survey of the species but rather collected data opportunistically. Between 2022 and 2024, field efforts significantly increased due to increased funding (Sahara Conservation, 2022, 2023, 2024). Approximately 40 days were dedicated specifically to targeted dama gazelle monitoring (e.g., direct observations and camera trap deployment), while 170 additional days were spent on broader patrols across the reserve, during which incidental data on gazelles were also recorded. Based on team sizes, this represents an estimated total of 120–280 person-days for monitoring and 510–1190 person-days for patrols, amounting to a combined effort of 630–1470 person-days during this period.

For each sighting, details such as group size, composition by sex and age were collected. Additionally, indirect observations of dama gazelle tracks and faeces in previously unrecorded areas were included. Dama gazelle tracks are nearly twice as large as the tracks of other gazelles and livestock and are shaped differently from barbary sheep tracks (Grettenberger and Newby, 1986). All this information was entered into a CyberTracker sequence (www.Cybertracker.org) as described in detail by Wachter et al. (2007, 2008, 2009).

4.2.2.2 *Camera trapping*

Between January 2017 and March 2020, a total of 13 camera traps were strategically placed according to a standardized protocol in a 2 × 2 km grid system, following the methodology outlined by Davey et al. (2014). These cameras were positioned in valleys where encounters with dama gazelles were more likely, based on indirect sightings. The camera traps comprised 12 Reconyx and 1 Bushnell models, with differing night regime types: no-glow IR flash for Reconyx and white flash for Bushnell. All cameras were operational round the clock with a Latency Period between triggers, capturing one photo per trigger. They also recorded key data such as date, time, and were configured for high image quality and camera sensitivity.

The installation of camera traps was conducted over five consecutive surveys (Fig. 2). Initially, a set of 13 cameras was deployed in the Takolokouzet massif from 06/01/2017–07/02/2018 (Grid 1). After one year of operation, 12 cameras were relocated to a different site following the same established protocol from 02/2018–10/2018 (Grid 2). Subsequently, this process was repeated twice after 6-month intervals from 10/2018–02/2019 (Grid 3) and 02/2019–09/2019 (Grid 4). The final phase from 09/2019–03/2020 (Grid 5) involved moving the cameras to areas where a higher number of dama gazelles had been photographed. Camera traps deployment covered all four seasons according to Morel (1985) (Table 1). The selection of these grid units was based on the likelihood of encountering gazelles, determined through prior sightings and habitat assessments, rather than being entirely opportunistic.

Table 4.1. Camera trap deployment according to the seasons: Cold Dry (CD), Hot Dry (HD), Rainy (R), and Transitional (T).

Deployment/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Season	CD	CD	HD	HD	HD	HD	R	R	T	T	CD	CD
Grid 1 (2017)												
Grid 2 (2018)												
Grid 3 (2018-19)												
Grid 4 (2019)												
Grid 5 (2019-20)												

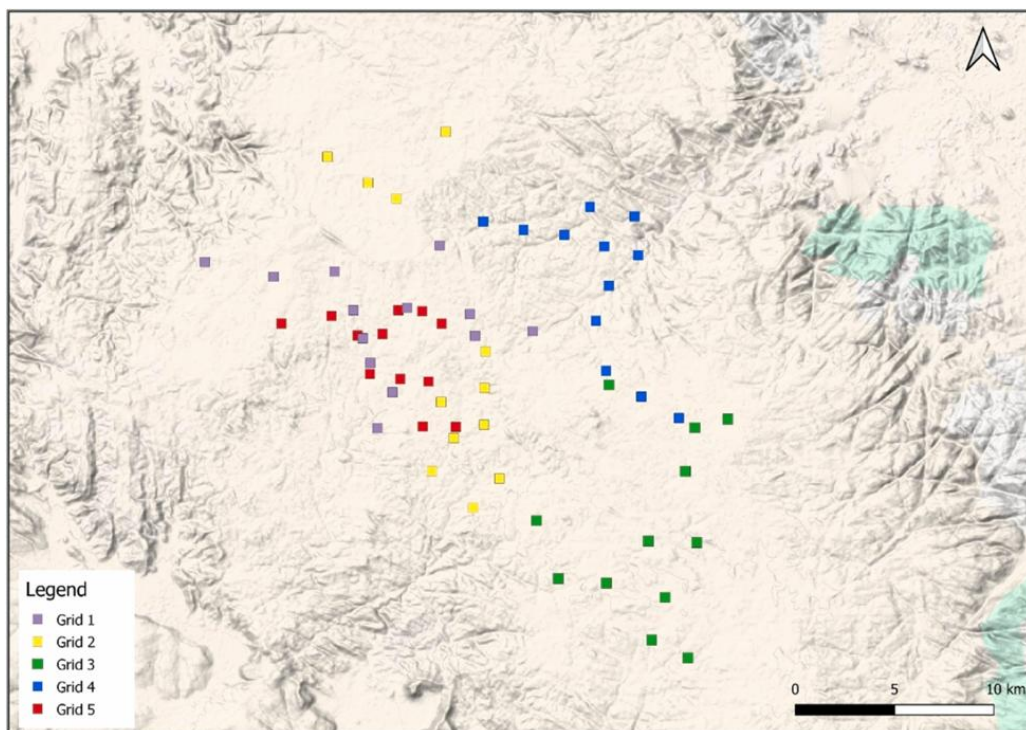


Figure 4.2 Deployment of the camera traps in 5 consecutive grids in the Takolokouzet massif, Niger

4.2.3 Data analyses

4.2.3.1 *Dama gazelle* relative abundance

Both direct visual observations and camera trap records were mapped using Geographic Information Systems (GIS) to assess the distribution and relative abundance of dama gazelles.

The Kilometric Index of Abundance (KIA) (Buckland et al., 2001) was used to calculate the relative abundance of gazelles recorded through both direct sightings and indirect detections by the field team during 15 field trips. The overall KIA for both direct and indirect observations was calculated using all sightings from all the walking field trips. Additionally, the mean, minimum, and maximum KIA values were determined separately for direct and indirect sightings, based on the number of field trips during which each type of sighting was recorded.

To estimate relative abundance from camera trap data, the images were sorted into independent events with a minimum interval between the events captured on the same CT set to 30 min. The Camera Trapping Rate (CTR) (O'Brien et al., 2003) was

calculated as the number of independent images (events) containing at least one dama gazelle per 100 camera-trapping days. The overall CTR was determined using all camera trap records from the study period and calculated separately for each grid.

4.2.3.2 Social structure and demographic parameters

Direct observations and camera trap data were analysed independently to describe the social structure and basic demographic parameters of the present dama gazelle population.

For direct observations, sex was assigned in the field from sexual characteristics, neck thickness, and the size/shape of the horns, which are very distinct in adults. For CT photos, the same diagnostic traits were applied to images when angles and resolution permitted. Across both datasets, age class was determined using horn development, facial mask patterning, and overall body size. For CT photos, these traits were explicitly compared against reference photo sets of known-age individuals developed by the Sahara Conservation project in Chad and by Cano's thesis (Wacher, 2023, unpublished data - see Supplementary material; Cano Pérez, 1991).

Individuals up to three months of age were considered calves, three months up to one year were considered juveniles, and one to two years of age were considered subadults. All others were considered adults, except for animals of an undetermined age group categorized as unknown (UNK).

Group size and structure were described with solitary individuals analysed separately and a mean group size calculated for groups of two and more individuals. Sex ratio was determined for all observations and for adults separately as the number of males per female (M: F). Age structure was determined based on horn development, which was used to assign individuals to specific age groups. Seasonal distribution of all three classes of young individuals was analysed using a goodness-of-fit test using the camera trap data records and described for the few observations recorded directly. A raw breeding rate was calculated as a ratio of calves and juveniles per adult female.

4.2.3.3 Individual identification

The camera trap images were carefully inspected by eye to identify individual animals. Besides age and sex category, the pelage pattern, shape and size of horns and spatial occurrence were used to distinguish different individual dama within each grid. The number of individuals can therefore be considered as a minimum

number of animals to be alive during the respective camera trap deployment period. The number of individually identified animals was then related to the overall number of images within the respective grid.

4.2.3.4 Colour pattern examination

Individually identified animals were classified into three categories based on the colour and pattern of their coat. We observed notable variations in coat coloration between individuals, including reduced brown patterns similar to those found in eastern populations (e.g., in Chad), and in some cases, darker coats resembling those of the mhorr gazelle. To explore this variability, we compared the observed phenotypes with known morphological characteristics to assess the frequency of these variations within the ATNNR population.

4.3 Results

4.3.1 Dama gazelle relative abundance

A total of 149 observations of dama gazelles, comprising 39 direct sightings and 110 indirect signs, were recorded during 15 field trips over the study period covering the total transect length of 1052 km. The mean duration of the field trip was 6 days with the mean distance covered 70.1 ± 4.6 km (range 40–91 km, $n = 15$).

The overall KIA was 0.205 sightings per km, with an average KIA for direct sightings 0.058 ± 0.017 (range 0.000–0.200, $n = 15$) and for indirect sightings 0.149 ± 0.025 (range 0.044–0.389, $n = 15$).

A total of 1986 original images of the dama gazelle were captured from January 2017 to March 2020 over five deployment periods for a total of 200 events. The resulting overall CTR was 1.54 detections per 100 days mean CTR 1.43 (Table 4.2).

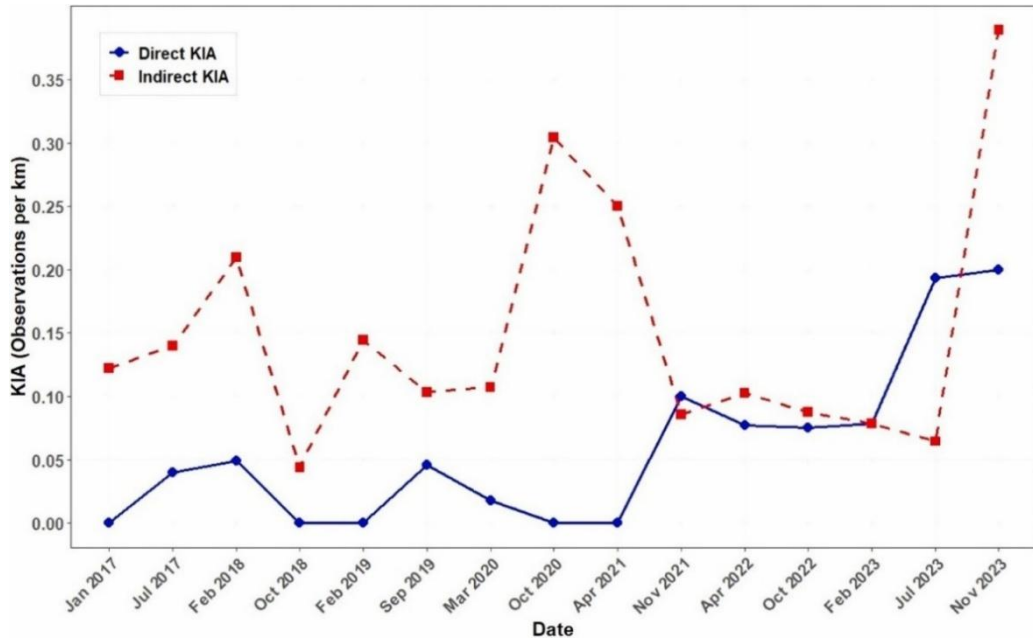


Figure 4.3 Direct and indirect Kilometric Index of Abundance (KIA) for dama gazelle observations on the Takolokouzet massif, Niger.

Table 4.2 Camera trap deployment and dama gazelle (*Nanger dama*, DG) capture information from five camera trapping periods on the Takolokouzet massif. Data include total camera trap days, the number of active camera trap stations (CT) that detected dama gazelles, the number of images and independent detection events, and the calculated Camera Trapping Rate (CTR) expressed as events per 100 trap-days.

	Deployment Camera	Number of CT	Number of Number	of CTR/100		
	trap days	(DG out of total)	Images DG	Events DG	days	
Grid 1	Jan 2017 – Feb 2018	4277	10 of 13	500	54	1.26
Grid 2	Feb – Oct 2018	2836	10 of 12	898	68	2.40
Grid 3	Oct 2018 – Feb 2019	1227	1 of 12	4	1	0.08
Grid 4	Feb- Sept 2019	2438	4 of 12	62	10	0.41
Grid 5	Sept 2019- Mar 2020	2208	9 of 12	522	67	3.03

Social structure and demographic parameters

Group size and composition

A total of 1986 camera trap images and 39 direct visual observations were analysed to assess the group size structure of the dama gazelle population on the Takolokouzet massif.

The data revealed a clear predominance of small groupings. Solitary individuals were the most frequently recorded group size, accounting for 83 % of detections in camera trap images and 41 % of direct observations. Pairs were the next most frequent configuration, representing 7 % of camera trap detections and 33 % of direct observations. Groups of three were rarely captured on camera traps (1 %) but were recorded in 10 % of direct sightings. Larger groups were not detected at all by camera traps, whereas direct observations recorded small proportions of groups of four (5 %), five (8 %), and a single group of seven individuals (3 %). The mean group size was 2.96 ± 1.40 (range 2–7, $n = 23$) for direct sightings and 2.94 ± 0.52 individuals (range 2–4, $n = 34$) for camera traps (Figure 4.4).

In 200 independent events on CT, 244 dama gazelles were recorded. The majority of events (83 %, $n = 166$) recorded solitary individuals. Solitary individuals were mostly adults (86 %, $n = 142$); the rest were subadult individuals ($n = 11$), yearlings ($n = 7$), calves ($n = 3$), and individuals of unknown age ($n = 3$). Males ($n = 77$) formed 54 % of solitary adults.

The groups larger than one individual were considered herds and recorded on 17 % of the events. The mean herd size was 2.94 ± 0.52 individuals (range 2–4, $n = 34$). Adult animals were present in all herds but two, where UNK individuals were present. Males were present in 68 % of herds ($n = 23$). Fifty-three per cent of herds ($n = 18$) contained young (non-adult) individuals, which were always accompanied by at least one female. Twenty-four per cent of herds ($n = 8$) contained male, female and young.

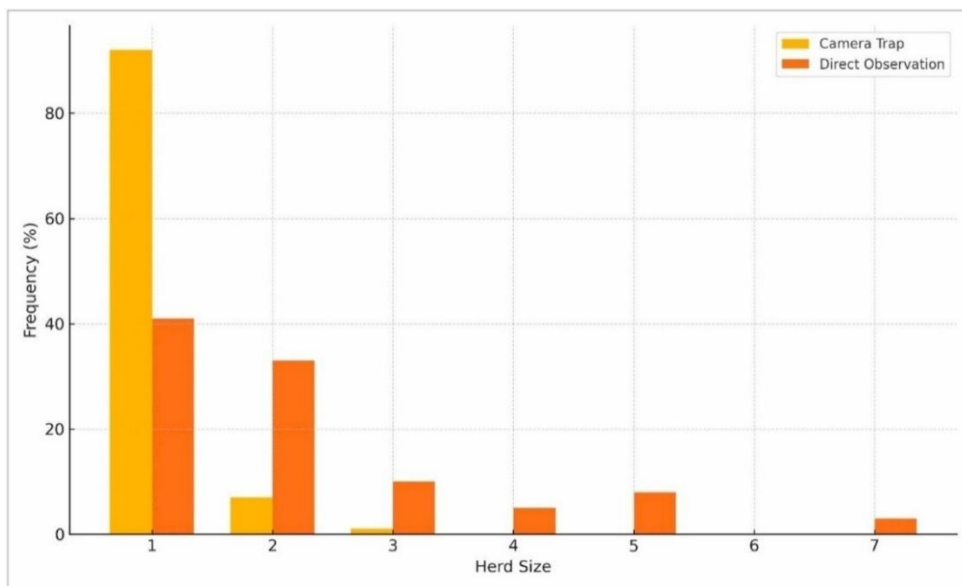


Figure 4.4. Frequency distribution of observed herd sizes of dama gazelles (*Nanger dama*) recorded through camera traps and direct observations on the Takolokouzet massif (2017–2023).

4.3.2 Sex ratio

The adult sex ratio based on the direct observation data was 0.66 male:1 female. The overall sex ratio based on the camera trap data was 1.16 male:1 female, the adult sex ratio was slightly more male-dominated, 1.18:1.

4.3.3 Age structure

Out of the total 84 dama gazelles observed directly, the age group was assigned to 48 % (n = 40). Out of these, 35 (83 %) were adults. Young individuals were represented by two calves and three juveniles. The remaining 44 records were animals of undetermined age.

Out of the total 244 dama gazelles recorded by camera traps, the age group was assigned to 97 % (n = 237). Out of these, 197 (83 %) were adults. Out of the 40 records of young, 10 (4 %) were calves up to three months, 17 (7 %) were juveniles from 3 months to one year and 13 (5 %) were subadults. The remaining seven records contained individuals of undetermined age. The detailed age structure within three consecutive years is shown in Table 4.3.

Table 4.3. Number of detections of different age and sex classes recorded through direct observations and by each of the camera trap (CT) grids.

	Adult total	Adult male	Adult female	Subadult	Juvenile	Calf
Grid 1	45(45%)	35(35%)	10(10%)	5(5%)	3(3%)	1(1%)
Grid 2	66(43%)	28(19%)	38(25%)	5(3%)	9(6%)	6(4%)
Grid 3	1(100%)	1(100%)	0(0%)	0(0%)	0(0%)	0(0%)
Grid 4	9(45%)	3(15%)	6(30%)	1(5%)	1(5%)	0(0%)
Grid 5	76(48%)	41(26%)	35(22%)	0(0%)	2(1%)	5(3%)
CT Total	197(45%)	108(25%)	89(20%)	11(3%)	15(4%)	13(3%)
Direct Total	35(46%)	14(19%)	21(28%)	0(0%)	3(4%)	2(3%)

4.3.4 Breeding rate and seasonality

A raw breeding rate calculated as a ratio of calves and juveniles per adult female was 24 % for the direct observations and 31 % using the camera trap data.

The two calves observed directly were spotted in February and July, the three juveniles in April, February and November. According to the camera trap data, calves were present in two clearly distinguished periods of the year, and the records of other categories of non-adult individuals were also seasonally distributed. The monthly distribution of pooled young differed significantly from uniformity ($\chi^2=29.0$, $df=11$, $p = 0.0023$, $n = 39$), and the proportions of calves, juveniles, and subadults varied significantly by month ($\chi^2=28.7$, $df=16$, $p = 0.026$, $n = 39$). Seasonal trends in demographic structure, highlighting peak occurrences in the early months of the year (January–March) and a secondary rise in September–October, are shown in Figure 4.5.

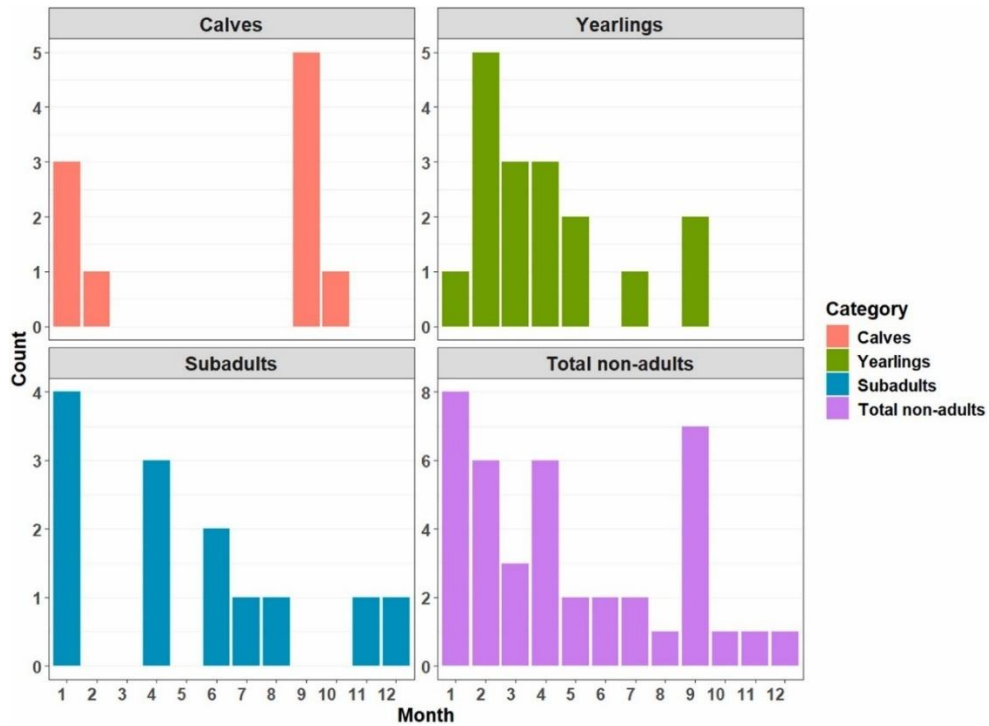


Figure 4.5 Monthly distribution of observations for non-adult individuals across age classes: Calves, Yearlings, and Subadults, with a combined category labelled Total non-adults.

4.3.5 Identification of individuals

The number of individually identified animals ranged from 1 to 17 per grid, with a mean individual identification rate of 48 % of all individuals (range 20 – 100 %, Table 4.4) displayed restricted brown pigmentation limited to the dorsal region, a characteristic feature of addra gazelle. This phenotype appeared to be largely confined to adult males.

Table 4.4. The minimum number of individually identified dama gazelles in all grids. ID/total shows the ratio of identified individuals out of the total number of records.

	Adult male	Adult female	Young male	Young female	Calf	Total	N° of Events	ID/total
Grid 1	3	5	1	1	1	11	54	0.20
Grid 2	3	5	1	2	5	16	68	0.24
Grid 3	1	0	0	0	0	1	1	1
Grid 4	2	3	0	0	2	7	10	0.70
Grid 5	6	8	0	0	3	17	67	0.25

4.3.6 Colour patterns

Photographic analysis of dama gazelle morphology (coat coloration) revealed the presence of three distinct phenotypes. At least six individuals (18 %) exhibited darker coats with traits resembling the mhorra gazelle. Twenty-four individuals (73 %) showed the typical coloration of the nominate subspecies, which was recorded across all surveyed localities. Additionally, at least three individuals (9 %) (Figure 4.6)

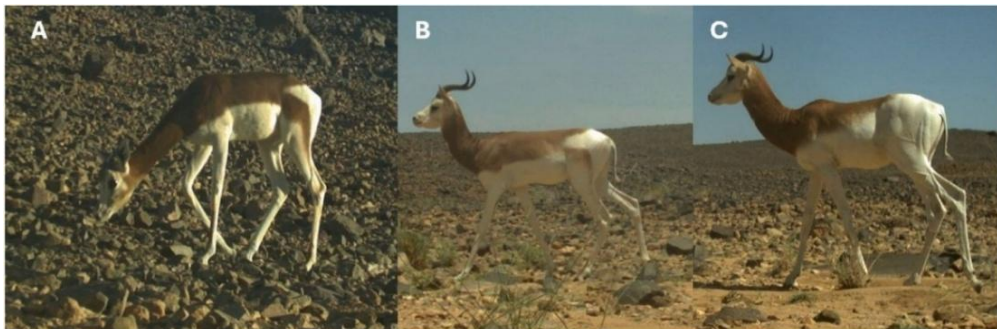


Fig. 4.6. Phenotypic variation in dama gazelles (*Nanger dama*) observed on the Takolokouzet massif based on camera trap images. A: Individual showing darker coat and extensive pigmentation; B: Individual with intermediate coloration; C: Adult male with restricted pigmentation confined to the dorsal area.

Discussion

4.3.7 *Dama gazelle relative abundance*

Our findings confirmed that the dama gazelle population in the ATNNR has undergone a pronounced contraction in both range and numbers. Historical records from the late 1970s estimated 150–250 individuals across diverse landscapes within the reserve, including the Tamgak Massif and southern sub-desert steppe (Grettenberger and Newby, 1986). In contrast, recent monitoring from 2014 to 2023 recorded the species exclusively on the Takolokouzet massif, with a population estimate of just 20–30 individuals (ASG, RZSS, SAF, 2024).

Alongside this decline in range, a marked reduction in group size is evident. Average group size decreased from 2.05 individuals in the 1980s (Newby, unpublished data) to 1.58 individuals in the present study. Solitary individuals and pairs now dominate group structures, with very few observations of larger herds. This pattern mirrors findings from other arid regions, such as the Western Sahara (Cuzin, 1996) and Chad (Newby, 1978; Wachter et al., in prep.), where small group sizes prevail under low-density or fragmented conditions. Although larger herds can still occur under optimal conditions, as illustrated by a recent sighting of 30 individuals in Chad (Dias, 2021), such events are rare.

The prevalence of solitary individuals, particularly adult males, is consistent with known behavioural ecology of the species outside the breeding season (Estes, 1991). However, the scarcity of mixed-age or family groups may indicate demographic stressors, including low reproductive output, high juvenile mortality, or environmental pressures such as habitat degradation and disturbance.

Despite the overall contraction in range, the recent survey data suggest signs of localized persistence. The KIA for direct observations remained low during initial monitoring years but began to rise from 2021, reaching 0.20 sightings/km by late 2023. Indirect KIA values, based on tracks and faeces, were consistently higher and peaked at 0.39 sightings/km. These increases coincided with expanded monitoring efforts, including 40 days of focused dama gazelle surveys and 170 days of general patrols between 2022 and 2024 (SCF, 2022, 2023, 2024), and therefore could not be interpreted as an indicator of genuine population increase.

The occasional higher KIA for direct observations may result from the difficulty in distinguishing individual animals from overlapping footprints, especially in areas of repeated use. In contrast, direct sightings when they occur offer more accurate counts and are less prone to such ambiguity (Wilson and Delahay, 2001; Durant et al., 2011).

Camera trap data further support these trends. Spatial variation in CTR revealed that Grids 5, 2, and 1 had the highest CTRs (3.05, 2.40, and 1.26, respectively), indicating that these areas currently function as refugia. In contrast, Grids 3 and 4 showed markedly lower CTRs, likely consistent with poorer habitat quality and/or higher disturbance. To maximise conservation effectiveness, cameras in Grid 5 were purposefully concentrated at high-use micro-sites identified from the elevated CTRs in Grids 1 and 2 and the movement corridors connecting them, thereby prioritising detections of breeding females, young, and mixed groups while maintaining sentinel coverage in lower- CTR areas. This adaptive placement both reflects and reinforces management priorities: secure the Grid 5 core (limit disturbance, enforce access controls), buffer and connect Grids 5, 1, and 2 (targeted patrols at passes/saddles; seasonal quiet zones during Jan–Mar and Sep–Oct), and reduce pressures in Grids 3 and 4 (restrict off-track motorbikes, curb artisanal mining, pilot habitat restoration). Overall, the CTR mosaic highlights a fragmented distribution of favourable habitat within the massif and points to clear, spatially targeted actions for dama gazelle conservation.

4.3.8 Social structure and demographic parameters

Our findings depict a dama gazelle population in the ATNNR that is facing considerable demographic and social challenges. Solitary individuals represented 41 % of direct sightings and striking 83 % of camera trap detections. However, the high proportion of solitary records in camera traps may partially reflect limitations inherent to this method, whereby only one individual in a group is captured by the camera rather than a true isolation. Similar underestimations of group size in camera trap data have been noted in other ungulate species (Brandlova et al., 2018; Gueye et al., 2021). When gazelles were seen in groups, these were generally small, typically comprising 2–3 individuals and rarely exceeding five. Such reduced group sizes and limited social diversity are consistent with patterns observed in declining or fragmented populations. They likely reflect the effects of low abundance and population density on social cohesion and structure (Newby, 1982; Mallon and Kingswood, 2001; IUCN SSC ASG, 2016). In small, isolated populations, these social constraints are compounded by genetic and demographic processes, including loss of genetic diversity and inbreeding depression, sex-ratio skew, and Allee effects, which together elevate extinction risk (Brook et al., 2002; Lande, 1993). Increased susceptibility to demographic and environmental stochasticity further destabilizes recruitment and accelerates decline, particularly where disturbance constrains access to high-quality habitat.

Historically, dama gazelle grouping patterns looked very different. In the 1950s, observers reported large groups of dama gazelles in the ATNNR, some as large as 500 individuals (Kingdon, 1997). In the late 1970s through the early 1990s, researchers recorded a variety of social structures, including harems (one male with several females), female groups with young, and mixed-sex groups, with an average group size of just over two (Grettenberger and Newby, 1986). Harem groups were once a common feature of dama gazelle society, but those structures have likely broken down under the pressure of increasing human activity and habitat loss (Kingdon, 1997).

In our current study, groups with both adults and young were rare (24 %), similar to what was observed by Newby and Grettenberger (1986). The sex ratio of dama gazelles in ATNNR appears to have remained relatively stable over time. In the 1990s, Poilecot (1996) reported a slight predominance of females, with approximately 0.89 males per female. Similar figures were observed in earlier datasets which reported sex ratios of 0.87 (Newby 1979–1990), and 0.76 males per female (Grettenberger and Newby, 1986).

Today, the picture is more nuanced. Camera trap data collected between 2017 and 2020 suggest a male-biased adult sex ratio, with approximately 1.18 males per female. In contrast, direct field observations indicate a female-biased ratio of 0.66 males per female, and our individual identification (ID) dataset, based on age and sex classification from photographs, shows an intermediate figure of 0.71 males per female.

This slight asymmetry in favour of females is typical of gazelle populations and reflects expected demographic patterns influenced by behaviour, social structure, and sex-specific survival (Hvidberg-Hansen and de Vos, 1971; Grettenberger and Newby, 1986).

These discrepancies can be partly explained by sex-specific space use. In low-density populations, adult males typically range across larger territories, which increases their likelihood of being captured on camera traps. Females, especially those with calves, often remain in smaller, more predictable areas, making them more likely to be recorded during direct observations (Newby and Grettenberger, 1986).

In such areas, camera traps would likely produce better estimates of females than males, as males travel among multiple areas occupied by females (Bleich et al., 1997; Taylor et al., 2022).

However, the observed age structure is concerning. Most of the gazelles recorded were adults, and very few young individuals were documented. This may

indicate low birth rates, high juvenile mortality, or both. Either scenario may compromise the long-term viability of the population.

Reproductive patterns documented in various regions of the Sahel and Sahara indicate that dama gazelle births tend to follow a seasonal cycle, often associated with rainfall and forage availability. In Niger, births occur mainly between October and March (Dragesco-Joff'e, 1993), while in Western Sahara they are concentrated between February and March (Cuzin, 1996). In the Aïr region, births typically follow the rainy season (Dekeyser, 1950). In the captive population in the Ouadi Rime-Ouadi Achim Reserve in Chad, the fact that births occur over 10 months of the year suggests an opportunistic reproductive pattern. Although two birth peaks are observed, similar to other populations, the overall distribution of births indicates a more flexible reproductive strategy (Wacher and Omar, pers. comm). Our data from the ATNNR partially align with seasonal trends. Calves were recorded in February and July, while juveniles were recorded in February, April, and November. Camera trap records revealed two distinct peaks in juvenile presence: a primary peak from January to March and a secondary increase around September and October. These patterns suggest that reproductive activity is temporally structured and likely influenced by environmental conditions.

4.3.9 Identification of individuals

Our results indicate that the individual identification rate for dama gazelles falls within the typical range reported in camera trap studies (Foster and Harmsen, 2012). However, in this species, the process is particularly challenging due to its relatively uniform coat and the absence of consistent, individually distinctive markings. Many images, particularly those taken at night or in low-light conditions, were unsuitable for reliable identification, and individuals lacking clear distinguishing features were therefore excluded. Consequently, the number of identified individuals likely represents only the minimum present and should be interpreted with caution (Choo et al., 2020).

4.3.10 Phenotypic variation and taxonomic considerations

While traditionally distinguished into *N. d. mhorh*, *N. d. dama*, and *N. d. ruficollis*, these morphological differences may appear to reflect gradual geographic variation rather than discrete taxonomic boundaries (Mungall, 2018; Cano Perez, 1991). This interpretation is supported by mitochondrial DNA analyses, which have shown a lack of clear genetic structure corresponding to these subspecies,

suggesting historical gene flow across the species' former continuous range (Senn et al., 2014; 2016). The observed phenotypic variation in dama gazelles in the ATNNR, particularly in pelage coloration, underscores the complexity of the putative subspecies classification.

The current pattern of variation may be best understood as part of a cline. In natural settings, particularly in transition zones such as central Niger, morphological traits likely represent intergradation between eastern and western lineages (Groves and Grubb., 2011; Mungall, pers. comm.). These findings highlight the need for an integrative taxonomic framework that combines morphological, genetic, and ecological data to inform conservation planning, especially amid ongoing habitat fragmentation and small population sizes (AAZ, ASG, RZSS2019). Additionally, it would be valuable to investigate potential effects of age and season on coat patterns within individuals for example, whether haunch stripes fade with age, perhaps more in males than in females, or under particular seasonal conditions.

4.3.11 Conservation implications

Overall, our results demonstrate small group sizes, a predominance of solitary detections, and restricted range, indicating a population at high risk and operating near thresholds where genetic, demographic, and stochastic processes may dominate dynamics. This underscores the urgency of targeted conservation measures.

In practical terms, securing the core refuges of Grid 5 and the connecting corridors to Grids 1 and 2 should be a priority through reinforced patrolling, reduced disturbance, and stricter access regulation. Regular monitoring with camera traps and field missions is essential to track trends and emerging threats. These measures directly build on the interventions already initiated under the SOS project, including intensified patrols and community outreach, particularly in areas with the highest CTR.

In addition, assessing the feasibility of establishing a captive safeguard population replicating the ongoing initiative in Chad would strengthen genetic and demographic resilience. Finally, sustained engagement with local communities remains fundamental to mitigating pressures and aligning conservation outcomes with livelihoods. Collectively, these actions aim to stabilize recruitment, preserve remaining social structures, and safeguard the ecological viability of the ATNNR population within a broader Sahelo-Saharan conservation strategy.

4.4 Conclusion

This study provides the first detailed population-level assessment of the critically endangered dama gazelle in the ATNNR, Niger, based on data collected between 2017 and 2023. Our findings reveal a small, spatially restricted, and socially fragmented population, with solitary individuals predominating and young cohorts underrepresented. Photographic analyses further indicate substantial phenotypic variation in coat coloration, consistent with a clinal gradient across subspecies, which highlights the need for integrated genetic and morphological studies.

Despite logistical and methodological constraints, including opportunistic sampling, uneven survey effort, and limited ability to identify individuals or age classes, the study establishes a critical baseline for monitoring this population. These results underscore the precarious conservation status of the dama gazelle in the ATNNR and its importance within the broader Sahelo-Saharan context. Ensuring the survival of this population will require sustained research, long-term monitoring, and effective implementation of the Roadmap for the Conservation of the Dama Gazelle in ATNNR 2024–2033.

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CHAPTER 5

5 Sharing the space with dama gazelle: Spatiotemporal niche partitioning of desert ungulates in a hyper-arid mountain refuge

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Abstract

Desert ungulate communities persist under extreme climatic variability and increasing human pressures, yet mechanisms enabling coexistence in spatially restricted refugia remain poorly understood. We investigated spatiotemporal niche partitioning and occupancy drivers of three sympatric Sahelo-Saharan ungulates dama gazelle (*Nanger dama*), dorcas gazelle (*Gazella dorcas*), and Barbary sheep (*Ammotragus lervia*) in the Takolokouzet Massif of the Aïr & Ténéré National Nature Reserve (Niger). Using seven years of camera-trap data (2017–2020; 2022–2024), we quantified relative abundance, diel activity, temporal overlap, and spatial occupancy with single-species models.

The three species showed distinct yet complementary activity patterns: the dama gazelle was predominantly nocturnal, the dorcas gazelle diurnal, and the Barbary sheep cathemeral. Despite high spatial overlap (Bhattacharyya coefficient > 0.7), these ungulates exhibited species-specific responses to climatic and anthropogenic drivers. Dama gazelle occupancy was lower in hotter sites and varied in relation to livestock and human tracks, indicating its sensitivity to disturbance. Dorcas gazelle occupancy increased with higher precipitation and positively associated with feral donkey and humans. Barbary sheep was more common at sites with lower daily thermal variation and closer to human tracks and showed negative association with goats during the first study period.

We discuss how coexistence of threatened desert ungulates in this hyper-arid ecosystem is maintained through niche partitioning across multiple axes, including temporal segregation, spatial thermal refugia and behavioural plasticity in response to humans and livestock/ other co-occurring species.

Keywords

Sahelo-Saharan antelope; Desert ungulate; Arid environments; Occupancy; Spatiotemporal activity; Niche segregation; Wildlife Conservation.

5.1 Introduction

Desert ecosystems are characterised by extreme aridity, low and highly variable primary productivity, and pronounced temporal unpredictability in resource availability (Noy-Meir, 1973). Large herbivores that inhabit these systems exhibit specialised morphological, physiological, and behavioural adaptations that allow them to exist near the limits of physiological tolerance. However, operating close to these limits renders desert ungulates particularly vulnerable to rapid climatic shifts and intensifying anthropogenic pressures, as their functional traits and adaptive capacity offer limited buffering against additional stressors (Vale & Brito, 2015).

Within multi-ungulate communities, species coexistence is typically maintained through niche partitioning, whereby sympatric species segregate along spatial, temporal, or trophic axes in relation to their functional traits and the degree of environmental heterogeneity (e.g. Boyer et al., 2013). In arid ecosystems, where resources are ephemeral and sparsely distributed, such trait-mediated partitioning is especially pronounced. Body size, particularly, determines various aspects of a species' behaviour, including foraging strategy, energetic requirements, thermoregulation, movement capacity, and sensitivity to predation. These factors shape how species use the landscapes and exploit ephemeral resources. Fine-scale decisions about habitat use and activity timing are therefore central to coexistence in deserts, where even subtle behavioural adjustments can determine survival.

However, these natural coexistence mechanisms do not operate in isolation. Across drylands globally, expanding human activities increasingly modifies both risk landscapes and resource distribution. Large herbivores often respond to human presence as a source of predation risk or disturbance, leading to shifts in movement, activity timing, and space use, frequently accompanied by elevated stress and reduced fitness (Ciuti et al., 2012; Gaynor et al., 2025). Meanwhile, responses to human-associated livestock are more context-dependent: social ungulates may habituate to pastoral activity or even associate with livestock as an indirect anti-predator strategy (Hejzmanová et al., 2024), thereby altering natural risk–reward trade-offs. Consequently, coexistence of wildlife and people in arid environments with limited resources increasingly reflect the interaction between ecological constraints (e.g. resource scarcity driven by climatic variability) and anthropogenic pressures (e.g., population growth and land use change (Gayo 2025)).

These dynamics are particularly evident Sahelo-Saharan ungulates, among the most specialised and threatened desert herbivores worldwide (Newby et al., 2016). The dama gazelle (*Nanger dama*), dorcas gazelle (*Gazella dorcas*), and Barbary sheep

(*Ammotragus lervia*) historically occupied vast Saharan and Sahelian landscapes but have suffered severe population declines due to overhunting, habitat degradation, and range fragmentation, and are now confined to isolated refugia (Newby et al., 2016; IUCN, 2020). One of the last strongholds where all three species continue to coexist is the Takolokouzet Massif, in the Aïr & Ténéré National Nature Reserve (ATNNR) in Niger. The steep, rocky terrain of this rugged mountain massif limits vehicle access and intensive grazing, while the surrounding lowlands are increasingly affected by the expansion of pastoralism and mining activities (Rabeil, 2014; Afane and Gagnol, 2020; Sahara Conservation, 2023).

This setting offers a rare opportunity to examine coexistence mechanisms under extreme spatial and climatic constraints. In Sahelo-Saharan systems, large-scale nomadic or seasonal movements typically mitigate resource scarcity and interspecific competition (Dragesco-Joffé, 1993; Newby et al., 2016). In Takolokouzet, however, such movements are largely restricted, creating a semi-closed system in which sympatric species must partition space, resources, and time within a limited landscape. Although these ungulates broadly overlap in diet (Kingdon, 1997), differences in body size imply contrasting sensitivities to predation risk and resource limitation, with smaller species expected to be more strongly regulated by top-down processes and larger species by bottom-up constraints (Hopcraft et al., 2010). How these trait-based differences translate into spatiotemporal segregation under restricted space remains poorly explored.

The dama gazelle, classified as Critically Endangered due to its extremely low population size (Zabeirou et al. 2025), can be additionally recognised as an umbrella species for Sahelo-Saharan antelopes and associated desert fauna. Its behavioural responses and space-use strategies may therefore provide early warning signals of broader ecosystem change. Despite its high conservation significance, the mechanisms that enable dama gazelle and sympatric ungulates to coexist within increasingly human-modified desert landscapes remain insufficiently understood.

Here, we use long-term, camera-trap data, collected over seven years, to investigate relative abundance, spatiotemporal activity patterns, and spatial overlap of dama gazelle, dorcas gazelle, and Barbary sheep in the Takolokouzet Massif. Specifically, we examine how species-specific functional traits mediate niche partitioning and quantify spatiotemporal responses to abiotic conditions, African wolf (*Canis lupaster*) presence as the dominant local predator, domestic and feral livestock, and human activity. By comparing two distinct survey periods, we further assess temporal shifts in behaviour and space use. Through this integrative approach, we aim to identify the mechanisms that shape the coexistence of large

herbivores in extreme environments, with implications extending beyond this exceptional Sahelo-Saharan refuge.

5.2 Methods

5.2.1 Study area

Our study was conducted on the Takolokouzet massif (18°–19°N, 8°–9°E) within the Aïr & Ténéré National Nature Reserve (ATNNR) in northern Niger (Figure 5.1), a vast Sahelo-Saharan protected area covering ~78,000 km² (Grettenberger & Newby, 1986). The massif forms a high rocky plateau (1,000–1,295 m a.s.l.) bordering the Ténéré Desert and is characterized by a warm desert climate (BWh) sensu Köppen, with extreme temperature fluctuations and highly irregular annual rainfall (~110 mm·yr⁻¹; CNEDD, 2000; WDI, 2020). Biogeographically, the massif sits within the West Saharan montane xeric woodlands, at the interface between South Saharan steppe and Sahelian Acacia savanna ecoregions (Olson et al. 2001). Vegetation is sparse and largely confined to ephemeral watercourses, dominated by *Panicum turgidum*, *Aerva javanica*, *Vachellia tortilis*, and *Balanites aegyptiaca*. This rugged massif serves as an important refuge for Sahelo-Saharan fauna, supporting species such as the dama gazelle, dorcas gazelle, Barbary sheep, and several small carnivores (Sahara Conservation, 2022). Local ecological knowledge recognizes four seasonal phases (Morel, 1985), i.e., cold dry season (November to March), a hot dry season (April to June), a rainy season (July to September), and a transitional season from mid-September to late October.

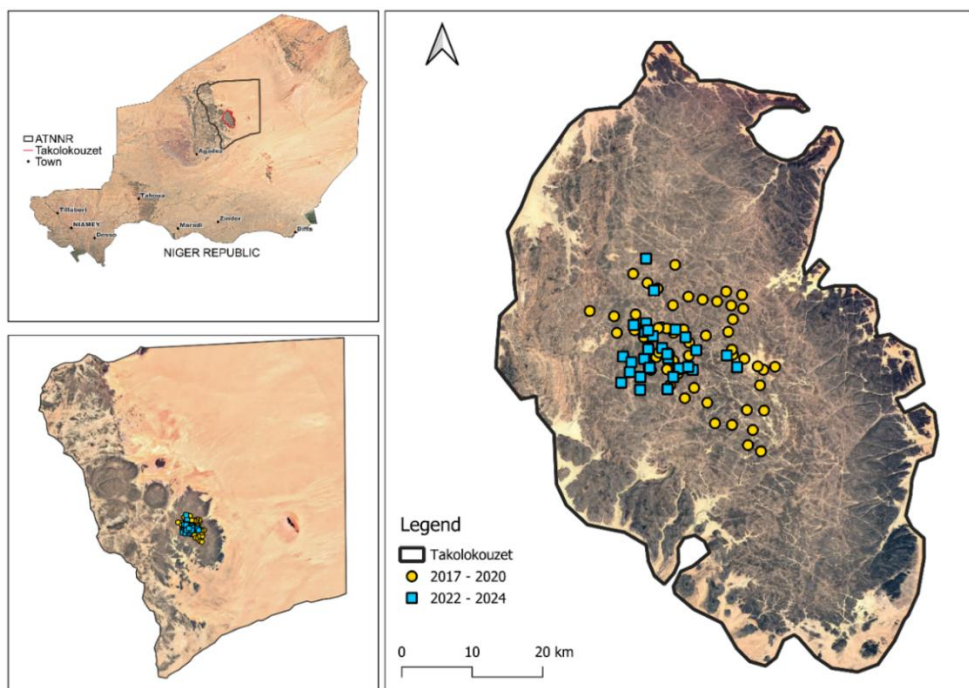


Figure 5.1. Geographical location of the Takolokouzet massif in the Air & Ténéré Nature Reserve in Niger and location of camera traps during the two surveys, in 2017 – 2020 and 2022 – 2024.

5.2.2 Camera trap design and deployment

Camera trapping was conducted in two survey periods (2017–2020; 2022–2024) using a standardized 2×2 km grid design (Figure 5.1) following Amin et al. (2016). Camera locations were selected within each grid cell based on terrain accessibility and the presence of natural wildlife movement corridors, informed by ranger knowledge and prior observations.

In the first camera-trap survey period, between January 2017 and March 2020, 13 camera traps (12 Reconyx HC600, one Bushnell Trophy Cam) were deployed across five consecutive deployments, each representing a distinct grid relocated after several months of sampling. Deployment durations and relocation steps were as follows: Grid 1: Jan 2017–Feb 2018; Grid 2: Feb 2018–Oct 2018; Grid 3: Oct 2018–Feb 2019; Grid 4: Feb 2019–Sept 2019; and Grid 5: Sept 2019–Mar 2020.

The second camera-trap survey period was conducted from May 2022 to February 2024 to increase spatial coverage and update species detections. A single expanded grid of 31 cameras (11 Reconyx; 20 Browning units) was deployed across a broader portion of the massif. The same grid-based protocol was applied to maintain methodological consistency with the first survey period. This intensified

configuration was designed to maximise detection probability for target ungulate species.

All cameras operated continuously (24 h), recording single-image triggers with time–date–temperature metadata. Reconyx and Browning units used no-glow infrared flash, while the Bushnell model used white flash.

5.2.3 Camera trap data processing and capture rate calculation

Camera-trap images were screened for target wildlife species and human-related activity. We considered detections of dama gazelle, dorcas gazelle, Barbary sheep, African wolf, camel, feral donkey, domestic goat, and human presence, including images of people (mostly herders).

To minimise temporal autocorrelation, images were aggregated into independent events, defined as all images of the same species at the same camera taken within a 30-minute interval. Events were therefore treated as the unit of detection for subsequent analyses.

Capture rates (CR), considered a relative measure of abundance, were calculated for each species separately as the number of independent events over the number of deployed days for each camera per 100 days (Burton et al 2015). Capture rates were calculated across both study periods and plotted over the space for visualization. Additionally, capture rates were computed separately for each study period, and summary statistics were generated for each dataset. The differences in CR among three ungulate species were tested for each survey period separately using non-parametric Kruskal-Wallis tests followed by post-hoc Dunn’s multiple comparisons with Bonferroni adjustment, as CR did not meet the assumption of normality (tested by the Shapiro-Wilk test).

5.2.4 Diel activity patterns and temporal overlap analysis

Temporal activity and interspecific overlap were analysed in R using ‘circular’ (Agostinelli & Lund 2024; version 0.5-1), ‘activity’ (Rowcliffe et al. 2023b; version 1.3.4) and ‘overlap’ (Meredith et al. 2024; version 0.3.9) packages. Analyses were conducted separately for each species and each survey period.

We first tested whether the temporal distributions deviated from uniformity using Rayleigh tests (Fisher 1993) and Watson’s U2 tests (Watson 1962). Afterwards, we fitted kernel density estimate (KDE) models to time-of-day data transformed into radians using the function `fitact()` with the model sampling method and 100 bootstrap iterations. From each fitted model, we extracted summary metrics,

including estimated hours of activity, standard error, and 95% confidence intervals. The peak activity time was identified as the hour corresponding to the maximum of the fitted probability density.

The diurnality index was calculated as:

$$\text{Diurnality Index (DI)} = \frac{A_{\text{day}} - A_{\text{night}}}{A_{\text{day}} + A_{\text{night}}}$$

where A_{day} and A_{night} represent the summed activity probabilities during daytime (07:00–18:30) and nighttime (18:30–07:00), respectively. This formulation expresses activity during the day relative to the night, corrected for the total activity ($A_{\text{tot}} = A_{\text{day}} + A_{\text{night}}$). It is a straightforward adaptation of indices used in previous studies that compare daytime and nighttime rates (e.g. Hoogenboom et al. 1984; Jacobs 1974), where similar ratios were originally applied to independent events. In our case, the same logic is retained but applied to activity probabilities derived from the KDE models rather than raw event counts. This index, similarly to Ivlev’s electivity index or Jacob’s selectivity index, is symmetrical around 0, and provides a continuous measure of diel tendency where positive values indicate predominately diurnal activity, whereas negative values indicate a nocturnal bias.

Activity curves were plotted for visual comparison. Pairwise temporal overlap between species of interest was quantified using the overlap coefficient Δ (Ridout & Linkie, 2009), estimated with `overlapEst()`, using the $\hat{\Delta}_4$ estimator. Differences in activity distributions between species were further assessed using Watson’s two-sample test of homogeneity ($\alpha = 0.05$; Watson, 1962).

5.2.5 *Environmental and anthropogenic data*

To investigate the effects of environmental and anthropogenic factors on species occupancy, we identified a set of biotic and abiotic variables (Table 5.1). Environmental factors included long-term and dynamic (daily) Modified Soil Adjusted Vegetation Index (MSAVI), Topographic Position Index (TPI), the distance from potential water courses, 20 climatic variables, moon phase, and relative abundance (i.e. capture rates) of wildlife and domestic species, namely African wolf, camel, donkey, and goat. Anthropogenic factors included people recorded by camera traps and indicators of human presence represented by motorcycle tracks, trails, and people observed and recorded during the camera trap installation. These data were transformed to distance from CTs at the 250m resolution.

To minimise the effects of multicollinearity on spatial model estimation and inference, we assessed correlations among all continuous predictor variables prior

to analyses. Pairwise Pearson correlation coefficients were inspected (Supplementary material 1, Figure S1), and variables with $|r| \geq 0.7$ were not included together in the same model.

Table 5.1. Environmental and human-related variables considered in the integrated step selection function models.

Factor	Indicator	Description	Source
Ecological factor			
Vegetation cover density	Long-term MSAVI	Modified Soil Adjusted Vegetation Index (MSAVI) that minimizes soil background effects, improving the detection of vegetation greenness and biomass in semi-arid landscapes dominated by sparse vegetation and exposed soil (Qi et al. 1994).	USGS / NASA Landsat 8 Level 2, Collection 2, Tier 1; Resolution 30m, revisitation time 16 days, extracted as median over each survey period using Google Earth Engine.
	Dynamic MSAVI	MSAVI values for actual camera trap deployment days	USGS / NASA Landsat 8 Collection 1 data, served via the AWS Landsat Public Dataset (landsat-pds S3 bucket); resolution 30 m; values extracted for specific dates.
Topography	TPI 90m	Topographic position index as indicator of local variations in elevation calculated as the difference in elevation between each surrounding pixel.	Shuttle Radar Topography Mission (USGS/STRMGL1_003) – Digital elevation model, resolution 90m; recalculated using terrain () function of “terra” package with 8 neighbouring cells used for computation.

Distance to water source			Distance from hydrographic network, calculated from the	National hydrography data of rivers and watercourses (shapefile) (Vector feature 250 m resolution
Bioclimatic variables	Bio_1 – Bio_19		Bioclimatic data derived from the monthly temperatures and rainfall, proxies of ecological conditions over the area.	WorldClim version 2.1 (average for years 1970-2000) extracted at 30 arc-seconds resolution (from “geodata” package).
Moon phase			A factor variable with four labels representing the lunar phases, numbered from 1 (new moon) to 4 (last quarter).	Lunar phase calculations based on Jean Meeus’ Astronomical Algorithms, as implemented by Stephen R. Schmitt (Sky & Telescope, Apr 1994) (from “lunar” package)
Other animal species	African wolf		Relative abundance of native predator.	Capture rates from camera trap surveys – each period separately.
	Donkey, Camel		Relative abundance of feral domestic herbivores as potential competitors for resources.	
	Goat		Relative abundance of livestock presence (pastoralism) as indicator of human presence.	
Anthropogenic factor				
Human presence	Human presence		Relative abundance of human occurrence in the area.	Capture rate from camera trap surveys – each period separately

Motorcycle tracks	Human presence	Indirect sign of human presence.	Field observation records of motorcycle tracks, georeferenced in GIS, then recalculated as distance to CTs, resolution 250 m
Trails	Human presence	Indirect sign of human presence.	Field observation records of trails used by people on foot, georeferenced in GIS, recalculated as distance to CTs, resolution 250m

5.2.6 *Spatial occupancy analysis*

To identify the environmental and anthropogenic factors influencing the space-use of wild ungulates, we fitted single-species occupancy models for each focal species and survey period in a Bayesian hierarchical framework using the `spOccupancy` package (Doser et al., 2022). These models integrated presence/absence data from camera traps, explicitly accounting for imperfect detection and spatial autocorrelation.

5.2.7 *Estimating the probability of detection p*

Detection probability was estimated separately using the variables that could influence the detection of the species, specifically the number of deployment days (a proxy for the camera effort), the year (to control for inter-annual differences), the season (wet season: June-September, dry season: October-May), the dynamic MSAVI (daily), and the moon phase (from 1 to 4). We first fitted detection formulas while keeping a fixed, comprehensive occurrence formula (i.e. including most of the occurrence variables), to evaluate the influence of detection covariates based on Bayesian p-values, WAIC and ecological meaning. The final detection formulas per species and survey period (Table 5.2) were applied in further analyses of spatial occupanc

Table 5.2. Structure of the detection and occupancy formulas in the best performing models for each species and each survey period (asterisk represent variables which CI does not cross zero, therefore are significant).

Species	Covariates	2017-2020	2022-2024
Dama gazelle	detection formula	$\sim \text{scale}(\text{dyn_MSAVI})^* + \text{scale}(\text{Season})^*$	$\sim (1 \mid \text{Days})$
	ecological factors	$\sim \text{scale}(\text{Bio_5})^* + \text{scale}(\text{Camel})$	$\sim \text{scale}(\text{Bio_5})^*$
	anthropogenic factors	$\sim \text{scale}(\text{tracks})^*$	$\sim \text{scale}(\text{Goat})^* + \text{scale}(\text{tracks})$
	mixed factors	$\sim \text{scale}(\text{tracks})^* + \text{scale}(\text{Bio_5}) + \text{scale}(\text{Camel})^*$	$\sim \text{scale}(\text{tracks}) + \text{scale}(\text{Bio_5}) + \text{scale}(\text{Goat})$
Dorcas gazelle	detection formula	$\sim (1 \mid \text{Days}) + (1 \mid \text{Year}) + \text{scale}(\text{Season})$	$\sim (1 \mid \text{Days})$
	ecological factors	$\sim \text{scale}(\text{Bio_12})^* + \text{scale}(\text{Donkey})^*$	$\sim \text{scale}(\text{Bio_12}) + \text{scale}(\text{Donkey}) + \text{scale}(\text{AfricanWolf})$
	anthropogenic factors	$\sim \text{scale}(\text{tracks})^*$	$\sim \text{scale}(\text{Hum})$
	mixed factors	$\sim \text{scale}(\text{Bio_12})^* + \text{scale}(\text{Donkey})^* + \text{scale}(\text{tracks})^*$	$\sim \text{scale}(\text{Hum}) + \text{scale}(\text{Donkey}) + \text{scale}(\text{AfricanWolf}) + \text{scale}(\text{Bio_12})$
Barbary sheep	detection formula	$\sim (1 \mid \text{Days}) + \text{scale}(\text{Season})^*$	$\sim (1 \mid \text{Days})$
	ecological factors	$\sim \text{scale}(\text{Bio_2})^*$	$\sim \text{scale}(\text{Bio_2}) + \text{scale}(\text{AfricanWolf})$
	anthropogenic factors	$\sim \text{scale}(\text{Goat}) + \text{scale}(\text{tracks})$	$\sim \text{scale}(\text{tracks})$
	mixed factors	$\sim \text{scale}(\text{Goat}) + \text{scale}(\text{Bio_2})^* + \text{scale}(\text{tracks})$	$\sim \text{scale}(\text{Bio_2}) + \text{scale}(\text{AfricanWolf}) + \text{scale}(\text{tracks})$

5.2.8 *Estimating the probability of occupancy ψ*

After selecting the best detection structure, we evaluated alternative occupancy sub-models. We first tested models including only ecological predictors, i.e. vegetation cover density, climate, topography, watercourse proximity, and capture rate for African wolf and feral domestic species donkey and camel. We then assessed models incorporating anthropogenic factors, including distance to trails and motorcycle tracks, and capture rates of humans and goats. Finally, we tested combined models that integrated the predictors retained from the previous steps. Model comparisons were based on WAIC, Bayesian p-values, and K-fold cross-validations (Supplementary material 1 Table S1).

Model fits were assessed through posterior predictive checks, including Freeman–Tukey and Chi-squared discrepancy measures. Additional diagnostics included plots of posterior ψ versus observed detection rates and examination of posterior latent occupancy states to identify sites with high uncertainty and evaluate how variation was partitioned between detection and true occupancy. To further assess the ecological plausibility and spatial pattern in occupancy, predictions were generated from selected models within the same Bayesian framework. In models including animal and human capture rates, layers were interpolated with Kriging method in the ArcGIS Pro (ESRI).

5.2.9 *Estimating the overlap in the probability of occupancy ψ*

The spatial overlap between the three ungulate species was quantified using model-based predictions of occupancy generated with the `predict()` function in `spOccupancy` package over the area around each camera trap point with a buffer of 7 km. For each species pair, similarity between predicted spatial distributions was assessed using the Bhattacharyya index (Bhattacharyya 1943, Carrol et al 2019), computed from posterior samples of occupancy probability (ψ) using the `distance()` function with the Bhattacharyya method implemented in the `Philentropy` package (Drost 2018). Bhattacharyya affinity values were calculated for each posterior sample and summarized as posterior means with 95% credible intervals. Spatial overlap maps were produced to visually represent the degree of overlap between species. In addition, the proportion of spatial overlap among core areas, defined as grid cells with mean occupancy probability $\bar{\psi} > 0.6$, was calculated.

5.3 Results

A total of 188,906 images was collected during this study, including 19,946 images of wildlife species (dama gazelle, dorcas gazelle, Barbary sheep, and African wolf), and 168,960 images of other species (feral camel, feral donkey and domestic goat). Among the total of 8,840 independent events, feral animals were detected most frequently ($n = 6,508$; 73.6%: donkey $n = 4,557$ and camel $n = 1,951$), followed by wild species ($n = 1,926$; 21.8%: dorcas gazelle $n = 1,437$, dama gazelle $n = 368$, and Barbary sheep $n = 101$), then domestic species (goats $n = 310$; 3.5%), while predators were least frequently detected (African wolf $n = 96$; 1.1%).

5.3.1 *Capture rate patterns across species*

Across both study periods, dorcas gazelle was the most frequently detected species among the three wildlife ungulate species (mean CR = 6.66, SD = 8.05), followed by dama gazelle (mean CR = 1.70, SD = 2.80), while Barbary sheep showed the lowest CR (mean CR = 0.52, SD = 2.30). Among the other species, feral donkey (mean = 24.70, SD = 27.24) and feral camel (mean = 10.00, SD = 9.70) were recorded far more frequently than any of the wildlife ungulates. African wolf (mean = 0.56, SD = 1.66) and domestic goat (mean = 1.74, SD = 6.05) showed the lowest CRs overall. These differences in CR patterns of all species were significant and consistent across both survey periods (Kruskal-Wallis tests for each period: $p < 0.05$), although goat detections showed a marked reduction in maximum CR during the 2022–2024 survey (Figure 2, Supplementary material 1: Table S1). Capture rates of dama and dorcas gazelles differed significantly in 2017–2020, while in 2022–2024, the CR of dorcas gazelle was lower and did not differ significantly from dama gazelle (Figure 5.2, Supplementary material 1: Table S2). Dama gazelle and Barbary sheep CRs did not differ significantly in either period and in contrast, while CRs of dorcas gazelle and Barbary sheep showed significant differences across both periods (Figure 5.2, Supplementary material 1: Table S2).

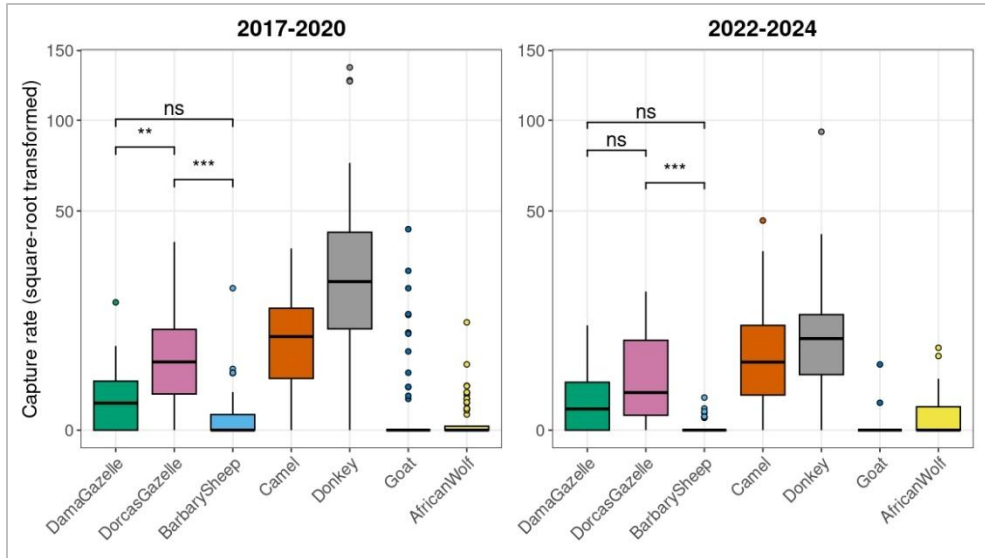


Figure 5.2. Capture rates of wildlife and domestic species for each camera trap survey. Note: capture rate (Y-axis) was square root transformed to facilitate the scale of display of high variability. Significance from Dunn's test represents differences among the three species of interest (ns = $p \geq 0.05$, ** = $0.001 \leq p < 0.01$, *** = $p < 0.001$).

5.3.2 *Diel activity patterns and species temporal overlap*

Kernel density estimates (KDEs) revealed distinct activity rhythms among species, but consistent across both survey periods (Figure 5.3). Inferential statistics indicated significant departures from uniformity for all species ($p < 0.05$), except for

Barbary sheep in both periods ($p = 0.14$ and $p = 0.69$, respectively) and African wolf during 2022–2024 ($p = 0.15$; Supplementary material 1: figure 5.3).

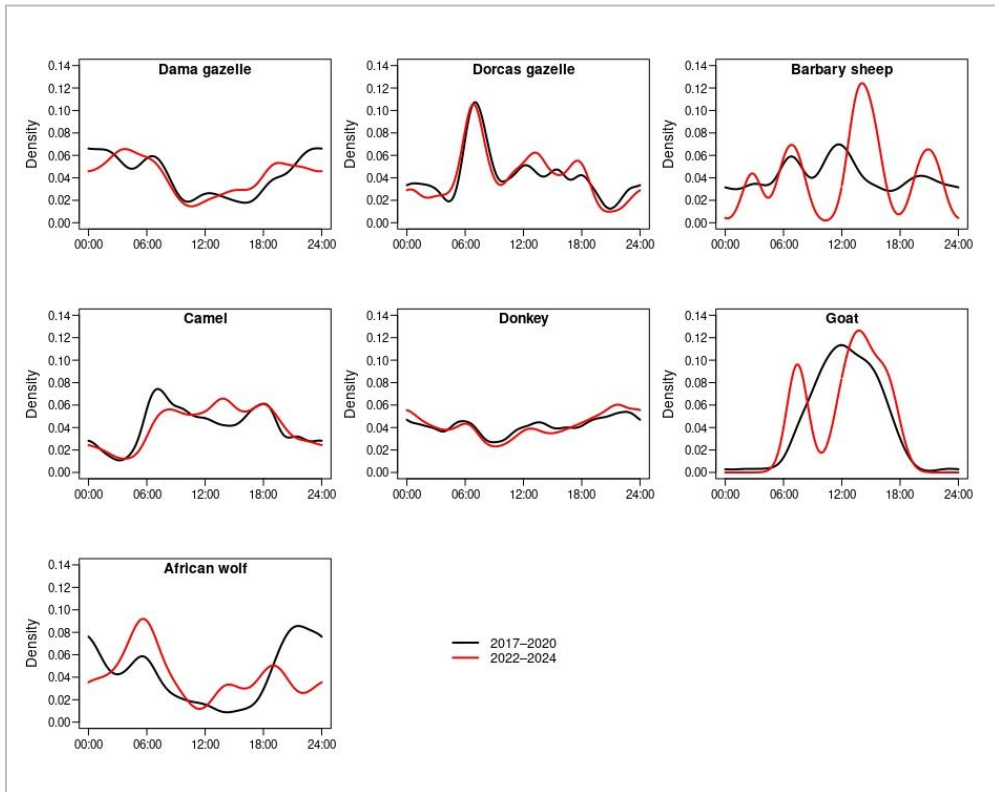


Figure 5.3. Temporal activity patterns of wildlife and domestic species in the Takolokouzet massif, Air and Ténéré Nature reserve, Niger. Lines represent circadian activity levels in the two camera trap survey periods (black line 2017 – 2020 and red line 2022 – 2024).

Dama gazelle was predominantly nocturnal, with higher activity during the night, across both study periods. Dorcas gazelle showed strong early-morning activity, peaking consistently around sunrise (7:02 in 2017-2020; 6:52 in 2022-2024; Supplementary material 1: Table S4). Barbary sheep exhibited broadly distributed activity across the diel cycle, without strong temporal concentration, and only with modest peaks around midday (Figure 5.4). Camel displayed primarily diurnal behaviour, with activity concentrated from early morning to midday, whereas donkey was active throughout the day with mild nocturnal–crepuscular maximums. In contrast, goats were strongly diurnal with higher levels of activity around midday. African wolf showed a marked nocturnal pattern, and activity concentrated during the night and early morning (Figure 5.4, for detailed temporal parameters see Supplementary material 1: Table S4).

Based on diurnality index (DI; Figure 5.4, Supplementary material 1: Table S5), dama gazelle were consistently nocturnal (-0.392 and -0.359 in the first and second survey period, respectively), while dorcas gazelle, feral camel, and domestic goat were predominantly diurnal (DIs: dorcas gazelle: 0.145 ; 0.210 ; camel: 0.220 ; 0.301 ; goat: 0.854 ; 0.781). Barbary sheep showed weakly positive diurnality values (0.055 ; 0.099), consistent with a cathemeral or crepuscular activity pattern. Feral donkey displayed slightly nocturnal tendencies (-0.143 ; -0.217), while African wolf was strongly nocturnal (-0.573 ; -0.277).

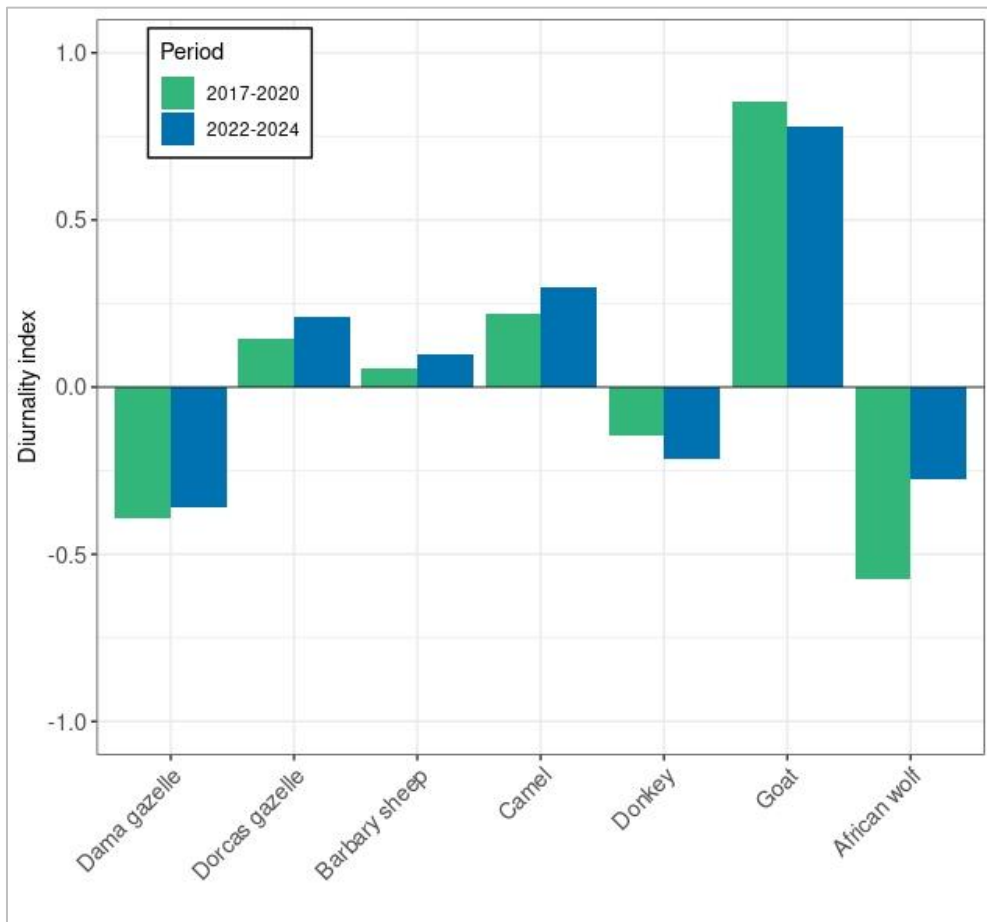


Figure 5.4. Diurnality index for wildlife and domestic species in the two camera trap survey periods in the Takolokouzet massif, Air and Ténéré Nature reserve, Niger. Value of 1 indicate diurnal behaviour, value of -1 the nocturnality, and value of 0 indifference to diurnal/nocturnal rhythm.

Temporal overlap coefficients (Δ) showed generally high overlap among the three wildlife ungulates in both survey periods ($\Delta > 0.65$; Figure 5.5; Supplementary Material 1: Table S6), while the overlap between wildlife ungulates with other

species was more variable (Supplementary Material 1: Table S6). Dama gazelle showed substantial overlap with all species ($\Delta = 0.64\text{--}0.88$), except for consistently low overlap with goats ($\Delta = 0.35; 0.37$) (Figure 5.6). This pattern was supported by Watson's two-sample tests showing significant differences between dama gazelle and goat activity curves, while activity distributions were not statistically different between dama gazelle and African wolf in either period, nor from Barbary sheep and from feral donkey in 2022–2024 (Supplementary Material 1: Table S6).

Dorcas gazelle also exhibited moderate to high overlap of temporal activity with most species ($\Delta = 0.56\text{--}0.85$) (Figures 5.6), while its activity distribution (due to the activity peak at dawn) was significantly different from all species, except Barbary sheep, across both survey periods (Supplementary Material 1: Table S6).

Barbary sheep demonstrated moderate to high overlap with other species ($\Delta = 0.57\text{--}0.84$). In 2017–2020, its activity distribution differed significantly from dama gazelle, donkey, African wolf, and goat, while in all other comparisons and throughout 2022–2024 they did not differ (Figures 5.6, Supplementary Material 1: Table S6).

Considering species pairs included in the spatial models (Table 2), moderate to high temporal overlaps were observed. In 2017–2020, pairs of dama gazelle – camel ($\Delta = 0.67$), dorcas gazelle – donkey ($\Delta = 0.78$), and Barbary sheep – goat ($\Delta = 0.57$) showed substantial temporal overlap. In 2022–2024, high overlap occurred between Barbary sheep – African wolf ($\Delta = 0.60$), dorcas gazelle – African wolf ($\Delta = 0.74$), dorcas gazelle – donkey ($\Delta = 0.70$). The dorcas gazelle – goat pair also showed high temporal overlap ($\Delta = 0.68$) and was considered a proxy for human temporal activity,

as human presence was included in the spatial model for dorcas gazelle during this period and was strongly collinear to goat.

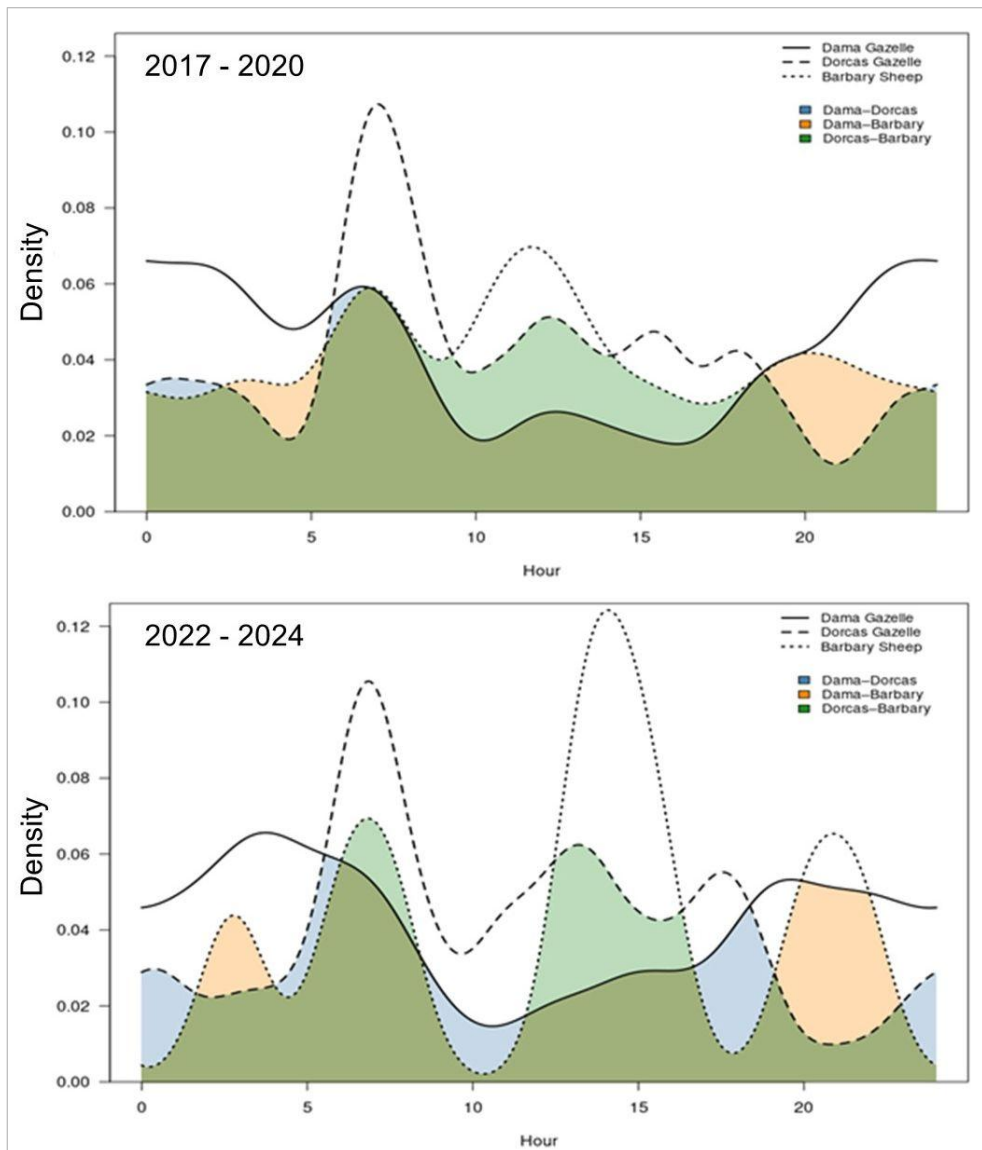


Figure 5.5. Overlap of the temporal activity patterns of the dama gazelle, dorcas gazelle, and Barbary sheep in the Takolokouzet massif, Air and Ténéré Nature Reserve, Niger. Lines represent circadian activity levels in the two camera trap survey periods 2017 – 2020 and 2022 – 2024.

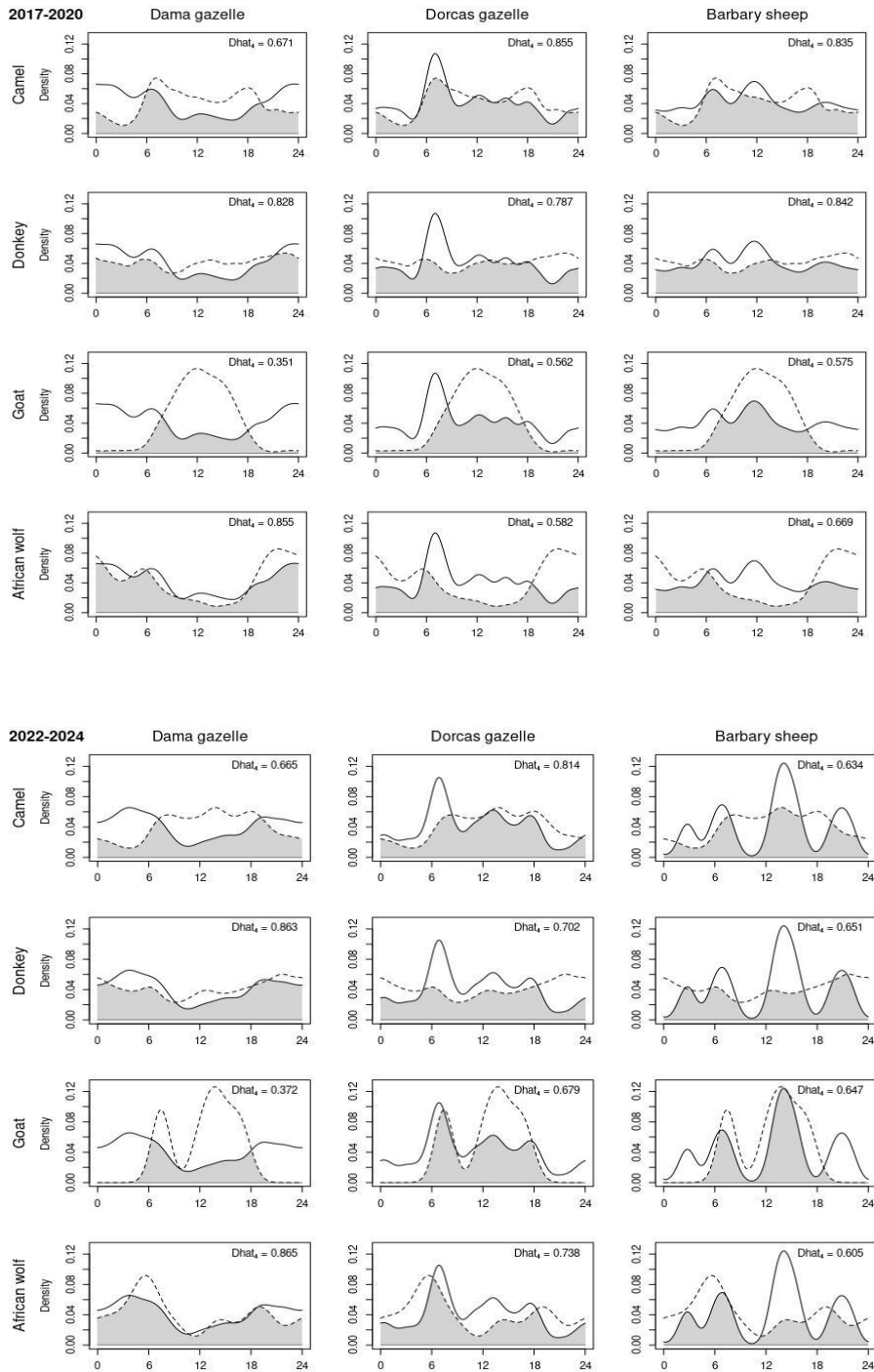


Figure 5.6. Temporal activity and degree of overlap of three wild ungulates with feral and domesticated livestock and predator. Overlap between activity is represented by shaded area,

quantified by overlap index Dhat4. The x-axis represents time where sunrise and sunset are approx. 07:00 and 18:30. The y axis represents the kernel density of activity.

5.3.3 *Environmental and anthropogenic drivers of species occupancy*

We fitted hierarchical occupancy models that jointly estimate detection probability and site occupancy for each species and study period (Table 5.2; Supplementary Material 2). Model selection using WAIC, Bayesian p-values, and K-fold cross-validation consistently showed improved fit when accounting for detection heterogeneity, followed by inclusion of ecological and anthropogenic covariates in the occupancy component.

Detection probability varied with survey conditions and sampling effort across species and study periods. During the 2017–2020 period, the best-supported detection model for dama gazelle included actual vegetation productivity (dynamic MSAVI) and season, whereas detection of dorcas gazelle and Barbary sheep was best supported by models including random effects of sampling effort and season. These models produced the lowest and statistically indistinguishable WAIC values ($\Delta\text{WAIC} < 2$) and Bayesian p-values approaching 0.5, indicating adequate fit. No additional covariates improved model performance. During the 2022–2024 period, detection models for all species were best supported with a random effect of sampling effort alone, yielding comparable or lower WAIC and Bayesian p-values closer to 0.5 relative to alternative models.

By integrating the best-fit detection models, we evaluated occupancy models to identify environmental and anthropogenic drivers of site use (Supplementary material 2). Species-specific effects of climatic, ecological, and anthropogenic covariates are summarised in the Table 5.3.

For dama gazelle, occupancy was consistently negatively associated with maximum temperature of the warmest month across both study periods, indicating reduced site use under hotter conditions (Table 5.3). In the 2017–2020 period, model support was improved by the inclusion of feral camel activity, whereas distance from tracks contributed to model performance in both periods but with contrasting directions of effect. In the 2022–2024 period, domestic goat activity further improved model support. Model diagnostics indicated adequate replicate-level fit in 2017–2020 but residual site-level heterogeneity, while both replicate- and site-level fit improved in 2022–2024, with occupancy predictions broadly consistent with observed detection patterns.

For dorcas gazelle, occupancy showed a positive association with annual precipitation in both periods (Table 5.3). Feral donkey activity contributed to model

performance consistently across periods. In 2017–2020, distance from tracks further improved model fit, whereas in 2022–2024 support was increased by the inclusion of human and African wolf activity. Model diagnostics suggested moderate replicate-level fit and residual site-level variation in the earlier period, while diagnostics in 2022–2024 fell within acceptable ranges, with predicted occupancy generally tracking observed detections despite moderate uncertainty across sites.

For Barbary sheep, occupancy was negatively associated with mean diurnal temperature range in both periods, indicating reduced site use in areas with greater thermal variability (Table 5.3). Distance from tracks contributed to model performance consistently across periods. In 2017–2020, domestic goat activity was negatively associated with occupancy, whereas in 2022–2024 African wolf activity improved model support. Detection-component diagnostics indicated good replicate-level fit in both periods, with some residual site-level heterogeneity in 2017–2020 and overall satisfactory fit in 2022–2024. Occupancy and detection estimates were consistent with observed patterns, with remaining uncertainty concentrated at a subset of sites.

Table 5.3. Posterior summaries of occupancy model coefficients. Values are reported as posterior means with 95% credible intervals (2.5% and 97.5% quantiles). Model convergence and sampling efficiency are indicated by the Gelman–Rubin statistic ($\hat{R}$) and effective sample size (ESS), respectively. Covariates camel, goat, donkey, African wolf, and humans represent relative abundance in terms of their capture rates.

2017 – 2020	Mean	2.5%	97.5%	Rhat	ESS	2022 – 2024	Mean	2.5%	97.5%	Rhat	ESS
			%						%		
Dama gazelle											
Intercept	0.476	-	1.463	1.00	497	Intercept	1.776	0.405	3.572	1.00	236
		0.427		2	2					0	9
Max temperature (Bio5)	-	-	0.191	1.00	477	Max temperature (Bio5)	-	-	0.084	1.00	392
	0.967	2.481		0	0		1.414	3.339		2	7
Distance to tracks	-	-	-	1.00	411	Distance to tracks	0.733	-	2.706	1.00	552
	2.246	3.599	1.169	1	8			0.873		1	0
Camel	0.945	0.044	1.945	1.00	538	Goat	1.137	-	3.476	1.00	573
				0	2			0.685		0	3
Dorcas gazelle											
Intercept	3.130	1.830	4.734	1.00	432	Intercept	2.573	1.268	4.188	1.00	554
				2	1					3	2
Annual precipitation (Bio12)	0.811	-	1.686	1.00	505	Annual precipitation (Bio12)	0.331	-	2.032	1.00	600
		0.039		2	3			1.606		2	0
Distance to tracks	-	-	-	1.00	550	Human presence	0.839	-	3.061	1.00	600
	1.217	2.311	0.217	1	7			0.835		1	0
Donkey	1.455	0.141	3.063	1.00	458	Donkey	1.372	-	3.238	1.00	591
				4	4			0.471		1	9

						African wolf	0.826	-	3.031	1.00	575
								0.885		1	9
Barbary sheep											
Intercept	-	-	1.023	1.01	140	Intercept	0.790	-	3.047	1.00	172
	0.330	1.535		4	2			1.129		4	5
Diurnal temperature range (Bio2)	-	-	-	1.00	535	Diurnal temperature range (Bio2)	-	-	1.707	1.00	286
	1.485	2.841	0.387	1	1		1.050	3.930		0	1
Distance to tracks	-	-	0.928	1.00	319	Distance to tracks	-	-	0.945	1.00	434
	0.648	2.212		4	9		1.230	3.692		0	4
Goat	-	-	-	1.00	458	African wolf	0.655	-	3.356	1.00	374
	2.111	4.246	0.460	1	2			1.935		0	4

Note: Credible intervals not overlapping zero indicate supported effects of covariates on occupancy probability.

5.3.4 Spatial overlap among sympatric ungulates

Spatial overlap among the three wild ungulate species was generally high across both study periods, as indicated by Bhattacharyya coefficients exceeding 0.7 for all species pairs. The most consistent overlap was observed between dama gazelle and dorcas gazelle, with consistently high overlap values in both periods, and a stable extent of the shared core area (ψ mean > 0.6), which covered approximately 55% of the study area. Overlap between dama gazelle and Barbary sheep was moderate and declined slightly between periods, accompanied by a reduction in the extent of their shared core area from 32% to 26% of the study area. In contrast, dorcas gazelle and Barbary sheep exhibited very high overlap in the earlier period, which decreased in the later period, while the spatial extent of their shared core area remained relatively stable at around 46%.

Overall, these results indicate substantial spatial overlap among sympatric ungulates, with temporal shifts in the intensity of overlap for some species pairs but comparatively stable core-use areas across periods (Supplementary material 1 Table S7).

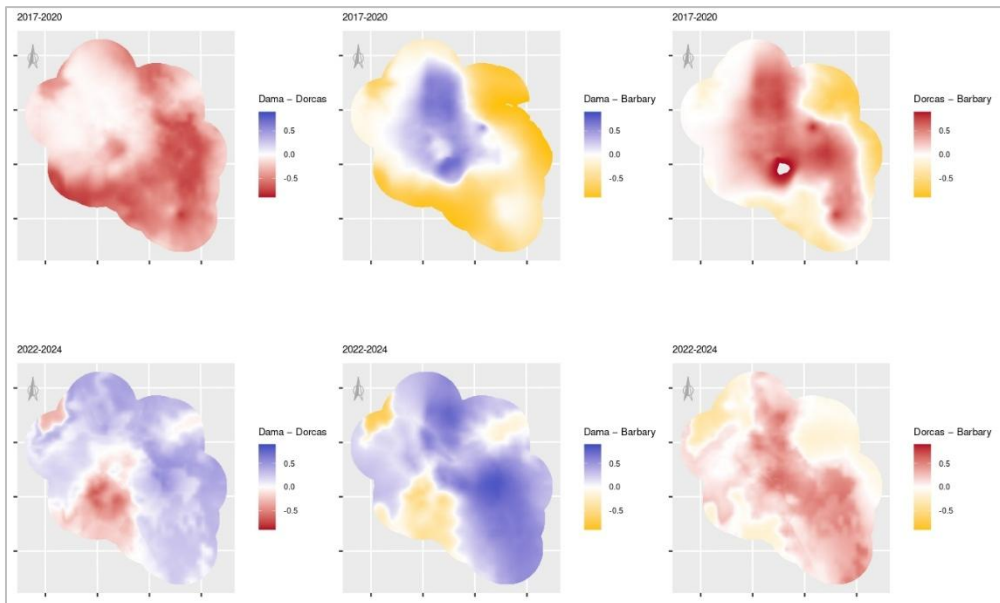


Figure 5.7. Spatial overlap of dama gazelle, dorcas gazelle, and Barbary sheep in the area around camera trap points delimited by buffer of 7 km, i.e. in the central part of the Takolokouzet massif. Colours indicate the prevalence of one of the species in pair, or the overlap (white area).

5.4 Discussion

Our study shows how sympatric desert ungulates persist under extreme environmental constraints through complementary use of temporal, spatial, environmental, and anthropogenic niche axes. Despite extensive spatial overlap among dama gazelle, dorcas gazelle, and Barbary sheep, the species displayed pronounced differences in their diel activity, detection patterns, and responses to climatic and human-related drivers. This indicates that their space use is structured rather than random. Temporal segregation emerged as a key mechanism reducing direct encounters with other species or humans, while species-specific sensitivities to climate, vegetation dynamics, and disturbance further shaped realised occupancy. High spatial overlap therefore reflected shared dependence on scarce favourable habitats rather than competitive equivalence, demonstrating that coexistence in hyper-arid systems is maintained through multi-dimensional niche differentiation operating at fine behavioural and temporal scales.

5.4.1 *Temporal niche partitioning as a primary coexistence mechanism*

Dama gazelle, dorcas gazelle, and Barbary sheep co-occur on the Takolokouzet Massif despite strong spatial constraint, yet they exhibited distinct and complementary diel activity patterns across both study periods. Dama gazelle, the largest gazelle, was predominantly nocturnal, whereas Barbary sheep with comparatively more robust body build displayed more evenly distributed, cathemeral activity. Dorcas gazelle, the smallest species, was largely diurnal, with a pronounced activity peak around dawn, consistent with pattern reported from another Saharan site, the Termit and Tin-Toumma in Niger (Wacher et al. 2014).

Pronounced temporal segregation observed among the wildlife ungulate species arises from body size-mediated differences in thermoregulatory constraints, leading to distinct behavioural strategies under extreme thermal conditions. The most robust species in the community, Barbary sheep displayed cathemeral activity, which is consistent with a flexible strategy that uses the dynamic timing of activity to buffer strong thermal inertia. This strategy enables to use short favourable thermal conditions which may occur particularly in rugged terrain. In contrast, the marked nocturnality of dama gazelle likely reflects a behavioural strategy that mitigates constraints on heat dissipation and increases net foraging efficiency by minimising locomotion costs and water loss during prolonged foraging, although larger body size is often associated with greater thermal inertia and lower mass-specific heat gain (Cain et al. 2006; Fuller et al. 2016). Such shifts towards nocturnal

activity can function as temporal refugia from thermal stress, even when accompanied by increased exposure to nocturnal predators (Brivio et al. 2024). In contrast, the diurnality of dorcas gazelle appears to reflect behavioural rather than physiological flexibility. Their small body size allows for efficient heat dissipation, i.e. rapid heat exchange during daylight hours. This facilitates visual detection of both forage and predators, and optimises thereby the trade-offs among thermal load, energy gain, and risk exposure.

Risk of predation and disturbance by human activities represent an additional axis of temporal niche differentiation. African wolf, the most abundant predator in the study area was primarily nocturnal. As the smallest and presumably most predator-sensitive ungulate, dorcas gazelle may reduce the encounters through diurnal activity, whereas the high temporal overlap between dama gazelle and African wolf suggests limited predation risk from this species. Larger predators, such as the Saharan cheetah (*Acinonyx jubatus hecki*) and the caracal (*Caracal caracal*) were reported at extremely low densities (Belbachir et al. 2015, Silero-Zubiri et al. 2015; Wacher et al. 2014, Zabeirou, 2017-2025 pers. obs.), potentially indicating a weakening or loss of predator-mediated regulation.

Beyond predators, temporal activity was also modulated by feral camels, donkeys, and goats, the latter always accompanied by a herder. Temporal niche thus extended into human-related components of the landscape. All three wildlife ungulates showed low or moderate temporal overlap with strongly diurnal goats despite their low relative abundance. This indicates avoidance of domestic goats as a source of disturbance and competition for scarce forage and shaded microhabitats. In contrast, temporal overlap was higher with feral camels and donkeys, which exhibited more cathemeral or nocturnal activity.

5.4.2 *Spatial overlap emerging under climatic and disturbance constraints*

Dama gazelle, dorcas gazelle, and Barbary sheep exhibited high spatial overlap across the study area, including within a shared core occupancy zone. Spatial overlap between dama and dorcas gazelles was stable across study periods, indicating persistent co-occurrence under arid conditions, as also documented at other extant dama gazelle sites (Wacher et al. 2014, 2023). Conversely, overlap between dama gazelle and Barbary sheep decreased over time, suggesting increasing spatial segregation within an already constrained habitat and resource base, although part of this pattern may reflect differences in spatial sampling design between survey periods.

Spatial occupancy of all three wild ungulate species was primarily structured by climatic parameters, with avoidance of high temperatures and selection of areas associated with higher precipitation. While dama gazelle showed lower occupancy in hotter sites, confirming their high vulnerability to thermal stress, dorcas gazelle showed higher occupancy in sites receiving more precipitation, consistent with their reliance on ephemeral vegetation following rainfall events (Grettenberger & Newby, 1986). Barbary sheep responded to climatic constraints by occupying thermally more stable areas found within microhabitats on rugged terrain. In hyper-arid environments, extreme thermal conditions and low, highly variable rainfall severely restrict usable space, forcing species into limited suitable refugia. Such climatic constraints act as a primary environmental filter (*sensu* Weiher & Keddy 1995), defining the spatial domain within which other processes operate. High spatial overlap therefore reflects partitioning and shared dependence on these favourable zones.

Beyond climatic constraints, spatial occupancy was further modulated by biotic context involving all other (wildlife, feral, and domestic) species. These associations most likely reflect indirect links to habitat characteristics rather than direct biotic interactions. Positive associations between dama gazelle and camels or goats, and between dorcas gazelle and donkeys or goats, likely arise from shared use of productive wadi habitats, i.e. with higher forage availability and shade. In contrast, Barbary sheep showed reduced occupancy in areas with a high occurrence of goats. This is because Barbary sheep naturally occupy rugged and high-elevation terrain that provides rapid escape opportunities and concealed food and water resources (Cassinello 1998), and these areas are not easily accessible to people and their herds.

Distance to human tracks represented an additional axis determining space use. During the first study period, all three species showed higher occupancy closer to tracks, which were primarily used by pastoralists as herding routes. This pattern is best interpreted as a habitat-mediated association rather than habituation or attraction to human activity per se, as those trails were created to access forage-rich areas subsequently used by livestock and, indirectly, by wild ungulates. Higher occupancy of wildlife ungulates near these tracks likely reflects spatial coincidence among tracks, livestock use, and areas of elevated resource availability. Such positive associations further suggest that, during this period, tracks did not constitute strong sources of disturbance, allowing wild ungulates to exploit these linear features without substantial behavioural and energetic costs.

In the later period, however, this relationship shifted from positive to negative, most markedly for dama gazelle, consistent with intensified human activity following the onset of artisanal gold prospecting from 2019 onwards. Field evidence, including

the increase of motorcycle tracks (Sahara Conservation, 2022), suggests that tracks increasingly functioned as disturbance features, prompting spatial avoidance.

5.4.3 Coexistence through multi-dimensional niche differentiation

Taken together, our results indicate that the coexistence of sympatric desert ungulates in the Takolokouzet Massif emerges from the interaction of multiple, hierarchically organised niche axes. Climatic constraints act as dominant driver, directing the species towards a space tightly delimited by a set of scarce suitable foraging and thermal characteristics, resulting in a high spatial overlap. Within this constrained spatial setting, species-specific differences in activity timing provide a key mechanism for reducing direct encounters and competition among herbivores, allowing behavioural segregation to buffer shared space use. Under this framework of natural constraints, human disturbance introduces a dynamic and context-dependent axis of niche differentiation, shifting from habitat-linked facilitation to avoidance as disturbance intensity increases. This multidimensional niche differentiation aligns with classical coexistence theory, in which species persistence is maintained through stabilising mechanisms operating across multiple niche axes (Chesson 2000). Therefore, the combination of climate-constrained spatial use, flexible temporal strategies and variable responses to other co-living species and human presence fosters coexistence in this hyper-arid system. This illustrates how fine-scale behavioural plasticity can maintain community structure, even when opportunities for spatial segregation are severely limited.

5.4.4 Implications for desert ungulate conservation under global change

Understanding how coexistence is maintained through the interaction of climatic constraints, temporal strategies, and disturbance responses is critical for anticipating the conservation consequences of accelerating environmental change in desert systems. Our results indicate that dama gazelle remain the species most sensitive to disturbance, relying heavily on behavioural and temporal refugia that could be progressively reduced by intensifying land use and expanding livestock. Dorcas gazelle exhibit greater ecological plasticity, which likely confers resilience in shared pastoral landscapes. Furthermore, Barbary sheep occupy natural spatial refugia. These species-specific sensitivities highlight the importance of maintaining heterogeneity in both space and time, as coexistence depends on the continued availability of spatial, temporal, and behavioural refugia across this hyper-arid landscape. As similar climatic limitations and anthropogenic pressures characterise arid and semi-arid systems globally, these mechanisms are likely to extend beyond

the Takolokouzet Massif to other ungulate communities facing increasing environmental constraints.

In conclusion, this study shows that coexistence in hyper-arid ungulate communities is sustained not by spatial segregation alone, but by the interplay of climatic filtering, temporal niche differentiation, and context-dependent responses to human disturbance. By revealing how fine-scale behavioural flexibility allows species to persist within climatically compressed landscapes, our findings highlight the importance of preserving spatiotemporal heterogeneity as a key buffer for biodiversity persistence in arid ecosystems undergoing rapid environmental change.

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CHAPTER 6

6 Linking social and ecological salience of wildlife in the Aïr and Ténéré National Nature Reserve, Niger: implications for conservation of the critically endangered dama gazelle

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Abstract

Understanding how people perceive and value wildlife is central to conservation, particularly in arid environments where human livelihoods and biodiversity are tightly interlinked. While ecological indicators are commonly used to guide conservation priorities, less is known about how these align with local ecological knowledge and social importance of species. We examined relationship between social and ecological salience of wildlife in the Aïr and Ténéré National Nature Reserve (Niger), with a particular focus on the *Critically Endangered* dama gazelle (*Nanger dama*).

We documented local ecological knowledge, perceptions of population trends, attitudes, and social salience through semi-structured interviews with local residents (n = 115), using a free-listing approach to quantify social salience. Ecological salience was assessed using camera-trap capture rates from wildlife monitoring (2017 – 2020). We then compared social and ecological salience across species and examined how species traits, human–wildlife interactions, and cultural values shaped alignment or mismatch between these dimensions.

Social and ecological salience were strongly positively correlated across species, indicating that local communities remain closely connected to wildlife with which they coexist. However, there were pronounced species-specific mismatches. Herbivorous ungulates were generally socially salient and positively valued, whereas carnivores and primates were often socially salient in negative ways associated with conflict, irrespective of their ecological occurrence. Perceptions of population trends were structured primarily by social salience rather than by ecological indicators alone. The dama gazelle represented a distinctive case in which social and ecological salience closely aligned, alongside strong cultural significance and widespread local awareness of its decline.

Our findings show that conservation relevance emerges most clearly where ecological vulnerability and social salience intersect. Integrating local ecological knowledge with ecological indicators provides a practical framework for anticipating local support or resistance and for designing conservation strategies that are both ecologically necessary and socially legitimate, particularly in arid social–ecological systems.

Key words (5 – 8 words)

Arid social-ecological systems, Local ecological knowledge, Human – wildlife relationships, Wildlife perceptions and values, Conservation legitimacy, Camera-trap ecological indicators, *Nanger dama*

6.1 Introduction

Biodiversity loss is a globally recognised phenomenon, typically documented using ecological indicators such as population dynamics, abundance, distribution, and assessments of threats and extinction risk derived from long-term monitoring. However, wildlife decline also occurs within human societies where people assign economic value to species and attribute cultural, symbolic, and spiritual meaning to them (Díaz et al. 2018) through day-to-day experience, livelihood practices, and cultural events. Perceptions of population trends do not necessarily reflect actual ecological abundance or rarity, as they are often influenced by encounter rates, economic relevance, and values attributed to a particular species. Furthermore, declining populations can alter local perceptions of 'normal' wildlife populations, a phenomenon known as 'shifting baseline syndrome' (Papworth et al. 2009; Turvey et al. 2010). The social importance of species may therefore diverge from their ecological abundance, with consequences for landscape and conservation management. Although local ecological knowledge and perceptions are increasingly acknowledged as a valuable source of information, the potential divergence from ecological reality is rarely examined quantitatively and comparatively.

Local ecological knowledge (LEK) understood as "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and transmitted across generations, concerning relationships among living beings (including humans) and their environment" (Berkes et al., 2000), contributes to how people interpret and respond to environmental change. In this context, LEK supports social resilience, defined as the capacity of individuals or groups to cope with the disruptions to livelihoods and security arising from social, economic or ecological change (Adger, 2000). Knowledge and perceptions of wildlife are shaped by people's experiences with the presence, absence, or decline of species, which in turn shape emotional responses and attitudes towards those species. These perceptions reflect multiple values of wildlife for local human societies, including direct and indirect use values, a variety of non-consumptive benefits, and/or intrinsic values, as well as perceived costs of living near wildlife and conservation interventions (Thondhlana et al. 2020; Gomez et al. 2022). Consequently, species vary in their prominence within local knowledge systems and social discourse. This relative prominence, referred to here as 'social salience' (sensu Smith & Borgatti 1997), captures the degree to which species are noticed, remembered, valued and considered important by local people (Garibaldi & Turner 2004). It provides a critical link between LEK and measurable ecological patterns.

Some species remain socially important even when they become ecologically rare, while others may receive little attention despite being relatively common. Conservation practice often assumes that local perceptions and knowledge reflect ecological change, so that a decline in perceived importance follows declines in abundance. However, this assumption has not been widely tested and may not apply to systems in which species have different cultural meanings, economic relevance, or encounter rates. As species decline, perceptions of what constitutes a 'normal' population size may not keep pace with ecological change, leading to discrepancies between social salience and ecological indicators (Papworth et al. 2009). Such divergence can influence how biodiversity change is recognised, prioritised, and addressed, with implications for conservation relevance and local engagement (Bennett et al. 2017). Quantifying whether social and ecological salience align or diverge is therefore essential for understanding human–wildlife relationships in coupled social–ecological systems.

Such divergence between social and ecological salience is significant in arid landscapes with long histories of human–wildlife coexistence, where livelihoods and resource use have developed in close connection with wildlife. The Sahara Desert and Sahel represent one of the most extreme examples of such coupled social–ecological systems, characterised by high environmental variability, biodiversity adapted to aridity, and a strong, long-standing dependence of human societies on natural resources (Noy-Meir 1973; Brito et al. 2014). Ecological fragility in this region is further amplified by climate change, which intensifies resource scarcity and variability, affecting both wildlife populations and human livelihoods that are tightly linked to environmental conditions (Loarie et al. 2009; Durant et al. 2013). Within this region, the Aïr and Ténéré National Nature Reserve (ATNNR) provides a particularly suitable context for examining the relationship between LEK, social salience, and ecological indicators. Established as a multiple-use protected area, the ATNNR was explicitly designed to allow predominantly nomadic pastoral societies to continue their residence and resource use, including access to water, pasture, and wild resources (Newby 1986, 1992). In such settings, understanding how local communities perceive the costs and benefits of living within or near protected areas, together with their socio-demographic context, ecological knowledge, and values attributed to wildlife and landscapes, is central to interpreting human–wildlife relationships (Allendorf 2010; Bragagnolo et al. 2016; Afriyie et al. 2022). At the same time, the reserve has experienced severe declines in wildlife linked to armed conflict, civil unrest, and political instability, with long-lasting effects on large vertebrate populations (Newby et al. 2016; Brito et al. 2018). These dynamics have created pronounced contrasts between historical presence, current low abundance, and

perceived importance of wildlife species, making the ATNNR a particularly suitable setting in which to assess whether, and how, social salience aligns with ecological evidence of wildlife persistence and decline.

Within the ATNNR, the dama gazelle (*Nanger dama*) serves as a focal species for examining how social salience aligns with or diverges from ecological salience. Formerly widespread across Sahelo-Saharan ecosystems, the species has undergone severe population declines driven by overhunting, armed conflict, and increasing environmental and anthropogenic pressures, and is now classified as Critically Endangered (Newby & Grettenberger 1986; Newby et al. 2016; IUCN SSC Antelope Specialist Group 2016). Despite its current low abundance, the dama gazelle retains strong symbolic and cultural significance in the region, making it well-suited for exploring potential mismatches between perceived importance and ecological presence. In addition, the ATNNR supports a diverse community of sympatric wildlife species and domestic feral species that differ in ecological traits, visibility, and interactions with people (Authors, in prep), allowing a comparative assessment of social salience across species with contrasting levels of abundance and detectability. By integrating LEK and perceptions with independent ecological indicators derived from camera-trap monitoring, this study uses the dama gazelle and associated wildlife community to examine how social and ecological salience align or diverge under conditions of biodiversity loss in a coupled social–ecological system. By explicitly connecting LEK with independent ecological indicators, this study advances beyond mere descriptions of wildlife perceptions. It examines how the social and ecological significance of various species either align or differ. This method offers a useful framework for analysing how perceived importance corresponds with ecological presence in arid social–ecological systems.

This study aimed to improve understanding of the LEK, perceptions, and social salience of wildlife among communities living in the ATNNR (Niger), and to examine how these social dimensions relate to ecological indicators of wildlife presence. While the analysis considers the broader wildlife community, particular attention was given to the dama gazelle due to its current low abundance and social and cultural significance. Specifically, we aimed to 1) document LEK and perceptions of wildlife ecology and population dynamics, including perceived past and current status, trends, and spatial distribution; 2) assess perceptions of human uses of wildlife and human–wildlife interactions, including motivations for hunting and perceived impacts; 3) quantify the social salience of wildlife species using free listing approach; and 4) compare social salience with ecological salience derived from camera trap data to evaluate the degree to which social and ecological salience align or diverge across species.

Achieving these aims requires conceptual clarity on how LEK informs social salience and how this differs from attitudes, values, and perceived population trends. Social salience is defined as the relative cognitive prominence of a species within LEK, as reflected in recall frequency and ordering during free-listing exercises (Smith & Borgatti 1997). Social salience indicates how conspicuous and socially prominent a species is, without implying a positive valuation. Attitudes reflect evaluative feelings, such as liking or disliking. Values pertain to normative meanings, whether instrumental, relational, or intrinsic. Perceived population trends involve interpretations of how species numbers change over time. Although these dimensions are interconnected, they remain conceptually separate, and social salience can be viewed positively or negatively based on species–human interactions.

6.2 Methods

6.2.1 Study site and local communities

The study was conducted within the Aïr and Ténéré National Nature Reserve (ATNNR), located in the northern part of the Agadez Region, in the Saharan zone of Niger (17°10 ' to 21°30'N, 8°20 ' to 11°00 E, Figure 6.1). Covering approximately 77.360 km², ATNNR is one of the largest protected areas in Africa. ATNNR was established in 1988 as part of the UNESCO World Heritage Site, Biosphere Reserve (Aïr et Ténéré), Ramsar Site (Gueltas et Oasis de l'Aïr) and an Important Bird and Biodiversity Area.

Within its hyper-arid environment, the ATNNR represents an island of the West Saharan montane xeric woodlands at the interface between the South Saharan steppe and the Sahelian Acacia savanna ecoregions (Olson et al. 2001). The climate is characterised by extreme aridity and high temperatures. In January, temperatures can drop just below freezing at around 8.5°C at night, while in May, temperatures can reach around 45°C. Rainfall is concentrated between June and September, typically ranging from 10 to 50 mm per event, with an average annual precipitation of 110 mm.

The human population inhabiting the Aïr massif is predominantly Kel Tamacheq (Touaregs), composed of two large socio-cultural groups. The first are the Kel Ferwan and the Kel Fadaï, who are the main breeders of camels, whereas the second are the Kel Ewey and the Imikkitan, who combine livestock breeding with oasis-based agriculture, particularly gardening in valleys and perennial water sources (Abdoulkader 2005). The population of the ATNNR is mainly distributed across the

communes of Iférouane, Timia and Tabelot, with an estimated population of approximately 84.800 inhabitants (Institut National de la Statistique, 2021).

Livelihoods in the ATNNR are diverse but remain strongly dependent on natural resources. Pastoralism is the dominant activity, with herds composed mainly of camels, goats, sheep, and donkeys. Livestock mobility is generally localised rather than strongly transhumant, reflecting the spatial concentration of key resources such as water points and productive wadis. Agriculture plays a complementary role, particularly in Timia, where market gardening is well developed. Onions and citrus fruits are the principal crops and represent an important source of income through regional and international trade. Additional economic activities include transport, commerce, artisanal gold panning, and small-scale handicrafts (UNESCO, 2021).

The ATNNR also has an exceptional cultural heritage. Rich palaeontological deposits, including dinosaur remains and fossilised trees, occur in the Gadafaoua area, while the Aïr massif contains numerous Palaeolithic and Neolithic sites and rock engravings (Giazzi et al., 1996), evidencing a long history of human occupation in this now extreme desert environment

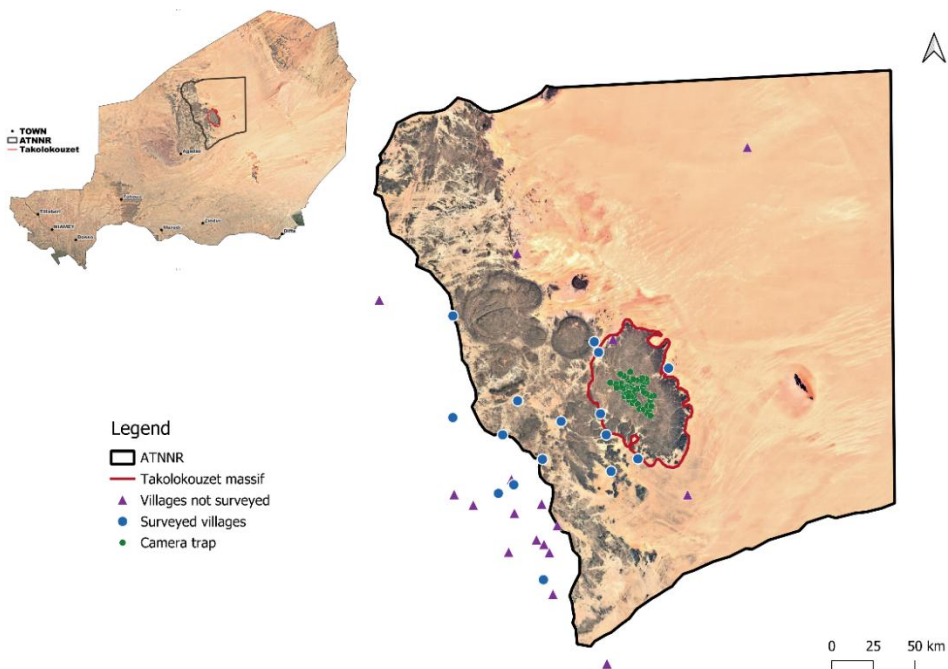


Figure 6.1. The location of the Air and Tenere National Nature Reserve in Niger, and human settlements (villages) where the study was conducted.

6.2.2 Data collection

Data were collected from November 2021 to March 2022 through semi-structured individual interviews with residents within and near the ATNNR. These interviews used a structured questionnaire, created in French and delivered orally in Tamacheq and Hausa. The principal author (ARMZ), a native speaker with an inherent knowledge of local culture and environment, led all interviews, with assistance from a second trained native speaker to ensure precise translation, understanding, and interpretation of responses. Linguistic data on vernacular terminology were documented during interviews and supplemented by consultation with local Tamacheq speakers to ensure lexical accuracy and contextual interpretation.

The questionnaire was pre-tested through pilot interviews with 10 respondents to assess clarity, cultural appropriateness, and question sequencing, and was refined accordingly before full deployment. Data collection used opportunistic sampling across selected settlements, an approach considered appropriate given the highly mobile pastoral livelihoods, dispersed settlement patterns, and logistical constraints typical of this hyper-arid region. At each location, the study objectives were explained publicly to community members, after which volunteers were invited to participate in individual interviews. This procedure followed locally accepted norms of engagement and ensured voluntary, informed participation.

In total, 115 respondents were interviewed across more than 15 localities within the study area (Figure 1), providing broad spatial coverage across the ATNNR. Participation was voluntary, and all interviews were conducted anonymously. While this sampling strategy does not allow statistical representativeness of the broader population, it is well-suited for documenting patterns of LEK, social salience, and shared perceptions across communities with broadly similar livelihood systems and environmental exposure. This approach is particularly appropriate for exploring how wildlife species are recognised, remembered, and valued within coupled social-ecological systems, rather than for estimating population-level prevalence of attitudes or behaviours. Accordingly, the aim was not statistical representativeness but the identification of shared patterns of LEK and social salience across communities with similar livelihoods and environmental exposure.

6.2.3 Questionnaire (to describe the logic of the questionnaire)

The questionnaire was structured in five parts and focused on the general knowledge, perception and attitude towards wildlife, their presence in the environment, threats, the benefits that a named wildlife species can provide, and how people act in regard to species (Supplementary material 3). The first part is a

free list exercise to evaluate the competence of their knowledge of wildlife, in which the respondents cite the wildlife in their areas, along with their diets and habitat types.

Secondly, part of the questionnaires started with general open-ended questions on wildlife to evaluate the knowledge of respondents, especially of the dama gazelle and then finally information on the socio-economic status of respondents.

The second part relates to wildlife in general, on the abundance and the projection of the evolution of wildlife in the future.

The survey then continues with questions on the perception of wildlife in the Air, the attitude between man and wildlife, local knowledge on the dama gazelle, and finally, information on the socio-demographic situation of respondents.

6.2.4 Free listing and salience index calculation

To quantify the social salience of wildlife species, we analysed free-listing data collected during individual interviews. Respondents (n=115) were asked to list wild animal species present in their region. Free listing provided information on species recognition and relative prominence within LEK.

Social salience was quantified using the Smith salience index (Smith & Borgatti 1997), which integrates species Frequency across respondents, the mean position within individual lists, and the total number of respondents. The salience index was calculated as:

$$S = \frac{1}{N} \sum \frac{Li - Rij + 1}{Li}$$

where Li represents the length of the list provided by respondent i, Rij is the rank of species j within the given list Li, and N is the total number of respondents. The salience index ranges from 0 to 1, where 1 indicates the most salient species, i.e., those mentioned more frequently and earlier in the list, reflecting greater prominence.

To assess whether observed salience values deviated from random expectations, we used a Monte Carlo null model following Chaves et al. (2019). Observed salience, frequency, and mean position for each species were compared against null distributions generated from 1,000 simulated free-list datasets with the same number of respondents (n = 115) and total (across all respondents) species richness (n = 33). Significance testing was implemented using the R scripts provided by Chaves et al. (2019). Species were considered significantly salient when observed

values had p-values < 0.05 for salience, frequency, or mean position relative to the null expectation.

In this study, salience derived from free listing is interpreted as an indicator of social salience, representing the relative prominence of wildlife species within local ecological knowledge. These estimates were subsequently compared with independent measures of ecological salience derived from camera-trap data.

6.2.5 Respondents' perceptions and attitudes to wildlife

To estimate the effects of respondents' socio-demographic characteristics (predictor variables: age, education level, and occupation) on their perceptions of wildlife, specifically whether they perceive any problems related to wildlife (binary yes/no), a binary logistic regression was applied. Analyses were conducted in the IBM SPSS Statistics (Version 29).

The association between the attitudes towards wildlife species (categorical variable: liked vs. disliked) and perceived abundance trends (categorical variable: increasing vs. decreasing) was tested using Pearson's chi-square goodness-of-fit test. To visualise the relationship between attitudes and perceived abundance trends, species were grouped into broad functional categories (ungulate, carnivore, small herbivore, birds), and associations were illustrated using a Sankey diagram generated with the 'ggsankey' package in R (R Core team, 2025).

6.2.6 Camera-trap data collection and capture rate calculation

Camera-trap data were collected as part of a long-term wildlife monitoring programme conducted in the ATNNR between 2017 and 2020. Camera traps were deployed on the Takolokouzet massif, located in the central part of the reserve (Figure 1) in a 2x2 km grid-based design, targeting key wildlife movement corridors and resource areas identified through ranger knowledge and previous surveys. A total of 13 camera traps were deployed in 5 consecutive grids following a standardised protocol; full details of camera specifications and settings are provided in Zabeirou et al. (2025)

Cameras were installed approximately 40–50 cm above ground level and operated continuously, recording images triggered by motion. Sampling effort was quantified as the total number of camera-trap days per station, accounting for variation in deployment duration among sites. Images were classified to species level, and detections of the same species at the same camera trap were considered independent events when separated by 30 minutes.

Camera-trap capture rates for each detected species in the area were used as a relative indicator of ecological salience reflecting encounter likelihood rather than absolute abundance. Capture rates (CR) were calculated as the number of species-independent events per 100 days divided by the number of deployed days for each camera (Rowcliffe et al. 2008). Statistical parameters (mean, median, SD, SE, minimum and maximum) were calculated across camera stations for each species. Spatial analyses were conducted in R (R Core team, 2025).

6.2.7 Relationship between social and ecological salience

To examine the relationship between the social and ecological salience of wildlife species, we assessed the association between the Smith social salience index derived from free listing and ecological salience operationalised as mean species-specific capture rates from camera-trap data. The strength and direction of the association were tested using Spearman's rank correlation coefficient, based on species-level salience values. The analysis was restricted to wildlife species detected in both datasets ($n = 12$) to ensure direct comparability between social and ecological measures.

6.3 Results

6.3.1 Socio-demographic profile of local communities

Most respondents were men (71%) and heads of households (Table 6.1). The mean household size was 5 individuals ($SD \pm 4.37$), comprising on average 2 adults and 3 children. The mean age of respondents was 46.9 years ($SD \pm 15.5$), covering the full range of adulthood up to high age (>70 years); the most respondents were from the age category 31 – 40 years. The majority of respondents had no formal education (84%), and livestock herding was the primary livelihood for 63% of respondents. Only one respondent had tertiary education. Full details of respondent socio-demographic profile are given in Table 6.1.

Table 6.1. Socio-demographic profile of the respondents.

Variable		N° respondents	Percentage
Gender	Male	82	71%
	Female	33	29%
Age	20-30	21	18.2%
	31-40	32	27.8%
	41-50	14	12.1%

	51-60	20	17.5%
	61-70	20	17.5%
	> 70	8	6.9%
Household size	<5	74	64%
	>5	41	36%
Occupation	Farmer	21	18%
	Herder	72	63%
	Gold miner	8	7%
	Trade	13	11%
	State employee	1	1%
Education	No formal education	96	84%
	Primary	13	11%
	Secondary	5	4%
	University	1	1%

6.3.2 Social salience and perceptions of wildlife

A total of 33 wildlife species were mentioned by the 115 respondents in the free listing exercise (Table 6.2). Of the species listed, 68% were herbivores, 27% carnivores, and 5% omnivores. Species with the highest social salience, as indicated by Smith salience indices, including the most frequently listed, were the dorcas gazelle and the African wolf with indices of 0.68 and 0.67, respectively, followed by Barbary sheep, gazelle dama, patas monkey, and Cape hare as other significantly salient species with a salience index > 0.2 (Table 6.2).

Regarding attitudes towards wildlife species, the dorcas gazelle was most frequently cited as the favourite species (73%), followed by the Barbary sheep (51%) and the dama gazelle (36%). Forty-seven percent of respondents considered these species non-harmful to humans, livestock, and crops. Positive attitudes were also attributed to the aesthetic value of wildlife (they add beauty to nature, 33%), and 4% of respondents cited cultural value (these animals "bring luck" and "are useful").

In contrast, the African wolf was disliked by most respondents (86%), followed by the patas monkey (25%), both mainly due to perceived attacks on livestock and crops, respectively. Mixed attitudes were reported toward five species, namely the Cape hare, squirrel, elephant, giraffe, and cheetah (Figure 6.2).

Overall, the majority of respondents (95%) expressed a positive attitude towards the presence of wildlife in the area. Aesthetic appreciation was the dominant reason (37%), followed by perceived economic benefits related to tourism

and development projects (25%), and mentioned contributions of wildlife to ecological balance (4%).

Despite these positive attitudes, 80% of respondents reported experiencing problems related to wildlife, most frequently citing African wolves, patas monkeys, and caracals. Perceiving wildlife as problematic was not associated with respondent age, education level, or occupation (likelihood-ratio $\chi^2 = 7.5$, $df = 7$, $p = 0.38$; Nagelkerke pseudo- $R^2 = 0.10$). Proposed solutions included killing harmful species (60%), either by using poison or traps; establishing designated wildlife areas (18%), and preventative measures such as fencing and guarding livestock or crops (14%).

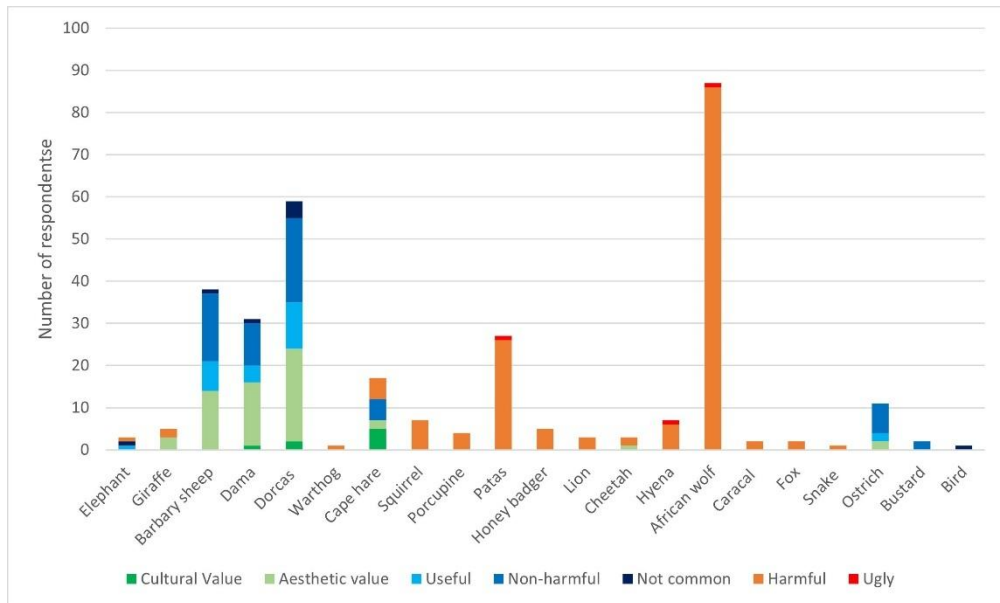


Figure 6.2. Frequency of reasons of local people for positive (like) and negative (dislike) perceptions of wildlife species in the villages located in the Air and Tenere National Nature Reserve in Niger.

Table 6.2. Animal species cited in 115 free-lists provided by respondents from people living in the surroundings of ATNNR (Niger), followed by their values of salience (sensu Smith and Borgatti 1997), frequency in the lists, the species' mean position, and respective p-values. The value marked with * indicates statistically significant values ($p < 0.05$). The species in the table are arranged in descending order of salience index. Abbreviation: P indicates species is present in the area, and A indicates absent in the area.

Species	Scientific name	Present/ Absent	Salience	Salience (p-value)	Frequency	Frequency (p-value)	Mean position	Mean position (p-value)
Dorcas	<i>Gazella Dorcas</i>	P	0.684	0.000*	111	0.000*	2.955	0.012*
Jackal	<i>Canis aureus</i>	P	0.677	0.000*	107	0.000*	2.738	0.003*
Barbary Sheep	<i>Ammotragus lervia</i>	P	0.510	0.000*	97	0.000*	3.598	0.179
Dama	<i>Nanger dama</i>	P	0.260	0.000*	50	0.000*	4.120	0.432
Patas	<i>Erythrocebus patas</i>	P	0.258	0.000*	54	0.000*	3.833	0.336
CapeHare	<i>Lepus capensis</i>	P	0.238	0.000*	50	0.000*	4.040	0.506
Squirrel	<i>Xerus erythropus</i>	P	0.192	0.002*	51	0.000*	4.882	0.048*
Ostrich	<i>Struthio camelus</i>	P	0.128	0.270	31	0.034*	5.065	0.022*
Hyena	<i>Hyaena hyaena</i>	P	0.124	0.323	32	0.021*	5.531	0.002*
Honey Badger	<i>Mellivora capensis</i>	P	0.099	0.290	23	0.499	5.261	0.009*
Porcupine	<i>Hystrix cristata</i>	P	0.078	0.067	15	0.041*	4.267	0.316
Caracal	<i>Felis caracal</i>	P	0.076	0.058	19	0.239	5.368	0.005*
Bustard	<i>Neotis nuba</i>	P	0.070	0.031*	19	0.239	5.579	0.002*

Fox	<i>Vulpes ruppelli</i>	P	0.059	0.007*	12	0.005*	4.417	0.218
Lion	<i>Panthera leo</i>	A	0.054	0.004*	17	0.116	6.412	0.000*
Rock Hyrax	<i>Procavia capensis</i>	P	0.035	0.000*	9	0.000*	4.333	0.276
Cheetah	<i>Acinonyx jubatus</i>	P	0.028	0.000*	6	0.000*	5.000	0.032*
Giraffe	<i>Giraffa camelopardalis</i>	A	0.024	0.000*	6	0.000*	5.667	0.001*
Baboon	<i>Papio Anubis</i>	P	0.018	0.000*	4	0.000*	5.500	0.003*
Elephant	<i>Loxodonta Africana</i>	A	0.017	0.000*	4	0.000*	5.000	0.032*
Addax	<i>Addax nasomaculatus</i>	P	0.015	0.000*	3	0.000*	4.667	0.103
Genet	<i>Genetta genetta</i>	P	0.015	0.000*	3	0.000*	4.333	0.276
Oryx	<i>Oryx dammah</i>	P	0.014	0.000*	3	0.000*	5.000	0.032*
Bird	---	P	0.013	0.000*	5	0.000*	4.600	0.133
Guinea Fowl	<i>Numida meleagris</i>	P	0.013	0.000*	2	0.000*	3.500	0.139
Wild cat	<i>Felis sylvestris</i>	P	0.011	0.000*	2	0.000*	4.500	0.180
Fennec	<i>Fennecus zerda</i>	P	0.008	0.000*	2	0.000*	5.500	0.003*
Lizard	<i>Agama agama</i>	P	0.008	0.000*	1	0.000*	2.000	0.000*
Urchin	---	P	0.004	0.000*	1	0.000*	4.000	0.495
Snake	---	P	0.004	0.000*	1	0.000*	4.000	0.495

Warthog	<i>Phacochoerus aethiopicus</i>	P	0.003	0.000*	3	0.000*	10.000	0.000*
Crow	<i>Corvus albus</i>	P	0.002	0.000*	1	0.000*	5.000	0.032*
Vulture	---	P	0.001	0.000*	1	0.000*	8.000	0.000*

6.3.3 Perceptions of wildlife population trends

Most respondents (96%) perceived wildlife as more abundant in the past than at present. Only 2% reported no change in wildlife abundance, while another 2% indicated that they had no opinion. Looking ahead, 68% of respondents believed that wildlife populations would continue to decline, whereas 32% believed that populations could increase if effective conservation and protection measures were implemented and properly enforced. As one respondent noted, *“In ten years’ time, if we strengthen protection measures, there is a chance of saving a few remaining species, although we have already lost more than half of the species that once existed.”*

Attitudes toward wildlife species were strongly associated with perceived population trends (Pearson’s $\chi^2 = 152$, $df = 1$, $p < 0.001$). Species that were positively valued were predominantly perceived as declining (119 cases) rather than increasing (11 cases), whereas negatively valued species were more frequently perceived as increasing (87 cases) than declining (9 cases). As illustrated in Figure 6.3, this relationship was structured by functional group: positive attitudes were largely directed toward herbivorous species and associated with perceived declines, while negative attitudes were concentrated on carnivores and omnivores and linked to perceived increases.

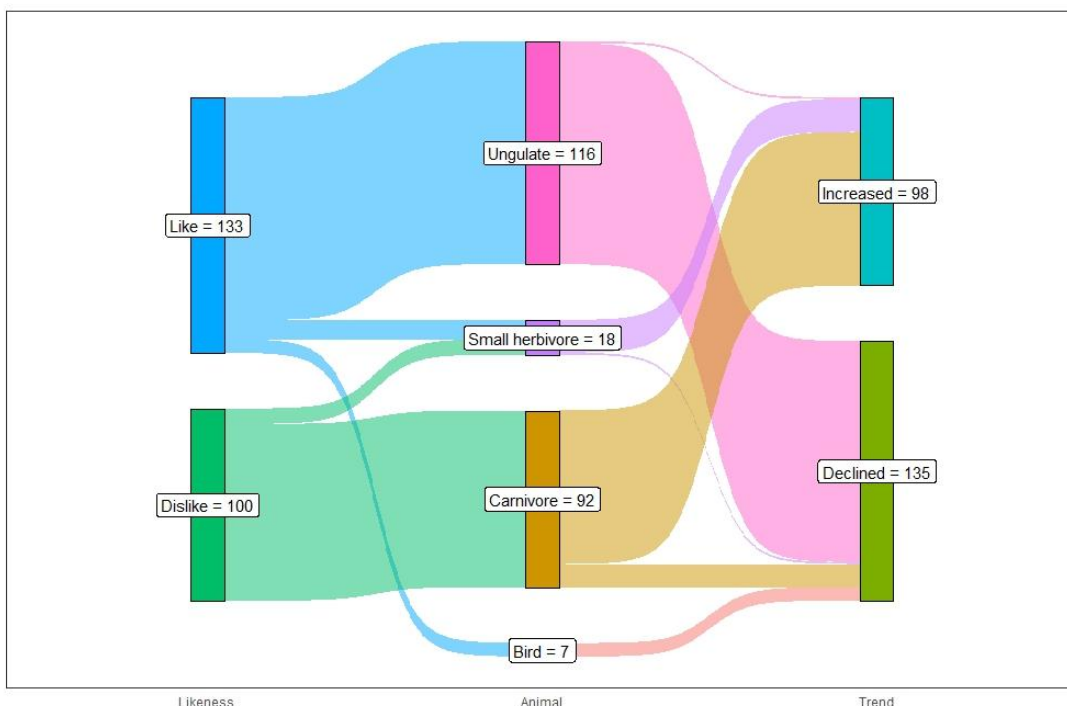


Figure 6.3 Sankey diagram illustrating the relationships between attitudes towards wildlife species (Likeness), functional groups (Animal), and perceived population trends (Trend), based on interview responses. The width of the flows represents the number of responses linking attitudes to functional groups and perceived trends, highlighting contrasting perceptions of population change between positively and negatively valued taxa.

6.3.4 Knowledge and perceptions of the dama gazelle

Most respondents (68%) reported they had seen the dama gazelle "with their own eyes" at least once, with a frequency of sightings described as occasional by 54% of respondents, frequent by 40%, and very rare by 6%. Most reported sightings occurred more than 20 years ago (53%), followed by 10 years ago (23%), and only 24% reported sightings within the last year.

Most respondents (95%) found out about the presence of the dama gazelle while traveling or seeking pasture for their livestock. The remaining 5% mentioned discovering dama gazelles during gold mining activities.

The majority of respondents (95%) stated that they knew the habitat of the dama gazelle. Respondents referring to approximately 50 years ago (70%) indicated that dama gazelle occurred in almost all the valleys of the reserve, 15% additionally

mentioned the Takolokouzet massif and the edge of the Ténéré desert, and 15% reported no knowledge.

Perceptions of distribution 10 years ago were more uncertain: 37% of respondents did not answer this question, and 18% of respondents reported not knowing where the dama gazelle occurred. 42% of respondents reported that it could be found in only some rare valleys and mentioned sites such as near the Ténéré Desert, Tafidet (valley), Takolokouzet Massif, Tchibossin, or Yarsut. 3% perceived the species as extinct.

In perception of the current situation, 58% of respondents reported that the dama gazelle occurred only on Takolokouzet Massif, 36% did not know their current distribution, and 6% perceived the species as extinct.

Human activities were identified as the primary threat to the dama gazelle by 90% of respondents, whereas drought was cited by 2%, and 8% reported no opinion. Opinions on hunting were mixed: 43% believed dama gazelles were not hunted, 34% believed they were hunted, and 23% did not know. Most respondents (89%) were aware that dama gazelle is a protected species.

Respondents perceived the dama gazelle as a significant and important species for them. Most of respondents (54%) stated that the dama gazelle had a particular significance for its aesthetic and cultural value, and as a sign of a good luck. One respondent claimed in particular: *"The dama gazelle is considered to be the queen of wildlife, so if you meet a dama gazelle on a trip, it's sure to be a promising one"*. 26% reported no particular significance, and 20% did not know.

Table 6.3. Values for wildlife species expressed by local communities in the RNNAT, Niger, categorised following the framework described by Chan et al. (2016).

Type of value	Articulated value	N°	Example quotes
Instrumental	Economic	27	The presence of wildlife generates money for us through tourists who can buy our handicrafts and the sale of hunting trophies...
	Development	1	Thanks to wildlife, we benefit from development projects (education, health, and income-generating activities, etc.).
Intrinsic	Ecological	4	The presence of wildlife helps to establish the ecological balance of Nature
Relational	Subsistence	10	Wildlife provides us with meat for consumption
	Cultural	4	Wildlife is seen as a good luck charm, bringing rain, and a sign of good luck when certain species are spotted during a trip.
	Aesthetic	40	We enjoy the beauty of nature, with wildlife embellishing our environment,
	Mental and physical health	5	The non-harmful species (antelopes) comforts our mind health and the security of our livestock, while certain harmful species (carnivores) constitute moral and physical threats.
	Identity	7	Our wildlife allows us to get to know our area, it's a part of our heritage.
	Tourism	12	Our area has become a tourist attraction thanks to the unique fauna and the beauty of our landscape.

6.3.5 Ecological salience

Camera trapping recorded 17 animal species, including wild, feral, and domestic species, in the Takolokouzet massif (Table 6.4). Mean species richness per camera trap was 6 species (SD ± 2.3), ranging from 1 to 11.

Feral donkey had the highest capture rate, followed by feral camel, and dorcas gazelle as the most frequently recorded wild species. Dog, sheep, and caracal had the lowest capture rates, each recorded only once (Table 6.4).

Table 6.4 Summary statistics of camera trap capture rates for species recorded in the Takolokouzet Massif within the Air and Ténéré National Nature Reserve, Niger .

Species	Scientific name	Mean	Median	SD	S	M	Max
African wolf	<i>Canis lupaster</i>	0.5	0	1.7	0.	0	12.
Barbary sheep	<i>Ammotragus lervia</i>	0.7	0	2.8	0.	0	21.
Camel	<i>Camelus dromedarius</i>	11.	8.54	10.	1.	0	44.
Cape hare	<i>Lepus capensis</i>	6.4	0.82	15.	1.	0	109
Caracal	<i>Caracal caracal</i>	0.0	0	0.0	0.	0	0.4
Common genet	<i>Genetta genetta</i>	0.0	0	0.2	0.	0	2.0
Crested porcupine	<i>Hystrix cristata</i>	0.3	0	1.6	0.	0	12.
Dama gazelle	<i>Nanger dama</i>	1.6	0.76	2.9	0.	0	17.
Dog	<i>Canis lupus domesticus</i>	0.0	0	0.0	0	0	0.2
Donkey	<i>Equus asinus</i>	32.	24.3	32.	4.	0	137
Dorcas gazelle	<i>Gazella dorcas</i>	7.7	4.84	10.	1.	0	45.
Goat	<i>Capra hircus</i>	2.5	0	7.3	0.	0	42.
Honey badger	<i>Mellivora capensis</i>	0.0	0	0.1	0.	0	0.8
Patas monkey	<i>Erythrocebus patas</i>	1.2	0.51	1.6	0.	0	7.0
Rüppel's fox	<i>Vulpes ruppelli</i>	0.2	0	0.6	0.	0	2.9

Sheep	<i>Ovis aries</i>	0.0	0	0.0	0.	0	0.4
		1	6	01	9		
Wild cat	<i>Felis sylvestris</i>	0.2	0	0.6	0.	0	2.5
		5	08	6			

6.3.6 Relationship between social and ecological salience

Social and ecological salience was positively associated across wildlife species (Spearman's $\rho = 0.73$, $p = 0.01$; Figure 6.4). Species nevertheless varied markedly in their position relative to the fitted relationship. Dorcas gazelle and Cape hare exhibited high ecological salience relative to their social salience, whereas African wolf and Barbary sheep showed lower capture rates than expected given their social salience. Dama gazelle occurred close to the fitted line, indicating close correspondence between social and ecological salience. Patas monkey showed a slightly higher social salience than ecological salience. Carnivores (except the African wolf) had very low ecological salience; however, their social salience was comparatively higher. Overall, the distribution of species around the fitted line highlights variation in the alignment between ecological occurrence and social prominence

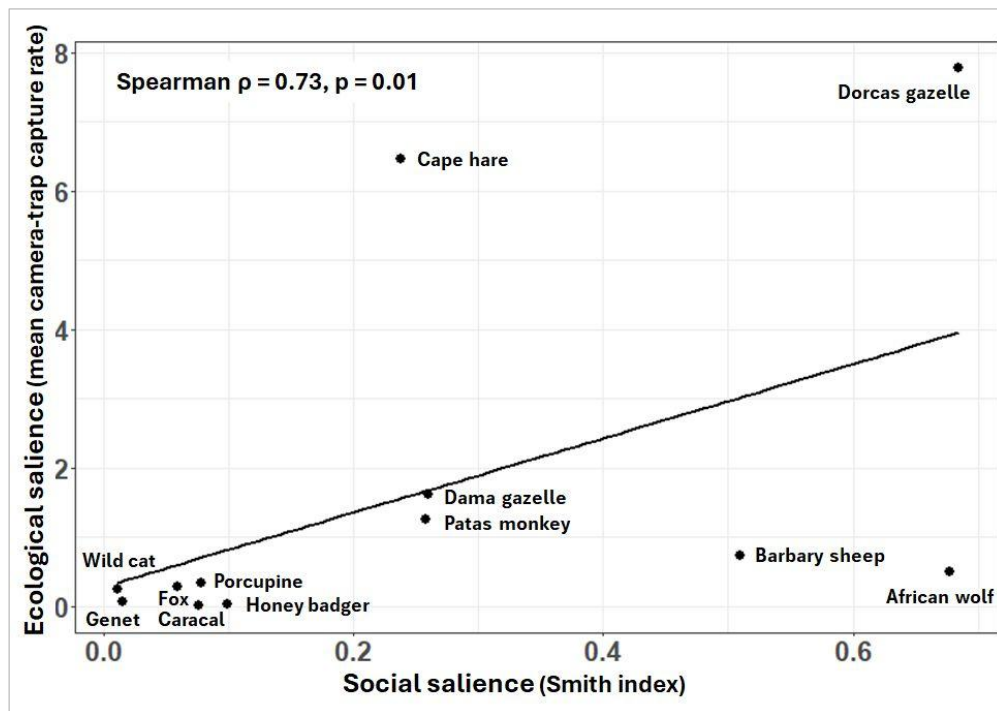


Figure 6.4. Relationship between social and ecological salience of wildlife species in the Aïr and Ténéré National Nature Reserve, Niger.

6.4 Discussion

We integrated measures of social importance and ecological salience to examine how local ecological knowledge and human perceptions interact with ecological realities to shape wildlife conservation in a fragile arid social-ecological system. Biological status, reflected in patterns of abundance and behaviour, provides an empirical basis for assessing population viability and guiding management interventions. However, conservation does not operate as an isolated ecological process (Bennett et al. 2017). Local communities are active components of social-ecological systems,

influencing species persistence through their daily activities, livelihoods, and relationships with wildlife and the environment (Ostrom 2009). Local ecological knowledge and perceptions mediate how people living alongside species recognise, value, tolerate, or act upon them. This, in turn, affects the effectiveness of conservation measures (Berkas 2004; Raymond et al. 2010). Integrating these knowledge systems creates a synergistic, multidimensional perspective in which ecological processes and social meaning are considered together. This approach moves beyond parallel assessments of wildlife and people, enabling conservation actions to be tailored not only to species' biological urgency but also to how species are perceived and valued within local social contexts. Our results revealed a strong positive correlation between social and ecological salience across wildlife species (Spearman's $\rho = 0.73$; Figure 4). This pattern suggests that communities living in a hyper-arid desert environment, whose livelihoods depend directly on natural resources such as forage and water, remain connected and sensitive to wildlife communities with which they coexist.

6.4.1 Alignment and mismatch of social and ecological salience

This contrasts with the patterns observed in systems undergoing rapid socio-economic transformation or environmental change where LEK is often eroded or disconnected from ecological reality (Gómez-Baggethun et al., 2013; Campos et al., 2021). In the ATNNR context, the persistence and continual updating of LEK appear to contribute to the resilience of the social–ecological system under conditions of climatic uncertainty and resource scarcity. This interpretation is consistent with evidence that LEK is most robust where it remains embedded in everyday practices, collective memory, and shared cultural responses to environmental stress (Gómez-Baggethun et al., 2012).

Importantly, the observed correlation does not imply uniformity of knowledge or perception across all respondents or species. Instead, it reflects the relatively homogeneous social context of our respondents. In the ATNNR, local communities share similar livelihoods, interactions with the environment, and direct dependence on scarce natural resources, i.e. factors that likely reinforce the strong correspondence observed between social and ecological salience. In contrast, studies comparing socially heterogeneous stakeholders often report weaker relationships between perceived importance and ecological prominence, as values, experiences, and exposure to wildlife diverge across social groups (Schwermer et al., 2021; Miller Hesed et al., 2022). This indicates that the strength of alignment between social and ecological salience is context dependent, reflecting both ecological conditions and the extent to which people's lives remain closely connected to local ecological processes.

6.4.2 Species-level patterns of alignment and mismatch

. At the species level, the strong overall relationship between social and ecological salience masked structured, non-random variation among taxa (Figure 4). These variations are informative: they reveal the mechanisms through which ecological prominence is translated (or not) into social importance. Across species, alignment depended not simply on detectability, but on the interaction between biological traits, perceived harmfulness, livelihood relevance, and culturally embedded meanings.

Herbivorous ungulates generally showed high social salience and predominantly positive attitudes relative to carnivores and omnivores. Respondents consistently described ungulates as non-harmful to people, livestock, and crops - an attribute repeatedly emphasised as central to their positive

valuation. Beyond the absence of harm, ungulates were associated with aesthetic appreciation, good fortune (e.g. rain or luck), and potential economic value through tourism or subsistence use. These relational and symbolic dimensions elevated their social prominence.

However, even within ungulates, alignment between social and ecological salience was not uniform. The dorcas gazelle, one of the most ecologically salient species based on capture rates, was comparatively under-represented in social salience rankings. Its small body size, behavioural plasticity, and widespread occurrence 'may render it socially less distinctive, resulting in ecological salience exceeding perceived social importance. In contrast, the Barbary sheep showed high social salience despite relatively low ecological salience. Here, recognisability, larger body size, and its association with rugged mountainous terrain likely amplified its symbolic and perceptual prominence beyond encounter frequency alone. These contrasts illustrate that ecological detectability is mediated by perceptual filters shaped by species traits and landscape symbolism.

Carnivores and primates displayed a different pattern. Species such as the African wolf and patas monkey showed mismatches characterised by comparatively high social salience but predominantly negative valence relative to their ecological salience. They were strongly associated with livestock predation or crop damage and were therefore widely disliked. This negative social salience persisted despite low capture rates, indicating that social representations were structured more by perceived risk and conflict experiences than by current population status.

Historical and cultural narratives further reinforce these patterns. Earlier accounts describe Touareg communities of the Aïr as viewing the African wolf as a favourable omen for successful hunts (Nicolaisen, 1963). More broadly, sociozoological classifications documented elsewhere in the region place the most useful (corresponding to 'edible') and least threatening species, such as gazelles, at the pinnacle of social valuation, while hyenas occupy the most negative positions. Legends describing hyenas as dangerous or misbehaving, including beliefs that they can transform into humans to attack livestock or villagers, appear to have crystallised enduring negative perceptions. As a result, hyenas remain strongly negatively perceived despite local extinction (Costa, 2013). This illustrates how culturally transmitted narratives can decouple social salience from present ecological reality.

A further dimension of mismatch emerged through the inclusion of species that do not currently occur in the ATNNR, or occur only outside the study area, such as giraffe, elephant, lion, addax, scimitar-horned oryx, and cheetah (Table 2). Their presence in the free lists reflects a combination of historical memory and extra-local ecological knowledge acquired through mobility, social networks, media, or experience in other regions of Niger where some of these species persist. Social salience is therefore not restricted to immediate ecological encounter; it may incorporate broader spatial and temporal reference frames. These species retain symbolic importance rooted in historical abundance and intergenerational transmission of knowledge. Such social memory may buffer against the erosion of awareness associated with shifting baseline syndrome, maintaining expectations of wildlife richness even under prolonged ecological decline. In this way, remembered species can continue to shape conservation aspirations and restoration narratives despite their current absence.

Perceptions of population trends were primarily structured by social rather than ecological salience. The tendency for ungulates with high social salience to be perceived as declining likely reflects heightened sensitivity to the loss of aesthetically, culturally, or economically valued species. Declines in such species may therefore be noticed earlier or interpreted more pessimistically, particularly where historical baselines and expectations of abundance remain important (Papworth et al., 2009; Soga & Gaston, 2018). In contrast, disliked species, particularly carnivores, were more frequently perceived as increasing. This perception may stem from their behavioural flexibility and capacity to persist in

human-modified landscapes (Carter & Linnell, 2016; Newsome et al., 2015; Crooks et al., 2011), combined with the disproportionate psychological impact of conflict-related encounters. Even infrequent livestock predation or crop damage can leave strong emotional and economic impressions, amplifying perceptions of population growth irrespective of actual trends. Thus, social salience influences not only which species are prioritised, but also how population trajectories are interpreted.

Finally, spatial correspondence between ecological and social datasets warrants consideration. Although both camera trapping and interviews were conducted within the ATNNR, camera placement did not necessarily coincide with areas most frequently used by respondents. However, most interviewees were nomadic pastoralists with wide-ranging mobility, increasing the likelihood that their knowledge spans areas overlapping with camera locations. Nevertheless, conflict-prone species such as African wolf or patas monkey may be encountered more often near settlements, livestock enclosures, or cultivated fields—areas not systematically targeted by camera deployment. Some discrepancies between ecological and social salience may therefore reflect differential spatial exposure rather than perceptual bias alone. Acknowledging this partial spatial overlap is essential for cautious interpretation of species-level divergence.

Taken together, these patterns demonstrate that alignment between social and ecological salience is inherently species-specific. Ecological occurrence or detectability alone does not determine social importance. Instead, salience emerges from the interplay of species traits, perceived costs and benefits of coexistence, historical memory, and culturally embedded symbolism.

6.4.3 The dama gazelle as a flagship species: alignment of social and ecological salience

The dama gazelle represents a distinctive case in which social and ecological salience converge, reinforcing its role as a flagship species for wildlife conservation and protected area management in the ATNNR. Unlike other taxa, the dama gazelle occupies a position close to the fitted relationship between social and ecological salience, indicating that its low ecological occurrence is matched by strong social recognition and concern. Its Critically Endangered conservation status is therefore not only a biological classification but is reflected in local awareness and perception.

Most respondents were familiar with the dama gazelle and its habitat, and a majority reported having seen a dama gazelle at least once, although sightings were predominantly occasional and often dated to more than two decades ago. This temporal distance, combined with substantial uncertainty regarding its current distribution and perception by some respondents that it may be locally extinct, signals a shared awareness of rarity and decline. LEK consistently indicated a pronounced reduction in the species' range. While dama gazelle was historically widely distributed across the valleys in the Air region, it is now perceived as largely confined to the Takolokouzet massif, with many respondents uncertain about their current occurrence elsewhere. These perceptions closely match the species' low ecological salience, as indicated by low capture rates and limited spatial occupancy (Authors, in prep.).

Respondents overwhelmingly identified human activities as the main threat to the dama gazelle. Drought and climatic stress were mentioned less frequently, reflecting broader trends of wildlife decline perceived in the region. These perceptions align with historical accounts suggesting that Saharan and Sahelian antelopes have experienced long-term pressure from overhunting rather than habitat loss alone (In Tanoust, 1932; Malbrant, 1952; Durant et al 2014). Positive attitudes towards the dama gazelle were not grounded in consumptive value — its meat is considered of relatively low quality compared with that of Saharan ungulates (Giazzi, 1996), but in aesthetic, cultural, and symbolic meanings. Dama gazelle was widely described as beautiful, rare, and associated with good fortune. Its

social salience thus derives primarily from relational and symbolic dimensions rather than utilitarian benefits.

This cultural dimension is further reflected in local linguistic structure. In Tamajeq, the local language, the dama gazelle is designated by distinct lexical forms according to gender and number: *ener* (masculine) and *tenert* (feminine), with plural forms *ineran* and *tineren*. The fawn is referred to as *awjem* (masculine) and *tawjem* (feminine), with plural forms *iwjeman* and *tiwjemen*. Such fine-grained lexical differentiation indicates detailed and longstanding familiarity with the species, embedded within the socio-ecological knowledge system of Tuareg communities. The species is not merely recognised, but categorised with linguistic precision.

Beyond nomenclature, the dama gazelle occupies a prominent place in Saharan symbolic systems. Personal names such as Tenert, Awjem, Tawjem, and Ener derive directly from the gazelle and evoke attributes of grace, beauty, agility, and harmony of movement. In particular, Tenert is poetically associated with balanced and luminous feminine beauty, mirroring aesthetic values attributed to the species itself. These anthroponymic practices function as cultural vectors, illustrating how attributes of wildlife are transferred to human identity and social values.

The historical depth of this symbolic relationship is further suggested by the recurrent depiction of gazelles in Saharan rock art, indicating their ecological and cultural importance in prehistoric societies. Linguistic richness, naming practices, and archaeological representations collectively demonstrate that the dama gazelle is not solely a species of conservation concern, but a culturally embedded entity. Its decline therefore represents not only ecological loss, but potential erosion of cultural memory and symbolic heritage.

Although the species is widely perceived to be declining despite formal legal protection, the strong positive attitudes expressed by local communities constitute a critical social foundation for conservation efforts

6.5 Conclusion

Our findings show that integrating social and ecological dimensions of wildlife importance provides critical insight into conservation priorities in arid social–ecological systems. Although social and ecological salience were strongly correlated overall, species level alignment and mismatch were structured by perceived species harmfulness, livelihood relevance, experienced human–wildlife interactions, and culturally embedded meanings. These results highlight that ecological occurrence alone does not determine conservation relevance; rather, it is mediated through socially grounded interpretations of wildlife.

Building on this multispecies perspective, conservation relevance emerges most clearly where ecological vulnerability intersects with social salience. Species perceived as non-harmful, aesthetically valued, or culturally embedded tend to attract concern and recognition, whereas species associated with conflict may become socially salient in negative ways, hindering management efforts. Recognising these differentiated patterns is essential that complicate management. Recognising these differentiated patterns is essential, because conservation measures are more likely to gain durable support when management priorities resonate with local perceptions, experiences, and value systems.

Within this framework, the dama gazelle illustrates how a species already recognised as a biological conservation priority can benefit from strong alignment between social and ecological salience. As a Critically Endangered and disturbance-sensitive antelope, it already constitutes a conservation priority on ecological grounds. Our results show that this ecological vulnerability is

matched by strong local awareness, symbolic value, and concern, positioning the species as a socially grounded flagship for protected area management in the Aïr and Ténéré National Nature Reserve.

More broadly, this study highlights the analytical value of integrating local ecological knowledge with ecological data to move beyond parallel assessments of people and wildlife. By identifying where social and ecological salience converge or diverge across species, this approach offers a practical framework for prioritising conservation actions, anticipating sources of local support or resistance, and designing strategies that are both ecologically necessary and socially grounded. Such integrative assessment is particularly critical in arid environments, where biodiversity persistence depends on balancing ecological constraints with human livelihoods and long-standing cultural connections to wildlife

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CHAPTER 7

7 General Discussion

This chapter synthesizes the main findings of this research and interprets them within the broader ecological and socio-environmental context of arid ecosystems. Drylands cover nearly half of the Earth's terrestrial surface and support unique biodiversity adapted to extreme climatic conditions, yet they are increasingly affected by human pressure, land-use change, and climate variability. Within these fragile ecosystems, large desert herbivores have experienced some of the most dramatic population declines recorded in recent decades (Durant et al., 2014; Ripple et al., 2015).

The dama gazelle represents one of the most emblematic examples of this broader crisis affecting Sahelo-Saharan wildlife. Once widely distributed across the Sahel and Sahara, the species now persists only in a few isolated and highly fragmented populations. The findings of this study from the Takolokouzet massif therefore provide important insights into the ecological constraints and conservation challenges faced by one of the last remaining wild populations of this critically endangered species.

Rather than representing an isolated case, the patterns observed in Takolokouzet reflect wider processes affecting desert ungulates across arid ecosystems. Habitat fragmentation, increasing pastoral pressure, and declining resource availability have progressively restricted the distribution of many large herbivores to small ecological refuges where vegetation and topographic complexity provide relatively favourable conditions. Understanding how these factors interact to shape the distribution, behaviour, and persistence of the dama gazelle is therefore essential for designing effective conservation strategies in the Sahara–Sahel region.

By combining ecological analyses with socio-ecological perspectives, this research highlights the importance of integrating scientific knowledge, habitat protection, and community engagement in order to ensure the long-term survival of desert-adapted species. The following sections discuss these findings in relation to previous studies and explore their broader implications for the conservation of the dama gazelle and other large herbivores inhabiting arid landscapes.

7.1 *Overview of Key Findings*

This research provides an assessment of the ecological and socio-ecological context of the last remaining population of dama gazelle in the Takolokouzet massif within the Aïr and Ténéré National Nature Reserve. By integrating multiple approaches including field observations, camera-trap monitoring, spatial analyses, and socio-ecological surveys, the study offers new insights into the population status, habitat use, interspecific interactions, and human dimensions influencing the persistence of this critically endangered species.

The results reveal that the population remains extremely small and spatially fragmented, with individuals concentrated in a limited number of favourable habitats, particularly vegetated valleys and sheltered topographic areas. These habitats appear to function as ecological refuges where vegetation productivity and reduced human disturbance provide relatively suitable conditions for survival. At the same time, the study highlights significant overlap between dama gazelles and domestic livestock, suggesting potential competition for resources during periods of environmental stress.

In addition to ecological findings, the socio-ecological component of the research demonstrates that local communities possess extensive ecological knowledge of the species and recognize its rarity

and cultural value. However, increasing livelihood pressures and pastoral expansion continue to shape the human-wildlife interface. Taken together, these findings highlight the complex ecological and social dynamics that determine the persistence of the dama gazelle in the Sahara region.

7.2 *Population Fragmentation and Demographic Constraints*

The small and fragmented nature of the dama gazelle population observed in the Takolokouzet massif reflects broader demographic patterns reported across the remaining range of the species. Similar patterns of restricted distribution and very low densities have been documented in Chad, Mali, and other parts of the central Sahara (Newby, 1980; Grettenberger & Newby, 1986; Wacher et al., 2013; Mallon et al., 2023). Throughout the Sahara–Sahel region, wild populations of dama gazelle have undergone dramatic declines due to overhunting, habitat degradation, and increasing human pressure (Durant et al., 2014; Mallon et al., 2023). As a result, the species now persists primarily in small, isolated subpopulations occupying remnant habitats that provide refuge from disturbance.

Such demographic fragmentation is a common feature among desert ungulates facing rapid environmental change. Similar patterns have been documented in other large herbivores inhabiting arid ecosystems, including the addax (*Addax nasomaculatus*) and the Arabian oryx (*Oryx leucoryx*), whose populations have also been reduced to small and spatially isolated groups.

In such contexts, small population size can lead to reduced genetic diversity, lower reproductive success, and increased vulnerability to stochastic events such as drought, disease outbreaks, or extreme climatic variability. Genetic studies of captive populations of dama gazelles have similarly revealed reduced genetic diversity and relatively high levels of inbreeding resulting from limited founder numbers and unequal genetic contributions (Domínguez et al., 2024). These genetic constraints further increase the vulnerability of small populations and highlight the importance of maintaining viable population sizes.

The predominance of small group sizes and the low number of juveniles observed in the Takolokouzet population may therefore indicate limited recruitment and demographic fragility. Reduced recruitment may result from several interacting factors, including low population density, habitat degradation, disturbance from human activities, or competition with livestock for limited forage resources. These patterns suggest that, without targeted conservation interventions aimed at improving habitat conditions and reducing anthropogenic pressures, the long-term viability of this population may remain uncertain.

By contrast, recent summaries from the Ouadi Rimé–Ouadi Achim Faunal Reserve (Chad) suggest somewhat higher recruitment levels. An aerial survey conducted in December 2023 recorded 64 dama gazelles, including 16 individuals less than one year old, corresponding to approximately 25% juveniles within the observed population (Wacher, 2024). Such differences may reflect variation in habitat conditions, management regimes, or population density between sites, and highlight the importance of long-term monitoring to better understand demographic trends across the remaining range of the species.

In addition to these demographic and genetic constraints, uncertainties remain regarding the taxonomic structure of the species. Traditionally, three subspecies of the dama gazelle have been recognised based mainly on phenotypic characteristics and geographic distribution (Cano, 1984). However, recent genetic studies have shown little correspondence between mitochondrial DNA variation and these subspecific classifications, suggesting that these morphological forms may not represent clearly distinct evolutionary lineages (Senn et al., 2014; 2016). Field observations conducted

during this study occasionally recorded individuals displaying morphological traits associated with different subspecies within the same population in the Takolokouzet massif, further suggesting that phenotypic variation may not necessarily reflect strict genetic differentiation.

Morphological studies have also described a gradual geographic variation in coat coloration across the historical range of the species. Descriptions of populations from the Atlantic Sahara to Sudan indicate a west–east gradient in colour patterns, ranging from the darker reddish coat typical of the mhor form in the west to paler and more diffuse colouration in eastern populations (Mungall, 2010). Such patterns have been interpreted as evidence of clinal variation rather than sharply separated subspecies.

Under this interpretation, morphological forms may have historically intergraded across a continuous distribution, with gene flow occurring between neighbouring populations. The current recognition of subspecies may therefore partly reflect the present-day fragmentation of populations rather than long-standing evolutionary isolation. This perspective is supported by experimental crossbreeding of western and eastern lineages in captive populations, which has produced viable offspring displaying intermediate phenotypes resembling the central dama gazelle form (Mallon et al., 2019). Ongoing genomic studies are expected to further clarify the evolutionary history and population structure of the species and will be essential for guiding future conservation strategies.

7.3 *Habitat Refuges and Ecological Constraints in Arid Ecosystems*

The spatial distribution of dama gazelles observed in the Takolokouzet massif highlights the importance of specific habitat features that act as ecological refuges. Most observations and detections were concentrated in vegetated valleys, wadis, and areas characterized by relatively gentle slopes and localized vegetation cover. In arid environments, where resources are highly heterogeneous in space and time, such microhabitats often provide essential resources for wildlife, including forage availability, shade, and protection from extreme climatic conditions.

Similar habitat associations have been documented in other parts of the species' range. In the Termit Massif, for example, dama gazelles have been observed occupying fragmented habitats dominated by rocky outcrops and vegetated wadis (Wacher et al., 2013). These landscape features may function as ecological refuges where vegetation productivity is relatively higher and human disturbance is reduced. In contrast, populations in the Ouadi Rimé–Ouadi Achim Reserve in Chad occur in more open Sahelian plains, reflecting regional variation in habitat structure and vegetation composition.

The preference for vegetated valleys observed in the Takolokouzet massif may also reflect behavioural strategies that reduce exposure to environmental stress. Valleys and wadis often support higher plant productivity following episodic rainfall events, providing key forage resources for browsing species such as the dama gazelle. In addition, these habitats may offer improved visibility and topographic shelter, allowing animals to detect predators and avoid areas of intense human activity.

Comparable habitat selection patterns have been reported in other Saharan and mountain-desert ungulates. For instance, Cuvier's gazelle (*Gazella cuvieri*) shows a strong association with rugged terrain and areas distant from human disturbance, which function as refuges within human-dominated landscapes (Herrera-Sánchez et al., 2020). Such patterns suggest that topographic complexity and localized vegetation productivity play a critical role in maintaining viable populations of desert-adapted ungulates.

The avoidance of open plains and heavily grazed areas observed in this study further emphasizes the influence of anthropogenic pressures on habitat use. Intensive livestock grazing can reduce vegetation availability and increase disturbance, potentially displacing wildlife from otherwise suitable habitats. Protecting key refuge habitats, particularly vegetated valleys and wadis, may therefore represent a priority for the conservation of the remaining dama gazelle population in the Takolokouzet massif.

7.4 Human Pressure and Pastoral Landscapes

Human activities, particularly pastoralism, represent one of the most important factors shaping wildlife distribution in Sahelo-Saharan ecosystems. Mobile livestock herding has historically been the dominant land-use system in these drylands and remains essential for sustaining rural livelihoods under highly variable environmental conditions. However, increasing livestock numbers and the expansion of grazing areas have intensified pressures on fragile desert ecosystems.

The analysis of interspecific interactions in the Takolokouzet massif revealed a pattern of partial spatial and temporal overlap between dama gazelles and domestic livestock and feral animal, including goats, sheep, camels, and donkeys. Such overlap may increase the potential for competition over limited resources, particularly during the dry season when vegetation and water become scarce. Similar interactions have been documented in other parts of the Sahara–Sahel region, where livestock grazing has been identified as a major factor influencing the distribution and behaviour of desert ungulates (Beudels et al., 2005; Newby et al., 2016).

Competition between wild ungulates and livestock in arid environments is often indirect, occurring through the depletion of shared forage resources rather than through direct interference. Intensive grazing can reduce vegetation cover, alter plant community composition, and degrade habitats that are essential for wildlife. In addition, the presence of herders and livestock may increase disturbance levels, potentially leading to the displacement of wildlife from otherwise suitable habitats.

Nevertheless, pastoral landscapes do not necessarily exclude wildlife. In many dryland regions, wildlife and livestock have historically coexisted within the same ecosystems, particularly where grazing pressure remains moderate and mobility allows resources to recover (Wacher, 2023). The challenge for conservation is therefore not simply to exclude livestock from wildlife habitats but to promote sustainable grazing practices that maintain ecological balance within these fragile systems.

In this context, integrating pastoral management into conservation planning may be essential for the long-term persistence of the dama gazelle. Measures such as regulating grazing intensity, protecting key wildlife refuges, and maintaining seasonal mobility of herds could help reduce pressures on critical habitats. These approaches highlight the importance of landscape-scale management strategies that reconcile biodiversity conservation with pastoral livelihoods across the Sahara–Sahel region.

7.5 Socio-Ecological Dimensions

The socio-ecological component of this research highlights the complex relationship between local communities and the natural environment in the ATNNR. The results demonstrate that the perception of wildlife, and particularly of the dama gazelle, is shaped by a combination of cultural, economic, and ecological factors. Many respondents expressed admiration for the gazelle, recognizing it as a rare and symbolic species representative of the Sahara heritage. However, this symbolic value

often coexists with growing livelihood pressures, mainly livestock herding, and resource extraction which indirectly increase competition and disturbance within the gazelle's remaining habitats.

The study revealed a strong local ecological knowledge (LEK) among herders, who can identify gazelle tracks, feeding areas, and seasonal movements. This knowledge provides crucial insights into species distribution and behavioral ecology that complement scientific data. This familiarity with the species is also reflected in the local linguistic system, where the dama gazelle is described through detailed lexical distinctions referring to gender and age classes. Such linguistic differentiation illustrates the depth of ecological knowledge embedded in Tuareg cultural traditions and highlights the long-standing relationship between local communities and the species. Yet, despite this awareness, the communities have limited means to actively participate in conservation activities, often due to insufficient institutional support, lack of incentives, or the perception that conservation primarily benefits external actors.

Bridging the gap between ecological science and traditional knowledge is therefore essential for the long-term protection of the dama gazelle. Community engagement initiatives such as participatory monitoring, education programmes, and the development of alternative livelihoods can reinforce positive attitudes and reduce dependence on resource extraction. Successful conservation programmes around the world have demonstrated the importance of community involvement. For example, the CAMPFIRE programme in Zimbabwe has shown that when local communities receive direct benefits from wildlife management, support for conservation increases and wildlife populations can recover (Child, 1996; Frost & Bond, 2008). This example demonstrates that community-based conservation can yield significant results when local actors are involved as full partners rather than passive beneficiaries. At a governance level, the integration of community representatives, local authorities, and conservation NGOs into co-management structures could strengthen both trust and accountability. Incorporating traditional rules of resource use and mobility into modern conservation frameworks would help reconcile biodiversity objectives with pastoral livelihoods. In Niger, the conservation of the West African giraffe provides a strong example of successful coexistence between large mammals and human communities, achieved largely through community-based protection, local ownership, and tolerance rather than strict exclusion. This experience demonstrates that, even in human-dominated landscapes, effective community engagement can play a decisive role in sustaining large vertebrate populations and offers valuable lessons for the conservation of the dama gazelle and other threatened Sahelo-Saharan species (Gašparová et al., 2023).

In summary, the socio-ecological perspective of this study underscores that conservation of the dama gazelle cannot rely solely on ecological protection measures. Sustainable outcomes will depend on social acceptance, local participation, and equitable benefit-sharing, ensuring that the protection of the gazelle also supports the well-being and resilience of the human communities that share its habitat

7.6 Ecological and Conservation Implications

The findings of this research provide valuable insights into the ecological requirements and conservation priorities of the dama gazelle in one of its last natural refuges. The persistence of a small population within the Takolokouzet massif demonstrates the species' remarkable capacity to survive under extreme Saharan conditions yet also highlights its vulnerability to stochastic events and habitat degradation. The observed population structure characterized by small, scattered groups and a low number of juveniles suggests demographic fragility and limited recruitment, which may ultimately compromise the long-term viability of this isolated subpopulation. According to IUCN criteria, very

small and isolated populations, particularly those comprising fewer than 50–250 mature individuals and showing ongoing decline, are considered non-viable in the long term without targeted conservation interventions (IUCN, 2012).

From an ecological standpoint, the concentration of dama gazelles in valleys and wadis with denser vegetation indicates the importance of microhabitats providing both forage and shelter. Such areas act as refuges during the dry season and may constitute key core zones for future conservation actions. Conversely, the avoidance of open plains and areas with intense livestock activity underscores the negative influence of human disturbance and competition with domestic animals on the distribution and behaviour of the species.

The partial spatial and temporal overlap between the dama gazelle and other ungulates particularly the dorcas gazelle, barbary sheep, and livestock (feral and domestic) suggests potential competition for limited resources, especially during periods of drought when vegetation is scarce. This overlap calls for a better integration of pastoral management within conservation planning. Regulating grazing intensity, securing water points, and establishing buffer zones around key gazelle habitats could significantly reduce pressure on these fragile ecosystems.

At the same time, the socio-ecological results highlight that local communities remain crucial allies for the conservation of the dama gazelle. Despite increasing livelihood pressures, many community members still recognize the ecological and cultural value of this species. Their local ecological knowledge can contribute meaningfully to adaptive management, provided that conservation actions are designed in a participatory manner and bring tangible benefits at the community level. This supports a community-based conservation approach, in which sustainable pastoral practices, environmental education, and livelihood diversification can be harmonized with biodiversity protection. Finally, the combined results emphasise that the conservation of the dama gazelle requires a landscape-scale strategy extending beyond the Takolokouzet massif. Within the ATNNR, the surrounding plains represent peripheral areas that historically supported the species but are now largely unoccupied. Current populations are highly fragmented and functionally isolated, with no connectivity to the nearest population in Termit; therefore, conservation efforts should focus on securing and managing each remaining population as an independent conservation unit. Such integration of scientific evidence, traditional knowledge, and multi-stakeholder collaboration forms the cornerstone of effective and sustainable conservation management in the Sahara.

7.7 Limitations and Future Research Perspectives

Despite the comprehensiveness of this study, several limitations should be acknowledged, as they provide important guidance for future research and monitoring efforts. First, the extremely low density of dama gazelles and the ruggedness of the Takolokouzet massif made systematic observations challenging. The resulting sample size, though sufficient to describe general trends, may underestimate demographic and behavioral variability. Similarly, the uneven distribution of camera traps and their occasional malfunction due to battery failure introduced spatial and temporal heterogeneity in detection probabilities. Future surveys could benefit from denser and more standardized camera networks, complemented by remote sensing and GPS tracking to better capture movement patterns and habitat connectivity.

Second, the historical data used for comparison while invaluable for temporal analysis were often collected using different methods and at varying spatial scales. This limits the precision of long-term comparisons, especially for population estimates. Establishing a standardized long-term monitoring protocol would help overcome these inconsistencies and allow for more robust assessments of population trends over time.

Third, socio-ecological data were obtained from a limited number of communities, which, although representative of key zones around the massif, cannot fully capture the diversity of perceptions and practices across the entire ATNNR landscape. Expanding the scope of participatory surveys could provide a more nuanced understanding of local attitudes toward conservation.

Furthermore, climatic factors and vegetation dynamics important drivers of habitat suitability were analysed through remote-sensing proxies such as MSAVI. While these indices provide valuable insights into general patterns of vegetation productivity, they cannot fully replace field-based ecological assessments of plant composition and quality. Integrating vegetation plot sampling, soil analysis, and microhabitat characterization into future fieldwork would strengthen the ecological interpretation of habitat use.

Finally, future research should adopt a more integrative and regional approach, linking the Takolokouzet population with other known or potential subpopulations of dama gazelles in the Sahelo-Saharan zone, particularly the populations in Termit and Chad. Genetic analyses could clarify the degree of isolation and inform transboundary conservation strategies. Strengthening regional cooperation, particularly under the IUCN Antelope Specialist Group and the Sahelo-Saharan Interest Group (SSIG), will be essential to ensure coordinated conservation actions across the species' remaining range. In conclusion, although this study faced the typical challenges associated with research in remote desert ecosystems, it represents the first a significant contribution to the understanding of the ecology, distribution, and conservation needs of the dama gazelle on the Takolokouzet massif. The lessons learned from its limitations provide a solid foundation for improving future monitoring and for building a more comprehensive, collaborative framework for the long-term survival of this critically endangered species.

Overall, this research provides new insights into the ecological and socio-ecological factors shaping the persistence of the dama gazelle in one of its last remaining refuges in the Sahara. By combining ecological monitoring with an understanding of human dimensions, this study highlights the importance of integrated conservation approaches that reconcile biodiversity protection with sustainable pastoral livelihoods. Such approaches will be essential for ensuring the long-term survival of the dama gazelle and other desert-adapted species in increasingly human-dominated dryland ecosystems.

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CHAPTER 8

8 General Conclusion

In summary, this study synthesizes ecological, spatial, and socio-ecological findings to provide an integrated understanding of the status and conservation needs of the dama gazelle in the Takolokouzet massif. The results confirm that this population, although extremely small, persists in a fragile balance between survival and extinction, supported by the presence of remote habitats that still provide partial refuge from human disturbance and increasing climatic stress.

The conservation challenges faced by the dama gazelle are not unique but are shared by many large and medium-sized herbivores of the Sahelo-Saharan and Arabian regions, including the addax, scimitar-horned oryx, Arabian oryx, Barbary sheep, and several gazelle species. These taxa exhibit similar patterns of range contraction, population fragmentation, and increasing dependence on a limited number of protected areas or managed landscapes. Their histories of decline and, in some cases, recovery through reintroduction programmes demonstrate both the vulnerability of desert fauna and the potential for conservation success when long-term commitment and coordinated action are implemented.

This research highlights that the effective conservation of the dama gazelle, and arid-land ungulates more broadly, requires adaptive, landscape-scale strategies that integrate ecological monitoring, habitat protection, and the active participation of local communities. Comparable experiences from the recovery of species such as the scimitar-horned oryx and the Arabian oryx underline the importance of combining in situ protection with ex situ management, strengthened law enforcement, and inclusive governance frameworks that engage local stakeholders.

Ultimately, the dama gazelle can be regarded as a flagship species for desert ecosystems. Its conservation extends beyond the protection of a single species and reflects a broader commitment to safeguarding the ecological integrity of arid landscapes that sustain both wildlife and human livelihoods. The lessons emerging from this study therefore extend beyond the Aïr and Ténéré region, offering valuable insights for the conservation of desert fauna across the Sahel, the Sahara, and the Arabian Peninsula in the face of ongoing environmental change and growing socio-economic pressures.

CHAPTER 9

9 General References

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Wacher, T., Amin, R., Newby, J., Hatcha, M. H., Abeye, K., Ali, H., ... & Banlongar, F. N. (2023). Gazelle–livestock interactions and impact of water resource development in the Ouadi Rimé–Ouadi Achim Reserve, Chad. *Oryx*, 57(2), 205-215.

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Watson, J. E. M., Dudley, N., Segan, D. B., & Hockings, M. (2014). The performance and potential of protected areas. *Nature*, 515, 67–73.

Western, D. (1994). The background to community-based conservation. In D. Western, R. M. Wright & S. C. Strum (Eds.), *Natural Connections : Perspectives in Community-Based Conservation*. Island Press.

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Woodroffe, R., Lindsey, P., Romañach, S., Stein, A., & ole Ranah, S. M. (2005). Livestock predation by endangered African wild dogs (*Lycaon pictus*) in northern Kenya. *Biological Conservation*, 124(2), 225-234.

Yang, X. (2012). Environmental Change in the Arid and Semi-Arid Regions. *Environmental Change*.

Zabeirou, A.R.M., Mahamadou, A.R.A, Ibrahim, M., Pourchier, C., & Barrios, V. 2023. Rapport synthétique des activités au Niger. Rapport trimestriel – Année 2023 Trimestre 4. Sahara Conservation

CHAPTER 10

10 Annexes

10.1 Curriculum vitae Abdoul Razack Moussa Zabeirou

	Contact	Technical Skills
	+227 90 01 68 68  razackmoussa87@gmail.com/ moussa_zabeirou@ftz.czu.cz Orcid:0000-0001-9333-3477 Langages French – C2, English – B2, Hausa – Native, Zarma – B2	 ArcGIS, QGIS, CyberTracker, GPS, UAV  SPSS, R  SMART, HotSpotter Microsoft Office

RESEARCH INTEREST

Conservation biologist with 10 years of experience (2016–present) in Sahelo-Saharan and desert ecosystems, focusing on endangered species including the dama gazelle, West African giraffe, and vultures. Extensive field experience in Niger (2016–present), Senegal (short-term missions, 2020), Namibia (short-term missions, 2022), and Saudi Arabia (faunal inventories, 2024). Experienced in ranger training, wildlife law enforcement, ecological monitoring, SMART patrol planning, UAVs, camera trapping, GPS, and GIS. Active participant in the UNESCO Mentorship Programme for African Heritage Professionals (2023–2025) and international collaborations with European institutions on biodiversity monitoring and conservation technology.

ACADEMIC EDUCATION

Doctoral Student, Czech University of Life Sciences Prague (CZU) Faculty of Tropical AgriSciences, Prague, Czech Republic (Part-time, remote)- September 2019 – present

PhD research focus:

Dama gazelle population structure, distribution and interactions in socio-ecological system

- Population monitoring methods and abundance estimation
- Individual identification and social structure using camera traps
- Species interactions
- Assessment of local ecological knowledge and conservation constraints
- Development of conservation recommendations

Master's in project management, Management, Economy and Informatics Science Institute, Niamey, Niger, 2020 – 2022

Master's in environmental management, Sup'Management, Fez, Morocco, 2014 – 2016

Bachelor's in biology, Biodiversity and Environmental Management, University of Maradi, Niger, 2009 – 2013

EMPLOYMENT HISTORY

Country Representative - Sahara Conservation, Niger - 2022 – present

- Project management: activity planning, human resources management (team of 7 people), budget management, administrative support
- Fundraising and applying for international grants
- Representation of the organization with institutional partners
- Technical and financial reporting
- Conduction of field work (cf. Project Officer)

Project Officer - Sahara Conservation and Giraffe Conservation Foundation, Niger – 2017 – 2022

- In charge of West African giraffe conservation project at local level: Yearly survey and identification of giraffes; In 2018 and 2022: Capturing, tagging and translocating 12 individuals to the Gadabedji Biosphere Reserve
- Monitoring in the Sahelo-Saharan range: Terrestrial surveys, use of diverse biomonitoring tools (drone, camera traps, Cybertracker, GPS, camera) - Main Species: Dama Gazelle, Giraffe, Vultures, Dorcas Gazelle
- Data Analysis, Reporting & GIS (QGIS and ArcGIS)
- Sensitisation activities and training stakeholders (officers and local communities)
- Environmental and Social Impact Assessment

Intern - Noe Conservation, Zinder, Niger - 2016 – 2017

- Ecological monitoring (Termit Tin-Touma and Aïr Ténéré National Natural Reserves); Data collection through direct and indirect observations, use of camera traps

Intern - Regional Directorate for the Environment, Zinder, Niger - 2012 – 2013

- Gained hands-on experience with institutional structures and procedures in regional environmental management

TRAINING

- UNESCO: Mentorship Programme for African Heritage Professionals: Technical support, strengthening competencies in governance, participatory management and ecological monitoring of World Heritage properties, 2023–2025
 - Preparatory workshop for the mid-cycle review of the Regional Action Plan for Africa and the World Heritage Strategy for Africa; field visits: mangroves and shell middens of Diorom Boumak, Kunta Kinteh Island and related sites, Senegal- February 2024.
 - Capacity building on risk management and protection systems; study mission to the Royal Palaces of Abomey, Benin- December 2024.
 - Reactive Monitoring Mission – assess the state of conservation of the Rainforests of the Atsinanana, Madagascar - March 2025.
 - UNESCO–Africa–China Symposium on World Heritage Capacity-Building and Cooperation, in Quanzhou, People’s Republic of China, October 2025.
- Ranger training on monitoring using SMART in ATNNR, GBR, TTNNR, Niger - Ongoing
- Faunal inventory – Imam Turki Royal Reserve, Saudi Arabia - 2024
- Biodiversity monitoring consultant – Savannah Energy (Wind Project), Niger- 2023-2024
- Biodiversity Expert – EIA of uranium project “Adrar Emoles 3”- Niger, 2021
- Ranger training on UAV use – Djoudj Bird Sanctuary- Senegal, 2020

MEMBERSHIPS

- IUCN SSC Antelope Specialist Group Member

Admission in 2022 based on unique experience on Sahelo-Saharan antelopes

- IUCN SSC Giraffe and Okapi Specialist Group Member

Admission in 2022 based on unique experience with West African giraffes

- Czech University of Life Sciences FTZ Wildlife Ecology LAB Member

Research group focused on habitat and species conservation management

10.2 Publications & key documents

SCIENTIFIC PUBLICATIONS

1. **Zabeirou, A. R. M.**, Rabeil, T., Barrios, V., Wacher, T., Newby, J., Mallon, D., et al. (2025). Status and social structure of the critically endangered dama gazelle (*Nanger dama*) in the Aïr & Ténéré National Nature Reserve, Niger. *Global Ecology and Conservation*, e03976.
2. Vukelić, M., White, E. W., Fennessy, J., **Zabeirou, A. R. M.**, Gašparová, K., Valle, S., et al. (2025). Monitoring African megafauna in an anthropogenic landscape: A 15-year case study of the vulnerable West African giraffe. *Animal Conservation*.
3. de Jong, Y. A., Alghoubas, A., **Zabeirou, A. R. M.**, Hassane, M., Butynski, T. M., et al. (2025). Distribution, abundance, and conservation status of the Aïr patas monkey (*Erythrocebus patas villiersi*) in the Aïr Massif–Gadabedji region, Niger. *Primate Conservation*, 39.
4. Kargopoulos, N., Marugán-Lobón, J., Chinsamy, A., Brown, M., Fennessy, S., Ferguson, S., et al. (2025). A reassessment of the cranial diversity of the West African giraffe. *International Journal of Zoology*, 2025(1), 8816347.
5. Gašparová, K., Fennessy, J., **Zabeirou, A. R. M.**, Abagana, A. L., Rabeil, T., Brandlová, K., et al. (2024). Saving the last West African giraffe population: A review of its conservation status and management. *Animals*, 14(5), 702.
6. Hejčmanová, P., Gašparová, K., Fedorova, T., Vukelić, M., Fennessy, J., **Zabeirou, A. R. M.**, et al. (2024). Diurnal activity and resting time allocation of the West African giraffe in a human-dominated agropastoral landscape. *Frontiers in Conservation Science*, 5, 1459960.
7. Kargopoulos, N., Marugán-Lobón, J., Chinsamy, A., Agwanda, B. R., Brown, M. B., Fennessy, S., et al. (2024). Heads up: Four Giraffa species have distinct cranial morphology. *PLOS ONE*, 19(12), e0315043.
8. Gašparová, K., Blanco, J., Glikman, J. A., Fennessy, J., **Zabeirou, A. R. M.**, Mahamadou, A. R. A., et al. (2023). Social development and biodiversity conservation synergies for the West African giraffe in a human–wildlife landscape. *Environmental Conservation*, 50(4), 259–266.
9. Oppel, S., Arkumarev, V., Bakari, S., Dobrev, V., Saravia-Mullin, V., Adefolu, S., et al. (2021). Major threats to a migratory raptor vary geographically along the Eastern Mediterranean flyway. *Biological Conservation*, 262, 109277.
10. Pourchier, C., **Zabeirou, A. R. M.**, Arkumarev, V., et al. (2023). Status of vultures in the Koutous Massif, Niger. *Acta Zoologica Bulgarica*, Supplement 17 (in press).
11. O'Connor, D., Stacy-Dawes, J., Muneza, A., Fennessy, J., Gobush, K., Chase, M. J., et al. (2019). Updated geographic range maps for giraffe (*Giraffa* spp.) across sub-Saharan Africa and implications for conservation. *Mammal Review*, 49(4), 285–299.

Submitted / under review

12. Zabeirou, A. R. M., Vicari A., Newby J., Barrios V., Rabeil, T., Brandlová, K., Hejčmanová P. 2026. Sharing the space with dama gazelle: Spatiotemporal niche partitioning of desert ungulates in a hyper-arid mountain refuge, Submitted to *Proceedings B*.
13. Zabeirou, A.R.M., Brandlová, K., Alghouba, A., Newby, J., Wacher, T., Barrios, V., Owusu Afriyie, J., & Hejčmanová, P. (2026). Linking social and ecological salience of wildlife in the Aïr and Ténéré National Nature Reserve, Niger: implications for conservation of the critically endangered dama gazelle. Submitted to *Conservation Biology*.

OTHER ARTICLES

Pourchier, C., **Zabeirou, A.R.M.**, Rabeil, T. 2019. Spending the winter in Niger. Sandscript 24: 11-12.

Available at: https://saharaconservation.org/wpcontent/uploads/2021/09/sandscript_24_web_min_e_n.pdf

Zabeirou, A.R.M., Pourchier, C. 2019. The vulture who lives in the hills. Sandscript 25: 9-10. Available at: https://saharaconservation.org/wp-content/uploads/2021/09/Sandscript_25_en_web.pdf

Zabeirou, A.R.M., Pourchier, C. 2019. On the tracks of Sahelian Vultures. Sandscript 26: 12-13. Available at https://saharaconservation.org/wpcontent/uploads/2021/03/Sandscript_26_en_web.pdf

Zabeirou, A.R.M. 2020. Better understanding the Aïr Damas. Sandscript 27: 8-9. Available at: https://saharaconservation.org/wp-content/uploads/2021/03/Sandscript_27_web_en.pdf

Zabeirou, A.R.M. 2020. A second health mission in the Gadabeji Biosphere Reserve, Niger. Sandscript 28: 8-9. Available at: https://saharaconservation.org/wp-content/uploads/2021/01/Sandscript_28_web_en.pdf

Zabeirou, A.R.M. 2021. Conservation Status and socio-ecological characterization of dama gazelle metapopulation in Niger. Available at: <https://www.rufford.org/projects/abdoul-razack-moussa-zabeirou/conservation-status-and-socio-ecological-characterization-dama-gazelle-metapopulation-niger/>

Zabeirou, A.R.M. 2023. Les vautours au Niger : quelles menaces et comment les combattre ? Sandscript 31 : 7-8. Available at: <https://lnkd.in/e9kZFU2j>

Pourchier, C., **Zabeirou, A.R.M. 2023.** The success of the Egyptian Vulture New LIFE project in Niger. Sahara Conservation website. <https://saharaconservation.org/the-success-of-the-egyptian-vulture-new-life-project-in-niger/>

TECHNICAL REPORTS

Produced in the framework of field activities.

Zabeirou, A.R.M. 2017. National Survey Report of the West African Giraffe, Niger. Giraffe Conservation Foundation. Available at: <https://giraffeconservation.org/wp-content/uploads/2018/09/West-African-giraffe-Census-2017-compressed.pdf>

Zabeirou, A.R.M. 2017. Rapport de mission dans la Réserve Naturelle Nationale de l'Aïr et du Ténéré (Niger). Sahara Conservation.

Zabeirou, A.R.M. 2018. Rapport de mission dans la Réserve Naturelle Nationale de l'Aïr et du Ténéré (Niger). Sahara Conservation.

Zabeirou, R. (2017). National Survey Report of the West African Giraffe, Niger–August 2017. Giraffe Conservation Foundation and Sahara Conservation Fund, Niamey, Niger.

Zabeirou, A.R.M. 2019. Giraffe conservation in Niger, Hot season survey report. Giraffe Conservation Foundation. Available at: https://giraffeconservation.org/wp-content/uploads/2019/06/Niger-Hot-Season-Survey-Report_April-2019.pdf

Zabeirou, A.R.M. 2018. Suivi de la reproduction du Vautour Oricou, du Vautour de Rüppell et du Vautour Percnoptère dans la bande Sahélo-Saharienne au Niger. Sahara Conservation.

Gasparova, K., Fenessy, J., Rabeil, T., **Zabeirou, A.R.M.**, Pourchier, C., Brown, M., Brandlova, K. 2019. 1st annual report, West African giraffe (*Giraffa camelopardalis peralta*), Republic of Niger. Giraffe Conservation Foundation. Available at: http://ruffordorg.s3.amazonaws.com/media/project_reports/27641-1%20West%20African%20Giraffe%20Annual%20Report%202018-19.pdf

Zabeirou, A.R.M. 2019. Suivi de la reproduction des vautours dans la Réserve de Biosphère Gadabedji et le massif de Koutous au Niger. Sahara Conservation

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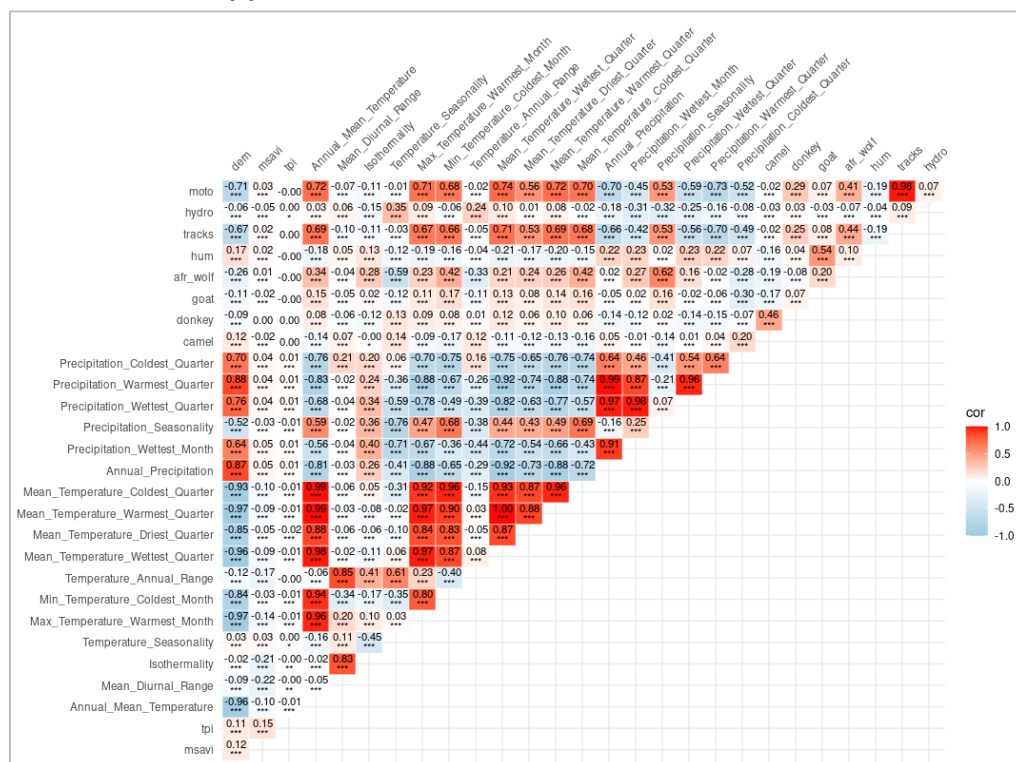
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10.3 Supplementary information

10.3.1 Supplementary material 1

Figure S1. Correlation matrix (Pearson's correlation coefficients) for collinearity testing of environmental and anthropogenic covariates.

2017 – 2020 survey period



2022 – 2024 survey period

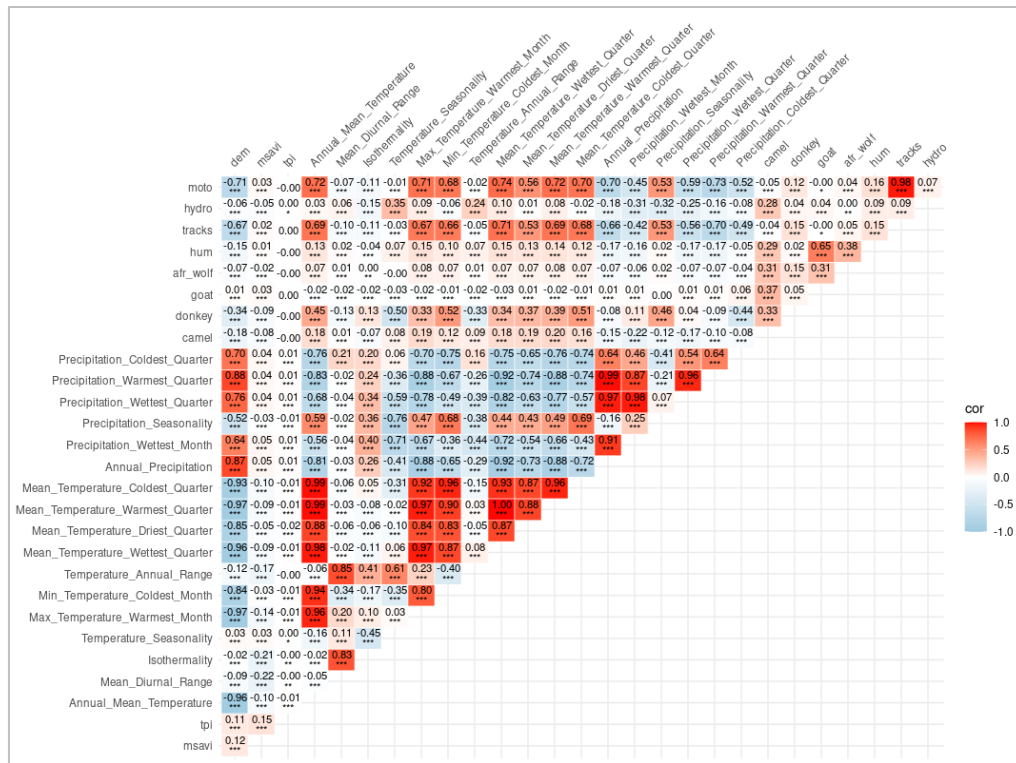


Table S1. Descriptive statistics of the capture rates for focal wildlife and domestic species over the all monitoring years and for each camera trap survey period in the Mount Takolokouzet, Air and Ténéré Nature reserve, Niger.

Capture rate - overall	Min	Q1	Median	Mean	Q3	Max	SD
Dama gazelle	0	0.000	0.587	1.698	2.500	17.000	2.802
Dorcas gazelle	0	0.545	4.154	6.666	9.850	36.889	8.048
Barbary sheep	0	0.000	0.000	0.515	0.170	20.976	2.301
Camel	0	2.153	7.053	9.997	14.705	45.714	9.706
Donkey	0	6.816	15.826	24.704	32.345	137.000	27.241
Goat	0	0.000	0.000	1.738	0.000	42.041	6.050
African wolf	0	0.000	0.000	0.564	0.392	12.097	1.667
Capture rate 2017-2020	Min	Q1	Median	Mean	Q3	Max	SD
Dama gazelle	0	0.000	0.759	1.624	2.494	17.000	2.703
Dorcas gazelle	0	1.372	4.835	7.779	10.565	36.889	8.968
Barbary sheep	0	0.000	0.000	0.734	0.252	20.976	2.812
Camel	0	2.786	9.110	10.487	15.485	34.375	8.999
Donkey	0	10.674	22.984	30.798	40.754	137.000	29.338
Goat	0	0.000	0.000	2.548	0.000	42.041	7.317
African wolf	0	0.000	0.000	0.503	0.063	12.097	1.696
Capture rate 2022-2024	Min	Q1	Median	Mean	Q3	Max	SD
Dama gazelle	0	0.000	0.467	1.841	2.387	11.429	3.027
Dorcas gazelle	0	0.231	1.467	4.513	8.421	20.000	5.372
Barbary sheep	0	0.000	0.000	0.090	0.000	1.105	0.226
Camel	0	1.287	4.815	9.048	11.423	45.714	11.042
Donkey	0	3.208	8.727	12.911	13.907	92.683	17.763
Goat	0	0.000	0.000	0.170	0.000	4.487	0.813
African wolf	0	0.000	0.000	0.681	0.566	7.059	1.630

Table S2. Inferential statistics of the capture rates for focal wildlife and domestic species over the all monitoring years and for each camera trap survey period in the Mount Takolokouzet, Air and Ténéré Nature reserve, Niger.

Shapiro test for normality	2017-2020	2022-2024
Species	p-value	p-value
Barbary sheep	1.01E-15	1.79E-09
Camel	0.000693	2.34E-05
Dama gazelle	3.03E-11	3.32E-07
Donkey	4.51E-08	1.78E-07
Dorcas gazelle	1.76E-07	9.77E-05
Goat	3.75E-14	9.94E-12
African wolf	3.59E-15	1.97E-09
Kruskal-Wallis chi-squared	2017-2020	2022-2024
chi-squared	233.87	108.47
df	6	6
p-value	< 2.2E-16	< 2.2e-16

Dunn's test	2017-2020			2022-2024		
Comparison	Z	P.unadj	P.adj	Z	P.unadj	P.adj
DamaGazelle - DorcasGazelle	-3.9691	7.21E-05	0.00151	-1.9712	0.0487	1
DamaGazelle - BarbarySheep	-2.2877	0.0222	0.465	-2.7247	0.00644	0.135
DorcasGazelle - BarbarySheep	-6.2568	3.93E-10	8.25E-09	-4.696	2.65E-06	5.57E-05
BarbarySheep - Camel	-7.7412	9.85E-15	2.07E-13	-6.3853	1.71E-10	3.59E-09
Camel - DamaGazelle	5.4535	4.94E-08	0.00000104	3.6605	0.000252	0.00529
BarbarySheep - Donkey	-10.9241	8.84E-28	1.86E-26	-6.9162	4.64E-12	9.74E-11
Camel - Donkey	-3.1829	0.00146	0.0306	-0.531	0.595	1
DamaGazelle - Donkey	-8.6364	5.8E-18	1.22E-16	-4.1915	2.77E-05	0.000582
Camel - DorcasGazelle	1.4844	0.138	1	1.6893	0.0912	1
Donkey - DorcasGazelle	4.6673	3.05E-06	0.0000641	2.2203	0.0264	0.554
BarbarySheep - Goat	-0.3858	0.699	1	0.4843	0.628	1
Camel - Goat	7.3553	1.9E-13	3.99E-12	6.8696	6.44E-12	1.35E-10
DamaGazelle - Goat	1.9019	0.0572	1	3.2091	0.00133	0.028
Donkey - Goat	10.5383	5.75E-26	1.21E-24	7.4006	1.36E-13	2.85E-12
DorcasGazelle - Goat	5.871	4.33E-09	0.000000091	5.1803	2.22E-07	4.65E-06
BarbarySheep - Africanwolf	0.2389	0.811	1	-1.1647	0.244	1
Camel - Africanwolf	7.98	1.46E-15	3.07E-14	5.2206	1.78E-07	3.75E-06
DamaGazelle - Africanwolf	2.5266	0.0115	0.242	1.56	0.119	1
Donkey - Africanwolf	11.163	6.19E-29	1.3E-27	5.7515	8.84E-09	1.86E-07
DorcasGazelle - Africanwolf	6.4957	8.27E-11	1.74E-09	3.5312	0.000414	0.00869
Goat - Africanwolf	0.6247	0.532	1	-1.649	0.0991	1

Figure S2. Capture rates of focal wildlife and domestic species over both camera trap survey periods, plotted over the study area in the Mount Takolokouzet, Air and Ténéré Nature reserve, Niger.

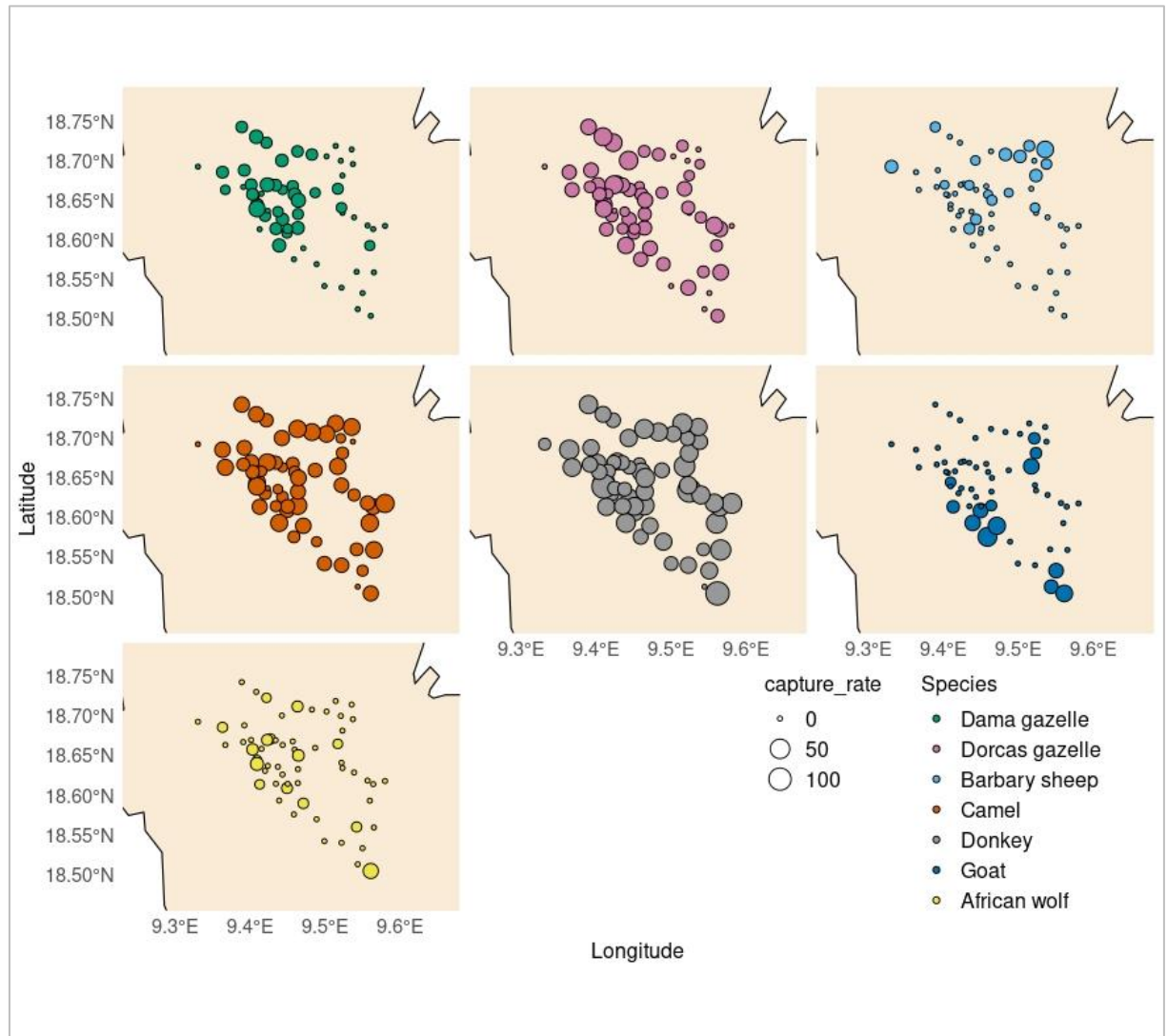


Table S3: Inferential circular statistics for the temporal activities of each species.

	2017-2020			2022-2024		
	Rayleigh	p_rayleigh	Watson U ²	Rayleigh	p_rayleigh	Watson U ²
Dama gazelle	0.28927	8.94E-10	1.100769	0.235363	0.00088	0.410632
Dorcas gazelle	0.222208	1.36E-24	3.368038	0.263993	1.11E-11	1.554143
Barbary sheep	0.143433	0.13876	0.144915	0.207351	0.691083	0.044766
Camel	0.200443	2.02E-24	3.47695	0.281462	2.69E-23	2.733065
Donkey	0.087508	4.32E-13	1.593781	0.157749	1.88E-12	1.430073
Goat	0.706124	2.02E-67	8.060892	0.636539	0.000212	0.454135
African wolf	0.399254	0.000133	0.503494	0.218056	0.149462	0.173214

Table S4: Summary metrics for the temporal activities of each species.

2017-2020	Hours				PeakHour	PeakHour	PeakHour
	Active	SE	LCL	UCL	radians	HHMM	SE
Dama gazelle	15.091	1.268	11.937	16.696	23.672	23:40	1.307
Dorcas gazelle	9.316	0.728	9.283	12.131	7.031	07:02	0.194
Barbary sheep	14.337	2.175	11.574	19.716	11.625	11:38	1.164
Camel	13.457	0.882	12.908	16.266	7.172	07:10	0.263
Donkey	18.542	0.754	17.206	19.94	22.266	22:16	0.456
Goat	8.819	0.515	7.972	9.922	11.953	11:57	0.583
African wolf	11.678	1.939	8.266	15.841	21.703	21:42	0.774

2022-2024	Hours				PeakHour	PeakHour	PeakHour
	Active	SE	LCL	UCL	radians	HHMM	SE
Dama gazelle	15.237	1.899	11.824	18.291	4.078	04:05	0.97
Dorcas gazelle	9.476	1.327	9.261	14.048	6.865	06:52	0.234
Barbary sheep	8.048	2.562	3.858	13.138	14.016	14:01	0.648
Camel	15.21	1.017	13.622	17.473	13.969	13:58	0.779
Donkey	16.583	1.035	14.998	19.037	21.844	21:51	0.512
Goat	7.913	1.577	5.07	10.882	13.828	13:50	1.468
African wolf	10.875	2.456	7.941	16.663	5.672	05:40	0.5

Table S5: Diurnality index (DI) for the temporal activities of each species.

Species	DI	Comments	DI	Comments
	2017-2020		2022-2024	
Dama gazelle	-0.392	mostly nocturnal or crepuscular activity	or -0.359	mostly nocturnal or crepuscular activity
Dorcas gazelle	0.145	moderately diurnal, some activity at night	some 0.21	moderately diurnal, some activity at night
Barbary sheep	0.055	crepuscular with activity spread between day and night	0.099	crepuscular with activity spread between day and night
Camel	0.22	mostly diurnal	0.301	mostly diurnal
Donkey	-0.143	slightly nocturnal or crepuscular tendencies	or -0.217	slightly nocturnal or crepuscular tendencies
Goat	0.854	clearly diurnal	0.781	clearly diurnal
African wolf	-0.573	mostly nocturnal	-0.277	mostly nocturnal

Table S6: Overlap coefficient (Dhat4) and Watson's two-sample test results (with critical value CV).

SpeciesA	SpeciesB	2017-2020			2022-2024		
		Dhat	Test Statistic	CV	Dhat	Test Statistic	CV
Barbary sheep	Camel	0.835	0.136553	0.187	0.634	0.042022	0.187
Barbary sheep	Dama gazelle	0.772	0.560131	0.187	0.645	0.095397	0.187
Barbary sheep	Donkey	0.842	0.289063	0.187	0.651	0.075043	0.187
Barbary sheep	Dorcas gazelle	0.824	0.103484	0.187	0.596	0.056799	0.187
Barbary sheep	African wolf	0.669	0.518757	0.187	0.647	0.066677	0.187
Barbary sheep	Goat	0.575	1.327758	0.187	0.605	0.070748	0.187
Camel	Dama gazelle	0.671	2.873574	0.187	0.665	1.632343	0.187
Camel	Donkey	0.781	4.479947	0.187	0.73	3.308816	0.187
Camel	Dorcas gazelle	0.855	0.910948	0.187	0.814	0.757956	0.187
Camel	African wolf	0.577	1.180288	0.187	0.635	0.205599	0.187
Camel	Goat	0.609	5.063443	0.187	0.682	0.577209	0.187
Dama gazelle	Donkey	0.828	0.79173	0.187	0.863	0.18505	0.187
Dama gazelle	Dorcas gazelle	0.691	2.00275	0.187	0.655	1.263481	0.187
Dama gazelle	African wolf	0.855	0.097875	0.187	0.372	0.739755	0.187
Dama gazelle	Goat	0.351	6.315642	0.187	0.865	0.089573	0.187
Donkey	Dorcas gazelle	0.787	4.703621	0.187	0.702	2.712568	0.187
Donkey	African wolf	0.775	0.35365	0.187	0.429	0.608615	0.187
Donkey	Goat	0.482	8.376116	0.187	0.781	0.191899	0.187
Dorcas gazelle	African wolf	0.582	1.008735	0.187	0.679	0.289437	0.187
Dorcas gazelle	Goat	0.562	5.418146	0.187	0.738	0.41485	0.187
African wolf	Goat	0.254	2.694852	0.187	0.415	0.543577	0.187

Table S7: Parameters of spatial overlap between species pairs in the two study periods: mean and credible interval values of Bhattacharyya index (BI) and proportions of overlap within the core occupancy area of each species (occupancy > 0.6).

Species pair	Study period	Resolution	Mean	2.5 0%	97.5 0%	Prop_overlap_union	Prop_overlap_sp1	Prop_Overlap_sp2	n_overlap_cells
Dama	2017–	150	0.885	0.794	0.963	0.561	1.000	0.561	
Dorcass gazelle	2020								7884
Dama	2017–	150	0.783	0.649	0.908	0.323	0.567	0.428	
Barbary sheep	2020								4470
Dorcass	2017–	150	0.922	0.858	0.969	0.459	0.548	0.739	
Barbary sheep	2020								7712
Dama	2022–	150	0.886	0.661	0.993	0.553	0.607	0.861	
Dorcass gazelle	2024								25443
Dama	2022–	150	0.744	0.253	0.987	0.268	0.308	0.672	
Barb									12931

ary	202								
shee	4								
p									
Dorc	202	150	0.7	0.27	0.98	0.464		0.523	0.804
as-	2-		48	6	6				
Barb	202								
ary	4								
shee									
p									15460

10.3.2 *Supplementary material 2*

SUPPLEMENTARY MATERIAL 2

OUTPUTS - FULL SUMMARIES OF FINAL OCCUPANCY MODELS

DAMA GAZELLE 2017-2020

Call:

```
spPGOcc(occ.formula = occupancy.formula, det.formula = detection.formula,
data = spocc_data_dama_17_20, inits = model.inits, priors = list(beta.normal
= list(mean = 0,
var = 2.72), alpha.normal = list(mean = 0, var = 2.72),
sigma.sq.ig = c(2, 1), phi.unif = c(3/max.dist,
3/min.dist)), tuning = list(phi = 5), cov.model = "exponential",
NNGP = TRUE, n.neighbors = 5, n.batch = 1000, batch.length = 25,
n.report = 100, n.burn = 5000, n.thin = 10, n.chains = 3)
```

Samples per Chain: 25000

Burn-in: 5000

Thinning Rate: 10

Number of Chains: 3

Total Posterior Samples: 6000

Run Time (min): 3.5404

Occurrence (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS

(Intercept) 0.4759 0.4763 -0.4265 0.4645 1.4628 1.0015 4972

scale(tracks) -2.2462 0.6189 -3.5993 -2.2078 -1.1692 1.0006 4118

scale(Bio_5) -0.9674 0.6805 -2.4809 -0.8981 0.1911 0.9999 4770

scale(Camel) 0.9452 0.4862 0.0437 0.9259 1.9454 1.0001 5382

Detection (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS
 (Intercept) -3.8083 0.0773 -3.9636 -3.8074 -3.6595 1.0031 3632
 scale(dyn_MSAVI) 0.3433 0.0651 0.2157 0.3434 0.4698 1.0018 4404
 scale(Season) -0.1982 0.0736 -0.3478 -0.1984 -0.0530 0.9999 4138
 Spatial Covariance:
 Mean SD 2.5% 50% 97.5% Rhat ESS
 sigma.sq 1.0148 1.4066 0.1828 0.6228 4.1804 1.0301 1189
 phi 0.0049 0.0030 0.0003 0.0048 0.0099 1.0000 2031

DAMA GAZELLE 2022-2024

Call:

```
spPGOcc(occ.formula = occupancy.formula, det.formula = detection.formula,
data = spocc_data_dama_22_24_full, inits = model.inits,
priors = model.priors, tuning = list(phi = 5), cov.model = "exponential",
NNGP = TRUE, n.neighbors = 5, n.batch = 1000, batch.length = 25,
n.report = 100, n.burn = 5000, n.thin = 10, n.chains = 3)
```

Samples per Chain: 25000

Burn-in: 5000

Thinning Rate: 10

Number of Chains: 3

Total Posterior Samples: 6000

Run Time (min): 2.7021

Occurrence (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS
 (Intercept) 1.7762 0.8156 0.4047 1.6991 3.5722 1.0004 2369
 scale(Bio_5) -1.4140 0.8846 -3.3393 -1.3311 0.0835 1.0023 3927
 scale(tracks) 0.7325 0.8935 -0.8732 0.6675 2.7060 1.0009 5520
 scale(Goat) 1.1372 1.0780 -0.6847 1.0383 3.4759 1.0002 5733

Detection (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS
 (Intercept) -4.3141 0.322 -4.9883 -4.3 -3.7185 1.0063 349

Detection Random Effect Variances (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS
 Days 1.5256 0.7983 0.5367 1.3413 3.6011 1.0025 1788

Spatial Covariance:

Mean SD 2.5% 50% 97.5% Rhat ESS
 sigma.sq 0.0453 0.0097 0.0299 0.0441 0.0671 1.0011 6000
 phi 0.0051 0.0029 0.0003 0.0051 0.0100 1.0023 3503

DORCAS GAZELLE 2017-2020

Call:

```
spPGOcc(occ.formula = occupancy.formula, det.formula = detection.formula,  
data = spocc_data_dorcgaz_17_20, inits = model.inits,  
priors = model.priors, tuning = list(phi = 5), cov.model = "exponential",  
NNGP = TRUE, n.neighbors = 5, n.batch = 1000, batch.length = 25,  
n.report = 100, n.burn = 5000, n.thin = 10, n.chains = 3)
```

Samples per Chain: 25000

Burn-in: 5000

Thinning Rate: 10

Number of Chains: 3

Total Posterior Samples: 6000

Run Time (min): 11.8994

Occurrence (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS

(Intercept) 3.1299 0.7462 1.8303 3.0764 4.7339 1.0016 4321

scale(Bio_12) 0.8106 0.4386 -0.0386 0.8012 1.6860 1.0024 5053

scale(Donkey) 1.4553 0.7359 0.1411 1.4117 3.0634 1.0039 4584

scale(tracks) -1.2165 0.5338 -2.3111 -1.2028 -0.2166 1.0011 5507

Detection (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS

(Intercept) -2.2293 0.6138 -3.2263 -2.3347 -0.8332 1.5055 42

scale(Season) -0.1610 0.0385 -0.2371 -0.1607 -0.0854 1.0028 5471

Detection Random Effect Variances (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS

Days 1.7713 0.6438 0.8647 1.6548 3.3280 1.0177 1522

Year 1.8555 3.0994 0.1987 1.0262 8.6413 1.1980 314

Spatial Covariance:

Mean SD 2.5% 50% 97.5% Rhat ESS

sigma.sq 0.0453 0.0100 3e-02 0.0440 0.0684 1.0019 6342

phi 0.0052 0.0029 4e-04 0.0051 0.0099 1.0031 3221

DORCAS GAZELLE 2022-2024

Call:

```
spPGOcc(occ.formula = occupancy.formula, det.formula = detection.formula,  
data = spocc_data_dorcgaz_22_24, inits = model.inits,  
priors = model.priors, tuning = list(phi = 5), cov.model = "exponential",
```

NNGP = TRUE, n.neighbors = 5, n.batch = 1000, batch.length = 25,
n.report = 100, n.burn = 5000, n.thin = 10, n.chains = 3)

Samples per Chain: 25000

Burn-in: 5000

Thinning Rate: 10

Number of Chains: 3

Total Posterior Samples: 6000

Run Time (min): 2.8403

Occurrence (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS

(Intercept) 2.5729 0.7509 1.2676 2.5257 4.1883 1.0033 5542

scale(Hum) 0.8393 1.0059 -0.8354 0.7444 3.0611 1.0008 6000

scale(Donkey) 1.3715 0.9487 -0.4710 1.3695 3.2377 1.0006 5919

scale(GoldJack) 0.8261 1.0071 -0.8847 0.7318 3.0306 1.0013 5759

scale(Bio_12) 0.3309 0.9208 -1.6056 0.3792 2.0323 1.0016 6000

Detection (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS

(Intercept) -3.4888 0.2702 -4.0521 -3.4753 -2.989 1.0379 403

Detection Random Effect Variances (logit scale):

Mean SD 2.5% 50% 97.5% Rhat ESS

Days 1.6607 0.6703 0.7509 1.5282 3.3001 1.0036 2270

Spatial Covariance:

Mean SD 2.5% 50% 97.5% Rhat ESS

sigma.sq 0.0454 0.0098 0.0299 0.0440 0.0677 1.0003 6000

phi 0.0051 0.0029 0.0003 0.0051 0.0099 0.9998 3878

BARBARY SHEEP 2017-2020

Call:

spPGOcc(occ.formula = occupancy.formula, det.formula = detection.formula,

data =

spocc_data_barbshp_17_20,

inits = model.inits, priors = model.priors, tuning = list(phi = 5),

cov.model = "exponential",

NNGP = TRUE, n.neighbors = 5, n.batch = 1000, batch.length = 25, n.report =
100,

n.burn = 5000, n.thin = 10, n.chains = 3)

Samples per Chain: 25000

Burn-in: 5000

Thinning Rate: 10
 Number of Chains: 3
 Total Posterior Samples: 6000
 Run Time (min): 3.7265
 Occurrence (logit scale):
 Mean SD 2.5% 50% 97.5% Rhat ESS
 (Intercept) -0.3302 0.6488 -1.5347 -0.3518 1.0227 1.0137 1402
 scale(Goat) -2.1110 0.9908 -4.2463 -2.0289 -0.4604 1.0007 4582
 scale(tracks) -0.6480 0.7971 -2.2122 -0.6467 0.9275 1.0043 3199
 scale(Bio_2) -1.4846 0.6284 -2.8412 -1.4322 -0.3872 1.0010 5351
 Detection (logit scale):
 Mean SD 2.5% 50% 97.5% Rhat ESS
 (Intercept) -5.2539 0.5112 -6.2827 -5.2458 -4.2513 1.0749 188
 scale(Season) -0.3415 0.1162 -0.5732 -0.3388 -0.1202 0.9998 3181
 Detection Random Effect Variances (logit scale):
 Mean SD 2.5% 50% 97.5% Rhat ESS
 Days 2.6063 1.7398 0.7498 2.1676 7.0612 1.0059 1400
 Spatial Covariance:
 Mean SD 2.5% 50% 97.5% Rhat ESS
 sigma.sq 0.0455 0.0097 0.0301 0.0443 0.0678 1.0009 5771
 phi 0.0052 0.0028 0.0005 0.0052 0.0099 1.0001 3639

BARBARY SHEEP 2022-2024

Call:
 spPGOcc(occ.formula = occupancy.formula, det.formula = detection.formula,
 data = spocc_data_barbshp_22_24, inits = model.inits, priors = model.priors,
 tuning = list(phi = 5), cov.model = "exponential", NNGP = TRUE,
 n.neighbors = 5, n.batch = 1000, batch.length = 25, n.report = 100,
 n.burn = 5000, n.thin = 10, n.chains = 3)
 Samples per Chain: 25000
 Burn-in: 5000
 Thinning Rate: 10
 Number of Chains: 3
 Total Posterior Samples: 6000
 Run Time (min): 2.4649
 Occurrence (logit scale):
 Mean SD 2.5% 50% 97.5% Rhat ESS
 (Intercept) 0.7896 1.0627 -1.1289 0.7235 3.0469 1.0035 1725

scale(Bio_2) -1.0500 1.4428 -3.9300 -1.0337 1.7068 1.0001 2861
scale(AfricanWolf) 0.6546 1.3570 -1.9346 0.6287 3.3555 1.0001 3744
scale(tracks) -1.2299 1.1595 -3.6922 -1.1802 0.9451 1.0002 4344
Detection (logit scale):
Mean SD 2.5% 50% 97.5% Rhat ESS
(Intercept) -6.3184 0.428 -7.1915 -6.313 -5.4814 1.0027 391
Detection Random Effect Variances (logit scale):
Mean SD 2.5% 50% 97.5% Rhat ESS
Days 0.4962 0.6917 0.0421 0.2776 2.2928 1.0724 686
Spatial Covariance:
Mean SD 2.5% 50% 97.5% Rhat ESS
sigma.sq 0.0454 0.0100 0.0302 0.0440 0.0685 1.0022 6000
phi 0.0052 0.0029 0.0003 0.0052 0.0100 1.0011 3941

10.3.3

Supplementary material 3

1) SOCIO-DEMOGRAPHIC DATA ON RESPONDENTS

- **Gender:** M, F
- **Age**
- **Role in the household**
- **How long have you lived in this community?**
- **Ethnicity:**
- **Main occupation:** Occupation: Cattle rancher/pastoralist, Livestock broker - buys and sells, Farmer, Tourism worker, Trade (except livestock), wildlife activities, Other
- **What is your highest level of education?** None Primary College High School University
- **Total number of adults living in the household**
- **Total number of children living in the household**

2) LOCAL ECOLOGICAL KNOWLEDGE (LEK) ABOUT ANIMAL COMMUNITIES IN THE AREA

1. **Can you list the wild animals in your area?** Did you tell them a limit? Create a column with number of listed animals, then create a table with the frequency of named animals (this will be on a separate sheet)

2. **Can you tell me what is the diet of....**

3. **Can you tell me where they live/where they can find.**

4. **Which of these animals is your favorite? Why ?** present list of species and % how many respondents selected that species

5. Which of these animals do you like the least? Why ?

6. Do you know these species? If yes, give their name?

IMAGES TO SHOW: Dama Gazelle, Dorcas Gazelle, Mouflon, Oryx, Derby Elk, Lion, Saharan Cheetah, Hyena, Elephant, Giraffe, Rhinos

B- Fauna in the Air

1. Is it more common to see wildlife now or when you were a child?

Before = 1

No change = 2

Now = 3

I don't know = IDK (I don't know)

2. Which species have increased (increase in number)?

3. Which species have decreased (decrease in number)?

C- Human-wildlife relationship

1. According to you, the presence of wildlife in the Air is:

A very good thing = 5

A good thing = 4

You are indifferent =3

A bad thing =2

A very bad thing =1

Why ? Enlist the mentioned reasons

2.Are there any problems related to the presence of wildlife?

3. If yes, what can be the solutions? Enlist suggested solutions

3) KNOWLEDGE ABOUT THE ECOLOGY OF DAMA GAZELLE

Have you ever seen a dama gazelle in the wild with your own eyes?

If so, how often ?

A) Less than once a year

B) Once a year

C) Once a month

D) Once a week

E) More

F) Never

G) Other_____

2. When was the last time you saw a wild dama gazelle with your own eyes?

- A) More than a year ago
- B) Less than a year ago
- c) a month ago
- d) a week ago
- E) Less than a week ago
- F) Never
- F) Other _____

Where ? In what context ? Does this happen often??

3. Have you heard of people in your family, village or friends talking about wild dama gazelles? YES NO

If yes, how many times?

- A) Less than once a year
- B) Once a year
- C) Once a month
- D) Once a week
- E) More
- F) Never
- G) Other _____

4. Do you know the habitat of the dama gazelle?

If yes,

Where could/can you find dama gazelles?

- A - 50 years ago
- B - 10 years ago
- C - Now

5. If the answers to A and B/C differ:

Why do you think the gazelle changed its habitat?

6. In your opinion, what is the main threat to the dama gazelle?

7. Do you think this could be the cause of the disappearance of the dama gazelle from this place?

8. Are dama gazelles hunted? Do you know people who do this??

9. If not,

Why don't you (and the locals) chase them away?

10. If yes,

What are the reasons people hunt them? (Example: Meat, Trade, Hobby, Ornament)

11. Does the dama gazelle have special meaning/usefulness to you/your community?

1. Do you know that the dama gazelle is a protected species, that there are very few left in the world and that it is forbidden to hunt it?

10.3.4 Supplementary material 4

Scientific	English	French	Tamacheq
Mammalia/Mammals/Mammifères			
Afrotheria/Afrotheres			
<i>Procavia capensis</i>	Rock Hyrax	<i>Daman de rocher</i>	Akoka
<i>Loxodonta africana</i>	African savanna elephant	<i>Éléphant a'Afrique</i>	Ilo/Elu
Primates			
<i>Papio anubis</i>	Olive baboon	<i>Babouin doguera</i>	Ewirkid kawalan
<i>Erythrocebus patas</i>	Patas monkey	<i>Patas, singe rouge</i>	Ewirkid zagaghan
Rodentia:Rodent/Rongeurs			
<i>Hystric cristata</i>	Crested porcupine	<i>porc-épic</i>	Akachan
<i>Xerus erythropus</i>	Striped ground squirrel	<i>Ecureuil fousseur du Sahel</i>	Akolan
<i>Lagomorpha</i>	Hares and rabbits		
<i>Lepus capensis</i>	Cape hare	<i>Lièvre du Cap</i>	Temarwalt
<i>Erinaceomorpha</i>	Hedgehogs	<i>Hérissons</i>	
<i>Paraechinus aethiopicus</i>	Desert hedgehog	<i>Hérisson du désert</i>	Tekonachit
Carnivora/Carnivores			
<i>Canis lupaster</i>	African wolf	<i>Loup africain</i>	Eggour

<i>Vulpes zerda</i>	Fennec fox	<i>Fennec</i>	Karzo
<i>Vulpes palida</i>	African sand fox	<i>Renard pale</i>	Ezagaz
<i>Vulpes rueppelli</i>	Rüppel's fox	<i>Renard du désert</i>	Karzo
<i>Mellivora capensis</i>	Honey badger	<i>ratel</i>	Zitten
<i>Panthera leo</i>	Lion	<i>Lion</i>	Amahluk
<i>Panthera pardus</i>	Leopard	<i>Panthere</i>	
<i>Caracal caracal</i>	Caracal	<i>Caracal</i>	Ouray
<i>Acinonyx jubatus</i>	Cheetah	<i>Guepard</i>	Adel
<i>Felis sylvestris</i>	Wild cat	<i>Chat sauvage/ganté</i>	Mus-nussuf
<i>Genetta genetta</i>	Common genet	<i>Genette commune</i>	Takayonkoya t
<i>Hyaena hyaena</i>	Striped hyena	<i>Hyene rayée</i>	Eridal
<i>Suidae/Pigs</i>			
<i>Phacochoerus africanus</i>	Common warthog	Phacochere	Adawaydawa y
<i>Giraffidae/Giraffe/girafe</i>			
<i>Giraffa camelopardalis</i>	Giraffe	<i>Girafe</i>	Amdagh/ala m n-assuf
<i>Cetartiodayctyla/Even-toed ungulates</i>			
<i>Gazella dorcas</i>	Dorcas gazelle	<i>Gazelle dorcas</i>	Azukud
<i>Nanger dama</i>	Dama gazelle	<i>Gazelle dama</i>	Ener
<i>Addax nasomaculatus</i>	Addax	<i>Addax</i>	<i>Emillal</i>
<i>Oryx dammah</i>	Scimitar-horned oryx	<i>Oryx algazelle</i>	<i>Ezam</i>
<i>Ammotragus lervia</i>	Barbary sheep	<i>Mouflon à manchette</i>	Efital