CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Behaviour and Husbandry of Zoo-housed Tree Hyraxes (*Dendrohyrax* spp.)

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Behaviour and Husbandry of Zoo-housed Tree Hyraxes (*Dendrohyrax* spp.)" independently, all texts in this thesis are original, AI was used for language editing and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague April 24, 2024

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Bc. Tereza Grégerová

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Abstract

Research on the *Dendrohyrax* species, nocturnal mammals indigenous to Africa, has been somewhat restricted, resulting in notable gaps in knowledge. Nonetheless, there has been significant growth in studies dedicated to these species in recent years, with a particular emphasis on habitat assessment and vocalizations, ultimately resulting in the detection of a new species. Despite this progress, there remains a scarcity of behavioural research conducted on these unique animals, especially in *ex-situ* conditions, with the last comprehensive studies dating back to the previous century. Furthermore, the presence of *Dendrohyrax* species in captivity is extremely rare even nowadays, further limiting our ability to gain comprehensive knowledge about them. Thus, there is still an abundance of fascinating information yet to be revealed about these remarkable animals.

This study examined, based on ethogram and behavioural observations, the differences in behavioural patterns between the species *Dendrohyrax arboreus* and *Dendrohyrax dorsalis*, kept in Czech zoological gardens, aiming to quantify their activity budgets. It was found that both species spend the majority of their time inactive, and the greatest differences observed were in types of movement with the conclusion that they used walking as a main form of locomotion. From the perspective of space utilization of the enclosures, both species spent the majority of their activity time on trees, or on hanging boxes where they rested. Both targeted Czech zoological gardens keep *D. dorsalis* and *D. arboreus* under similar conditions.

The results of this study shed light on the poorly investigated behavioural patterns exhibited by *Dendrohyrax* species. Given their rarity in ex-situ facilities, the summarized husbandry practices outlined in this research could serve as a valuable resource for promoting the breeding of these animals in other captive institutions.

Key words: Afrotheria, Hyracoidea, nocturnal activity, small mammals, time sampling, zoo animals

Contents

List of figures

List of graphs

List of tables

List of the abbreviations used in the thesis

am/ pm: Ante Meridiem/ Post Meridiem

EAZA: European Association of Zoos and Aquaria

FID: Flight Initiation Distance

GLM: Generalized Linear Model

GLMM: Generalized Linear Mixed Model

IUCN: International Union for the Conservation of Nature

LED: Light Emitting Diode

Lme4: Linear Mixed-Effects Models using 'Eigen' and S4

Spp.: Species

Uc.: Uncertain

UV: Ultra Violet

1. Introduction

It is imperative to conduct research on "non-charismatic" or less popular animal species for various reasons, as they often do not receive the same level of interest or attention as charismatic ones. Focusing on less popular species promotes a more comprehensive and fair approach to conservation (Kidd et al. 2018). This guarantees that conservation efforts go beyond charismatic megafauna and encompass the entire range of biodiversity, which includes smaller or less visually appealing species (Albert et al. 2018). Tree Hyraxes (*Dendrohyrax* spp.) are small nocturnal mammals with arboreal lifestyles, whose populations are declining due to human activities, especially habitat fragmentation and poaching (Lawes et al. 2000; Hoeck et al. 2015) The taxonomy of Tree Hyraxes remains unclear, as demonstrated by the recent discovery of a new species, *Dendrohyrax interfluvialis* (Oates et al. 2022). Although several studies have described their behaviour in the wild, it was particularly concerning their natural habitat (Milner & Harris 1999; Topp-Jørgensen et al. 2008; Rosti et al. 2022). It is important to study their behaviour in *ex-situ* conditions as well, because so far there have been only sporadical studies in captive populations (Rudnai 1984; Milner & Harris 1999).

This study focused on behavioural observations of two species of Tree Hyraxes, specifically *Dendrohyrax arboreus* and *Dendrohyrax dorsalis*, as they both are rarely kept in captivity across Europe and they are present in Czech zoological gardens. The behavioural differences between these two species remain unexplored, leading us to investigate and summarize their behavioural patterns using summary descriptive statistics, as well as evaluate their activity levels, as significant differences in movement types between the two species are apparent at first sight, and consequently determine spatial utilization within the enclosure using mixed binomial linear models to address the research questions. Furthermore, this study aimed to summarize the husbandry practices related to these species.

2. Literature review

2.1. Hyraxes

Hyracoidea (Hyraxes) are medium-sized well-furred mammals with stocky bodies resembling rodents (Freeman 2018), belonging to the group Afrotheria, which also includes orders Proboscidea (Elephants), Sirenia (Dugongs and Manatees), Macroscelidea (Elephant Shrews), Afrosoricida (Golden Moles and Tenrecs), and Tubulidentata (Aardvarks) (Svartman & Stanyon 2012; Oates et al. 2022; see in Figure 1). Although Afrotheria was not initially proposed based on anatomical studies, there is evidence supporting the monophyly of this clade. This evidence comes from geography and the fossil record. The six extant orders within Afrotheria share early fossil representatives that have been discovered in Africa or along the edges of the ancient Tethys Sea. That is the reason why Afrotheria is now recognized as a distinct group (Springer 2022). Despite their different appearances, this group shares several common features, such as their lack of testicular descent (Sharma et al. 2018), female mammary glands located between the front legs (Schlitter et al. 2014), late eruption of permanent teeth, and in addition vertebral anomalies (Asher & Lehmann 2008).

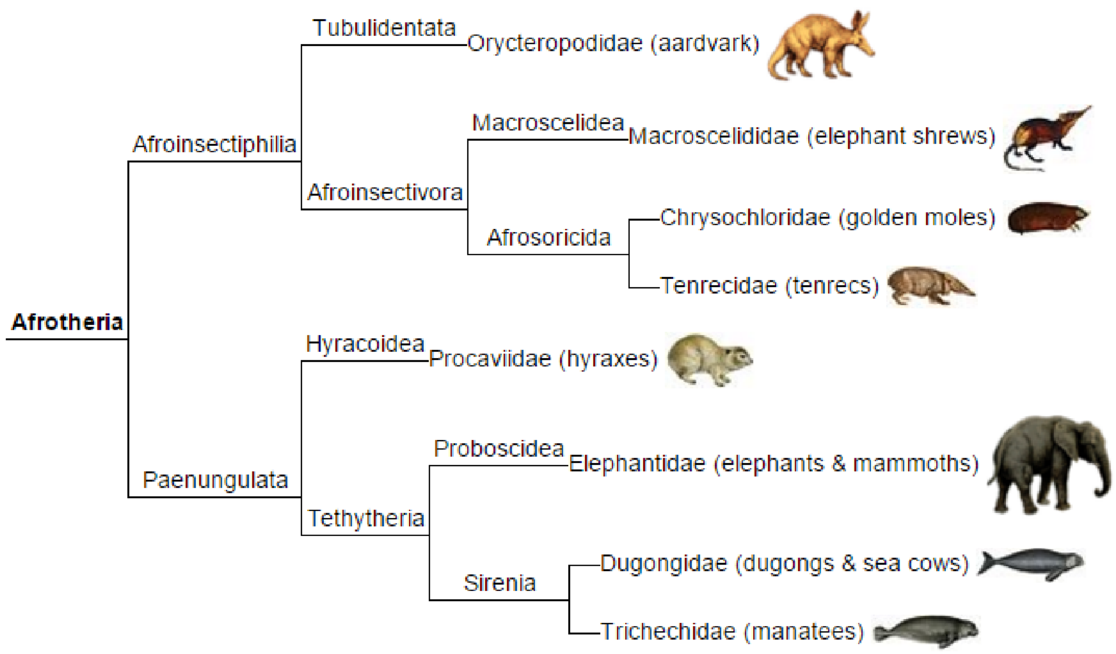


Figure 1 Afrotheria phylogeny (Foresman et al. 2017)

2.2. Taxon History

The Hyracoidea thrived as a mammalian order in Africa during the early Eocene to the mid-Miocene period. During the Eocene/Oligocene period, hyracoids were the prevailing group of “ungulates” in the local terrestrial ecosystems (Tabuce et al. 2018). Within this group, the genus *Titanohyrax* included both exceptionally large species called *T. ulitmus* weighing up to 1,300 kg, and a smaller one, *T. tantulus* weighing around 50 kg (Tabuce 2016), which was solely documented from the early/middle Eocene era in Chambi, Tunisia (Tabuce et al. 2018). *Titanohyrax* stands out from other Paleogene hyracoids due to its unique combination of lophoselenodont teeth, fully molariform premolars, and high-crowned cheek teeth. These dental features indicate that the genus likely had a diet primarily consisting of leaves (Thewissen & Simons 2001). Procaviids were recently discovered at two additional Late Miocene locations in Kenya, more specifically in Lemundong´o near Narok and Tugen Hills – Lukeino. Specimens from Lukeino which consisted of isolated teeth and palate were attributed to *Dendrohyrax* with the closest resemblance to extant species *Dendrohyrax validus*. This discovery is considered to be the earliest known record of this genus (Pickford & Hlusko 2007). The descendants of the giant Hyracoids underwent diverse evolutionary paths. A portion of them decreased in size and eventually developed into the contemporary hyrax lineage. Interestingly Hyraxes possess myoglobin with a high oxygen-binding capacity, suggesting a potential aquatic origin (Mirceta et al. 2013).

2.3. Taxonomy

Hyraxes are traditionally divided into three genera within Procaviidae, the sole surviving family in the mammalian order Hyracoidea – Rock Hyraxes (genus *Procavia*), Bush Hyraxes (genus *Heterohyrax*), and Tree Hyraxes (genus *Dendrohyrax*) (Kutner et al. 2011; Oates et al. 2022; see Figure 2). The closest surviving relatives of Hyracoidea are the orders Sirenia and Proboscidea. Together these three groups are classified as Paenungulata, whereby they can be described as a monophyletic group from morphological and molecular points of view (Nishihara et al. 2005). One species is currently recognized in the genus *Procavia*, as it is in the case of the genus *Heterohyrax*, and four species are currently distinguished in the genus *Dendrohyrax*. The taxonomy of Hyraxes has always been problematic, as they are animals that have variable colouration, and in the case of *Dendrohyrax spp.* this phenomenon is emphasized by their nocturnal and arboreal lifestyle (Rosti 2022). It is difficult to distinguish individual species and subspecies based on their coat colouration since high variability can be seen not only at the subspecies level but even at the population level (Djossa et al. 2012; Oates et al. 2022). Therefore, identification based on morphology and especially coat colouration has not proved to be very suitable, and their taxonomy gives rise to several inconsistencies depending on the publications (Kingdon 2015).

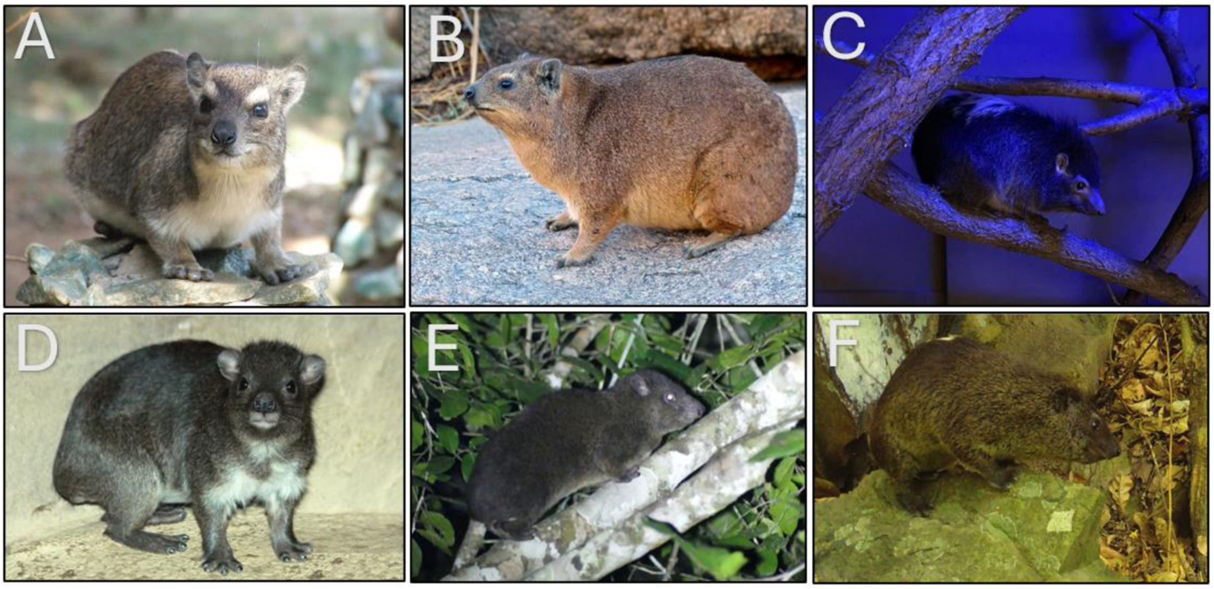


Figure 2 Species of Procaviidae; (A) Bush Hyrax (*Heterohyrax brucei*) (Obbard 2016), (B) Rock Hyrax (*Procavia capensis*) (Dupont 2012), (C) Western Tree Hyrax (*Dendrohyrax dorsalis*) (photo author), (D) Southern Tree Hyrax (*Dendrohyrax arboreus*) (Sloviak 2011), (E) Eastern Tree Hyrax (*Dendrohyrax validus*) (Moser 2017), (F) Benin Tree Hyrax (*Dendrohyrax interfluvialis*) (Oates et al. 2022).

An example of the unclear taxonomy may be studies focused on *Procavia* species as they differ in the number of recognized subspecies (Maswanganye et al. 2017). In general, *Procavia capensis* is considered to be the only species of the genus *Procavia* (Oates et al. 2022). Their pelage colouration differs on an individual and regional basis. Specifically, the dorsal patches (present in both sexes) of the central populations show a high degree of variability, ranging from yellow to black, or speckled. In more distant populations, these patches are more consistent in colour, but this dorsal margin is not easily recognizable in the *Procavia capensis* population inhabiting southern Africa. A larger, longer-haired population was found in the moraines in the alpine zone of Mount Kenya (Kingdon 2015). Depending on the source, the number of recognized subspecies varies, with most agreeing on 17, with some sources occasionally recognizing 5 of those subspecies as separate species (Ellerman et al. 1953; Olds & Shoshani 1982; Maswanganye et al. 2017). These are namely Cape Rock Hyrax (*Procavia capensis capensis*), Ethiopian Rock Hyrax (*Procavia capensis habessinicus*), Black-necked Rock Hyrax (*Procavia capensis johnstoni*), Red-headed Rock Hyrax (*Procavia capensis ruficeps*), and Kaokoveld Rock Hyrax (*Procavia capensis welwitschii*) (Kingdon 2015).

Hyraxes are also studied with the use of molecular-genetic approaches, (Prinsloo & Robinson 1992; Gerlach & Hoeck 2001; Maswanganye et al. 2017), but these studies mainly focus on *Procavia*. These animals are highly vocal mammals, and the analysis of their vocalizations seems to be a well-applicable method, as their vocalizations are highly species-specific (Kershenbaum et al. 2012; Rosti et al. 2023). This approach has even led to the recent discovery of a new species of Tree Hyrax, *Dendrohyrax interfluvialis* (Oates et al. 2022).

Vocalization is a powerful tool in the research of *Procavia* as it can be also used for the identification of male *Procavia capensis* who use their vocalizations to express their individual identity (Koren & Geffen 2011; Kershembaum et al. 2012). As mentioned above, *Dendrohyrax* species are particularly challenging for taxonomic classification, due to their lifestyle. Their subspecies have several colour variations and therefore create confusion in the taxonomy, but in recent years, light has been shed on the examination of their vocalizations as they are species different, and in the case of *D. validus* even subspecies differ (Wilson & Mittermaier 2011; see Figure 3).

Figure 3 Different coat colouration of Dendrohyrax validus; (a) Eastern Tree Hyrax (*Dendrohyrax validus*) from Shimba Hills, Kenya; (b) *D. validus* from limestone cave in Vipingo near Mombasa, Kenya (Rosti et al. 2023)

Currently, there are four recognized species of *Dendrohyrax* (see Figure 2, pictures C, D, E and F) (Oates et al. 2022). These species include the Southern Tree Hyrax (*Dendrohyrax arboreus*), the Eastern Tree Hyrax (*Dendrohyrax validus*), the Western Tree Hyrax (*Dendrohyrax arboreus*), and the recently discovered Benin Tree Hyrax (*Dendrohyrax interfluvialis*) (Djossa et al. 2012; Roberts et al. 2013; Rosti et al. 2024). The subspecies counts for individual *Dendrohyrax* species are of uncertain validity because, as mentioned, some subspecies have been determined based on colouration, which has not proven to be an accurate method. The Western Tree Hyrax is currently classified into six subspecies (Jones 1978; Hoeck 2001), Southern Tree Hyrax into four (Jones 1984; Milner & Harris 1999), Eastern Tree Hyrax is known to have also four distinct subspecies (Roberts et al. 2013), and Benin Tree Hyrax has no reported subspecies, which is probably due to the fact of its recent discovery (Oates et al. 2022).

Heterohyrax (Figure 2, A) is regarded as a monotypic genus under the classification proposed by Barry and Hoeck (2013). Nevertheless, in other classifications, it was believed to be polytypic, with the forms *Heterohyrax antineae* and *Heterohyrax chapini* recognized sometimes as separate and isolated species (Schlitter 1993). In that study, *H. chapini* was included within *H. brucei*. On the other hand, the *Heterohyrax antineae* was considered to be synonymous with *Procavia capensis* which again points to ambiguities in their taxonomy. According to the study of Kutner et al. (2011), *Heterohyrax brucei* is divided into two well-supported clades that do not align with geographical distribution. The absence of sister clades within these groups suggests a high level of genetic diversity within the current classification of *Heterohyrax brucei*, raising the possibility of taxonomic differentiation among these populations. A total of 24 subspecies have been described, although the validity of many of them is uncertain. Nonetheless, some of these subspecies may indeed represent distinct species (Barry and Shoshani 2000; Barry & Hoeck 2013).

Given the ongoing research on the taxonomic affiliation of Procaviidae, it can be expected that changes in the taxonomy will occur in the future. Evidence can be found, for example, in the study by Schneiderová et al. (2024), where a misidentification of *D. arboreus* in the Ostrava Zoo was found using bioacoustic methods.

2.4. Distribution and Habitat

Distribution of Hyraxes is limited to Africa, except for *Procavia capensis* which extends into the Middle East (Teklehaimanot & Balakrishnan 2018.). The distribution of *Procavia capensis* spans sub-Saharan Africa, extending to North-East Africa and the Middle East (Figure 4, A). Genus *Heterohyrax*, on the other hand, is mainly concentrated in the eastern part of Africa, with a separate population in Angola as can be seen in Figure 4, picture B (IUCN Red List 2015). These two species often coexist in rocky outcrops, with *Procavia* preferring dry habitats in arid savannas, while *Heterohyrax* is typically found near rocks and boulders surrounded by bush or woodland (Freeman 2018). *Procavia* uses rock crevices to avoid harsh environmental conditions during summer (Brown & Downs 2005). The species is occasionally found on small rocky areas that seem unsuitable for living due to the absence of crevices and the presence of predators. The size of their population changes in response to drought, food availability, and possibly disease. Sometimes, there is a sudden increase in population, leading them to inhabit less favourable habitats (Maswanganye et al. 2017). *Heterohyrax* lives in specific habitats such as rocky kopjes, sheer rock faces, and large boulder piles. These habitats provide them with suitable living spaces due to the presence of numerous crevices for nesting and seeking shelter from weather and predators (Kingdon et al. 2013).

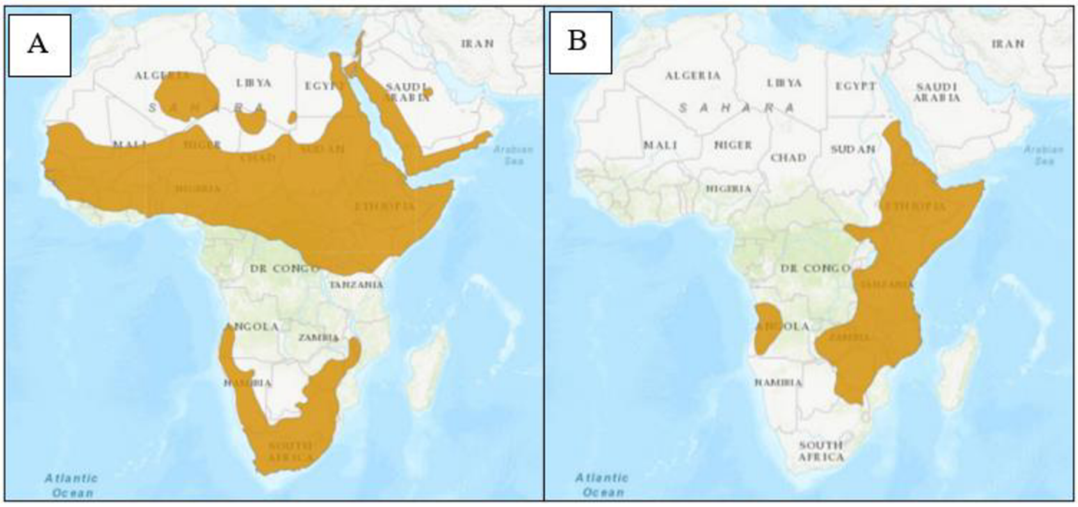


Figure 4 Distribution map; (A) Distribution map of *Procavia capensis*, (B) Distribution map of *Heterohyrax brucei* (IUCN Red List 2015)

Since *Dendrohyrax* species are scattered by distribution across Africa, as it can be seen in Figure 5, this also causes differences in their habitats. As they have an arboreal lifestyle, which is a major difference from the other two species that are terrestrial, their distribution is dependent on forests, in which they use cavity-bearing trees as dens. According to the study of Gaylard & Kerley (2001) which asses the habitat of *D. arboreus* these animals use the tallest canopy trees (4-8 m) as den trees (Gaylard & Kerley 2001; Rosti et al. 2022). They occur in low densities in niches of arboreal folivores and share this environment with sympatric primates (Omifolaji & Modu 2016).

The distribution range of *Dendrohyrax dorsalis* is limited to West and Central Africa, spanning from Sierra Leone to northern Uganda, and extending southwards to northern Angola and the northeastern Democratic Republic of the Congo (Schulz & Roberts 2013), and this species is frequently observed to inhabit lowland forests and degraded forest fragments, with a usual elevation range of around 1,500 m. However, this species has been recorded at elevations as high as 3,500 m in Central Africa. Its habitat encompasses moist forests, moist savannas, and montane habitats (Wilson & Mittermaier 2011).

Dendrohyrax arboreus is distributed sporadically within forested regions of Central and Eastern mainland Africa. It can be found from central Kenya, extending southwards through Southwest Kenya, southern Uganda, Rwanda, Burundi, Tanzania, Malawi, southern and extreme eastern Democratic Republic of the Congo (DRC), northeast Angola, Zambia, and reaching as far south as the Zambezi River in Mozambique. Additionally, there is a limited population located south of the Zambezi River in Mozambique, as well as in the Eastern Cape and KwaZulu-Natal provinces of South Africa (Milner & Gaylard 2013) They occur from rocky areas through subtropical or tropical dry forests, (sub)tropical moist montane forests, (sub)tropical moist lowland forests to moist savanna, and temperate forests reaching elevations up to 4,500 m (Kingdon et al. 2013).

Dendrohyrax validus exhibits a confined and fragmented distribution, being constrained to the montane forests found in Mt. Kilimanjaro and Mt. Meru, as well as the Eastern Arc Mountains, and the coastal forests of Tanzania, Southern Kenya, and the surrounding offshore islands such as Pemba, Zanzibar, and Tumbatu. (Kundaeli 1976; Topp-Jørgensen et al. 2008). They can be found in montane forests, but also nearby lowland forests and even tropical dry forests on coral in Zanzibar and Pemba. The species is most commonly observed at lower elevations, but it has been documented at altitudes as high as 3,070 meters on Mt. Kilimanjaro. However, at these higher elevations, the population density of this species is lower due to the limited availability of large trees (Kingdon et al. 2013).

Dendrohyrax interfluvialis can be found in coastal regions of southeastern Ghana, southern Togo and Benin, and southwestern Nigeria occupying wet and dry forests that lie between the rivers Niger and Volta where they have been until recently recognized within the population of *D. dorsalis* (Oates et al. 2022).

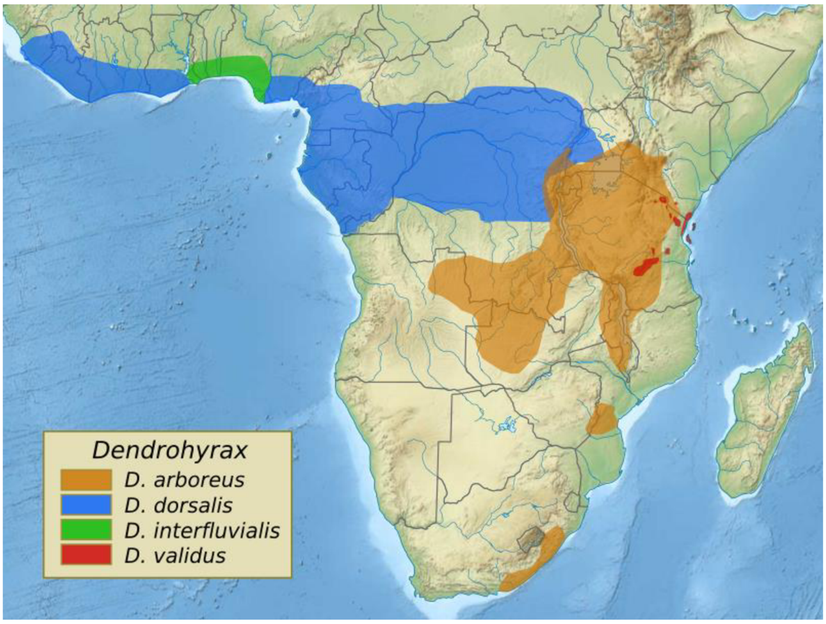


Figure 5 Distribution map of *Dendrohyrax* species (Kraasch 2017)

2.5. Ecology of Hyraxes

Hyraxes may resemble rodents such as rabbits or big guinea pigs, with a sturdy body and rudimentary tails. They have dense fur with long sensory hairs that serve a purpose similar to a cat's whiskers (Eley 1994). Despite that fact, Procaviidae have several unusual characteristics for mammals their size. They have high brain function and excellent memory (Benoit et al. 2013), a characteristic that is similar to their bigger relatives – Elephants (Safaris 2024). Compared to other small mammals, these animals have a relatively long lifespan, with individuals living up to 10-12 years in the wild and potentially even longer in captivity (Cordiero et al. 2005). It is also worth noting the length of the gestation period. In Hyraxes, the gestation period is usually between 7-8 months, which is quite long compared to other species of similar size, although slight variations may occur depending on individual factors and environmental conditions (Barocas et al. 2011; Girmay et al. 2016; Freeman 2018). The newborns are precocial and relatively well-developed at birth (see Figure 4) and are capable of movement shortly after being born. They rely on their mother for nursing and protection (Jones 1978). These small mammals typically reach sexual maturity between the ages of 2 and 3 years, although this timeline can vary depending on environmental factors and social dynamics within the group (Cordiero et al. 2005).

Figure 6 Newborns of *D. arboreus* from Pilsen Zoological Garden half hour after being born (photo Rothová)

2.5.1. Social Structure and Mating Behaviour

Heterohyrax and *Procavia* are considered to be social gregarious species that live in groups usually consisting of about 30 individuals in the case of *Heterohyrax* and up to 80 individuals in *Procavia*. They utilize scent markings or vocalizations to delineate their territories and display territorial behaviour by protecting them from intruders (Kundaeli 1976; Barry & Shoshani 2000). Genus *Heterohyrax* has groups that are hierarchically organized, with the dominant territorial male in the role of a group leader. This male is responsible for organizing group activities and protecting the group's territory. The social unit includes females, offspring, and dispersing males, creating a unified group that helps in maximizing resource use, reducing the risk of predation, and promoting successful reproduction in the population (Barry & Shoshani 2000; Girmay et al. 2016). Likewise, the social groups of *Procavia* are also based on family units, with each group being headed by a dominant adult male. Within this social system, the immature males are usually the dispersers, while the females tend to be philopatric. Through their communal living setups, they display social interactions, fostering relationships and dividing tasks among members to guarantee the well-being of their community in the harsh terrains they inhabit (Olds & Shoshani 1982; Maswanganye et al. 2017).

Bush Hyraxes reproduce every year, with two distinct peaks in reproductive activity observed near the equator, where two rainy seasons are common. The synchronization of breeding cycles in regions with higher latitudes is influenced by photoperiod, whereas breeding patterns in equatorial areas tend to be more variable seasonally, possibly due to nutritional or other environmental factors triggering the onset of sexual activity (Glover & Sale 1968; Barry & Shoshani 2000). Rock Hyraxes exhibit a synchronized mating season that typically spans 2 to 3 weeks in either July or August. While male Hyraxes engage in vocalizations year-round, the frequency of their singing reaches its peak several months before and during the mating period. Both males and females engage in copulation with multiple partners during this time (Bar Ziv et al. 2016; Damartsev et al. 2023). On average, females of both species give birth to one to four offspring (Barocas et al. 2011).

2.5.1.1. Social Structure and Mating Behaviour of Tree Hyraxes

The population dynamics and social organization of the *Dendrohyrax* species remain inadequately understood, characterized primarily by solitary tendencies, and territorial delineation via olfactory cues and vocalizations (Gaylard et al. 2016). The reason why they are described usually as solitary species may be explained by the note of Jones (1974) claiming that in most cases home range for one individual of *Dendrohyrax* consists only of its home tree. While solitary behaviour predominates (Gaylard et al. 2016), observations indicate that *D. arboreus* occasionally forms modest groupings, typically comprising 2 – 3 individuals (mother and her subadult offspring), with sporadic instances of a male living together with multiple females. A seminal contribution by Hanna Rosti et al. in 2022 posited the potential for increased sociability within *D. validus* populations, inferred from territorial overlap, thereby suggesting previously unacknowledged social complexities within this taxon. Genus *Dendrohyrax* displays a range of reproductive strategies to maximize their reproductive success. These strategies include for example cooperative care of offspring and flexible breeding behaviour that allows for year-round breeding in response to environmental cues. Unlike some other species, tree hyraxes do not adhere to a strict breeding season. However, breeding activity may peak during specific periods of the year, often corresponding to environmental conditions such as increased food availability (Skinner & Chimimba 2013). During breeding, dominant males typically mate with multiple females. While these animals usually give birth to a single offspring, the occurrence of twins is not unheard of (Cordiero et al. 2005).

2.5.2. Diet

All Procaviidae can be described as hindgut fermenters which assigns them to the same category as for example lagomorphs and rodents, in which the fermentation takes place in the caecum. Their stomach is unusual mostly due to two-chambered structure divided into glandular and non-glandular parts. Their digestive tract is well developed and efficient due to long transit time which allows microbial fermentation to help with the digestion. Microbial fermentation also produces volatile fatty acids serving as a source of energy. All species of Procaviidae are known to defecate in a single spot called a latrine or midden (Carr et al. 2016; Freeman 2018). For *Dendrohyrax* spp. latrines are most commonly found in cavities or at the base of trees, and their density is quite significant in the utilized area (Pluháček & Svobodová 2016).

Hyraxes are primarily herbivorous, feeding on a variety of plant materials such as leaves, fruits, and grasses, including tough plant parts that they can digest very efficiently (Carr et al. 2016). Reports from Hoeck (1975) indicated that the herbivorous *Heterohyrax* and *Procavia* exhibit similar ecological niches when they are allopatric but display differences in feeding behaviour when they are sympatric. These two species may potentially compete for food resources, particularly during the dry season when both species rely on browsing (Girmay et al. 2016). Research findings revealed that *Procavia* exhibits a strong preference for grasses during the wet season. However, as the grasses become parched and of poor quality in the dry season, this species extensively engages in browsing. On the other hand, *Heterohyrax* predominantly browses on bushes and trees throughout both the wet and dry seasons (Girmay et al. 2016). Interestingly, they tend to consume more grass and engage in less browsing during the wet season (Hoeck 1975). *Dendrohyrax* spp. on the other hand, is recognized for primarily consuming leaves from woody plants. As a result, their diet heavily relies on trees for sustenance (Topp-Jørgensen et al. 2008).

2.5.3. Behaviour and Daily Pattern

Hyraxes use a range of vocalizations, such as grunts, squeaks, and screams, for communication. These vocalizations play a crucial role in group cohesion, territorial demarcation, and alerting others to potential threats and serve as one of the key factors utilized in their taxonomy (Koren & Geffen 2011; Kershembaum et al. 2012; Rosti et al. 2023). Olfactory communication also represents an important source of information, because, in the case of *Dendrohyrax* spp., they establish social connections through vocal calls and scent-marking signals (Rosti et al 2020). These species are mostly vocal during the period immediately after dusk and before dawn, and regarding their nocturnal activity vocalization serves as the main form of interaction for them (Rosti et al. 2020; Rosti et al. 2022).

Despite being quick and agile climbers, both in trees and on rocky slopes, the extant Procaviids have feet that are not typical of climbing animals. This could be since Hyraxes developed their climbing abilities relatively recently in their evolution. Their foot structure, including the naked and rather elastic pads on the soles of their feet and their nails, is similar to the feet of Elephants (Meyer 1978). Their agility appears to rely on the flexibility of their limb articulations and a strong grip, which is attributed to abundant skin glands on the surface of their foot pads and a specialized musculature that contracts the pad into a suction cup (Meyer 1978; Fisher 1994). Concerning their feet, all Hyraxes possess a long nail on the inner toe of the hind foot (Figure 5), which serves for scratching, as noted by Milner & Harris (1999). Grooming behaviour, in which individuals use their lower incisors for brushing through the fur, has been observed in most Procaviidae species and it has been also observed in captivity settings in the *Heterohyrax* and *Dendrohyrax dorsalis* species (Jones 1978).

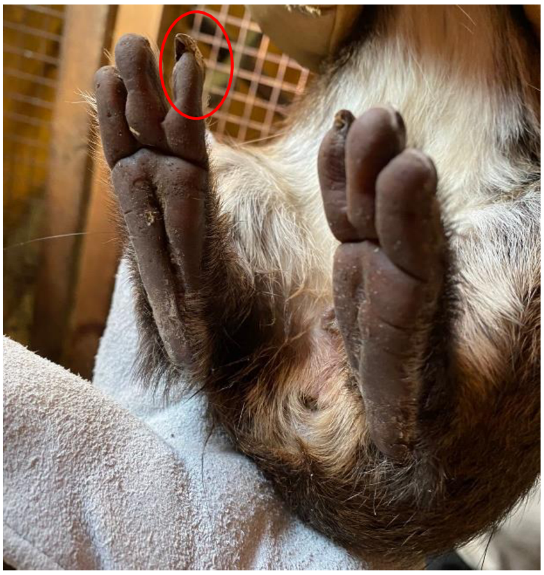


Figure 7 Hind limbs with prolonged nail in *D. arboreus* from Ostrava zoo (photo Drastíková)

The behaviour of an animal can be influenced by the environment in which it lives, resulting in the expression of different behaviour patterns depending on the specific environmental conditions (Brown & Downs 2005). In general, animals are categorized as diurnally active (active during the day) and nocturnal (active during the night) (Rifinetti 2008). Various mammals are adapted to all gradients between being totally diurnal to fully nocturnal. That may be an example of crepuscular (active during the twilight) or cathemeral (sporadic and random intervals of activity during the day or night) species (Ashby 1972; Cox et al. 2021). In the case of Hyraxes *Heterohyrax* and *Procavia* are described as diurnally active (Milner & Harris 1999; Chase et al. 2012) opposite to *Dendrohyrax* spp. which have predominantly nocturnal activity (Oates et al. 2022). In the study by Milner and Harris (1999), which assessed activity patterns of *D. arboreus*, it was discovered that bimodal activity patterns were present, with peaks occurring after dusk and later at night for males, and during the day for females. Because Hyraxes generally have poor thermoregulation (Freeman 2018), *Procavia* and *Heterohyrax* often perform sun basking, especially in the winter. Poor quality of food and its limited source may be insufficient to meet their metabolic demands at low ambient temperatures, and therefore sun basking is not only an energy conservation mechanism but also essential for the survival of these species during the winter (Brown & Downs 2005; Freeman 2018). The two social species also gather in groups to keep warm, and *Dendrohyrax* spp.

can protect themselves from colder nights by seeking shelter in tree hollows. Milner & Harris (1999) during their research on the *D. arboreus* also observed reduced activity levels when the temperature dropped.

The behavioural pattern of *Dendrohyrax* spp. is very difficult to describe, especially due to its arboreal lifestyle and nocturnal activity. Therefore, most studies measure their activity based on acoustic monitoring (Djossa et al. 2012; Rosti et al. 2023; Rosti et al. 2024). This species makes use of den trees for shelter, while the dense canopy serves for easy movement between trees (Topp-Jørgensen et al. 2008). In a behavioural study done by Milner & Harris (1999) on *D. arboreus*, was discovered that this species displayed activity only 16% of the time. While there was no significant contrast in the proportion of active versus inactive behaviours between males and females, young individuals exhibited notably higher activity levels than older ones. The main activity observed was feeding, particularly on mature leaves of *Hagenia abyssinica*. Movement within and between trees took up 4% of their time, mainly occurring during daylight. The prevalent inactivity could be justified due to the low metabolic rate of these animals. Similar conclusions were mentioned in the study of Rudnai (1984) with findings that *D. arboreus* spent most time inactive, during the night (95%) and even during the day (70%). With most activity observed during the day hours, this author suggested that this species may be more diurnal than nocturnal.

2.6. Conservation and Threats

Procavia has according to the IUCN Red List stable population with unknown number of individuals. For *Heterohyrax* neither population size nor population status is known. Both of these species are listed as least concerned (Butynski et al. 2015b,c). The conservation status of *Dendrohyrax* varies depending on the species, with *D. validus* being near threatened with decreasing population trend (Hoeck et al. 2015) and *D. dorsalis* with unknown status of population trend (Dowsett-Lemaire et al. 2015) together *with D. arboreus* (decreasing population trend) being least concerned (Butynski et al. 2015a). However, it is known that opposite to *Heterohyrax* and *Procavia*, species of *Dendrohyrax* can be found in smaller populations, mainly due to forest fragmentation. From the conservation point of view, small populations are more likely vulnerable to a significant decline in genetic diversity on their own, especially if the number of breeding individuals is very low (Gerlach & Hoeck 2001). In populations with a small number of individuals, the Allee effect is commonly observed, indicating a positive correlation between population density and individual fitness. This phenomenon is widespread yet challenging to identify, as populations experiencing Allee effects tend to quickly evolve new mechanisms to avoid reduced fitness in small population sizes (Drake et al. 2019; Surendran et al. 2020). Furthermore, in small populations inbreeding may increase the proportion of homozygous genes which could ultimately lead to a reduction in fitness (Gerlach & Hoeck 2001). The decline in their populations is attributed not just to human activity, but also to natural predation, especially by African Wild Cats (*Felis lybica*) and Caracals (*Caracal caracal*) (Palmer & Fairall 1988). *Procavia capensis* and *Heterohyrax brucei* are the nearly exclusive prey of the Black Eagle (*Aquila verreauxii*) (Barry & Barry 1996).

Despite the threat posed by anthropogenic land-use changes to wildlife globally, certain species can capitalize on these changes and move into urban areas. The presence of wildlife in urban environments frequently leads to conflicts with humans, particularly when animals are linked to the spread of zoonotic diseases. An example of this is the ongoing urban invasion of Rock Hyraxes (*Procavia capensis*) in Israel (Ben-Moshe & Iwamura 2020).

However, another problem is that the forests are witnessing a decline in the number of species as a result of isolation and fragmentation and there are only a few studies that investigate the population statuses and sizes of these species (Girmay et al. 2016). Despite the ability of *Dendrohyrax* spp. to survive in closed-canopy forests, the act of logging, which includes the selective removal of large trees, eliminates shelter trees, disrupts arboreal pathways, and increases the susceptibility of animals to ground trapping (Freeman 2022). Hyraxes are among other things targeted for their meat and skin, with occasional instances of hunting for medicinal or ritual purposes (Gaylard & Kerley 2001). *Dendrohyrax validus* displays a patchy distribution pattern, with population density showing significant variability among different locations and numerous forest fragments are insufficient in size to sustain viable populations (Lawes et al. 2000). This species together with *Dendrohyrax arboreus* is at risk throughout its range due to illegal logging, wildfires, and hunting activities (Topp-Jørgensen et al. 2008).

When faced with disturbances caused by human activities, certain animal species exhibit a variety of behavioural responses that may come with potential costs. These responses include an increase in antipredator behaviour or a decision to relocate to different areas. Flight initiation distance (FID), which refers to the distance between a predator and its prey when the prey begins to flee, is a commonly used measure to assess animals' tolerance towards humans' presence. Through repeated exposure to a potential predator with low risk, animals can undergo habituation, which involves a change in their risk assessment towards that specific predator (Stankowich & Blumstein 2005; Mbise et al. 2019). A study by Mbise et al. (2019) to investigate the flight initiation distance (FID) of two hyrax species, namely *Procavia capensis johnstoni* and the *Heterohyrax brucei*. The researchers found that hyraxes residing in areas with human presence exhibited a significantly shorter FID compared to those inhabiting other locations. This suggests that the presence of humans may influence the behaviour and response of Hyraxes, leading to a reduced flight initiation distance. The findings indicate that animals that have regular interaction with humans exhibit reduced levels of attentiveness, which could potentially pose a threat for example in terms of poaching.

2.7. Hyrax Species in Human Care

There are very few sources that provide more detailed information about Procaviidae, especially about *Dendrohyrax* spp. in human care, and most studies were conducted on *Procavia* species (Freeman 2018). One of these studies is from 2009 concerning the reintroduction of *Procavia capensis* into the KwaZulu-Natal province, where this species became locally extinct in the late 90s. This study provides information about ten individuals who were held in captivity for health and disease monitoring for 16 months before being released into the wild. Roughly a year after being captured, the initial group of ten individuals was relocated to an outdoor cage containing wooden shelves for climbing and four hutches filled with hay. Their daily diet included fresh cabbage, apples, carrots, and rabbit pellets, with water being accessible ad libitum. The reintroduction proved to be unsuccessful, with the failure of the release likely stemming from predation and the subsequent disruption of the group (Wimberger et al. 2009).

In the late 1970s and 1980s, research on *Dendrohyrax* species was restricted to captive studies (Rudnai 1984; Milner & Harris 1999). However, with the advancement of technology, there has been an increase in studies conducted on these species in the wild. As a result, research in *ex-situ* conditions has been infrequent, and since then there has been a lack of those studies (Freeman 2018).

All *Dendrohyrax* species currently kept in Czech zoological gardens were obtained through direct capture in Tanzania between 2009 and 2010 for the zoological gardens of Ostrava, Pilsen, and Prague. In total, 9 animals were acquired (five to Ostrava, three to Prague, and one to Pilsen). On 28th February 2012, the first successful breeding of a *Dendrohyrax arboreus* offspring was achieved. Apart from Ostrava, these Tree Hyraxes had only reproduced in captivity once, back in the 1970s, at Twycross Zoo in England (Pluháček & Svobodová 2016). A recent *ex-situ* study conducted in 2023 in Ostrava Zoological Garden has revealed that their zoo population of Tree Hyraxes from Tanzania previously classified as *Dendrohyrax arboreus* closely vocally resembled the population of Tree Hyraxes discovered in 2020 in the Taita Hills of Kenya. Taita Hills' population exhibited a unique vocal repertoire that did not entirely align with any known Tree Hyraxes. This finding raised the possibility that these rarely kept captive *Dendrohyrax* spp. may have been misidentified as *Dendrohyrax arboreus* and could actually be related to the population in Taita Hills, Kenya (Schneiderová et al. 2024).

The following section lists the standards for Hyraxes husbandry practices in sanctuaries, which are the locations that offer refuge, either temporarily or permanently, for animals that are in need. They are following the rules of the handbook written by the Global Federation of Animal Sanctuaries (2019):

The living conditions and habitat provided are suitable for the species and aim to closely resemble the natural environment of Hyraxes. The lighting provided, whether natural or artificial, is suitable for the species in terms of intensity, spectrum, and duration. Special consideration is given to nocturnal species to ensure they have enough hours without artificial illumination. Temperature and humidity are set according to the requirements for each species. The minimum vertical dimension in arboreal species is 1.8 m. Mixed species groupings are carefully studied to guarantee compatibility and prevent any unnecessary stress for all the species involved. The feeding areas, automatic water devices, and water and food containers are cleaned and disinfected every day. It is necessary to regularly sanitize all hard surfaces, including walls, floors, ceilings, benches, climbing structures, and cage mesh, to the possible extent.

Fresh and clean water must be provided every day. Hyraxes should have access to multiple water sources to prevent dominant individuals from controlling the water supply. Individual animals are provided with diets that are customized to suit their physiological requirements. This includes vitamin supplementation and a careful balance of quality, quantity, and variety in the diet, taking into account factors such as age, life stage, species, condition, and size. The primary components of the diet for all Hyrax species consist of browse, which encompasses bark, leaves, twigs, and bulbs. Additionally, complete feed mixtures specifically formulated for each species are provided.

The preventive healthcare program consists of quarantine protocols, parasite monitoring, and management, vaccination, birth control, screening for infectious diseases, dental cleanings, and regular evaluations of nutrition, animal care practices, and invasive species control. Timely postmortem examinations are essential, as necropsies conducted beyond 24 hours after death may be less informative due to autolysis. Justifiable reasons for euthanasia could encompass an untreatable disease or injury that is likely to result in unmanageable pain or suffering; a disease or injury where treatment is expected to cause unreasonable pain or suffering; a disease or injury where the treatment available will not be effective in restoring the animal to an acceptable quality of life; in the situation of presenting a risk of infectious disease to some or all of the resident population.

Regarding the most common causes of death of Hyraxes in captivity, Kruse et al. (2015) in their study on *Procavia capensis* examined the causes of death of this species in captivity in the USA between 1997 and 2013 based on necropsy reports. Of the 111 necropsies, 87 individuals died naturally, and 24 were euthanized. The primary factors leading to mortality or the justification for euthanasia were bacterial septicaemia and degenerative cardiomyopathy. Additionally, other prominent causes included hemosiderosis, pancreatic islet and interstitial fibrosis, pneumonia, enteritis and colitis, and renal tubular necrosis. Numerous animals in this study exhibited multiple lesions that affected various organs.

3. Aims of the Thesis

The aim of the thesis was to quantify and compare the behaviour of two *Dendrohyrax* species through behavioural observations conducted in *ex-situ* conditions.

In this thesis, we were asking these specific research questions:

1) What is the amount of time spent resting and active and is there any difference between *D. dorsalis* and *D. arboreus* in this regard?

2) What is the amount of time spent on the ground and is there any significant difference between the species?

3) What are the most frequent locomotion modes and is there any significant difference in the locomotion mode (i.e., walking, running, jumping, vertical climbing) between the two species?

Additionally, the thesis aimed to summarize the existing knowledge about the husbandry practices of this species in zoological gardens based on the questionnaire.

4. Methods

4.1. Composition of Observed Groups

Two species of *Dendrohyrax* were observed in two Czech Zoological Gardens in Pilsen and Ostrava. The first observed species was *Dendrohyrax dorsalis*, second observed species was during the time of observations classified as *Dendrohyrax arboreus*, but a recent study done by Schneiderová et al. (2024) revealed, that the species kept in Ostrava Zoological Garden may have been misidentified and may be conspecific with the population currently known from Taita Hills in Kenya. Despite this fact, this species will be referred to in this research by its original taxonomic name *Dendrohyrax arboreus* (with added *uc.* at the end of the name – standing for "uncertain"). One group of *D. dorsalis* and one group of *D. arboreus uc.*, was observed in each zoological garden, in which all groups were situated in the visitor section of the exhibits. Total number of observed individuals was 15, eight of them of *Dendrohyrax dorsalis* species and seven *Dendrohyrax arboreus uc.* species. During the research, some individuals either suddenly died or were relocated, therefore they were not further included in this study. Detailed group composition can be found in Table 1.

Table 1 Detailed information about observed indiviuals

Species[a]	Zoological Garden	Individual Code[b]	Gender[c]	Year of Birth
D. arboreus	Pilsen	P_A_1	F *	2020
D. arboreus	Pilsen	P_A_2	M *	2019
D. arboreus	Pilsen	P_A_3 ×	F	2022
D. dorsalis	Pilsen	P_D_1 ×	M *	2018
D. dorsalis	Pilsen	P_D_2	F *	2018
D. dorsalis	Pilsen	P_D_3	F	2023
D. arboreus	Ostrava	O_A_1	F *	2020
D. arboreus	Ostrava	O_A_2	M *	2021
D. arboreus	Ostrava	O_A_3	M	2023
D. arboreus	Ostrava	O_A_4	M	2023
D. dorsalis	Ostrava	O_D_1	F *	2016
D. dorsalis	Ostrava	O_D_2	M *	2016
D. dorsalis	Ostrava	O_D_3	M	2022
D. dorsalis	Ostrava	O_D_4	M	2023
D. dorsalis	Ostrava	O_D_5 ×	M	2020

[a] Scientific name of the species; *D.* stands for *Dendrohyrax*

[b] Each individual was coded as X_Y_N – X stands for Zoological Garden (P – Pilsen, O – Ostrava); Y – species code (A – *Dendrohyrax arboreus uc.;* D – *Dendrohyrax dorsalis*); N – assigned number of observed individual; individuals marked with symbol × were not included in this study

[c] Gender of an individual M – male; F- female; individuals marked with * are the breeding ones

4.2. Behavioural Observations

The ethogram of Tree Hyraxes behaviours (see Appendix I) was created based on the research and ethogram of Rudnai (1984) and a preliminary observation conducted at the Pilsen Zoo in May and June 2023.

Observations were conducted from July to November 2023, each group was observed for three hours either during the forenoon (9 am – 1 pm) or afternoon (1 pm – 5 pm) for 7 days. In total, each group was observed for 21 hours, which amounted to a total of 84 hours of observations for all the groups. The data collection process for one day involved observation of the group *D. dorsalis* and the *D. arboreus uc.* group residing in the same zoological garden. In total, there were 14 observational instances, with seven occurring at the Pilsen Zoological Garden and the remaining seven at the Ostrava Zoological Garden. For detailed information on behavioural observations and group composition see Table 2. On each day of observation, groups of both species in one zoological garden were observed during a three-hour period. These intervals were broken down into five-minute sections, allowing to score the type of the individual's behaviour, as well as their location (see Appendix II) and any interactions with other individuals, or periods of inactivity. To ensure accurate identification of the individuals, it was essential to accompany the Tree Hyraxes keepers on multiple visits to both zoos before conducting the actual testing. Individuals of *D. dorsalis* species were mainly identified based on differences in the bald spots on the head and body size. Identification of *D. arboreus uc*. was made only based on body size and preferred locations of exhibit, as identification based on other characteristics was not possible.

Table 2 Detailed information on study groups of *Dendrohyrax* species, including their identity, home zoo, group size and composition, housing conditions, and the behavioural observation schedule.

Study Group			Housing Conditions				Behavioural Monitoring
No.	Species	Zoo	Group Composition[a]	Night Cycle	Public Activity[b]	Other Species[c]	Monitoring months
1	[e]*D. arboreus*	Pilsen	1,2,0	9 am - 9 pm	8 am – 7 pm	*Galago senegalensis*	September, October, November (2023)
2	*D. dorsalis*	Pilsen	1,2,0	9 am - 9 pm	8 am –7 pm	X	September, October, November (2023)
3	*D. arboreus*	Ostrava	3,1,0	9 am - 9 pm	9 am – [f]4/5/6/7/8 pm	X	July, August, September (2023)
4	*D. dorsalis*	Ostrava	4,1,0	9 am - 9 pm	9 am – [f]4/5/6/7/8 pm	X	July, August, September (2023)

[e]D. stands for *Dendrohyrax*.

[f]Closing hours in Ostrava differs according to month of the year (November, December, January – 4 am; February – 5 am; March, September, October – 6 am; April, May, June – 7 am, July, August – 8 am).

[a]Stated for male, female, and unidentified individuals.

[b]Opening hours of the pavilion.

[c]Other species sharing the same exhibit.

4.3. Questionnaire

The questionnaire (see Appendix III) was created with a focus on the husbandry practices for Tree Hyrax species in *ex-situ* conditions. The questions focused on information about the composition of the observed groups, housing conditions, feeding regime, daily routines, and veterinary care and handling for both target species separately. In total, there were eight questions with subquestions for each species. Most questions had open answers, in order to obtain the most accurate description of husbandry practices, but a few questions were included in the questionnaire, with a selection from predefined answers. The questionnaire was subsequently sent in digital form to the Zoological Gardens in Pilsen and Ostrava, where it was filled by professional staff working with this species.

4.4. Data Transformation

To get an overview of behavioural patterns, behaviours observed in all groups were chosen for further examination. In total 10 of 25 predefined behaviours were selected, specifically standing, laying, jumping, running, walking, vertical climbing, feeding from a bowl, nuzzling and non-visibility.

For the statistical investigation, the data had to be transformed and 4 groups were formed from the individual behaviours. The first group "Activity" divided all behaviours scored to active, including walking, running, jumping, vertical climbing, and feeding from the bowl, and inactive, including standing, lying, grooming, nuzzling, and non-visibility. The second group “Movement type” contained behaviours used for locomotion and coded them using numbers 1– walking, 2– running, 3 – jumping and 4 – vertical climbing. The third group “Location” contained the location of behaviours as B – Box, E – equipment of the enclosure, G– ground, T– tree, W– Wall, and 0– non-visible (without location). The last group “Ground” determined for each individual whether it was on the ground (1) or elsewhere in the enclosure (0).

4.5. Statistical Analyses

For the summary statistics, proportions of behaviour types for each species, group, and individual were analyzed in MS Excel through the utilization of summary and other functions connected to descriptive statistics. Subsequently, these results were transformed into average percentages taking into account the number of observed individuals of each group or species by summing up the values for the given categories of one group, dividing by the number of individuals, and then recalculated into average percentages. These data were then plotted graphically using the graphing function in MS Excel. Additionally, the overview of space utilization of the enclosure for each species was calculated and graphically visualized

For the evaluation of defined research questions the R 4.3.1 scripting language (R Core Team 2023) was used for statistical data analysis, specifically binomial mixed models from the "lme4" library (Bates et al. 2015) with a logistic link function. The generalized linear mixed model (GLMM) has proven to be a valuable tool in analyzing data with clustered structures, particularly in fields such as medical sciences, ecology and evolution, epidemiology, social and behavioural sciences, and various other areas of study. GLMMs are particularly useful for modelling binary outcomes in repeated or clustered measures. By incorporating random effects into the generalized linear model (GLM), the GLMM can account for sources of heterogeneity and dependence in the data, thereby enhancing statistical inference. The R^2 statistic has many good qualities that make it a great measure of goodness-of-fit. It shows how much of the variance is explained by the model, making it easy to assess the fit. Also, it is unitless and goes from 0 to 1, allowing investigators to objectively evaluate model fit (Jaeger et al. 2016).

4.5.1. Statistical Analyses of Research Questions

The first question addressed overall differences in activity between the species *Dendrohyrax arboreus uc.* and *Dendrohyhax dorsalis*. In this case, species affiliation was treated as a fixed effect and individual identity as a random factor. The second question about differences in activity on the ground vs. at other enclosure sites was also addressed. Here again, species affiliation was taken as a fixed explanatory variable and individual identity as a random factor in a mixed binomial model. The final series of analyses addressed differences in modes of movement between both *Dendrohyrax* species. Overall, each activity was analyzed separately using the mixed binomial models and then the results were compared using the Benjamini-Yekutieli false discovery rate (Benjamini & Yekutielli 2001) in multiple tests. In each model, species was again used as a fixed effect and individual identity as a random effect.

5. Results

5.1. Activity Types

An overview of the daily behavioural budget for all four observed groups has been created (Table 3) by the calculations of 11 selected types of observed behaviours. Total counts and mean values were calculated using a summary statistic as mentioned in methods. For *D. arboreus uc.* there were 2,098 scores of behaviour in total which corresponds to a mean value of 350 scores per individual. Inactivity, i.e., standing, laying, grooming itself and nuzzling accounted for a mean value of 231 scores (66%) per individual. For *D. dorsalis* there were 2,254 scores of behaviour in total which corresponds to a mean value of 376 scores per individual. For this species, inactivity accounted for a mean value of 270 scores (almost 72%) per individual. The animals not visible were scored on average at 15% in *D. arboreus uc.* and at 6% in *D. dorsalis*, which further increases the time spent inactive as the animals were probably resting in their nest boxes or hidden somewhere else

The GLMM did not find significant differences (p-value 0.43) in the amount of time spent inactive between the two species (see Table 4). Staying was scored on average at 54.04% of total inactivity in *D. arboreus uc.* and at 44.69% in *D. dorsalis*. Laying was the second most scored behaviour for inactivity described at 35.49% for *D. arboreus uc*. and at 42.69% for *D. dorsalis*. The rest of the scores of inactivity accounted for grooming itself and nuzzling (see Graph 1). When the animals were active, the locomotion, i.e., walking, running, jumping or climbing, was scored on average, at 13.4% in *D. arboreus* and at 14.9% in *D. dorsalis.* There were significant differences in modes of locomotion used by the two species (Graph 2) as revealed by GLMM (see in Table 4). Both species preferred walking over other types of movement with a prevalence of 80.07% in *D. dorsalis* and 61.48% in *D. arboreus uc.*. Followed by jumping at 11.74% in *D. dorsalis* and at 26.5%. The rest of the scores accounted for running and vertical climbing. Results of GLMM, where each movement type values were tested separately and subsequently compared through false discovery rate, values confirmed significant differences between the movement types of both species.

Subsequently, the evaluation of feeding preferences was conducted, on a total of 256 recorded scores for the behaviours of browsing and feeding from a bowl. Out of these scores, 165 were assigned to *D. arboreus uc.* and 89 to *D. dorsalis*. It concluded that both species displayed a higher inclination towards browsing. Specifically, *D. arboreus uc.* showed a preference for browsing at 75.23% compared to feeding from a bowl at 24.77%. Likewise, *D. dorsalis* exhibited a preference for browsing at 57.82%, while feeding from a bowl accounted for 42.18% of its behaviour.

When analyzing rest time in the company of another animal, we determined that the most time spent on group rest was by the following individuals of *D. dorsalis*: P_D_3 (96.94%), P_D_2 (93.69%), P_A_3 (87.88%) and *D. arboreus uc.* were P_A_3 (87.87%), O_A_3 (92.97%) and O_A_3 (93.69%). In contrast, two *D. aboreus uc.* individuals, more specifically P_A_1 (9.5%) and O_A_2 (1.41%) were the least involved in joint rest, and one *D. dorsalis* individual P_D_1 was not involved in group resting at all.

Table 3 Total counts and average percentages of observed behaviours for all groups

Group[a]	G1		G2		G3		G4		G_{sum}	
	Sum[b]	%	Sum	%	Sum	%	Sum	%	Sum	%
Behaviour										
Standing	479	35.14	579	32.08	290	34.56	258	31.24	1606	33.23
Laying	230	16.87	578	32.52	303	36.11	248	30.02	1359	28.12
Walking	130	9.54	196	10.86	48	5.72	94	11.38	486	9.68
Non-visible	283	20.76	145	8.03	54	6.44	32	3.87	514	10.64
Grooming Itself	68	4.99	107	5.93	63	7.51	63	7.63	301	6.23
Running	23	1.69	10	0.55	6	0.72	3	0.36	42	0.87
Jumping	31	2.27	19	1.05	49	5.84	23	2.78	122	2.52
Vertical Climbing	5	0.37	7	0.39	1	0.12	8	0.97	21	0.43
Feeding from a Bowl	7	0.51	8	0.44	23	2.74	60	7.26	98	2.03
Nuzzling	15	1.10	55	3.05	2	0.24	12	1.45	84	1.47
Other Behaviours	92	6.76	101	5.10	0	0.00	25	3.04	218	4.51
Summary	**1363**	100%	**1805**	100%	**839**	100%	**826**	100%	**4833**	100%

[a] Group identification; G1 – *D. arboreus uc.* (Ostrava Zoo); G2 – *D. dorsalis* (Ostrava Zoo); G3 – *D. arboreus uc.* (Pilsen Zoo); G4 – *D. dorsalis* (Pilsen zoo)

[b] Total counts of observed behaviour

Table 4 Results of statistical analysis

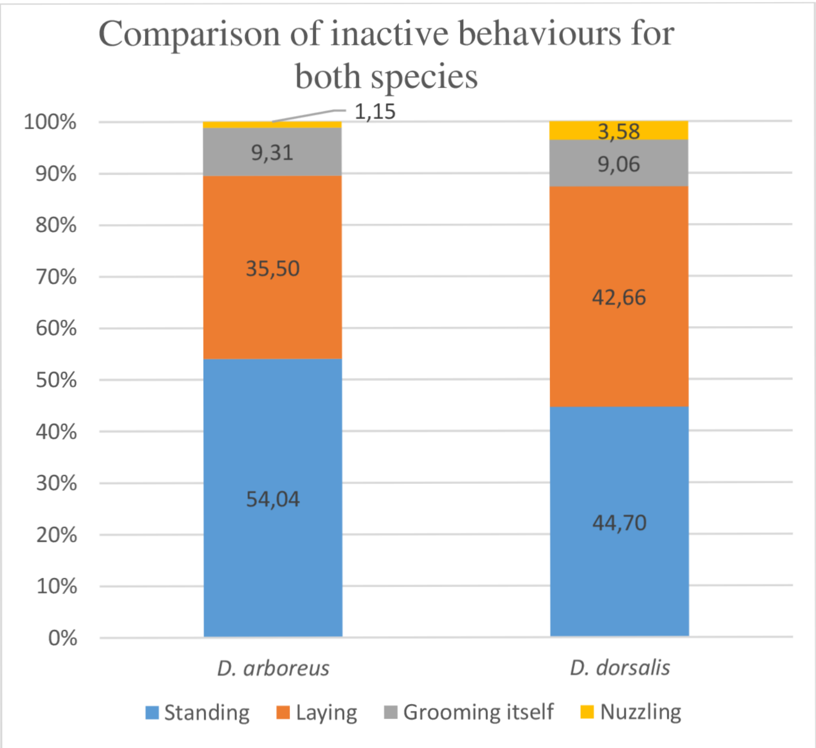
Research Question	Fixed explanatory variable	DF	SE	p-value	R^2
1) Activity vs inactivity	Activity	1	0.304	0.43	0.01
2) Ground vs elsewhere	Ground	1	0.018	<0.001	0.37
3) Types of movement	Climbing	1	0.141	0.004	0.08
	Running	1	0.256	0.024	0.06
	Jumping	1	0.183	0.038	0.04
	Walking	1	0.023	<0.001	0.43
	Whole model	3	-	0.018	-

DF – Degrees of Freedom

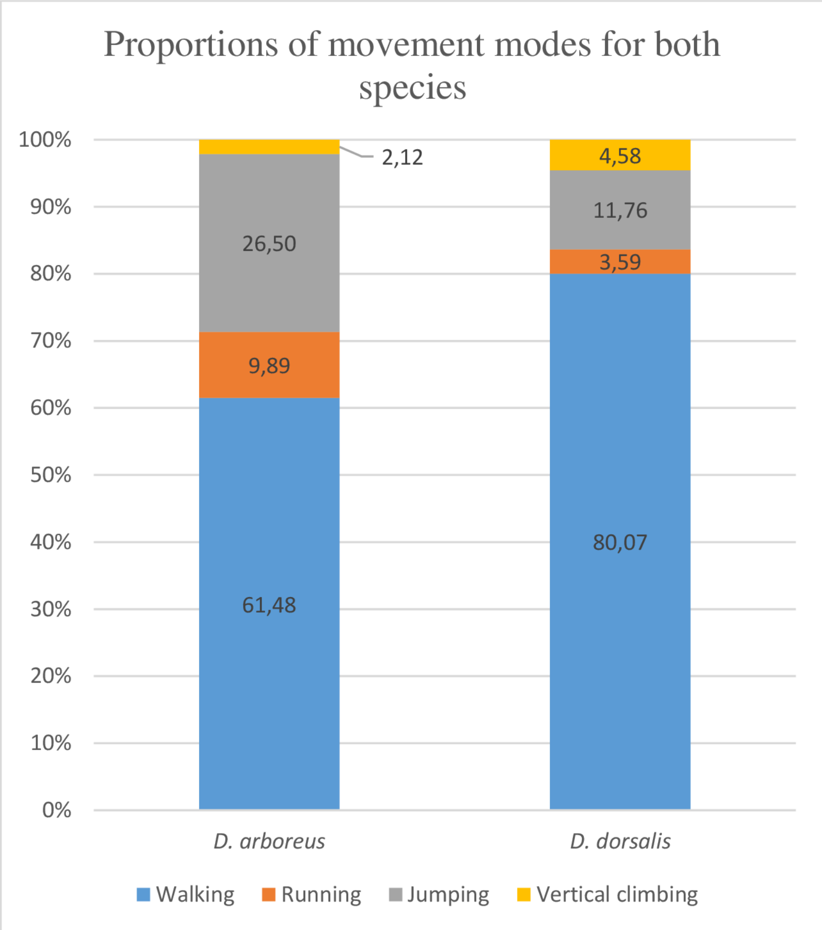
SE – Standard Error

R^2 – Coefficient of Determination

Graph 1 Comparison of active and inactive behaviours for both species



Graph 2 Proportions of movement modes for both species

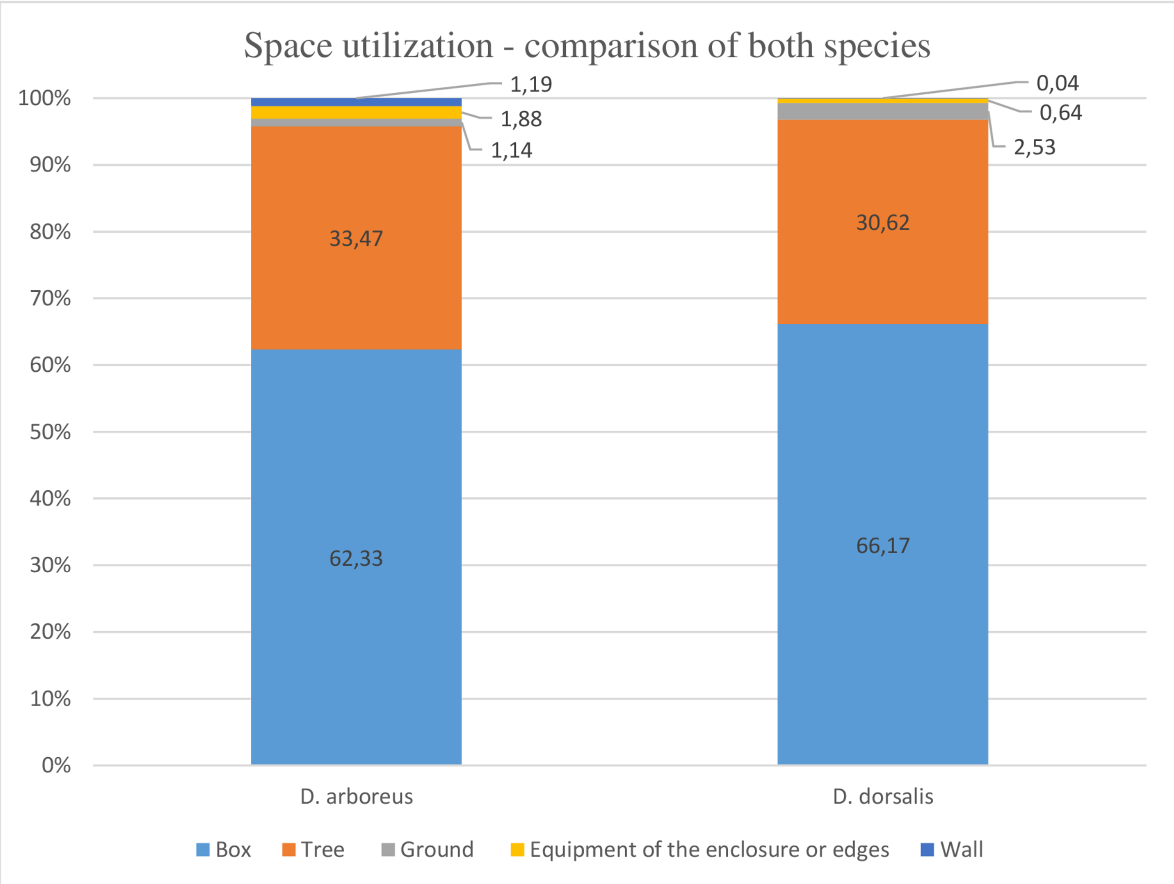


5.2. Space utilization

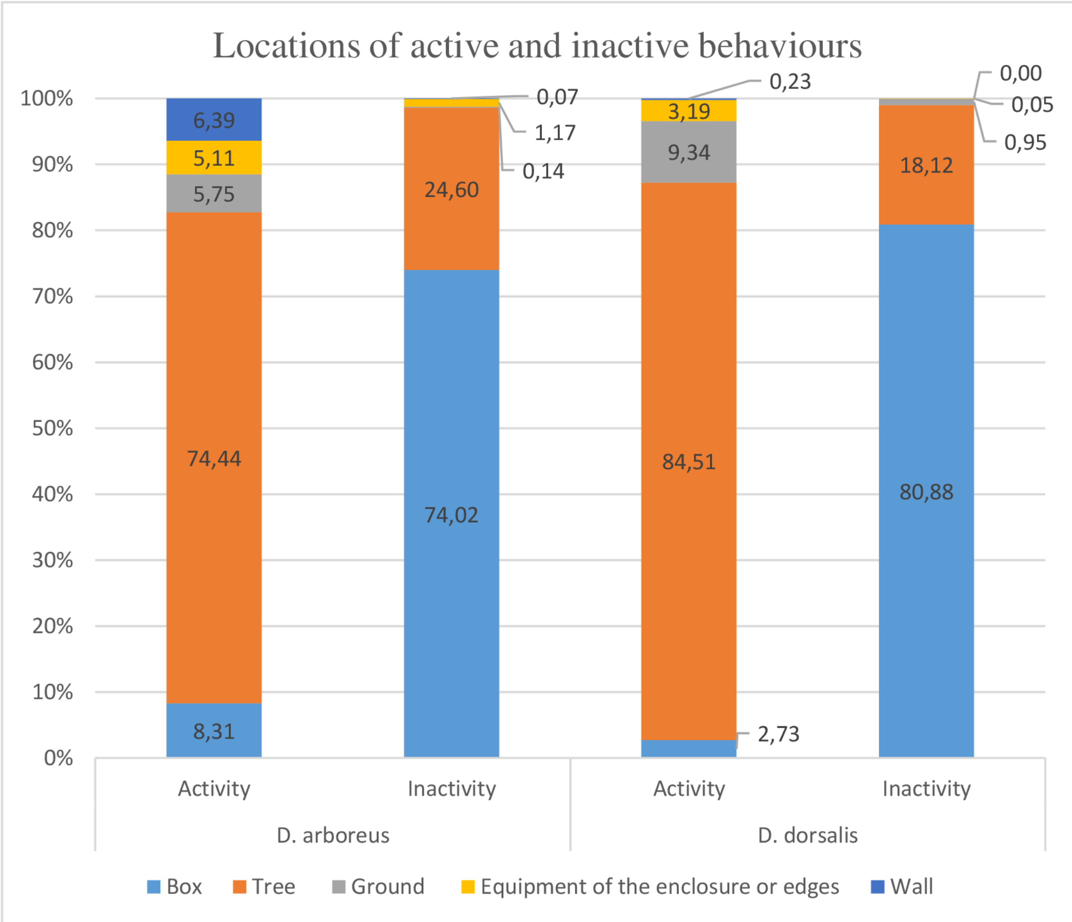
Examination of the enclosure space utilization revealed that the predominant locations for both species were hanging boxes (64.51%) or trees (31.84%), whereas the differences between species' presence at these locations were not much different as can be seen in Graph 3. The remaining locations assessed were the ground, walls, and equipment of the enclosure or its edges. The analysis involved a total of 4,092 location scores, with a focus on comparing the differences in active and inactive behaviours between the two species examined. The results revealed that the location of inactive behaviours occurred in 3340 scores (81.62%), while active behaviours were present in 752 scores (18.38%). In terms of inactive behaviour, both species were predominantly located on boxes, with percentages of 74.02% for *D. arboreus uc.* and 80.88% for *D. dorsalis*. On the other hand, active behaviour in both species was most commonly observed on trees, with percentages of 74.44% for *D. arboreus* and 84.51% for *D. dorsalis* (see Graph 4).

The scores of these animals on the ground were recorded 79 times and GLMM revealed a significant difference (see Table 4) in the occurrence frequency on the ground among the observed species. Specifically, it was found that *D. dorsalis* exhibited a higher tendency to occur on the ground compared to *D. arboreus uc.*.

Graph 3 Space utilization - comparison of both species



Graph 4 Locations of active and inactive behaviours



5.3. Questionnaire Results

The questionnaire underwent a manual evaluation, and the results from both zoological gardens were compared and summarized. The initial factor that was assessed was the enclosure. All enclosures were structured as glass exhibits and were located in the visitor area of the zoos. The sizes of the enclosures varied, with the enclosure for *D. arboreus uc.* measuring 13 m^2 (33.8 m^3) and 8 m^2 (20.8 m^3) for *D. dorsalis* in Pilsen. In Ostrava, both enclosures were larger approximately 20 m^2. Furthermore, there was discovered a distinction in the substrate used. In Pilsen, for *D. arboreus uc.* peat and sand were used as the substrate, while *D. dorsalis* was kept only on peat. In contrast, the enclosures in Ostrava did not have a substrate but instead featured a washable floor. All enclosures were equipped according to the arboreal lifestyle of those species (see Figures 8,9), with timber wooden structures, branches, feeding places, and hanging boxes. No additional enrichment is involved.

All enclosures were found to have consistent temperature and humidity levels, regardless of the season. In Ostrava, the temperature was maintained between 23-24 °C, while in Pilsen it ranged from 20-25 °C. The standard levels of humidity were set at 40% in Pilsen, although it was temporarily increased to 70% after showering during the cleaning. In Ostrava, the humidity level was stable at 50%. The light regime in both zoos remains stable throughout the year, with a reversal of our daily regime. Dark period is from 9 am to 9 pm, while light is from 9 pm to 9 am. However, there was a noticeable difference in the type of lighting used. Pilsen Zoo utilized blue light to illuminate the enclosures, whereas Ostrava Zoo used red light along with UV light.

Dendrohyrax species diet in both zoos did not change throughout the seasons. All groups were fed twice, until 9 am and 3 pm. In both zoological gardens, species are fed the same ratio per individual: 50 g Browser Maintenance pellets, 30 g celery, 15 g carrots with the addition of 150 g of leafy vegetables (ice salad, red/green chicory, kale, chinese cabbage, rome salad - changed according to their preference) in Ostrava. Browsing materials such as raspberry branches, willow, hornbeam, hawthorn, pyracantha, bramble, blackthorn, choke cherry, and elm, are provided based on availability and current animal preference.

Feeding and cleaning of the enclosures were provided on a daily basis, with four keepers involved in Pilsen and one keeper in Ostrava. Both zoological gardens cleaned the enclosures until 9 a.m. Deep cleaning was performed in Pilsen four times a year compared to Ostrava, where the performed deep cleaning monthly and changes the wooden structures of the exhibits annually.

The final part of the questionnaire focused on veterinary care and handling. The results from both zoos indicated that animal handling and microchip readings were only carried out when necessary, such as during transportation or veterinary checks. Deworming was not administered as a preventive measure, but rather based on the results of faecal analysis. This analysis was conducted four times a year in Pilsen and twice in Ostrava during autumn and spring. Neither of the zoos conducted ectoparasite checks. No dental problems had been detected, and in terms of injuries, only one case was identified. Specifically, a male *D. dorsalis* in Ostrava suffered a serious bite on its leg and received repeated antibiotic treatments. Animal keepers in Ostrava were unable to determine a predominant cause of death in those species, while in Pilsen, diseases caused by *Yersinia* bacteria were recognized as the primary factor leading to death. Furthermore, a singular case of paralysis resulting in death was reported on the *D. arboreus uc.* in Pilsen.

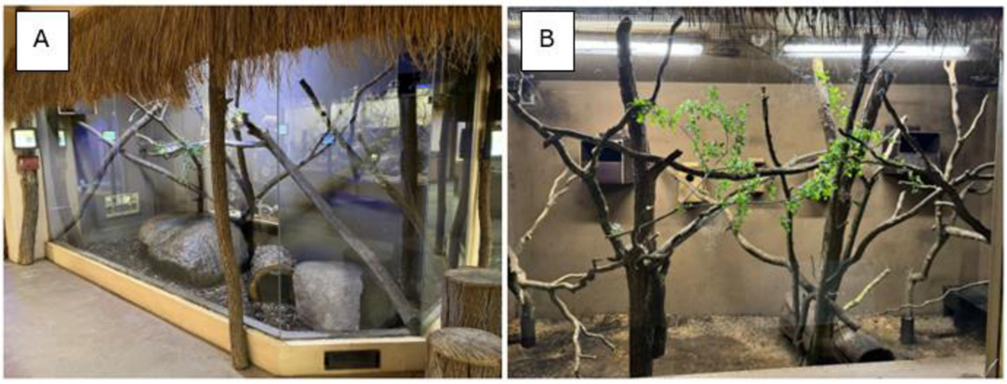


Figure 8 Enclosures of *Dendrohyrax* spp. in Pilsen Zoo; (A) Exposition of *D. dorsalis*, (B) Exposition of *D. arboreus uc.* (photo Rothová)

Figure 9 Enclosures of *Dendrohyrax* spp. in Ostrava Zoo; (A) Exposition of *D. dorsalis*, (B) Exposition of *D. arboreus uc.* (photo Drastíková)

6. Discussion

For a long time, Tree Hyraxes have been a very understudied group. Research on them in captive conditions has been very sporadic, mainly dating back to the 1970s and 1980s. With increasing interest in these species, recent years have revealed a plenty of surprising information about their lifestyle and taxonomy, exemplified by the discovery of the new species *D. interfluvialis* (Oates et al. 2022). *D. arboreus* and D. dorsalis are rarely kept in ex-situ conditions, thus focus on analyzing their behaviour within controlled zoo environments was key for proper understanding of differences between these two species. Brown & Harris (2005) have noted that animal behaviour can be influenced by different environmental factors, however, in our study, this concern was mitigated because all observed groups were housed under similar conditions.

6.1. Activity

It was found that both species exhibit a high level of inactivity, primarily characterized by standing and lying. Similar findings were reported by Milner & Harris (1999) in their study of *D. arboreus* in its natural habitat, as well as by Rudnai (1984) in her examination of *D. arboreus* in semi-captive settings. The inactive behaviour also included situations where individuals were non-visible, with scores being higher in *D. arboreus uc.*. Currently, we do not have an explanation for this result, but we suspect that it could be due to individuals of this species being more shy according to behavioural observations. The prevalent lack of activity in these animals could be attributed to their low metabolic rate, as indicated by Freeman et al. (2018). Rudnai (1984) even proposed that these Tree Hyraxes are diurnal rather than nocturnal, based on her observations of increased daytime activity in this species. Upon comparison with two other nocturnal species, *Nycticebus javanicus* (Ellison et al. 2023) and *Galago senegalensis* (Romdhoni et al. 2022), it was discovered that those species indicated higher activity (more than 50% of the whole time during the night) with the prevalence of movement and feeding, and only a quarter of their time being inactive. We suggest additional research to gain a better understanding of why Tree Hyraxes display such high levels of inactivity when compared to other nocturnal species.

The analysis of activity and inactivity scores conducted did not show any disparity between the activity of the two observed species. Consequently, we proceeded to investigate the predominant types of movement exhibited by *Dendrohyrax* spp., wherein walking on the trees emerged as the prevailing form of locomotion for both species. This particular movement accounted for more than 50% of the total time spent in activity. This result was not surprising, as it was described by Topp-Jørgensen et al. (2008) that *Dendrohyrax* spp. are known to regularly walk on the trees when moving between trees in their natural environment.

Every animal underwent an assessment to ascertain whether it preferred group rest or solitary. The findings clearly indicated that individuals most engaged in group rest were mothers accompanied by their offspring, aligning with previous research findings by Gaylard et al. (2016), which noted that the offspring of these species tend to stay close to their mothers. Conversely, males across all groups exhibited the lowest propensity for group rest, likely attributed to their solitary tendencies in their natural habitat (Jones 1974).

6.2. Space Utilization

Upon evaluating the utilization of space within the exhibit, it became evident that both species predominantly occupied the hanging boxes or the trees, accounting for a significant majority (96.37%) of their time, whereas the differences between species' presence at these locations were not much different. This preference aligns with their natural behaviour in the wild, where they primarily reside in their home trees near cavities, utilizing them as protective shelters, as described in the study conducted by Gaylard & Kerley (2001). An unexpected finding revealed a notable variance in occurrence on the ground between the two species, as *D. dorsalis* exhibited a higher frequency of being on the ground compared to *D. arboreus*. The camera trapping conducted in Ghana's Volta Region by Oates et al. (2022) has captured *D. interfluvialis*, previously misclassified for *D. dorsalis*, moving in and out of rock crevices on steep hill slopes, both during the day and at night. This raises the question of whether these Hyraxes may indeed be more active during the day and less arboreal than previously assumed.

This study involved a thorough examination of active and inactive behaviours across a space of enclosures. Notably, active behaviours like walking, climbing, and feeding were most commonly observed on trees for both species, underscoring their preference for arboreal activities (Topp-Jørgensen et al. 2008). On the other hand, inactive behaviours, including standing or lying, were predominantly seen on hanging boxes within the enclosures. These patterns are also consistent with the research conducted by Gaylard & Kerley (2001).

6.3. Husbandry Practices

The *Dendrohyrax* species are usually kept in glass enclosures with a reversed day-night cycle, allowing visitors to see these animals active as they are nocturnal species as animal visibility plays a crucial role in ensuring visitor satisfaction and accomplishing educational objectives. The enclosures consisted of wooden structures and hanging boxes designed to replicate the natural habitat of the species, which are arboreal and typically build nests in tree cavities (Milner & Harris 1999). Both zoological gardens provided a similar diet to both species of *Dendrohyrax*. The diet primarily consisted of browsing material, which is a natural part of their diet, supplemented with pellets for maintenance and a mixture of leafy vegetables, celery, and carrots. The keepers at Ostrava Zoological Garden observed an improvement in the fur quality of these animals after incorporating carrots into their diet. This observation aligns with the fact that carrots are a rich source of vitamin B7 (Numan 2019), which according to the Lipner study (2017) indeed promotes hair growth.

The illumination of enclosures differed as blue light was used in Pilsen and red light with the addition of UV light in Ostrava. In the study by Baskir et al. (2021) was suggested that LED bulbs emitting red and infrared lights with longer wavelengths are less prone to causing changes in the behavioral patterns and movements of animals in their enclosures. On the other hand, as mentioned in a study by Brando & Buchanan-Smith (2018) the influence of artificial blue light can have a negative impact on the activity budgets, health, and reproductive capabilities of nocturnal species. Therefore we would suggest using a red type of lightning in nocturnal exhibits to promote optimal welfare for captive animals.

In terms of veterinary care, both species undergo regular faecal analysis and receive medication for endoparasites as needed. The Ostrava Zoological Garden recently faced a situation where a male of *D. dorsalis* was injured by a bite. This particular animal required multiple rounds of antibiotic treatment due to the ineffectiveness of orally administered antibiotics. Consequently, the antibiotics had to be administered locally. The challenges with oral antibiotics could potentially be attributed to the well-developed stomach microbiome that these animals possess (Carr et al. 2016). The prevailing cause of death at Pilsen Zoological Garden was attributed to bacterial infection by Yersinia. A similar outcome was noted in the examination conducted by Kruse et al. (2015) which evaluated the primary causes of mortality in captive Hyrax species. The study indicated that bacterial septicaemia, resulting in blood poisoning, was the primary reason for euthanasia. On the other hand in Ostrava Zoological Garden the prevalent cause of death was not reported.

Conclusions

In thesis, behavioural patterns of two *Dendrohyrax* species, *namely Dendrohyrax dorsalis* and *Dendrohyrax arboreus uc.*, which were kept in two Czech zoological gardens were summarized and evaluated based on behavioural observations. Data were collected using an ethogram containing predefined behavioural types based on the ethogram of Rudnai (1984) and previous observations of these animals in zoological gardens. Obtained data were evaluated using summary statics and GLMMs.

By analyzing the data, behavioural patterns of the two species were identified, revealing several differences such as the prevalence of non-visibility in *D. arboreus uc.*. Standing and lying were the most common behaviours exhibited by both species, indicating that they spent most of their time inactive. Notably, there were no significant differences in activity levels between the two observed species when they were active. Further analysis provided insight into the types of movements of these species and revealed that there was a species difference in preferred movement types. *D. dorsalis* walked and climbed more, compared to *D. arboreus uc.*, which jumped and ran more. Both species moved most frequently by walking. The evaluation of spatial utilization of enclosures was subsequently conducted, leading to the finding that both species predominantly occupied hanging boxes or trees, with *D. dorsalis* displaying a higher tendency for ground movement in comparison to *D. arboreus uc.*.

Following analysis of husbandry practices for both *Dendrohyrax* spp., it was concluded that they are housed in highly comparable environments, with minimal variations noted between zoological gardens and between the two species.

Despite the fact, that not all animals from European EAZA populations of *Dendrohyrax* species were not included in this study, this thesis has provided many valuable insights into their behavioural patterns in *ex-situ* conditions, which contributed to a better understanding of these animals, as they are difficult to observe in the wild due to their lifestyle. That is highly desirable considering their declining population trend. All of our discoveries may be used to improve the housing conditions of both *Dendrohyrax* species.

Given the uncertainty in the taxonomy of these species, it would be appropriate to use molecular methods and bioacoustics analyses to determine the species affiliation of individuals kept in *ex-situ* conditions. We would also recommend studying the behaviour patterns of these *Dendrohyrax* species using a camera placed in the enclosure throughout the day to determine if these species are active during the day, as suggested, for example, by Rudnai's publication (1984).

7. References

Albert C, Luque GM, Courchamp F, Maldonado JE. 2018. The twenty most charismatic species. Plos One **13**: 1–12.

Ashby KR. 1972. Patterns of daily activity in mammals. Mammal Review **1**:171–185.

Asher RJ, Lehmann T. 2008. Dental eruption in afrotherian mammals. BMC Biology **6**: 1–18.

Bar Ziv E, Ilany A, Demartsev V, Barocas A, Geffen E, Koren L. 2016. Individual, social, and sexual niche traits affect copulation success in a polygynandrous mating system. Behavioral Ecology and Sociobiology **70**:901–912.

Ben-Moshe N, Iwamura T. 2020. Shelter availability and human attitudes as drivers of rock hyrax (*Procavia capensis*) expansion along a rural–urban gradient. Ecology and Evolution **10**:4044-4065.

Barocas A, Ilany A, Koren L, Kam M, Geffen E, Waterman JM. 2011. Variance in Centrality within Rock Hyrax Social Networks Predicts Adult Longevity. PloS One **6**.

Barry RE, Barry LM. 1996. Species Composition and Age Structure of Remains of Hyraxes (Hyracoidea: Procaviidae) at Nests of Black Eagles. Journal of Mammalogy **77**:702–707.

Barry RE, Hoeck HE. 2013. *Heterohyrax brucei* Bush Hyrax. Mammals of Africa. Vol. I: Introductory Chapters and Afrotheria, pp. 161–165. Bloomsbury Publishing, London.

Barry RE, Shoshani J. 2000. *Heterohyrax brucei*. Mammalian Species **4**:1–7. American Society of Mammalogist.

Baskir EA, Hazen RE, Powell DM. 2021. Documenting nocturnal activity of dragon-headed katydids (*Lesina blanchardi*) under artificial light. Zoo Biology **40**:342–345.

Bates D, Mächler M, Bolker B, Walker S. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software **67**:1–48.

Benjamini Y, Yekutieli D. 2001. The control of the false discovery rate in multiple testing under dependency. The Annals of Statistics **29**:1165–1188.

Ben-Moshe N, Iwamura T. 2020. Shelter availability and human attitudes as drivers of rock hyrax (*Procavia capensis*) expansion along a rural–urban gradient. Ecology and Evolution **10**:4044–4065.

Benoit J, Crumpton N, Mérigeaud S, Tabuce R. 2013. A Memory Already like an Elephant's? The Advanced Brain Morphology of the Last Common Ancestor of Afrotheria (Mammalia). Brain, Behavior and Evolution **81**:154–169.

Brando S, Buchanan-Smith HM. 2018. The 24/7 approach to promoting optimal welfare for captive wild animals. Behavioural Processes **156**:83–95.

Brown KJ, Downs CT. 2005. Seasonal behavioural patterns of free-living rock hyrax (*Procavia capensis*). Journal of Zoology **265**:311–326.

Butynski T, Hoeck H, de Jong YA. 2015. *Dendrohyrax arboreus*. The IUCN Red List of Threatened Species 2015a.

Butynski T, Hoeck H, de Jong YA. 2015. *Heterohyrax brucei*. The IUCN Red List of Threatened Species 2015b.

Butynski T, Hoeck H, Koren L, de Jong YA. 2015. *Procavia capensis*. The IUCN Red List of Threatened Species 2015c.

Carr AS, Chase BM, Boom A, Medina-Sanchez J. 2016. Stable isotope analyses of rock hyrax faecal pellets, hyraceum and associated vegetation in southern Africa: Implications for dietary ecology and palaeoenvironmental reconstructions. Journal of Arid Environments **134**:33–48.

Chase BM, Scott L, Meadows ME, Gil-Romera G, Boom A, Carr AS, Reimer PJ, Truc L, Valsecchi V, Quick LJ. 2012. Rock hyrax middens: A palaeoenvironmental archive for southern African drylands. Quaternary Science Reviews **56**:107–125.

Cordeiro NJ et al. 2005. Notes on the ecology and status of some forest mammals in four eastern arc mountains, Tanzania. Journal of East African Natural History **94**:175–189.

Cox DTC, Gardner AS, Gaston KJ. 2021. Diel niche variation in mammals associated with expanded trait space. Nature Communications **12**:1–10.

Demartsev V, Haddas-Sasson M, Ilany A, Koren L, Geffen E. 2023. Male rock hyraxes that maintain an isochronous song rhythm achieve higher reproductive success. Journal of Animal Ecology **92**:1520–1531.

Djossa B, Zachee B, Sinzin B. 2012. Activity patterns and habitat use of the western tree hyrax (*Dendrohyrax dorsalis*), within forest patches and implications for conservation. Ecotropica **18**:65–72.

Dowsett-Lemaire F, Butynski T, Hoeck H. 2015. *Dendrohyrax dorsalis*. The IUCN Red List of Threatened Species 2015.

Drake JM, Berec L, Kramer AM. 2019. Allee Effects. 6-13 in Encyclopedia of Ecology. Elsevier, Armsterdam.

Dupont B. 2012. Rock Hyrax (*Procavia capensis*). Available at https://commons.wikimedia.org/wiki/File:Rock_Hyrax_(Procavia_capensis)_(7042223567).jpg (accessed April 2, 2024).

Eley R. 1994. The hyrax - a most mysterious mammal. Biologist **41**:141–144.

Ellerman JR, Morrison-Scoott TCS, Hayman RW. 1953. Southern African Mammals 1758 to 1951: a reclassification, 1st edition. BM(NH), London

Ellison G, Jones M, Cain B, Bettridge CM. 2023. Activity Budget and Sociality of the Northern Lesser Galago, *Galago senegalensis*. International Journal of Primatology **45**:1–26.

Fischer MS. 1994. Crouched posture and high fulcrum, a principle in the locomotion of small mammals: The example of the rock hyrax (*Procavia capensis*) (Mammalia. Journal of Human Evolution **26**:501–524.

Foresman PS, Smit J, Cuvier G, Brehm AE, Protheroe E, Hardwicke T. 2017. Afrotheria phylogeny. Available at https://upload.wikimedia.org/wikipedia/commons/1/16/Afrotheria_phylogeny_%28eng%29.png (accessed April 11, 2024).

Freeman MS. 2018. Hyracoidea. . 1–7 in Encyclopedia of Animal Cognition and Behavior. Springer International Publishing, Cham.

Freeman MS. 2022. Hyracoidea. 3333–3339 Encyclopedia of Animal Cognition and Behavior. Springer International Publishing, Cham.

Gaylard A, Kerley GIH. 2001. Habitat assessment for a rare, arboreal forest mammal, the tree hyrax *Dendrohyrax arboreus*. African Journal of Ecology **39**: 205–212.

Gaylard A, Venter JA, Smith YCE, Child MF. 2016. A conservation assessment of *Dendrohyrax arboreus*. The Red List of Mammals of South Africa, Swaziland and Lesotho. The Red List of Mammals of South Africa **1**:1–7.

Gerlach G, Hoeck HN. 2001. Islands on the plains: metapopulation dynamics and female biased dispersal in hyraxes (Hyracoidea) in the Serengeti National Park. Molecular Ecology **10**:2307–2317

Girmay T, Welegerima K, Lemma H, Meheretu Y. 2016. Population Size and Diet of Bush Hyrax, *Heterohyrax brucei* (Gray 1868) in the Isolated Romanat Michael Church Forest in Northern Ethiopia, Implication for Conservation. Momona Ethiopian Journal of Science **8**:104–115.

Global Federation of Animal Sanctuaries. 2019. Standards For Lagomorph, Rodent and Hyrax Sanctuaries.

Glover TD, Sale JB. 1968. The reproductive system of male rock hyrax (*Procavia* and *Heterohyrax*). Journal of Zoology **156**:351–362.

Hoeck HN, Bloomer P. 2013. Rock Hyrax *Procavia capensis*. The Mammals of Africa **1**:166–171. Bloomsbury Publishing, London.

Hoeck HN, Rovero F, Cordeiro N, Butynski T, Perkin A, Jones T. 2015. *Dendrohyrax validus*. The IUCN Red List of Threatened Species 2015.

Hoeck HN. 1975. Differential feeding behaviour of the sympatric hyrax *Procavia johnstoni* and *Heterohyrax brucei*. Oecologia **22**:15–4.

Hoeck HN. 2001. Hyraxes. The New Encyclopedia of Mammals. 1:448-451. Oxford, UK: Oxford University Press.

Jaeger BC, Edwards LJ, Das K, Sen PK. 2016. An R 2 statistic for fixed effects in the generalized linear mixed model. Journal of Applied Statistics **44**:1086–1105.

Jones C. 1978. *Dendrohyrax dorsalis*. Mammalian Species **113**:1–4. American Society of Mammalogists.

Jones JK, Nowak RM, Paradiso JL. 1984. WALKER'S MAMMALS OF THE WORLD. The Johns Hopkins Univ. Press, Baltimore, 4th ed. 2. Journal of Mammalogy **65**:553–784.

Kershenbaum A, Ilany A, Blaustein L, Geffen E. 2012. Syntactic structure and geographical dialects in the songs of male rock hyraxes. Proceedings of the Royal Society B: Biological Sciences **279**:2974–2981.

Kidd LR, Gregg EA, Bekessy SA, Robinson JA, Garrard GE. 2018. Tweeting for their lives: Visibility of threatened species on twitter. Journal for Nature Conservation **46**:106–109.

Kingdon J. 2015. The Kingdon Field Guide to African Mammals, 2nd edition. Bloomsbury Publishing.

Kingdon, J.; Butynski, T.; Hoffmann, M.; Happold, M.; Kalina, J. 2013. "Genus Dendrohyrax". Mammals of Africa. Vol. 1. London: Bloomsbury Publishing. 1:152–171.

Koren L, Geffen E. 2011. Individual identity is communicated through multiple pathways in male rock hyrax (*Procavia capensis*) songs. Behavioral Ecology and Sociobiology **65**:675–684.

Kraasch R. 2017. Distribution of Dendrohyrax species. Available at https://commons.wikimedia.org/wiki/File:Dendrohyrax_distribution_map.svg

Kruse TN, Garner MM, Bonar CJ. 2015. A retrospective study of pathologic findings in captive rock hyrax (*Procavia capensis*) in the United States. Journal of Zoo and Wildlife Medicine **46**(4):798–805.

Kundaeli JN. 1976. Distribution of tree hyrax (*Dendrohyrax validus validus* True) on Mt Kilimanjaro, Tanzania. African Journal of Ecology **14**:253-264.

Kuntner M, May-Collado LJ, Agnarsson I. 2011. Phylogeny and conservation priorities of Afrotherian mammals (Afrotheria, Mammalia). Zoologica Scripta **40**:1-15.

Lawes MJ, Meakin PE, Piper SE. 2000. Patch occupancy and potential metapopulation dynamics of three forest mammals in fragmented Afromontane Forest in South Africa. Conservation Biology **14**:1088–1098.

Lipner SR. 2018. Rethinking biotin therapy for hair, nail, and skin disorders. Journal of the American Academy of Dermatology **78**:1236–1238.

Martin P, Bateson P. 2007. 10-47 in Measuring Behaviour: An Introductory Guide. 3rd edition. Cambridge University Press, New York.

Maswanganye KA, Cunningham MJ, Bennett NC, Chimimba CT, Bloomer P. 2017. Life on the rocks: Multilocus phylogeography of rock hyrax (*Procavia capensis*) from southern Africa. Molecular Phylogenetics and Evolution **114**:49–62.

Mbise FP, Fredriksen KE, Ranke PS, Jackson C, Fyumagwa R, Holmern T, Fossøy F, Røskaft E. 2019. Human habituation reduces hyrax flight initiation distance in Serengeti. Ethology **126**:297–303.

Meyer GE. 1978. XIV: Hyracoidea. 284-314 in Evolution of African Mammals. Harvard University Press.

Milner JA, Gaylard A. 2013. *Dendrohyrax arboreus*, Southern Tree Hyrax. The Mammals of Africa **1**:152–155. Bloomsbury Publishing, UK, London.

Milner JA, Harris S. 1999. Activity patterns and feeding behaviour of the tree hyrax, *Dendrohyrax arboreus*, in the Parc National des Volcans, Rwanda. African Journal of Ecology **37**:267–280.

Mirceta S, Signore AV, Burns JM, Cossins AR, Campbell KL, Berenbrink M. 2013. Evolution of Mammalian Diving Capacity Traced by Myoglobin Net Surface Charge. Science **340**:1278–1282.

Moser V. 2017. Eastern Tree Hyrax (*Dendrohyrax validus*). Available at https://www.inaturalist.org/photos/11841805 (accessed April 7, 2024).

Nishihara H, Satta Y, Nikaido M, Thewissen JGM, Stanhope MJ, Okada N. 2005. A Retroposon Analysis of Afrotherian Phylogeny. Molecular Biology and Evolution **22**:1823–1833.

Numan IN. 2019. Identification of Vitamins and antioxidant in Carrot by HPLC. Journal of Pharmaceutical Sciences and Research **11**:1006–1009.

Oates JF et al. 2022. A new species of tree hyrax (Procaviidae: Dendrohyrax) from West Africa and the significance of the Niger–Volta interfluvium in mammalian biogeography. Zoological Journal of the Linnean Society **194**:527–552.

Obbard D. 2016. Bush Hyrax (*Heterohyrax brucei*). Available at https://www.inaturalist.org/photos/262790174 (accessed April 2, 2024).

Olds N, Shoshani J. 1982. *Procavia capensis*. Mammalian Species **3**:1–7. American Society of Mammalogist

Omifolaji JK, Modu M. 2016. Appraisal of repercussion of Western Tree Hyrax (*Dendrohyrax dorsalis* (Fraser, 1855)) on land use pattern in Cross River National Park Nigeria. Journal of Forest Science & Environment **1**:31–36. Nigeria.

Palmer N, Fairall R. 1988. Caracal and African wild cat diet in the Karoo National Park and the implications thereof for hyrax. South African Journal of Wildlife Research **18**:30–34.

Pickford M, Hlusko LJ. 2007. Late Miocene Procaviid Hyracoids (Hyracoidea: Dendrohyrax) from Lemudong'o, Kenya. Kirtlandia **56**:106–11. Cleveland Museum of Natural History, Cleveland, Ohio.

Pluháček J, Svobodová Y. 2016. Tree Hyraxes – a Forgotten Treasure in Czech Zoological Gardens. Živa **4**:197–200. Nakladatelství Academia, SSČ AV ČR.

Prinsloo P, Robinson TJ. 1992. Geographic mitochondrial DNA variation in the rock hyrax, *Procavia capensis*. Molecular Biology and Evolution **9**:447–456.

Pullin AN, Pairis-Garcia MD, Campbell BJ, Campler MR, Proudfoot KL. 2017. Technical note: Instantaneous sampling intervals validated from continuous video observation for behavioral recording of feedlot lambs1. Journal of Animal Science **95**:4703–4707.

R Core Team (2023). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org (accessed March, 2024).

Refinetti R. 2008. The diversity of temporal niches in mammals. Biological Rhythm Research **39**:173–192.

Roberts D, Topp-Jorgensen E, Moyer D. 2013. "*Dendrohyrax validus*, Eastern Tree Hyrax". 158–161 inMammals of Africa, Volume 1: Introductory Chapters and Afrotheria.

Romdhoni H, Perwitasari-Farajallah D, Iskandar E, Hedger K, Campera M, Birot H, Nekaris KAI. 2022. The Influence of Sex and Weather on the Activity Budget of Javan

Slow Lorises (*Nycticebus javanicus*) in Garut Regency, West Java. Journal of Tropical Biodiversity and Biotechnology **7**:1–12.

Rosti H, Heiskanen J, Loehr J, Pihlström H, Bearder S, Mwangala L, Maghenda M, Pellikka P, Rikkinen J. 2022. Habitat preferences estimated abundance and behavior of tree hyrax (*Dendrohyrax* sp.) in fragmented montane forests of Taita Hills, Kenya. Scientific Reports **12**: 6331.

Rosti H, Pihlström H, Bearder S, Maeda E, Loehr J, Räsänen M, Mwangala L, Maghenda M, Pellikka P, Rikkinen J. 2024. Seasonal and diel variations in the acoustic communication of tree hyraxes in Taita Hills, Kenya. Mammalian Biology **104**:1-14.

Rosti H, Pihlström H, Bearder S, Pellikka P, Rikkinen J. 2020. Vocalization Analyses of Nocturnal Arboreal Mammals of the Taita Hills, Kenya. Diversity **12**:473.

Rosti H, Pihlström H, Rottcher N, Bearder S, Mwangala L, Maghenda M, Rikkinen J. 2023. Species identity and behavior of cave-dwelling tree hyraxes of the Kenyan coast. Ecology and Evolution 13.

Rudnai J. 1984. Activity cycle and space utilization in captive *Dendrohyrax arboreus*. South African Journal of Zoology **19**:124–128.

Safaris T. 2024. Guinea Pig Lookalikes, Elephant Cousins: Rock Hyraxes. Available at https://thomsonsafaris.com/blog/rock-hyraxes/ (accessed April 15, 2024).

Schlitter DA, Ferguson AW, McDonough MM. 2014. Mammals of Africa (Vol. I-VI.). Journal of Mammalogy **95**:1299-1303.

Schlitter DA. 1993. Order Hyracoidea. 373–374 in Mammal Species of the World: A Taxonomic and Geographic Reference. Smithsonian Institution Press, Washington DC, USA.

Schneiderová I, Pluháček J, Bearder S, Rosti H. 2024. Bioacoustics reveals the uniqueness of an ex-situ tree hyrax population. Journal of Zoo and Aquarium Research, **12**(1): 42–48.

Schulz S, Roberts RD. 2013. *Dendrohyrax dorsalis*, Western Tree Hyrax. The Mammals of Africa **1**:155–157. Bloomsbury Publishing, UK, London.

Sharma V, Lehmann T, Stuckas H, Funke L, Hiller M, Hurst L. 2018. Loss of RXFP2 and INSL3 genes in Afrotheria shows that testicular descent is the ancestral condition in placental mammals. PLOS Biology **16**: 1–22.

Skinner JD, Chimimba CT. 2013. 41–51 in The Mammals of the Southern African Sub-region. Cambridge University Press.

Sloviak M. 2011. Southern Tree Hyrax (*Dendrohyrax arboreus*). Available at https://www.biolib.cz/cz/taxonimage/id148913/?taxonid=32453&type=1 (accessed April 2, 2024).

Springer MS. 2022. Afrotheria. Current Biology **32**:205–210.

Stankowich T, Blumstein DT. 2005. Fear in animals: a meta-analysis and review of risk assessment. Proceedings of the Royal Society B: Biological Sciences **272**:2627–2634.

Surendran A, Plank MJ, Simpson MJ. 2020. Population dynamics with spatial structure and an Allee effect. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences **476**: 1–19..

Svartman M, Stanyon R. 2012. The Chromosomes of Afrotheria and Their Bearing on Mammalian Genome Evolution. Cytogenetic and Genome Research **137**:144–153.

Tabuce R, Adaci M, Amar HK, Bensalah M, Mabrouk EE, Marzougui W, Mebrouk F, Marivaux L, Temani R. 2018. A dwarf among giants: *Titanohyrax tantulus* (Hyracoidea, Mammalia) from the Eocene of Chambi, Tunisia and Glib Zegdou, Algeria. International Paleontological Congress.

Tabuce R. 2016. A mandible of the hyracoid mammal *Titanohyrax andrewsi* in the collections of the Muséum National d'Histoire Naturelle, Paris (France) with a reassessment of the species. Palaeovertebrata **40**: 1–13.

Teklehaimanot G, Balakrishnan M. 2018. Distribution and Population Status of the Endemic Rock Hyrax Sub-species (*Procavia capensis capillosa*) of the Bale Mountains, Ethiopia. International Journal of Ecology and Environmental Science **44**:1–9.

Thewissen JGM, Simons ELV. 2001. Skull of Megalohyrax eocaenus (Hyracoidea, Mammalia) from the Oligocene of Egypt **21**:98–106.

Topp-Jørgensen JE, Marshal AR, Brink H, Pedersen UB. 2008. Quantifying the Response of Tree Hyraxes (*Dendrohyrax Validus*) to Human Disturbance in the Udzungwa Mountains, Tanzania. Tropical Conservation Science **1**:63–74.

Visser JH, Robinson TJ, Jansen van Vuuren B. 2020. Spatial genetic structure in the rock hyrax (*Procavia capensis*) across the Namaqualand and western Fynbos areas of South Africa — a mitochondrial and microsatellite perspective. Canadian Journal of Zoology **98**:557–571.

Wilson DE, Mittermaier RA. 2011. Procaviidae. 41-47 in Handbook of the Mammals of the World, 2nd edition. Lynx Edicions, Barcelona.

Wimberger K, Downs CT, Perrin MR. 2009. Two Unsuccessful Reintroduction Attempts of Rock Hyraxes (*Procavia capensis*) into a Reserve in the KwaZulu-Natal Province, South Africa. South African Journal of Wildlife Research **39**:192–201.

Appendices

List of the Appendices:

Appendix I: Ethogram

Date	Time	Individual	Imobility				Locomotion						Climbing						Nv	Grooming			
			L1	Is	L2	Il	L3	Lw	L4	Lr	L5	Lj	L6	Ch	L7	Cv	L8	Cu		L9	Gi	L10	Go
	0 min	N1																					
		N2																					
		N3																					
		N4																					
		N5																					
	5 min	N1																					
		N2																					
		N3																					
		N4																					
		N5																					
	...	N1																					
		N2																					
		N3																					
		N4																					
		N5																					
	180 min	N1																					
		N2																					
		N3																					
		N4																					
		N5																					

Feeding						Social activities								E	Nursing						Other				Notes
						Saf				Saa															
L11	Fbr	L12	Fbo	L13	Fco	L14	Safn	L15	Safp	L16	Saaf	L17	Saac	L18	L19	Ng	L20	Nbf	L21	Npb	L22	Ob	L23	Ov	

Appendix II: Ethogram Explanations

Description of Behaviours:

Immobility (code I) the animal does not show any movement activity; it can be either (1) **standing (Is)**– we can observe daylight between the underside and substrate; or (2) **laying (Il)** – we cannot see the daylight between the underside and the substrate, the animal has flexed legs and abdomen fully or partially in contact with the substrate. This behaviour does not include brief (a few seconds) interruptions of other activity.

Locomotion (code L) – the animal is moving from one location to another (from the place A to the place B); it can be either (1) **walking (Lw**)– the animal moves at regular pace by lifting and setting down each foot in turn, never having both feet off the ground at once, the animal is moving on the ground level, or (2) **running (Lr)**– the animal is moving rapidly on foot; or (3) **jumping (Lj)**– the animal pushes itself off a surface and into the air by using muscles of its hind limbs and forelimbs, it uses this movement to cover the distance between 2 objects, not within the game

Climbing (code C) – The animal moves on steep objects (most often on branches) with the help of a special grip of the limbs ; (a) **horizontal (Ch)**- the animal climbs in a horizontal direction, for example along the side branches of the tree; (b) **vertical (Cv)** – the animal climbs in a vertical direction, for example along the tree trunk; (c) **upside down (Cu)** – the animal climbs in the way, that its dorsal part of the body is directed to the ground, the animal climbs the object from the bottom part

Non–visible (code Nv) – the animal is not in a visible spot

Grooming (code G) – the animal is brushing and cleaning the fur of (1) **itself (Gi)** or the fur of (2) **another individual (Go)**

Feeding (code F) – the animal opens a mouth and accepts food which was offered by keepers; (1) **browsing (Fbr)** – the animal feeds on tree branches provided by the keepers; (2) **food from a bowl (Fbo)**– the animal feeds on food other than branches, this food is placed in a bowl; (3) **coprophagy (Fco)–** the animal is feeding on faeces or dung, which were not provided by keepers

Social activities (code Sa) – the animals are in contact for different reasons, it can be divided to (1) **friendly (Saf)** which can be further divided into (a) **nuzzling (Safn)** – the animal is touching another animal's body with a muzzle; or (b) **play-chasing (Safp)** – the animal is running from another animal in term of play behaviour, not because of danger; (2) **aggressive (Saa)**– the animal shows (a) **fighting behaviour (Saaf)** (nipping, muzzle sparing, lunging and chasing, turning face towards another with open mouth, with or without vocalization); (b) **chasing (Saac)** – an animal may attempt to flee in response to threat behaviour

Excreting (code E) – the animal uses a latrine to excrete or urinate

Nursing (code N) – the animal provides care for the young, including (1) **grooming (Ng)** – the adult animal brushes or cleans the fur of the young**;** (2) **breastfeeding (Nbf)** – the female adult provides a breast milk to the young; and (3) **protective behaviour (Npb)** – an individual prevents closer contact of the young with another individual for example chases the individual away

Other (code O) – the animal is behaving in a different way than previously mentioned; (1) **bouncing behaviour (Ob)** – the animal jumps in the air and shakes its head; (2) **vocalization (Ov)** – the animal is vocally active, and it is creating a sound

Description of Locations:

Listed as L1-L23 in the ethogram table. Each number of locations is connected with a specific behaviour. Ex. L1 = Location where the behaviour "Immobility standing" (Is) occurred, L2 = Location where the behaviour "Immobility laying" (Il) occurred, etc. Used locations: **Box (B); Ground (G); Tree (T); Rock (R); Equipment of the enclosure, or edge parts of enclosure (E); Wall (W).**

External Circumstances:

External circumstances were mentioned in the "notes" column in case they occurred.

- **Reaction to keepers (Rk)** – the animal changes its behaviour after sighting **the keeper**
- **Reaction to visitors (Rv)** – the animal changes its behaviour after sighting **the visitor**
- **Other (Eo) -** external influences, sudden events, etc., which can affect the animal's behaviour

Appendix III: Questionnaire

HUSBANDRY PROTOCOL FOR *DENDROHYRAX* SPP.

In the first part please describe the husbandry of *Dendrohyrax dorsalis*, the second part of questionnaire is containing the same questions but will be filled for *Dendrohyrax arboreus.*

In questions marked with * please select one option

In questions 4b, 4d, 4g, 5b, 5c, 5d – if you previously selected changes during seasons write down information for all seasons separately

DENDROHYRAX DORSALIS

1) **Please name the zoological garden/institution:**

2) **Specify the group composition:**
    a. Number and dates of birth (/imports) of males:
    b. Number and dates of birth (/imports) of females:
    c. Number and dates of birth of unidentified animals:

3) **Description of enclosure/s:**
    a. *Location: Public enclosure/ Off-show enclosure
    b. Size (m^2):
    c. General design (e.g., glass window, cage, etc.):
    d. Floor substrate
    e. Equipment (e.g., branches, ropes, ledges and stands, rocks etc.)
    f. Number and type of shelters:

4) **Specify enclosure/s condition:**
    a. *Temperature: Stable/ Seasonally changed
    b. Mean temperature (°C):
    c. *Humidity: Stable/ Seasonally changed
    d. Mean humidity (%):
    e. *Light regime: Stable/ Seasonally changed
    f. *Central Europe time change adaptation: Yes/No
    g. Light schedule (from hour x to hour y)
    h. Type of lightning (e.g., red, blue, etc.)
    i. Additional lighting (e.g., UV):

5) **Feeding regime:**
    a. *Feeding regime: Stable/ Seasonally changed

b. Feeding schedule (e.g., once/ twice a day):
c. Feeding time/s (e.g. 10 am and 3 pm)
d. Diet composition (with grams, please specify in an appropriate way if different diets relate to different feeding times or seasons):
e. Browsing material (names of species):

6) **Information about daily routine:**
   a. *Daily cleaning (yes/no, approximately what time):
   b. Deep cleaning (how often):
   c. Number of keepers involved:
7) **Enrichment**
   a. Please describe types of enrichment in enclosures (e.g. special feeding box) and how often you provide it to animals:

8) **Veterinary care and handling (please describe how often you perform these procedures)**
   a. Handling:
   b. Microchips readings:
   c. Deworming:
   d. Endoparasite control (please specify the type of control):
   e. Ectoparasite control (please specify the type of control):
   a. Other reported health issues (e.g., gastrointestinal, respiratory) in currently kept animals:
   f. Any reported dental issues:
   g. Observed injuries and following treatment:
   h. Prevalent cause of death: high age/ long-term disease/ injury/ other:

DENDROHYRAX ARBOREUS

2) **Specify the group composition:**
   a. Number and dates of birth (/imports) of males:
   b. Number and dates of birth (/imports) of females:
   c. Number and dates of birth of unidentified animals:

3) **Description of enclosure/s:**
   a. *Location: Public enclosure/ Off-show enclosure
   b. Size (m^2):
   c. General design (e.g., glass window, cage, etc.):
   d. Floor substrate
   e. Equipment (e.g., branches, ropes, ledges and stands, rocks etc.)
   f. Number and type of shelters:

4) **Specify enclosure/s condition:**

a. *Temperature: Stable/ Seasonally changed (in this case, please indicate the temperatures for all seasons in the following question)
b. Mean temperature (°C)
c. *Humidity: Stable/ Seasonally changed
d. Mean humidity (%):
e. *Light regime: Stable/ Seasonally changed
f. Central Europe time change adaptation: Yes/No
g. *Light schedule (from hour x to hour y)
h. Type of lightning (e.g., red, blue, etc.)
i. Additional lighting (e.g., UV):

5) **Feeding regime:**
   a. *Feeding regime: Stable/ Seasonally changed
   b. Feeding schedule (e.g., once/ twice a day):
   c. Feeding time/s (e.g. 10 am and 3 pm)
   d. Diet composition (with grams, please specify in an appropriate way if different diets relate to different feeding times or seasons):
   e. Browsing material (names of species):

6) **Information about daily routine:**
   a. *Daily cleaning (yes/no, approximately what time):
   b. Deep cleaning (how often):
   c. Number of keepers involved:
7) **Enrichment**
   a. Please describe types of enrichment in enclosures (e.g. special feeding box) and how often you provide it to animals:

8) **Veterinary care and handling (please describe how often you perform these procedures)**
   a. Handling:
   b. Microchips readings:
   c. Deworming:
   d. Endoparasite control (please specify the type of control):
   e. Ectoparasite control (please specify the type of control):
   f. Other reported health issues (e.g., gastrointestinal, respiratory) in currently kept animals:
   g. Any reported dental issues:
   h. Observed injuries and following treatment:
   i. Prevalent cause of death: high age/ long-term disease/ injury/ other: