The Effect of Weather on Sleep and the Welfare of Drills in Captivity

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Masters by Research.

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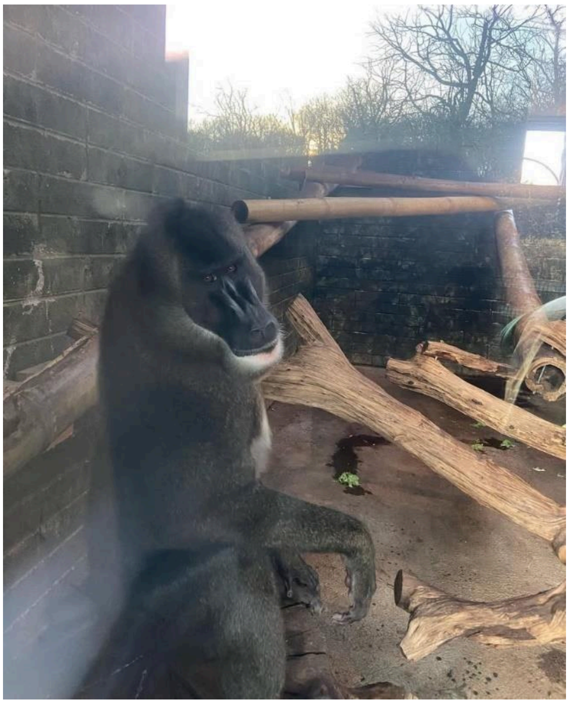

(Photo of male drill at Fota Wildlife Park, Gary Moscarelli 2024)

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This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism and intellectual property.

Gary Moscarelli.

Overall Summary

All living organisms are influenced in some way by the weather in which they live. Careful attention to the influence of weather is important for captive animals, which are often housed under conditions that differ dramatically from those experienced in the wild. A review of background literature accompanies this research thesis highlighting what is understood about primates today. This includes the diversity and evolution of primates, the role of zoos in conservation, primate behaviour, primate welfare and sleep or rest, the general behaviour and ecology of drills, and Fota Wildlife Park's history with the species. However, the main part of my thesis focuses on the relationship between the local weather of Carrigtwohill, Co Cork and sleep. The importance of sleep is well documented in nearly all animals, and is especially important to mammals such as primates, who live in complex social structures and environments that require high levels of problem solving and brain activity. Specifically, my thesis investigates the effect that variation in the local weather of Carrigtwohill, County Cork has on the total sleep and welfare of their captive troop of drills *Mandrillus leucophaeus*. The effect of weather conditions on the drills' total sleep, habitat use, expression of stereotypies and normative behaviours was investigated during the day and at night from December 2023 to February 2024. Sleep was non-invasively monitored using night vision trail cameras within their housing. It was hypothesised that the noise of wind and rain hitting off the housing roof could lead to sleep disturbance. Total night-time "sleep" was measured using and combining non-invasive observational methods to create an index of "total sleep". It was difficult to be sure whether the drills were fully asleep or resting due to the lighting in the enclosure coupled with their elusive nature and therefore I generated an index of "total sleep" by adding two different behavioural states together: "sleep" and "deep rest". In line with expectations, analyses revealed that variation in the local weather affected many aspects of drill life, including reduced sleep and habitat use, and increased stereotypic behaviours. In order to improve the sleep quality and welfare of the troop, it is suggested that the implementation of a bioactive roof on the drill house could reduce weather-related noise. The implementation of summer "roosting" boxes on the island is also recommended in the hopes to provide a more natural sleeping setting compared to the low bungalow style housing they currently occupy during the night. It is hoped that the results of this research will improve and support the known knowledge of both the husbandry of this charismatic African species and all primate species captive in regions that differ climatically from their native ranges.

Chapter One

Literature Review

One of the fundamental principles in nature is that animals should behave in a way that maintains their health and by doing so maximise their chance of survival and reproductive success (Ozella et al., 2017). Thus, a major focus of research in many subdisciplines of ecology, evolution and conservation is understanding the factors that influence the physical and mental condition of animals in the wild. However, the same is also true of animals held in captivity, for example in zoos or on farms, where maintaining healthy animals can be extremely challenging. Ozella et al. (2017) suggested that such challenges in captivity are exacerbated when the climatic and social conditions from which the animals originate differ considerably from those in the wild. This is perhaps especially true in primates, due to their complex social structure, social behaviours, and their high intelligence (Jacobson et al., 2016). The focus of my research was to study how climatic conditions affected behavioural indicators of welfare in an endangered Old World species of primate, the drill, kept under captive conditions in a zoo environment. First, in this literature review, I set the broader scene and describe the diversity and evolution of primates, the role of zoos in conservation and society, primate behaviour in the wild and in captivity and primate welfare issues in captivity, including current knowledge about the importance of sleep in maintaining healthy animals. I then introduce the study species and outline the central aim of the research project in more detail.

The Diversity and Evolution of Primates

Approximately 522 different primate species have been described to date, though this number is uncertain due to disagreement regarding the classification of tree dwelling members of the prosimian group e.g. Tarsiers. Primates are currently divided into 5 main groups (see Figure 1), which include the great apes e.g. *Pongo pygmaeus,* small or lesser apes e.g. *Symphalangus syndactylus,* Old World monkeys e.g. *Mandrillus leucophaeus,* New World monkeys e.g. *Ateles fusciceps* and prosimians e.g. *Lemur catta* (Osada 2015). This study focuses on a member of the Cercopithecidae family, which includes all Old World monkeys.

The evolution of the primates is only partially understood. The first proto-primates are thought to have evolved from small arboreal mammals, phenotypically similar to modern day squirrels and tree shrews, approximately 65 million years ago at the end of the cretaceous extinction event. Radiation of these new species began rapidly as a plethora of new ecological niches became available, allowing these small mammals to leave the shadows of the dinosaurs and diversify across the environment (Sineo and Stanyon 2006). The earliest undisputed primate fossil was discovered in basin deposits from the High Atlas Mountains of Morocco, dated to approximately 60 million years ago (Goodman et al., 1990). *Altiatlasius* was confirmed to be a euprimate, due to the positioning of the teeth along with the high complete trigonids of its lower molars (Rasmussen 2007). In more recent years, advances in molecular science have challenged this divergence date of 60 million years ago, proposing that divergence and the first appearance of true primates occurred earlier, somewhere between 87-85 million years ago (Sineo and Stanyon 2006). Palaeontologists argue that these dates formed by molecular science are inflated estimates, due to the likelihood of the molecular clock accelerating during the initial mammalian radiation event, into the newly available ecological niches 60-65 million years ago (Sineo and Stanyon 2006). All in all, the lack of sufficient fossilised remains leaves doubt in accurately confirming the date that true primates diverged from their mammalian ancestors, but the newly available arboreal and terrestrial niches left behind by the non-avian dinosaurs allowed the behaviours and social systems we see in modern primates to begin to evolve.

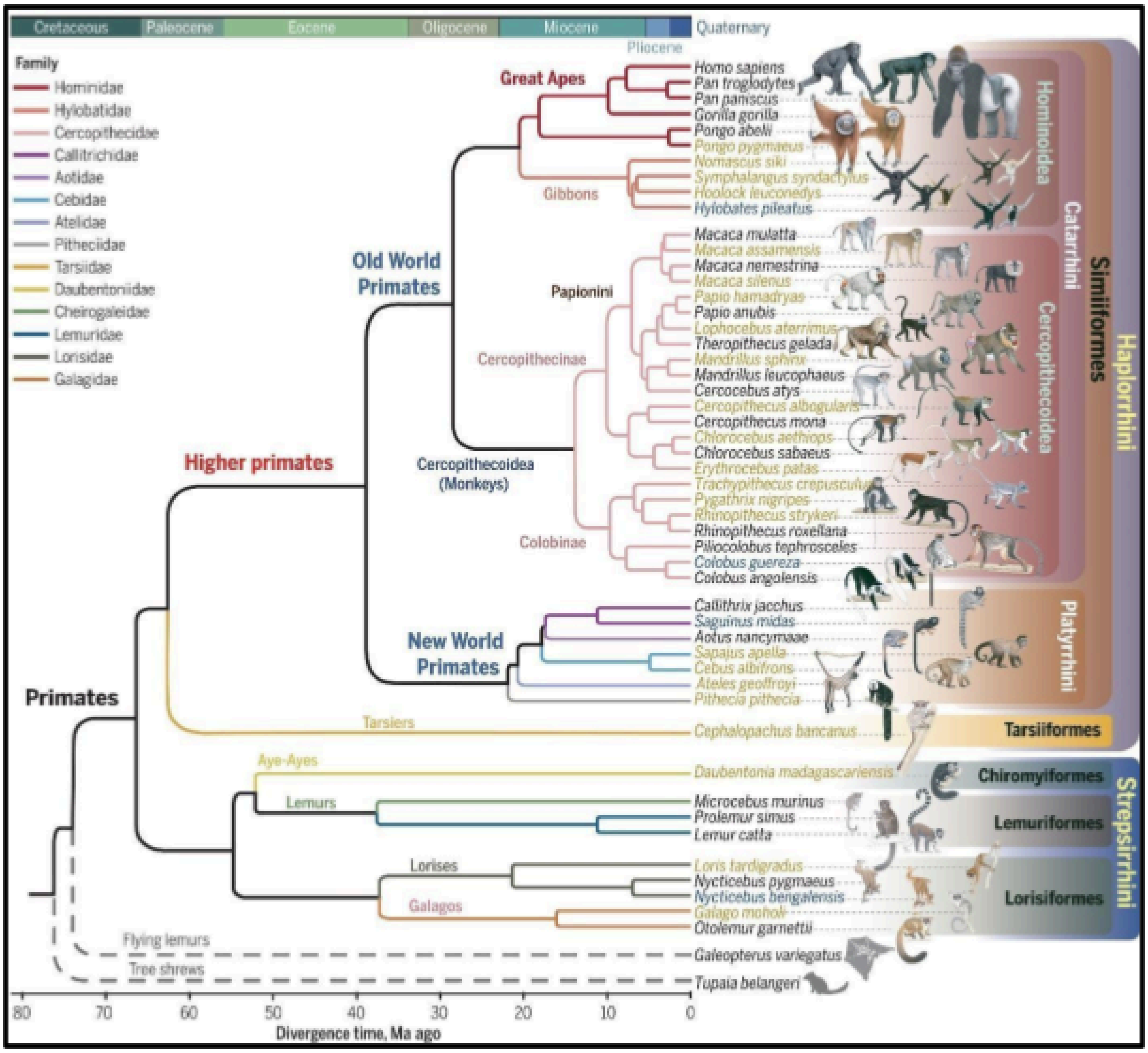

Figure 1: Phylogenetic tree of all living primate groups (Zhao et al., 2016).

All present day Old World monkeys evolved from a common ancestor during the early middle Miocene in Africa, between 23.03 – 5.3 million years ago (Rasmussen et al., 2019). Despite the huge success of Old World monkeys globally, with over 130 species radiating over a wider geographical range than any other extant non-human primate group, little is known about their evolutionary history (Rasmussen et al., 2019). This is partly due to the first ~12 million years of their fossil records being described by only two singular teeth (Rasmussen et al., 2019). Despite our lack of evolutionary knowledge on this diverse branch of primates, the group's successful radiation around the planet, coupled with their intelligence and social characteristics, have made them a prominent point of study for biologists and anthropologists, leading to a spike in popularity of Old World primates in zoological facilities and private collections during the 20th and 21st century.

Role of Zoos in Conservation

The role that zoos and other wildlife facilities play in species conservation has changed greatly in recent years. Zoos, aquariums and other similar collections of animals used to solely exist for the entertainment of the public, allowing Americans and Europeans to experience the wonders of their biologically diverse world without having to embark on expensive and potentially dangerous expeditions (Greenwell et al., 2023). In more recent times zoos have widely become regarded as centres of excellence for wildlife conservation, public education and scientific communication, with the long term goals of all modern zoos now being outlined as research, education, conservation, welfare and recreation (Greenwell et al., 2023). Modern day zoos and wildlife parks are now important allies for *in-situ* wildlife conservation groups, with captive collections of endangered species acting as genetic banks for their species' wild counterparts (King et al., 2011).

The conservation success of zoos and other accredited facilities can be quantified in two ways. Firstly, zoos' captive populations are seen to be positively impacting their wild counterparts when they are providing an environment that promotes normative social behaviours, a high quality of fitness, low levels of habituation and most importantly regular breeding behaviours that produce healthy offspring (Moloney et al., 2023). The second parameter that modern day zoos base their conservation efforts on is the *in-situ* success of their supported reintroduction programs (Fernandez et al., 2017). In long lived and relatively slow reproducing species like primates, reintroduction success can be difficult to achieve due to the disproportionate effects of poaching, genetic bottlenecks and low survivorship rates of habituated individuals ill- equipped to deal with natural conditions (King et al., 2011). The success of a zoo's reintroduction program can be quantified by comparing survivorship and reproductive rates of the released individuals to the rest of the wild population (King et al., 2011). Scientists must also monitor how the reintroduced individuals are integrating back into the environment, paying close attention to interactions with their surrounding flora and fauna (Fernandez et al., 2017). The reintroduction of populations of the Western lowland gorilla (*Gorilla gorilla)* back into their natural range within the Democratic Republic of Congo and Gabon is an excellent example of how captive collections of endangered species can positively affect wild populations (King et al., 2011). Fifty-one gorillas between two groups were reintroduced back into the wild after being illegally kept in private collections as victims of the exotic animal trade. The groups exhibited a 97.4% annual survivorship rate amongst the 51 individuals, with

9 females giving birth to 11 infants with a birthrate of 0.196 per adult female (King et al., 2011). Although successful reintroduction of captive individuals back into the wild can be challenging, it is clear, that zoos and other wildlife facilities can have major positive effects on *in-situ* populations of endangered species, especially long lived and slowly reproducing species, such as primates.

Primate Behaviour

Due to their high levels of intelligence, complex social structures and varying ecological ranges wild primates must exhibit a plethora of behaviours to thrive in their respective environments. The expected baseline behaviours of wild primates includes auto- and allo-grooming, group foraging, play, inter and intraspecific aggression and collaborative efforts such as predator surveillance (Whiten and Van De Waal 2016). Nearly all primate species live in social groups or systems, apart from some members of the Strepsirrhini suborder (Lorises, bushbabies and some lemur species) and the orangutan *Pongo pygmaeus.* The expression of these baseline behaviours is indicative of a functioning wild social group of primates (Whittaker 2006). More complex behaviours are also commonly expressed in wild primate groups, such as tactical concealment (Le Roux et al., 2013) and tool use (Silva and Silva, 2021).

The evolution of tool use was once believed to be limited to the great apes e.g. chimpanzees *(Pan troglodytes)* within non-human primates, but now it is understood that many species of non-human primates use tools in their daily life; for example, Capuchin monkeys use tools to access underground food sources (Valença et al., 2024). Tactical concealment is another advanced behaviour exhibited by many primate species living in social groups. This level of forethought even extends past the concealment of food sources and is often expressed in complex social relationships, where subordinate males will engage in extra-pair copulations, deceptively cuckolding the dominant male (Le Roux et al., 2013). This benefits both the subordinate individual and the overall troop, as successful concealed breeding can improve the genetic diversity of the group (Le Roux et al., 2013). Approximately 20% of all tactical concealment behaviours result in aggressive retaliation by the dominant male, which is important for maintaining group social structure and hierarchy (Le Roux et al., 2013).

Although negative behaviours such as aggression are observed in nature and are important in wild primate society, in captivity these problems can be especially pronounced and need to be minimised due to space and group size being limiting factors (Pascual et al., 2023).

Welfare in Captivity and Primate Behaviour

Humans have kept primates in captivity for 5000 years and in facilities that we would regard as zoos for the last 200 years (Hosey 2023). Modern animal welfare standards have improved exponentially in comparison to historic zoological standards, with constant monitoring of species-specific indicators now an industry standard, to ensure correct welfare of captive individuals (Wolfensohn et al., 2018). The welfare of animals in captive conditions is assessed using both resource and animal-based indices, looking at behavioural, physiological and pathological indicators to dictate the best course of action for each individual organism (Wolfensohn et al., 2018). According to Ozella et al. (2017) the identification of negative stereotypies and the promotion of normative behaviours should be the major focus of all facilities that house captive animals. Stereotypies are defined as repetitive behaviours caused by the animal's repeated attempts to adapt to an unsuitable environment (Manteca and Salas 2015), while normative behaviours in captive animals can be described as behaviours that promote the success and survival of an individual that is appropriate to its natural or non-natural environment (Poole 1988). Ozella et al. (2017) pointed out that even in modern zoos, captive primates still face a wide array of environmental challenges that can cause negative physiological stress on the animal, and affect their physical health and mental wellbeing. These captive environmental stressors are often species specific and identifying them is vital to give the proper care needed for the species in question (Scarlata et al., 2013).

The spatial ecology of Old World primates is quite difficult to replicate in captivity due to many species occupying large home ranges, and travelling several kilometres a day foraging (Whittaker 2006). The relationship between animal size and enclosure design on the wellbeing of captive species is well documented with these variables having a greater effect on animal well-being than other stimuli, such as visitor presence (Li et al., 2007). Primates can struggle in spatially confined captive environments due to their varied feeding ecology, especially when many facilities house their primates inside during the night (approximately 15/24 hours of the day). Environmental enrichment is a vital component of captive animal welfare and is critical for the expression of normative behaviours and the reduction of stereotypies (Young 2003). Environmental enrichment refers to the addition or alteration of the environment for the benefit of the inhabitants (Young 2003). Beneficial enrichment can take many forms depending on the creativity of a facility's animal care team, and can be in the form of social, occupational, physical, sensory or nutritional enrichment (Young 2003). Lack of enrichment, coupled with standardised diets with limited simulating foraging opportunities, can lead to a decrease in the expression of normative behaviours (Whittaker 2006).

The diet of zoo animals is fundamentally linked to their welfare, and is critical to their physiological and mental wellbeing (Wisbroek 2022). The use of diet sheets to monitor daily food intake is essential for giving each individual animal the correct nutrition, as the necessary nutrition for an organism is not only species-specific but specific to the individual and their life history stage. The use of species-specific body condition scoring is important to evaluate whether an animal is receiving the correct amount of food daily (Wisbroek 2022). Water is the most essential nutrient for any animal, which must be closely monitored in a captive setting to avoid contamination (Wisbroek 2022).

Apart from some recent novel developments in multispecies enclosures, the majority of Old World monkeys are housed in singular-species habitats with significantly less individuals than would be seen in their wild social groups (Neal Webb et al., 2019). This lack of intraspecific and interspecific socialisation can also affect the expression of normative behaviours and can lead to an increase in stereotypies exhibited by each captive individual (Whittaker 2006). In order to combat the challenges faced by Old World monkeys in captive environments, different behavioural training methods have been implemented to increase the expression of normative group social behaviours and to decrease the number of stereotypies/unnatural levels of interspecific aggression expressed (Cox 1987). Cox (1987) used desensitisation and gentle touch and proximity training on a troop of captive drills who were expressing very low levels of socialisation. This behavioural training was used to promote social and breeding behaviours within the troop (Cox 1987). The methods employed significantly increased social behaviours within the troop, which remained consistent after the training period. In contrast, few studies have been done on the effect that weather has on the welfare of captive species in outdoor enclosures. The local weather of zoos can greatly differ from a primate's natural habitat, leaving animals living in climatic environments to which their physiology and anatomy are not adapted (Morgan and Tromborg 2007). Furthermore, even less research has been conducted on the effect of weather on primate sleep (Wells and Ritchie 2020), which is vital for the overall health of a cerebral, social animal such as *Mandrillus leucophaeus*.

Local Environmental Factors, Sleep and Welfare

Sleep is an active state of unconsciousness in organisms, where the brain enters a resting state, for the most part only being responsive to internal stimuli (Brinkman et al., 2023). Sleep in all human and non-human primates is controlled by two fundamental neurological processes, which control fatigue, while also driving alertness (Satterfield and Killgore 2019). The homeostatic process (process S) controls the mounting need for sleep as time awake increases, while the circadian process (process C) mediates the 24hr rhythm of the body driving daytime alertness and night-time sleepiness in diurnal species (Satterfield and Killgore 2019). During the day the homeostatic process accumulates with each passing hour awake, but is simultaneously followed by the circadian process's drive for alertness. These two processes work in conjunction with each other to keep daytime functioning at a consistent level (Satterfield and Killgore 2019).

Sleep is vital for many essential human and non-human primate physiological functions such as memory formation (Rasch and Born 2013), immunological enhancement (Besedovsky et al., 2012), metabolic regulation (Sharma and Kavuru, 2010), thermoregulation (Parmeggiani 1988), tissue repairing (Oswald 1987) and energy saving (Siegel 2005). Improper or disrupted sleep, due to inadequate captive conditions, may cause a reduction in the overall physical and mental well-being of primates. Disturbed sleep may contribute to the expression of abnormal behaviours such as motor stereotypies (pacing, rocking etc.), self-directed abnormal behaviours (hair plucking, eye poking, self-clasping etc.), withdrawn behaviour, abnormal appetitive behaviours (urophagia, coprophagy etc.) or self-inflicted injury (Lutz et al., 2022). Members of the Cercopithecidae family sleep between 9-10 hours a night, exhibiting longer sleeping times and less active REM sleep times than other ground dwelling primates, including humans (Nunn and Samson 2018). This longer sleeping time may be attributed to evolving to sleep in the safety of trees where they are less vulnerable. My aim was to investigate the effect that several environmental variables (rainfall, temperature, wind speed) have on the duration and quality of sleep obtained by Fota Wildlife Park's captive drill population, and how disturbed sleep may affect expression of normative behaviours (such as allo-grooming, play, auto- grooming), social structure, habitat use as well as its effects on negative abnormal behaviours mentioned above.

Drills

General behaviour and ecology

Drills are a highly social group of omnivorous old world monkeys found in West Central Africa that usually reside in "troops" of between 25 to 77 individuals (Astaras et al., 2007). The drill is one species within its own genus *Mandrillus* with two distinct subspecies which includes the mainland drill (*Mandrillus Leucophaeus Leucophaeus)* and the Bioko Island drill (*Mandrillus Leucophaeus Poensis)* (Platt and Ghazanfar 2010). The drill has a restricted geographical distribution and occurs only in Nigeria, Cameroon and on the island of Bioko which is a part of Equatorial Guinea. However, it occurs in a wide-range of habitats, from sea-level lowland rainforests of the Sanaga river in Cameroon (Hearn and Morra 2001), through premontane and montane forests and into mountain grasslands as high as 2000m (Wild et al., 2005). Drills vary greatly in their feeding ecology, depending on their geographic location and available habitat (Owens 2013). This variation makes their welfare and husbandry very challenging for captive facilities. The diet and feeding ecology of drills has been seen to be influenced greatly by the altitude that the habitat is found in. Members of this species found on Bioko Island at 0-300m above sea level are found to indulge in a mainly frugivorous diet, with 90% of their foraging intake consisting of fruits. Contrastingly, other groups of drills located at higher altitudes on Bioko island (500-1000m) exhibit a heavily florivorous diet, with 74% of their foraging intake consisting of fungi, leaves, insects and herbaceous pith (Owens et al., 2015). The complexity and variation shown in the species' feeding ecology is difficult to replicate within a captive setting, especially in much colder weather conditions such as Ireland. This further emphasises the need to maximise the quality of controllable variables that directly affect welfare, for example sleep.

Across their natural range, drills also exhibit large variation in their group structure, social needs and habitat use, which also adds difficulty in promoting normative behaviours in captivity. For example, drill troops found on the island of Bioko are on average 17 times smaller and exhibit far less polyspecific behaviours then their mainland counterparts (Owens et al., 2015). Habitat seems to be an influence on the social dynamics of the genus *Mandrillus*, with multi-male and female groups of mandrills common in the forest-savannah mosaics of Gabon, with an entirely different social structure, consisting of one dominant male and multiple females, the normative social expression for populations of drills and mandrills living in the rainforests of Cameroon (Abernethy et al., 2002). Seasonal factors also seem to influence the occurrence of singular/multi male troops of this genus (Hoshino et al., 1984). Breeding interactions and the occurrence of monogamy vary heavily across this species, depending on their geographic location, with higher levels of monogamy seen in populations where large predators are absent (McGraw and Bshary 2002). Monogamy is rare in primates, only being exhibited in 15% of species (Rutberg 1983), with many of these species found on islands such as Bioko, Madagascar and the Mentawai islands, where there is no large feline predator. The intricacy and complexity of the needs of *Mandrillus leucophaeus* social behaviour and group structure is incredibly hard to replicate in a captive setting, which adds further emphasis to the need to maximise the quality of controllable environmental variables in their captive environment.

Conservation Status of the Drill

Drills are one of Africa's most threatened mammals faced with extinction, and are considered endangered by the IUCN Red List, both on the African mainland and on Bioko island (www.TheDrillProject.com). The main threats to the wild population of this species include illegal hunting, habitat destruction and poor farming practices. The illegal hunting of this species for bush meat is a major threat to the survival of this primate species, with hunting reported across their entire range within continental Africa, as well as the population found on Bioko island (Morgan et al., 2013). Due to the development of infrastructure and increased access to the once remote areas of the island, Bioko's wet market has sold over 4,500 drill carcasses within the last 13 years (www.TheDrillProject.com). Hunting methods, such as the use of dogs to poach drills from the wild, further exacerbates their accelerated population decline. Drill troops are especially vulnerable to this method of hunting, resulting in a large number of casualties with every hunt (Astaras et al., 2007). During this hunting practice the dogs force the troop up into trees where they are easily shot, with the dogs' presence keeping the whole troop up the tree and in view, preventing them from fleeing after the first shot is fired (Astaras et al., 2007). These unsustainable hunting practices have contributed to a 58% decrease in drill habitat range on the island, from 525 km^2 in 1986 to just 220km^2 as of 2010 (Cronin et al., 2010).

Habitat degradation, such as logging and pastoral farming practices, is another major threat to the conservation of this primate. The clearing of land by loggers or farmers destroys the drill's natural habitat while also fragmenting the remaining populations (Morgan and Sanz, 2007). Oil palm plantations are emerging as one of the biggest threats to drills. Planned inland development of prime drill habitat in the Libangenie area of Cameroon threatens to destroy the only corridor of habitat between the Banyang-Mbo and Korup and Bakossi Mountains' populations, which currently rank as population strongholds for the species (Morgan et al., 2013). Drills are closed canopy forest specialists, who do not thrive in disturbed or developed environments such as farmland or human settlement (Morgan et al., 2013). This makes the species especially vulnerable to habitat disturbances and population fragmentation. Although there is significant pressure on the population of drills across their native range, a small hope remains, since the species likely experienced a dramatic decrease in population between 3000- 5000 years ago and recovered in numbers (Ting et al., 2012). Although the drill's genetic resilience to historic demographic change is encouraging, it is still unclear how the population will react to the current pressures facing these African primates.

The Drills at Fota Wildlife Park and Study Objectives

Fota Wildlife Park is a 100-acre BIAZA and EAZA-accredited wildlife park located near Carrigtwohill, County Cork. Fota Wildlife Park is involved in several *in-situ* and *ex-situ* conservation initiatives, including the conservation and re-introduction of the native natterjack toad, the European Bison and the Madagascan Pochard duck (www.FotaWildlifePark.com). Fota Wildlife Park in collaboration with the National Parks and Wildlife Service have initiated a head start breeding program for the native natterjack toad, with reintroductions taking place in several locations within Co. Kerry (NPWS 2023). Fota Wildlife Park is also involved in the conservation and re-introduction of the European bison, with members of the park's breeding herd being released back into the wild of the UK and Poland (Ryan, 2022). The park also works to protect the wetland habitats of Madagascar with research collaborations underway to protect many endangered waterfowl species, while also holding the European stud-book for cheetahs in captivity (www.FotaWildlifePark.com). Fota Wildlife Park is home to over 100 species of animals including over 50 species of mammals and 30 bird species (www.livingyoughal). The park is also home to approximately 15 species of primate with members of the prosimians, Old World monkeys, New World monkeys and lesser apes present (Newman et al., 2024). It houses a small (n=4) population of the subspecies of mainland drills (*Mandrillus leucophaeus*) which have been little studied. Originally the troop consisted of 5 individuals, 3 females (Banni, Inoka and Lewa) arriving from Stuttgart, along with a male and a female (Buddy and Julian) arriving from Bristol Zoo (ZIMMS 2024). Since 2019 we have seen the arrival of Ikona, another male drill from Strasbourg in Germany after the death of Julian and Buddy (ZIMMS 2024). Previous behavioural research has been carried out on the drills by undergraduate university students examining how the introduction of new members of the group can effect social hierarchy (Elliot 2020; Foster 2022; Keane 2023). Fota Wildlife Park is the only facility to house drills in Ireland, with this species in captivity being greatly understudied (www.FotawildlifePark.com).

In this study the effect that the local weather conditions in Cork had on the sleep quality of the troop of drills at Fota Wildlife Park was examined (see Chapter 2), and how this affected their habitat use, expression of normative behaviours and stereotypies. Changes in weather conditions was chosen as a likely cause for disturbed sleep, due to the researcher's observation of the noise created within the primate's indoor housing, caused by the sound of rain and wind hitting the metal-alloy roof during weather events. My aim was to understand the effect that several environmental variables (rainfall, temperature, wind speed) has on the duration and quality of sleep obtained by Fota Wildlife Park's captive drill population, and how disturbed sleep may affect expression of normative behaviours (such as allo-grooming, play, auto- grooming), social structure, habitat use as well as its effects on negative abnormal behaviours aforementioned above. This study looks to investigate how the local weather conditions of Carrigtwohill affect some key behaviours expressed by the troop of drills. We investigated how the Irish weather affects the sleep achieved, habitat use and social behaviours of the troop. The effect that the lack of sleep had on the expression of negative stereotypies (hair plucking, pacing, foot biting etc) was then subsequently investigated.

Chapter Two

The effect of weather on sleep and other behaviours linked to welfare in a captive troop of drills *Mandrillus leucophaeus leucophaeus*

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Photography: Sinead Donnachie, Fota Wildlife Park

Abstract

One of the greatest challenges faced when keeping animals in captivity is maintaining normative behaviours and limiting stereotypies, which is especially difficult in species with a sophisticated social system. The role of key husbandry practices during the daytime, such as environmental enrichment and diverse feeding regimes, is well understood across most species in accredited wildlife facilities. However, less is known about the importance of night-time husbandry and in particular the effect of sleep quality on normative behaviour and stereotypies, or indeed, how external factors, such as the weather, influence sleep quality. The aim of this study was to understand the effect of the weather in Western Europe on the sleep achieved by a troop of drills, an endangered primate species from Africa with advanced sociality, and whether this affected stereotypies, normative behaviours and habitat use. I recorded these behaviours at night using trail cameras and by direct observation during the day after, during 25 day/night focal and scan samples between December 2023-February 2024. Total night-time "sleep" was measured using and combining non-invasive observational methods to create an index of "total sleep". Because sleep was measured by observation rather than physiologically, it was difficult to be sure whether the drills were fully asleep or resting due to the lighting in the enclosure coupled with their elusive nature and therefore I generated an index of "total sleep" by adding two different behavioural states together: "sleep" and "deep rest". Weather data was recorded daily from Fota Wildlife Park's weather station. The results showed that the variation in local weather has a significant effect on total sleep, while also having a strong influence on the expression of stereotypies, normative behaviours and habitat use. Rainfall and increased wind speed correlated negatively with the total sleep achieved by the troop. General linear mixed models showed that the less total sleep the primates achieved at night, the more stereotypies were exhibited that same night and the next day. This study adds to our understanding of primate sleep in captive facilities and suggests practical solutions to improve the welfare of the troop of *Mandrillus leucophaeus* at Fota Wildlife Park. Specifically, the study suggests that the use of bioactive or "green" roofs consisting of native meadow flower species on the top of the drill housing may help to mitigate the negative effect of inclement weather on primates when sleeping.

Introduction

Scientific research on captive animals in zoos and wildlife parks plays a crucial role in breeding programs and in the conservation of biodiversity globally (Roe et al., 2014). Due to their charismatic nature Old World monkeys have long been prominent in zoological facilities and private collections (Whittaker, 2006). Although zoological facilities have made major innovations regarding the husbandry and care of the mental and physical wellbeing of their captive monkeys, the expression of abnormal behaviours and stereotypies remains a major problem (Mason, 2006).

Stereotypic behaviours commonly arise in all groups of animals that are exposed to poor and stress inducing captive conditions (Mason, 2006). Repetition and the development of unnatural behavioural loops are inherent in stereotypic behaviour, which is caused by disinhibition, reinforcement and sustained or continual elicitation by internal or external stimuli (Mason, 2006). Animals are said to begin to express stereotypic behaviours in captivity when their ability to indulge in appropriate behavioural responses is limited or removed, despite their motivation to express them (Pomerantz et al., 2013). The most common stereotypies expressed by captive primates include self-clasping, hair plucking, eye poking, pacing and coprophagy (Lutz et al., 2022). To prevent or reverse the expression of these stereotypic behaviours, introducing or increasing the appropriate social stimuli such as varying enrichment activities, habitat changes and scatter feeding has been proven to be effective. Similarly, increasing enclosure complexity rather than enclosure size benefits physical and mental wellbeing (Pomerantz et al., 2013). In Old World monkeys habitat manipulation can have major effects on the frequency and severity of the expression of stereotypic behaviour (Whittaker, 2006). Changing enclosure layout can also dramatically reduce the production of the stress hormone faecal glucocorticoid, which indicates a reduction in hypothalamic–pituitary–adrenal activity, which are both major stress indicators (Cannon et al., 2016). The introduction of new individuals can also be a major cause of the development of stereotypic behaviours of captive populations. Composing natural groupings, closely mimicking social ecological settings, is also a vital component of captive introduction (Cannon et al., 2016). Thus, welfare can be managed in a wide variety of ways.

Modern standards for captive animals dictate that a 24-hour approach must be taken regarding welfare, with night-time hours when no staff are present being equally as important as normal opening hours (Brando et al., 2023). To reduce stereotypic behaviours at night, animals must be given the ability to interact with, control and alter their sleeping environment. Allowing captive diurnal animals to control their night-time environment promotes normative behaviours and reduces stress and stereotypic behaviours (Brando et al., 2023). The primary role of sleep in all living organisms that engage in the activity is energy allocation, health and cognition (Fruth et al., 2018). The forces of natural selection have shaped the characteristics of sleep and sleep behaviour in nearly all species, including primates. The role of animals within their ecosystem's food web shapes their sleep architecture throughout their evolutionary history, with different pressures of natural selection dictating the sleeping patterns of organisms (Fruth et al., 2018). Furthermore, sleep may be interrupted by periods of wakefulness, when animals may be relaxed or otherwise, depending on the cause of being awake. Although little is known about the prevalence or causes of wakefulness in animals, social interactions and predation risk are likely to be the main causes. Weather is likely to be another. Due to the absence of predators in the captive environment we predict unnatural wakefulness is caused by rainfall and windspeed creating stress for the captive troop of drills.

Weather plays a vital role in the lives of wild animals, influencing almost all aspects of an organism's life history (Knape and Valpine 2010). Weather can limit food availability, habitat availability, homeostasis and can act as a catalysis for vital life history behaviours such as breeding and migration (Knape and Valpine 2010). It may also have a major influence on the expression of stereotypies in captive animals, especially when the captive animal has evolved to live in a climatic environment that differs from the captive setting. The prolonged exposure of animals to weather conditions to which their physiology is not adapted can lead to a significant increase in stress behaviours (Jones et al., 2016). Important behaviours such as foraging, resting and locomotion have been found to be strongly influenced by weather, leading to the decrease in normative behaviours of species in captivity (Jones et al., 2016).

Primates are considered prey across their range in Africa, Asia, Central America and South America, with at least 176 confirmed or potential predators of primates recorded. Larger body size in arboreal species seems to lessen the threat of predation from birds of prey and smaller carnivores, with the majority of these predators being crepuscular or nocturnal hunters (Hart, 2000). Out of the 176 confirmed or potential predators of primates, 11 species have been identified as primate specialists. The niche occupied by Old World monkeys, as secondary consumers in their ecosystems, has led to them becoming a food source for many apex and meso-predators who share their environment, with this influencing their sleeping patterns (Hart, 2000). However, adult drills are large and robust Old World monkeys, which excludes them from predation from many smaller African mammalian predators, but they are still susceptible to predation from primate specialists such as leopards and large birds of prey (Hart, 2000). Due to the risk of predation, all Old World monkeys are at least semi-arboreal and spend their nights or nest in the trees. The pressures of predation have shaped both the sleeping behaviour and the length of bouts of sleep for all primate species (Fruth et al., 2018). Primates in Africa, such as chimpanzees, balance the need for sleep with the pressures of predation by adjusting the height of their nests in accordance with predator abundance. Sylla et al. (2022) found that chimpanzees build their nests higher and in closer proximity to each other in areas where predator abundance was higher than surrounding areas.

The first animals arrived at Fota Wildlife Park in 1983 shortly before the park's opening to the public. Primates were amongst the first animals to be held in captivity at Fota Wildlife Park, with 10 species initially being introduced to the collection. At the time of opening in 1983 the park was home to 1 species of prosimian (*Lemur catta),* 8 species of Old and New World monkeys which included the White-lipped tamarin *(Saguinus labiatus)*, Guianan squirrel monkey *(Saimiri sciureus)*, Tufted capuchin *(Sapajus apella)*, Spider monkey (*Ateles)*, Geoffroy's spider monkey *(Ateles fusciceps),* the Black-handed spider monkey *(Ateles geoffroyi),* Black crested mangabey (*Lophocebus aterrimus)* and the Dusky leaf monkey (*Trachypithecus obscurus)* along with one ape, the Lar gibbon (*Hylobates lar).* In 2019 Fota Wildlife Park became the only wildlife facility to house drills in Ireland, with 3 females (Banni, Inoka and Lewa) arriving from a zoo in Stuttgart, along with a male and a female (Buddy and Julian) arriving from Bristol Zoo (ZIMMS 2024). In 2019, another male drill named Akona arrived from Strasbourg in Germany after the death of Julian and Buddy (ZIMMS 2024). The troop currently consists of 4 individuals (Akona, Lewa, Banni and Inoka) with the hopes that the troop will breed. The mainland drill's conservation status remains as endangered by the IUCN classification, with only 120 total mainland drills found in captivity globally. Due to their low numbers in captivity overall, this species is poorly studied in a captive setting, although Elliot (2020) has carried out behavioural research on the troop of drills at Fota Wildlife Park during the introduction of new members of the troop. Drills are a medium sized, semi arboreal Old World monkey that lives in large social groups known as troops. The drill is a diurnal species that spends their days foraging mostly terrestrially in large groups, while spending its nights high up in trees to avoid predators, with larger older males sleeping lower in the canopy to protect their troop from predators ascending the tree (www.Tengwood.com). This study aims to investigate whether the local climatic conditions of Carrigtwohill, County Cork are influencing the sleep achieved by this troop of drills, and whether or not sleep is affecting the primate's expression of stereotypies, normative behaviours and habitat use. Given that sleep is important for welfare but that the night-time represents a dangerous time for prey in the wild, especially when weather conditions make it difficult to detect predators, I predicted that variation in local weather conditions would impact sleep patterns in the drill, and that this would have a negative impact on normative behaviours, at night and the following day, and increase stereotypic behaviour within the troop at Fota Wildlife Park. Finally, to build on the research carried out by Keane (2023), Foster (2022) and Elliot (2020) and to help provide information to staff at Fota Wildlife Park that might be useful for the management of individual Drills, I also examined if there were individual differences in the behaviours observed.

Methodology

Recording Total Sleep Achieved and Behavioural Data

Sleep is defined as "a reversible behavioural state of perceptual disengagement from and unresponsiveness to the environment" (Carskadon and Dement, 2011). Without the use of intrusive physiological monitoring, however, it is often difficult to differentiate between sleep and rest, especially in elusive easily disturbed species, such as drills, and when viewing conditions are challenging. Thus, two states were categorised for this study during ostensible periods of sleep — "deep rest" and "sleep" — which were added together to generate an index of "total sleep" measured in seconds. Sleep was defined as the animal sitting motionless with no eye shine visible for a minimum continuous period of 10-minutes, when the eyes were viewable from the video footage. In practice, it was frequently difficult to be sure whether drills were asleep in the video recordings because the drills' eyes were often out of view, and partly because the ambient light levels were low. Thus, deep rest was defined as when the animal was not obviously alert, sitting motionless for long periods, and included periods when eyes/eyeshine was occasionally visible when eyes were viewable. Thus, the measure of "total sleep" includes periods when the drills may not have been asleep but were at least in a state of deep rest, and therefore we assume was a good measure of sleep quality achieved during the course of the evening.

Throughout the winter months of December 2023, January and February 2024 behavioural data was collected on the troop of drills. This behavioural data was collected by daytime and night-time focal samples. During preliminary data collection and analysis, scan samples recording 15 individual behaviours were carried out, in order to understand which baseline behaviours were likely relevant to weather and sleep. The occurrence and frequency of 7 key behaviours were selected as likely significant, and these behaviours were as follows (night-time sleep, night-time deep rest, night-time stereotypies, daytime stereotypies, daytime play, and daytime allogrooming).

General Methods

Surveillance of the duration and quality of drill sleep was recorded via carefully placed trail cameras within the drill house. Five *SPYPOINT LINK DARK LTE* trail cameras were placed in the drill house to observe the five indoor sleeping areas labelled C1-C5 (Table 1*)*. Camera 1, monitoring C1, was mounted on the wall at a height of 275cm, with cameras 2-5 all mounted on the wall at a height of 266cm. These heights were chosen to allow the widest view of each indoor area. Priority was given to a view of the upper climbing structures of C1-C5 as drill sleeping ecology indicates that these animals exclusively sleep high off the ground to avoid predators (Astaras et al., 2007). These cameras were set on a timer to record between 22:00 and 04:00 during the night. This time frame was chosen as studies of both wild and captive drills indicate that their social day begins at dawn at the base of the tree that they have chosen to sleep in the night previously (Astaras et al., 2007). The cameras were checked each day at 14:30 to remove the data from the SD cards and uploaded to a laptop for observational focal data to be taken on the drills' sleeping patterns. Focal sampling was scheduled for 150 hours (25 nights) for the months of December, January and February to calculate the effect that weather conditions had on the quality of sleep exhibited by the troop. Four focal samples were taken nightly with a focus of 1.5 hours on each individual. The order in which the primates was observed was randomly selected by assigning the primates numbers (1-4) and using a random number generator. Approximately 37.5 hours of focal sampling was carried out on each member of the troop. The behavioural data was rounded to the nearest whole second before being entered into an excel sheet. These focal samples were recorded on the *ZooMonitor.org* recording system developed by Lincoln Park Zoo in 2016, as well as directly into a mobile version of excel. Data on the weather experienced by the primates throughout the night and during the day was downloaded from Fota Wildlife Park's on site weather station. This allowed the potential effect of rainfall, windspeed and temperature had on the primates over this period of time to be quantified. I have also assumed the observed effects were unaffected by any temporal autocorrelation between days.

The drills were observed directly and in person during their daytime social interactions after each night's sleep observation. For daytime sampling, six viewing areas were decided on in order to get the best perspective on their daily social interactions and behaviours. Position 1 and 2 were situated at the glass viewing windows of the drill house, while positions 3, 4 and 5 were located at the smaller windows found either side of the door of the drill house and within the door. Position 6 was located on a small peninsula across from the drills' habitat. Binoculars were used to view the primates when they were on the island. Focal sampling was used during daytime observations to quantify the effect that quality of sleep was having on the drills' expression of normative behaviours and stereotypic behaviours. Scan surveys were conducted each day between 09:00-14:30 for 25 days, with each survey varying in length of time from 1- 3 hours. Scan surveys were used to record the habitat use of the drills during the day. One-hour breaks were taken between each survey longer than one hour to reduce stress on the primates. It was imperative to survey for no longer than 1 hour at a time and to avoid direct eye contact with the individuals, as this was seen to increase stress and lead to aggression toward the researcher. Their social interactions and behaviours were recorded using a behavioural ethogram during focal sampling (Table 2), and their location in their habitat was recorded using a habitat ethogram during scan sampling (Table 1). The location of each drill during the scan sample was recorded in 5 minute intervals. Scan sampling was carried out between the hours of 09:30 and 14:30, with the location of each drill in the habitat recorded every 5 minutes using the habitat ethogram (Table 1). This data was then entered into the *Zoomonitor.org* app or into a mobile version of excel. Focal sampling was also carried out during the daytime on each of the four individual drills. This was done to better quantify the total time each drill was exhibiting a behaviour throughout the day. Each focal sampling survey lasted 15 minutes and focused on one individual at a time. The method of randomising the order of focal samples was identical to the night-time sampling. These survey times coincided with the scan samples (09:30-010:30, 011:30-12:30 and 13:30-2:30). Twenty-five fifteen-minute focal samples were carried out on each drill rounded to the nearest second, with every behaviour exhibited by the individual drill being surveyed recorded and entered into excel during the behavioural ethogram (table 2). The effect of quality of sleep on drill habitat use was examined using the scan sampling method. During scan sampling observations, the position of each drill in the habitat was recorded every 5 minutes during an hour long survey. The habitat available to these primates consisted of 11 distinct areas (Table 1) These included five inside areas (C1-C5), the tunnels connecting the inside house to the island (T), along with the island being sectioned off into six areas (SA, NA, WA, EA, MA). Recording of data began in December and all data had been gathered by the end of February 2024.

For all analyses regarding weather, separate general linear mixed models were run for each individual variable (rain and wind) under a negative binomial distribution. This was done as rain and wind data were found to be highly co-linear, leading to skewed results when grouped together. General linear mixed models were used for all other analyses under a negative binomial distribution

.

Table 1: Habitat use ethogram: 11 distinct areas spatially available to the drills.

Area:	*Code:*
Indoor cage 1	**C1**
Indoor cage 2	**C2**
Indoor cage 3	**C3**
Indoor cage 4	**C4**
Indoor cage 5	**C5**
South area of the island	**SA**
North area of the island	**NA**
West area of the island	**WA**
East area of the island	**EA**
Middle area of the island	**MA**
The tunnel	**T**

Table 2: List of main variables used in the analysis, adapted from Elliot (2020)

Behaviour (units)	*Code*	*Description of behaviour*
Deep rest (seconds)	DR	Animal is not alert, sitting motionless for long periods. Eyeshine/eyes open occasionally visible
Sleep (seconds)	SP	Animal is sitting motionless with no eye shine visible for a continuous 10-minute period.
Daytime stereotypies (number of events)	DS	Animals exhibit stress related negative behaviours during the day (Pacing, rocking, foot biting, eye touching, self- clasping.)
Night-time stereotypies (number of events)	NS	Animals exhibit stress related negative behaviours during the night (Pacing, rocking, foot biting, eye touching, self- clasping.)
Play (number of events)	P	Non-aggressive interaction with object or another individual in a spontaneous, apparently non-goal-oriented manner. Behaviours include chasing, wrestling, lunging, spinning in circles, throwing and catching sticks. During these behaviours there was no aggressive body language or vocalisations and generally a play face would be used while interacting with another individual.
Allo-grooming (number of events)	ALG	Grooming of other individuals in the group.

Table 3: Other variables recorded during early observations but not used in the analysis (adapted from Elliot 2020).

Behaviour	*Code*	*Description*
Aggression	AG	Includes aggravated vocalisations, chasing, biting, aggressive posturing, and displays.
Auto-grooming	AT	Individual grooms' self, using hands, feet or teeth.
Climbing	CL	Climbing any of the structures or trees within the habitat
Sexual	SX	Male or female displaying/presenting, touching or sniffing of genitals, mounting.
Vigilance	V	Alert focused, scanning surrounding area, other animals or people
Locomotion	L	Animal is moving terrestrially on all four legs along the same height gradient.
Foraging	F	Looking for, finding or eating food.
Active rest	RS	Animal is awake, calmly not expelling energy.
Out of sight	OOS	Animal not visible to researcher

Figure 2: Arial view of the drills outdoor island habitat, the tunnels and their housing (Dr Declan O'Donovan, Fota Wildlife Park).

Analysis

The main analyses were organised around six behavioural response variables: total sleep at night, night-time stereotypies, daytime stereotypies, daytime play, daytime allogrooming), and use of the island habitat during the day. Together this analysis asked four main questions:

1) Is total sleep predicted by weather conditions (rain and wind) during the night-time?
2) Is stereotypy behaviour observed during night-time or daytime predicted by total sleep or weather during the night?
3) Are normative social behaviours during the daytime, including play and allo-grooming, predicted by total sleep or weather the previous night?
4) Is use of the island habitat predicted by local weather conditions the previous night?
5) Do individual drills differ consistently from one another in their patterns of sleep, stereotypy behaviour, social behaviour and use of island habitats?

The data was not normally distributed and the variance was higher than the mean of the data. Therefore, I ran mixed models using a negative binomial distribution using the "glmmTMB" package, with "day" and "individual" selected as random affects. The "glmmTMB" package does not use sequential sums of squares and only uses type II or type III, so the order of the effects in the analysis made no differences to the conclusion. Residuals were analysed using the package "DHARMA". In most cases the residuals were normal but in some cases there were patterns in the residual/predicted quantile plots which no transformation was able to remove. I assume this was caused by the skewed nature of the weather data and that this did not influence the conclusions.

Rainfall and wind were highly correlated (Pearson correlation coefficient = 0.81) and were not included in the same models to avoid collinearity. Therefore, for Question 1, I ran total sleep against rainfall in one model, and against windspeed in another model. When examining the effect of sleep on the main response variables for Questions 2-4, I ran models for sleep on its own, and in combination with either rainfall or windspeed to explore if effects on the response variables were best explained by my measure of sleep or weather itself. Thus, for Question 2, I ran three models of night-time stereotypies against i) sleep ii) rainfall and sleep and iii) wind and sleep. I did the same for daytime stereotypies. Identical sets of three models were run for daytime play and daytime allo-grooming when answering Question 3, and for daytime island habitat use when answering Question 4. For Question 5, the best model with and without the individual random term was compared.

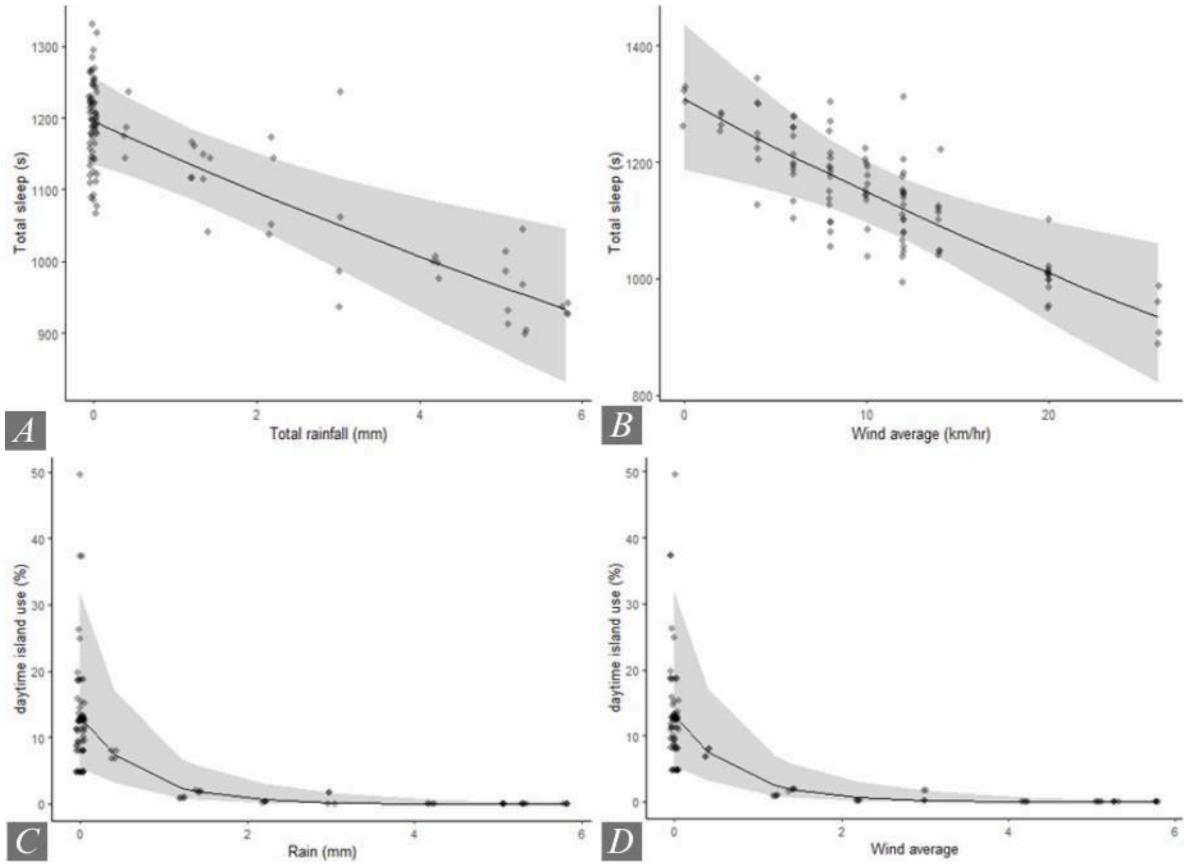
In all cases, statistical significance of the fixed effects was established using the z tests from the summary command. However, when exploring the significance of the individual random term, the Anova command was used to compare the model with and without the individual random effect, the significance of which was tested using a log likelihood ratio test against a chi-squared distribution.

Version 4.41 of the programming system R was used alongside version 2024.09.0+360 of RStudio. All plots from models were done in R using partial residuals from the “ggeffects” package.

Results

Question 1: Was Sleep Influenced by Weather?

Total sleep achieved was significantly related to rainfall the same night ($t = -3.66$, $df = 95$, $P < 0.001$, $\beta \pm SE = -0.043 \pm 0.012$, intercept $\pm SE = 7.085+0.026$.). Total sleep achieved was significantly related to wind speed (km/h) ($t = -3.23$, $df = 95$, $P = 0.001$, $\beta \pm SE = -0.0123 \pm 0.004$, intercept $\pm SE = 7.175+0.049$)".

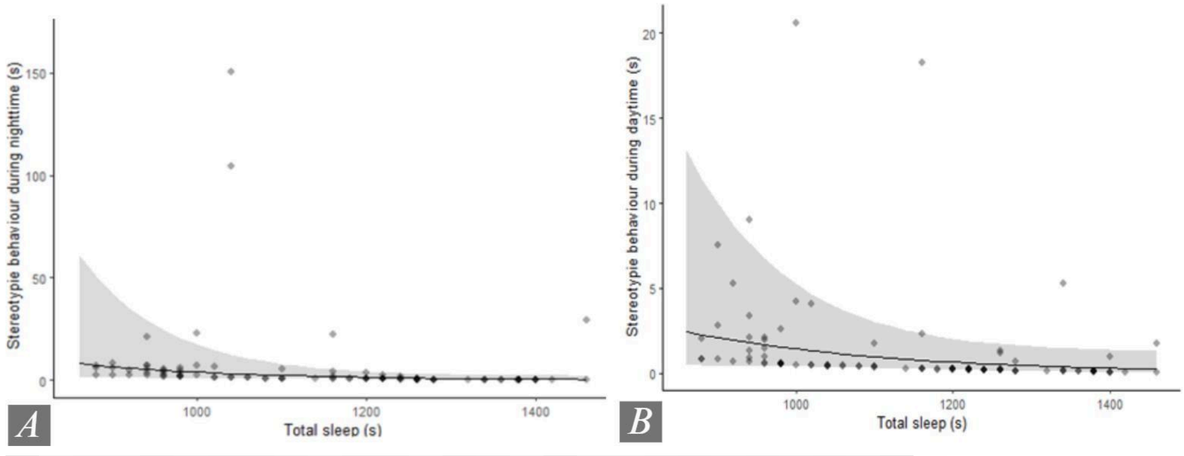


Question 2: Were Stereotypies at Night-time or Daytime Influenced by Sleep?

Night-time stereotypies were related to sleep (s) achieved that night ($t =-1.983$, $df = 95$, $P= 0.0474$, $\beta \pm SE =-0.005 \pm 0.003$, intercept $\pm SE = 6.462 +3.112$). Day time stereotypies were related to sleep (s) achieved that day ($t =-1.775$, $df = 95$, $P = 0.0758$, $\beta \pm SE = -0.004 \pm 0.002$, intercept $\pm SE = 4.146+2.541$). When the weather variables were also included in the models, sleep did not have an independent effect on either daytime (Table 4a) or night-time stereotypies (Table 4b).

Table 4: A) Shows that when rain and wind were also included in the daytime model the weather variables became significant and sleep was no longer significant. B) Shows that when rain and wind were also included in the night-time model the weather variables became significant, and sleep was no longer significant.

Model	*Variable*	*Parameter*	*SE*	*t*	*P*
A) Daytime	intercept	-0.761306	3.200894	-0.238	0.812
i)	Average windspeed (km/h)	0.172942	0.060907	2.839	0.005
	Total sleep (s)	-0.001181	0.002233	-0.529	0.597
ii)	intercept	-1.4008531	2.7275688	-0.514	0.608
	Rainfall (mm)	0.6523491	0.1689326	3.862	< 0.001
	Total sleep (s)	0.0003625	0.0020951	0.173	0.86
B) Night-time	intercept	0.423	3.186	0.133	0.894
i)	Average windspeed (km/h)	0.243	0.071	3.417	< 0.001
	Total sleep (s)	-0.002	0.002	-1.037	0.300
	intercept	1.592	2.528	0.630	0.529
ii)	Rainfall (mm)	0.682	0.172	3.955	< 0.001
	Total sleep (s)	0.001500	0.001962	-0.765	0.444


Stereotypie behaviour during nighttime (s)
150
100
50
0
1000
1200
1400
Total sleep (s)
A
Stereotypie behaviour during daytime (s)
20
15
10
5
0
1000
1200
1400
Total sleep (s)
B

Question 3: The Effect of Total Sleep Achieved on Allogrooming and Play

The results of the link between allogrooming and sleep indicated a potential trend, though not meeting the threshold for statistical significance. (t = 1.879, df = 95, P = 0.0603, β±SE =0.002 ±0.001, intercept ±SE = -0.760 +1.898; Figure 4) when sleep was the only explanatory variable in the model. The effect disappeared when either rainfall or wind were included in the same model, and there were weak tendencies for a negative effect of rainfall at night-time on allogrooming the day after (Table 5).

Sleep did not have an overall effect on the frequency of play behaviours exhibited by the drills (t = 1.422, df = 95, P = 0.155, β±SE =0.002 ±0.002, intercept ±SE = -2.7231 +2.083978).

Table 6: Shows that when weather variables a) windspeed and b) rainfall are included that rainfall (mm) indicates a potential trend, though not meeting the threshold for statistical significance, which overshadows the effect of total sleep. Average windspeed did not have an effect.

Variable	*Parameter*	*SE*	*t*	*P*
Intercept	1.033	2.148	0.481	0.631
A) Average windspeed (km/h)	-0.074	0.046	-1.617	0.106
Total sleep (s)	0.001	0.001	1.057	0.291
Intercept	0.805	2.001	0.402	0.688
B) Rainfall (mm)	-0.263	0.149	-1.759	0.078
Total sleep (s)	0.001	0.001	0.912	0.362

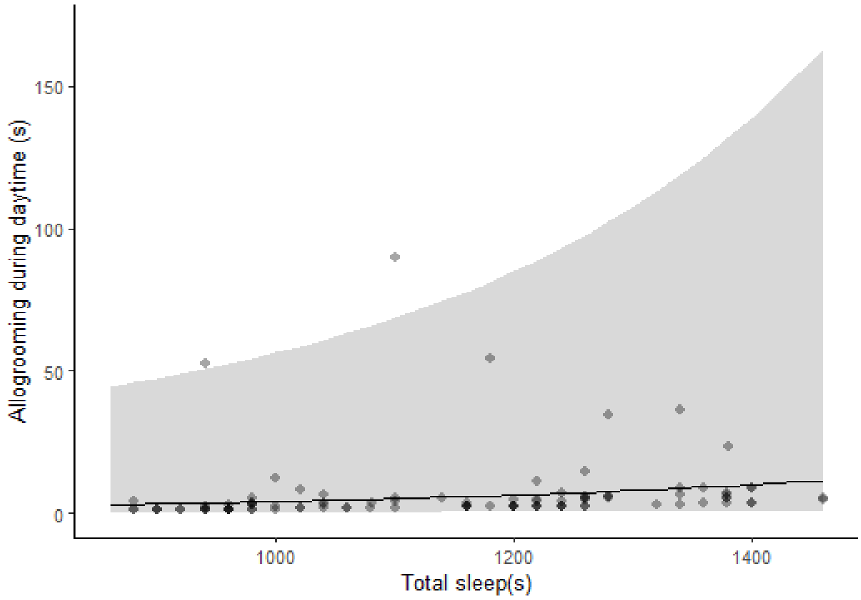


Figure 4: How total sleep affects allogrooming behaviour in the captive drill

Question 4: Was Day-time Island Use Affected by Weather and Sleep the Previous Night?

During the months of December, January and February combined the drills spent 81.4% of their time within their housing and 18.6% using their naturalistic island habitat. Sleep was seen to have no effect on daytime island use in a model that only included sleep as an explanatory variable ($t = 0.761$, $df = 95$, $P = 0.446$, β±SE = > 0.001±> 0.001, intercept ±SE = 0.554+1.043).

The same was true in models where both weather variables were included (Tabe 6). However, daytime island use decreased with increasing night-time rainfall (mm) ($t = -3.606$, $df = 95$, $P = 0.0003$, β±SE = -1.392±0.386, intercept ±SE = 2.573+0.451). It also decreased with night- time wind speed (km/h) ($t = -2.651$, $df = 95$, $P = 0.000804$, β±SE =-0.289 -±0.109, intercept ±SE = 4.220+1.148).

Table 7: Island use GLMMs showing the link with total sleep and weather at night-time.

Variable	*Parameter*	*SE*	*t*	*P*
Intercept	2.243	0.993	2.259	0.024
Night-time rainfall (mm)	-1.382	0.388	-3.563	< 0.001
Total sleep (s)	0.0003	0.0007	0.373	0.709
Intercept	3.691	1.496	2.467	0.014
Night-time windspeed (km/hr)	-0.283	0.109	-2.593	0.001
Total sleep (s)	0.0004	0.0007	0.549	0.583

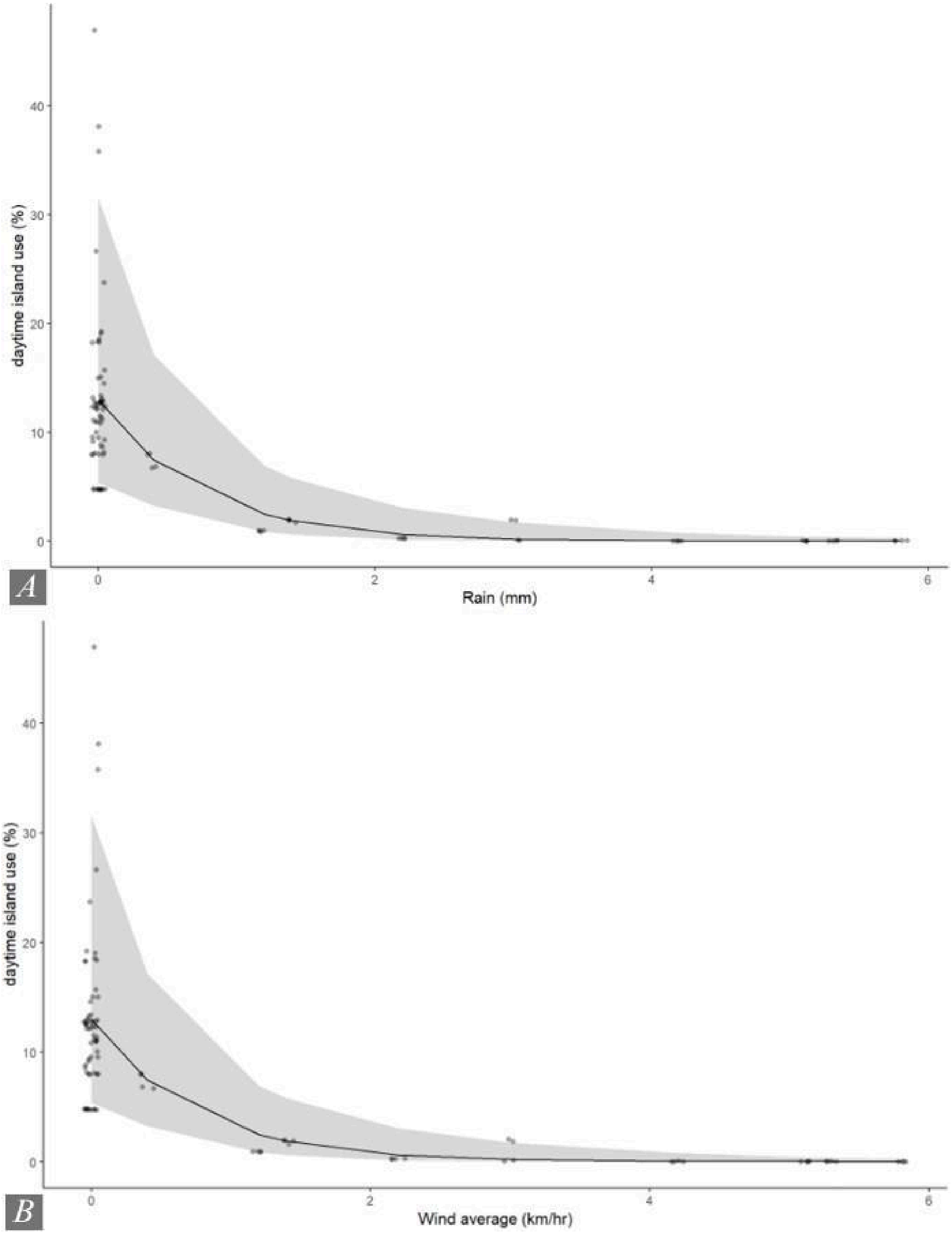


Figure 5: How weather a) rainfall and b) wind average effects outside island use.

Question 5: Did Individual Drills Differ in their Behaviours?

The analysis of the individual random effect showed that there were significant individual differences for night-time stereotypies, daytime stereotypies, play and allogrooming, but not of total sleep or island use (Table 7).

Table 8: Summarises the differences in individual behaviour of the troop using Chi squared and P value results providing log likelihood ratio tests of models with and without individual as a random term in the models in the main tables, as tested against a Chi-squared distribution.

Drill name	Akona	Anoka	Banni	Lewa	Chi-squared	P
Drill sex	M	F	F	F		
Sleep					0.0013	0.972
Night-time stereotypies					3.8492	0.050
Daytime stereotypies					6.4321	0.011
Play					16.867	< 0.001
Allogrooming					62.966	< 0.001
Island use					0.1391	0.932

Discussion

This study sought to investigate how the stereotypies, social behaviours and habitat use of the troop of drills at Fota Wildlife Park are influenced by total sleep achieved and local weather conditions. The individual differences in these behaviours between members of the troop was also investigated. Firstly, local weather (rain and wind) was found to significantly influence the total sleep achieved by the troop of drills. Secondly, although sleep was found to significantly influence night-time stereotypies, and indicated a potential trend in day-time stereotypies, when the weather variables of rain and wind were included in the models these weather variables became significant and sleep was seen to be less significant. The results of the link between allogrooming and sleep indicated a potential trend, though not meeting the threshold for statistical significance. When weather variables (rain and wind) are included in the model the results from rainfall (mm) indicated a potential trend, which overshadows the effect of total sleep. Both night-time rainfall (mm) and windspeed average (km/hr) were found to significantly affect day-time island use, with sleep not having an effect. When investigating individual differences between members of the troop the social behaviours of allo-grooming and play were seen to be highly significant, likely due to these behaviours being influenced more by hierarchical standing then environmental variables. All of the questions raised in this study were hypothesised with the hope to improve primate welfare and better understand the husbandry needs of this enigmatic African species.

Weather and its Effects on Sleep Achieved

Sleep plays an essential role in the homeostasis and overall health of almost every creature on earth (Fruth et al., 2018). Sleep is vital for essential bodily functions such as tissue repair and energy allocation (Fruth et al., 2018), immunological enhancement (Besedovsky et al., 2012) and metabolic regulation (Sharma and Kavuru, 2010). We hypothesised that the noise created from night-time weather events (wind speed and rainfall) and rain hitting off the metal roof of the drills indoor sleeping quarters was causing the primates to achieve less total sleep each night. After plotting both the residual and raw data it was clear that weather conditions were having a significant effect on the drills total achieved sleep each night. When analysed in two separate models both wind speed average and total rainfall exhibited highly significant effects on the total sleep achieved by the drills. This is similar to findings with respect to chimpanzees (*Pan troglodytes).* Videan (2006) found that the temperature and humidity of captive chimpanzees' sleeping quarters significantly affected the quality and duration of their sleep. This evidence is supported by a separate similar study focusing on chimpanzees, that also found that climatic factors such as temperature and humidity negatively affect the organisms' sleep duration and quality (Ayuso et al., 2023). Our study may have better practical applications than these previous studies, due to extreme differences in climate experienced by the captive drills in Carrigtwohill, County Cork compared to the environment that their physiology is adapted for, within their west African range. These extreme differences in climatic conditions make environmental variables such as weather more likely to have an effect on animal welfare compared to the chimpanzees studied by Videan (2006). These chimpanzees were captive in Texas, whose climate is far more similar to the chimpanzees' natural African range.

Disrupted Sleep and Expression of Stereotypies

Although the importance of sleep to the physical health and mental wellbeing of human and non-human animals is well documented, little research has been conducted into the effects of disrupted sleep for captive zoo animals, especially Old World primates which are some of the most common additions to zoological facilities worldwide due to their relative small size and charismatic connection to the public (Fuentes 2012). Firstly, the effect of disrupted sleep on the expression of night-time stereotypies was examined. We predicted that the less total sleep achieved by the troop, the more stereotypic behaviours would be expressed. It was found that disturbed sleep had a significant effect on the frequency of stereotypic behaviours expressed each night. Although sleep was found to significantly affect the expression of night-time stereotypies, when the climatic variables of rain and wind were included in the models, the weather variables became significant, and sleep was seen to be less significant. Although the correlative nature of our study means that we cannot discount the possibility that sleep had no direct effect on stereotypies, I suggest that weather perhaps reflected sleep quality better than our non-invasive observational measure of sleep, perhaps capturing the effect on deep sleep more effectively. This is supported by further studies on chimpanzees by (Wells et al., 2023). This research found that the impact of noise on primate welfare extends into periods of rest. In sanctuary chimpanzees, nighttime disturbances have been shown to cause sleep disturbance, which led to reduced social engagement, increased inactivity, and more stress-related behaviours the following day (Wells et al., 2023). This highlights how nighttime noise disruptions may impair the drills' capacity to recover physiologically and socially, which is essential for maintaining welfare in a captive setting.

The effect of disrupted total sleep during the night on the expression of stereotypies the next day was also examined in this troop of captive drills. It was predicted that the less sleep achieved by the drills at night, the more stereotypies would be expressed the following day. The analysis of the data collected during daytime focal surveys showed disrupted sleep the previous night influenced the expression of stereotypies the next day, although not statistically significant. Similarly to the night- time models, when the weather variables of rain and wind were included in the day time models, the weather variables became significant. Sleep was then seen to be less significant, once again possibly for the same reasons suggested above. Other research into the effect of disrupted sleep on the behaviour of primates the following day has been examined in chimpanzees (*Pan troglodytes)* yielding similar results (Ayuso et al., 2023). The researchers showed that disturbances during the chimpanzees' sleep had negative effects on their behaviour the following day, with individuals exhibiting higher frequencies of inactivity and stereotypic behaviours (Ayuso et al., 2023). Ayuso et al. (2023) recorded and categorised disturbances as a variety of chimpanzee vocalisations e.g. screaming, pant hooting etc, but did not consider outside environmental disturbances e.g. storms, while it also lacked visual data to record physical stress behaviours

e.g. foot biting. For these reasons our study may compliment and strengthen previous research on this topic. Previous research also shows that primate species who live in large groups and have wide ranges *(e.g. Mandrillus leucophaeus*) can be more susceptible to stereotypic behaviours developing in captivity (Pomerantz et al., 2013). This may be due to the difficulties in recreating the complexity of a wide and diverse habitat range and changing environmental conditions, like those experienced by drills in the wild.

Disrupted Sleep and Social Behaviours

The effect of disrupted sleep at night on the expression of daytime social behaviours was investigated, focusing on the behaviours of allogrooming and play. It was predicted that the less total sleep achieved by the troop of drills, the less social behaviours of play and allogrooming would be expressed. From the analysis of the daytime focal sample data no significant effect was seen in the expression of playing behaviour from the troop of drills. Analysis of the behavioural data did show that disrupted total sleep influenced the frequency of allogrooming that occurred between the troop. The results showed that the more sleep achieved by the drills at night the more allogrooming that occurred the next day. When the models were analysed including the climatic variables of rain and wind, once again they became more significant than sleep in affecting the expression of allo-grooming behaviours. The above results of weather and poor sleep quality decreasing allogrooming behaviour are supported by a similar sleep study carried out on lemurs. Samson et al. (2019) examined the effects that lack of sleep had on a variety of lemur species being held in captivity. Their results found that lack of sleep had a negative effect on the memory consolidation for all lemurs, and that reduced sleep at night led to changes in behaviour across multiple species of lemur that were examined (Samson et al., 2019). These results are important because allogrooming is key to forming group bonds and supporting harmony within most primate social groupings, leading to less instances of aggression and intraspecific violence (Easley et al., 1989). We believe our study strengthens previous research on the role of primate sleep in social behaviours as few if any previous studies have looked at the effect of lack of total sleep on vital social behaviours such as allogrooming and play in the little studied and endangered *Mandrillus leucophaeus.*

Weather and its Effects on Habitat Use

The effect of the local weather of Carrigtwohill was also investigated in terms of the drills' use of their island habitat. For all analyses regarding weather, separate general linear mixed models were run for each individual variable (rain and wind) under a negative binomial distribution. This was done as rain and wind data were found to be highly co-linear, leading to skewed results when grouped together. When total rainfall and average wind speeds during the night were modelled separately to see if night-time weather was negatively affecting the drills' use of their habitat during the following day, both factors were found to have highly significant effects. The models showed that the more rainfall (mm) or the higher average windspeed (km/hr) that occurred at night the less the troop of drills used their habitat during the following day. Sleep was not seen to influence outside island use. The effect of weather on captive zoo animals' habitat use can be seen across species which find themselves living in a climate that their physiology is not adapted for (Said 2018). For example, a study on captive herds of African eland antelope have shown that increased wind speed along with low temperatures lead to these ungulates resting more and moving around their habitat less (Said 2018). The evolution of drills during the early middle Miocene in Africa has given them physiological adaptations that evolved for a hot, tropical climate with year-round high temperatures (Rasmussen et al., 2019), with the stark contrast of the cool temperate oceanic conditions of Carrigtwohill, Co Cork seemingly leading to a reduction in the drills' use of their outside environment (Current Results 2025). Drills have also evolved specific behavioural adaptations that allow them to thrive in a hot, humid and tropical environment, which is the opposite of the climatic environment the captive troop of drills experience in Fota Wildlife Park in Carrigtwohill, Co Cork. These behaviours include specific activity budgets, habitat preference and dietary flexibility that have evolved around the need to stay cool and conserve energy in a tropical environment (Owens, 2015; Astaras et al., 2007). The behavioural adaptations of primates living in tropical regions vary greatly from primates living in cooler temperate weather conditions, especially in thermoregulation (Hanya et al., 2007). Hanya et al., (2007) found that Japanese macaques evolved two main social behaviours to thermoregulate in a cooler environment: - sunbathing and group huddling. The lack of evolved behavioural adaptations to deal with the local environment is another likely reason for the drills lack of use of the outside island environment.

Individual Differences in Behaviour

Due to the complex and hierarchical nature of the drills' social systems, we explored whether there were individual differences in the behaviours expressed between members of the troop. From analyses using a chi- squared test, four behaviours were found to be expressed significantly differently by individuals of the troop. These included night-time stereotypies, daytime stereotypies, allo-grooming and play. Stereotypic behaviour during the night and the following day were found to be expressed differently between individuals. This is likely due to the hierarchical structure of most group living primate social systems, where specifically ranked individuals are more vigilant for potential threats, such as predators, which can lead to less sleep achieved and higher levels of stress (Allan and Hill 2018). The social behaviours of play and allo-grooming were found to be expressed significantly differently between individuals of the troop. This variation in the expression of these behaviours is likely due to how fundamental the behaviours of play and allo-grooming are to most aspects of the drills' lives, with each drill expressing each behaviour to a varying degree depending on their social standing e.g. lower ranking individuals will groom higher ranking individuals more regularly to gain acceptance. Old World primates will use play and allo-grooming to strength group bonds, achieve a higher group rank and to teach juvenile members of the group survival skills and social competence (Mancini and Palagi 2009)

Significant differences in individual expression of both allo-grooming and play is also likely due to the correlation between these two behaviours. Mancini and Palagi (2009) found a positive correlation between play and the beginning of allo-grooming behaviours in a captive troop of gelada baboons. They found that the behaviours of play and allo-grooming were not restricted to individuals of similar rank or age but were expressed between all members of the group regardless of rank or age to different degrees depending on the situation. Mancini and Palagi (2009) found that the only variable that influenced the expression of these behaviours was sex, with females being more likely than males to engage in play and allo-grooming with baboons of different ages and rank. These findings further support our results as the captive troop of drills at Fota Wildlife Park is comprised of 75% females, meaning variation in the expression of these behaviours is likely.

Conclusion

The critical importance of good quality sleep or sleeping states to nearly all animals is well documented (Miyazaki et al., 2017). Sleep is especially important to mammals such as primates, who live in complex social structures and varied environments that require high levels of problem solving and brain activity (Nunn and Samson, 2018). Our research on the captive drills of Fota Wildlife Park has produced some very interesting results regarding their relationship with the local weather of Carrigtwohill, Co. Cork. Although sleep was found to significantly affect the expression of night-time stereotypies, when the climatic variables of rain and wind were included in the models, the weather variables became significant, and sleep was seen to be less significant. This shows us that due to the limited non-invasive measure of sleep we have, weather may have more effects other than just reducing sleep, leading us to conclude that the weather variables of rainfall (mm) and windspeed (Km/hr) significantly affect the major behaviours examined in this study, and may be a better indicator of these behaviours than sleep, supplemented with evidence showing that these negative behaviours may be caused by an impact on sleep quality.

Our results show that the cool temperate oceanic climate present in Western Europe is a strong predictor for negatively affecting social behaviours and exacerbating the expression of stereotypic behaviours by the drills, while presenting evidence that these highlighted behaviours are caused by an impact on sleep quality. It is hypothesised that the noise created from rainfall and wind speed colliding with the metal roof of the drills' sleeping quarters caused a reduction in the total sleep achieved by the drills each night. Further research should be carried out examining the effect of a noise cancelling medium (e.g. bioactive roofing) on the drills' achievable sleep. The effect of seasonal change on the sleep achieved by the drills should also be investigated.

The effect of night-time weather conditions on the drills' habitat use was also investigated, generating similar results. It was found that the higher the total night-time rainfall and wind speed, the less these primates would use their island habitat the following day. It can be deduced from these findings that adjustments need to be made to the housing of the drills in order to improve sleep quality, encourage habitat use and increase the overall husbandry of these primates.

The effect of reduced sleep on the welfare and mental wellbeing of these primates was then investigated, yielding very interesting results. The expression of self-directed behaviours and stereotypies was found to be correlated with reduced total sleep, both during the nights of unrest and during the next day. The expression of stereotypies in primates is a challenging welfare issue and is a field that is still evolving and expanding, as institutions gain a better understanding of the physical and physiological needs of captive primates such as drills. Allogrooming was a behaviour that was not found to be significantly negatively affected by the reduction in primate sleep, but results of the link between allogrooming and sleep indicated a potential trend, though not meeting the threshold for statistical significance. This was a cause for concern since allogrooming is a vital social behaviour of all group living primates (Easley et al., 1989) and further highlights the need to address the issue of weather influencing the drills' sleep. The influence of an alien climatic environment on the expression of these negative behaviours is an understudied area of primate welfare and we hope this study can help improve facilities' care of primates originating from tropical regions.

After analysing the results found in this study, some novel suggestions to address the issues faced by the local weather were formulated. These suggestions have simplicity and cost effectiveness at their core, while also aiming to support the biodiversity of the park. Firstly, in order to mitigate the noise created from rain and wind colliding with their metal roof we suggest the implementation of a bioactive roof. A bioactive roof would serve a dual purpose, it would stop or greatly reduce the noise created by weather systems hitting the roof while also raising the biodiversity of the park. A thin layer of material e.g. plastic, recycled carpet etc. could be covered in topsoil, with native wildflowers planted to support the park's resident pollinators (Michalik-Śnieżek, 2024). Secondly, we believe that the creation of higher sleeping platforms on their naturalistic island could encourage them to use their island habitat more, while also increasing their sleep quality. In a natural setting drills are closed canopy specialists who sleep high up in trees at night to avoid predators (www.Tengwood.com). The current sleeping quarters of the drills at Fota do not match their wild sleeping ecology. The drills currently are housed in a bungalow style building that does not offer the safety of height for sleeping.

Mandrillus leucophaeus is one of Africa's most endangered and enigmatic species. An improved understanding of their captive husbandry needs is vital for the protection of this species and facilitate reproduction of the valuable individuals being kept in captivity.

CHAPTER Three – General Discussion

Drills are one of Africa's most endangered mammals, and the implementation of geographically and species-specific husbandry techniques are vital to promote normative behaviours to insure a healthy captive population of this species (Moloney et al., 2023). The goal of any facility with captive animals that are endangered within their natural range should be to promote breeding behaviours and to produce offspring adding to the genetic bank of the species (Greenwell et al., 2023). The troop of drills present at Fota Wildlife Park have expressed breeding behaviours, but only one out of three confirmed pregnancies have been successful (unpub. data, primate keepers, Fota Wildlife Park). It is hoped that the research carried out for this study can support Fota Wildlife in creating an optimum environment for the troop to continue to successfully breed.

Main Research Findings of this Study

Researching the effects of the local weather on the sleep and welfare of the troop of drills at Fota Wildlife Park gave a deeper understanding of the intricacies of primate behaviour, the complexity and fragility of sleep to external stimuli (weather) and the species-specific welfare needs that must be provided by zoological facilities for its species collection. The main research findings of this study are that i) the weather variables of both rain and wind are significant predictors of stereotypic behaviours, and island use, ii) the weather variables of both rain and wind are significant predictors of total sleep achieved by the troop, iii) total sleep achieved by the troop was correlated with the expression of both night-time and daytime stereotypies and iv) total sleep achieved by the drills was correlated with the expression of allogrooming behaviours.

Climatic Differences between Carrigtwohill and Western Africa

Carrying out this research project has made it evident that the local climatic conditions of Carrigtwohill, County Cork are directly affecting the sleep and wellbeing of the troop of drills at Fota Wildlife Park, due to the night-time noise created from rain and wind colliding with the metal roof on their indoor housing area. Ireland has a cool temperate oceanic climate that is mostly controlled and influenced by the Atlantic Ocean (Met Eireann 2025). This constant influence of the Atlantic Ocean allows Ireland to maintain relatively consistent weather patterns compared to nearby countries of similar latitude. Atlantic low-pressure systems keep the weather wet and mild for most of the year with polar fronts bringing a sequence of cloudy, humid weather with rain followed by brighter colder weather with showers (Met Eireann 2025). The local weather of Cork, Ireland experienced 1270 millimetres of rain in 2024 with an average of 105.83 millimetres falling each month. The region also experienced an average windspeed of 19.4 km/h in 2024 (Current Results 2025). This combination of consistent rainfall coupled with high wind speeds, which peak during the winter months, are seen to be the cause of the disturbance that is interrupting the drills' sleeping bouts. The effect that the cool temperate oceanic climate has on the troop of drills at Fota Wildlife Park may be exacerbated due to the contrasting climatic conditions found in the regions where drills are native compared to Carrigtwohill, County Cork. Drills are native to mainland West Central Africa and Bioko Island where they experience a climate that rotates between a wet and dry season due to interactions between two migrating air masses (Food and Agriculture Organization). The hot, dry continental air mass of the Northern high-pressure system which brings about dry, dusty Harmattan winds from the Sahara Desert meets the moisture laden tropical maritime air mass that produces South Westerly winds collide at the Intertropical Convergence Zone (ITCZ). The migration of the ITCZ follows the sun from North to South and controls the climate of the region. Due to these climatic factors much of the region experiences consistent sunshine and high temperatures with areas within 10 degrees of the equator having an average temperature of 26^C year-round (Food and Agriculture Organization). The climatic conditions of Carrigtwohill, County Cork are drastically different to the hot and tropical climate that the drills' physiology evolved to thrive in, which is thought to be negatively affecting the troop's sleep, expression of normative and stereotypic behaviours and habitat use.

The Importance of Sleep for Living Organisms

Sleep is essential for both human and non-human brain and bodily functions and is controlled by the circadian rhythm along with the organism's sleep-awake history (Reinhardt, 2020). Primate sleep is also influenced by their surrounding environment with variables such as predation, weather and anthropogenic disturbance influencing how much sleep primates can achieve (Reinhardt, 2020). Primates engage in both monophasic and polyphasic sleeping patterns. Monophasic sleep consists of a singular bout of deeper sleep with a higher arousal threshold, this allows the organism to engage in less overall time asleep. Less time spent sleeping allows the organism more time to forage, maintain social systems, find mates, and avoid predators (Reinhardt, 2020). Polyphasic sleep is a basal trait in the mammalian group that is common amongst members of the Cathemeral primates. Cathemerality in primates is seen as primates who have irregular sleeping patterns, not fitting under nocturnal, diurnal or crepuscular activity budgets e.g. the common brown lemur (Reinhardt, 2020). The findings of our study suggest that the troop's disrupted sleep caused by local climatic conditions are causing an increase in the expression of stereotypies, while also affecting the drill's use of their island habitat. These findings are supported by several studies examining primate sleep both in the captive environment and in the wild. Promsote et al. (2023) examined the effect of sleep deprivation on a group of captive rhesus macaques' immune system and cognitive abilities. Six male macaques were subjected to three 48hr sleep deprivation sessions that were followed by domain specific cognitive ability assessments using the Cambridge Neuropsychological Test Automated Battery (CANTAB) protocol. The effect that the lack of sleep had on the immune system of the primates was also investigated by measuring immune activation markers in the blood using multiplex assay and flow cytometry. All six macaques showed both a decrease in cognitive function and immune dysregulation. These results support our hypothesis that the disrupted sleep of the troop of drills at Fota Wildlife Park is affecting their mental states, causing the increased expression of stereotypic behaviour and is decreasing the troops use of their island habitat.

Other observations on Primates in Captivity

Zoological facilities have included primates in their collections for centuries due to their alluring personalities and affinity with the public (Hosey 2023). But due to most primate species having complex social systems, high cognitive intelligence and large dynamic social groups modern day facilities must design species specific enclosures to cater for each primates' husbandry needs. If these needs are not adequately met by the captive facility the captive animals will begin to express abnormal behaviours and stereotypies (Young, 2003). Although great advancements have been made in the realm of primate care and husbandry, all primates housed in zoological facilities must adapt and deal with four unavoidable variables, noise disturbance, presence of zoo visitors, restricted space and being managed by humans. The effect of noise disturbance on captive primates was central to this study and is an issue faced by every facility that house captive animals. Noise disturbance has been consistently shown to affect the welfare of captive primates, both behaviourally and physiologically. In a study on *Macaca fascicularis* exposed to construction-related noises (blasting, hammering etc), Westlund et al. (2012) found significant short-term elevations in stress markers, namely glucocorticoids, alongside altered behavioural responses, suggesting that even short-term, acute noise events can cause a measurable stress response. Similarly, a study at a primate research centre housing macaques revealed that although average ambient noise levels (58–62 dB SPL) were within accepted safety standards, intermittent peaks of sound up to 109 dB, caused by metal banging and human activity, led to observable startle reactions in *Macaca mulatta* (Heffner and Heffner, 2022). These unpredictable spikes in volume, rather than consistent noise exposure, are particularly potent in causing acute stress. While low-level ambient noise is common in captive environments, these findings highlight that short, loud noise creating events may cause stress on the primates even when overall noise levels remain low. Behavioural responses also appear strongly linked to sound intensity and specific sound type. In a study of captive chimpanzees (*Pan troglodytes*), Coffman (2019) reported a positive correlation between higher noise levels in the environment and the frequency of agonistic and stress related behaviours. Similarly, White-handed gibbons (*Hylobates lar*) and tamarins exposed to different auditory stimuli within their captive environment such as ambient zoo noise, waterfall recordings, and rainforest recordings displayed stress behaviours in response to the more intrusive sounds. In particular, the sound of a waterfall was found to be stress inducing, while rainforest noises and classical music offered little enrichment benefit but seemingly no negative effects (Wells et al., 2006). These previous studies support our hypothesis that the unpredictable spikes in decibel level within the drill's housing can lead to increased expression of stereotypic behaviours and acute stress behaviours.

The effect of zoo visitors is an unavoidable potential stressor for all primates in captivity as zoological facilities need paying visitors to finance the running of the organisation (Hosey, 2023). The behaviour of the visitors and the design of enclosure viewing areas can play a significant role in the effect that the public have on the primates, with Hosey (2005) finding that active audiences (visitors actively trying to interact with the primates) caused far more stress and stereotypic behaviours to be expressed by the primates than passive audiences (who did not try and interact with the primates). Similar results have been documented with the troop of drills at Fota Wildlife Park who have been seen to react aggressively to park visitors who touch the glass of the viewing areas and intentionally make eye contact with the drills, with these aggressive behaviours not being expressed toward passive viewers of the enclosure who follow the park's rules regarding distance from the glass (unpub. report Fota Wildlife Park). Space will always be a limiting factor for all captive animals, but this is especially an issue for captive Old World primates such as drills due to their natural foraging style and semi arboreal nature, which calls for both terrestrial grassland habitat and closed canopy cover to be included in the enclosure design (Astaras et al., 2007). Overcrowding can be an issue for primates in captivity with Waterhouse and Waterhouse (1971) observed an average of 4.4 examples of aggressive behaviour per hour while observing a troop of 41 rhesus macaques in captivity, with this mean average dropping to 1.5 aggressive observations per hour when half of the primates were removed. The management of species in captivity will always have a significant effect on the species in question, as the feeding, breeding, health and enclosure size is all dictated by the management of zoo staff (Hosey, 2005). Presenting food in a naturalistic way (whole fruit and vegetables), scatter feeding, enrichment activities and varied daily feeding times can help combat the effects of constant human intervention (Hosey, 2005).

Suggested Improvements to Drill Habitat and Husbandry

BIAZA and EAZA guidelines for drills (*Mandrillus leucophaeus*) emphasize the importance of maintaining social structures, as drills are highly social animals that thrive in group environments (BIAZA, n.d.; EAZA, n.d.). Enclosures should offer sufficient space and complexity, incorporating climbing structures and naturalistic elements to encourage natural behaviours like foraging and social interaction. Enrichment activities are crucial for mental stimulation and preventing boredom, ensuring drills remain engaged and active.

Dietary recommendations for this species highlight the need for a varied and nutritionally balanced diet that reflects their natural omnivorous habits. Regular health checks and behavioural monitoring are essential to quickly address any stress or health issues (BIAZA, n.d.). Staff training is critical for understanding drill-specific behaviours and needs, enabling caretakers to provide optimal care and adapt management practices as needed (EAZA, n.d.).

The troop of drills at Fota Wildlife Park are housed in a large naturalistic island habitat that provides excellent outdoor foraging space, but the aforementioned literature has highlighted some areas that can be changed to improve the husbandry and possibly reduce stereotypic behaviours expressed by the drills. Drills are naturally semi arboreal, diurnal closed canopy specialists that retreat to the tops of trees for security at night (Astaras et al., 2007). The inside sleeping quarters of the drills at Fota Wildlife Park consists of a short bungalow style building that does not have high vegetation covered roosting areas, this may be contributing to the stress of these animals. Similarly, the high climbing structures found outside on the drills' island are bare, exposed and not vegetated. This can lead to the drills feeling unsafe without proper cover to hide as they would in a wild setting. Varying the time and location of the daily scatter feeding may also improve the mental well-being of the troop and encourage them to explore other areas of their habitat.

After observing the behaviour of the troop of drills for three months both day and night several novel changes to the husbandry of the troop have been suggested to improve sleep achievable. Firstly, the addition of a bioactive roof on top of the drill housing is suggested. The benefits of this include its potential cost-effectiveness, its sound proofing capabilities during weather events and its support of the park's native biodiversity (Michalik-Śnieżek, 2024). Secondly, it is suggested that the park add higher sleeping platforms throughout the drills island habitat, since naturally drills seek protection high in trees at night when sleeping (www.Tengwood.com). This would allow the drills to feel more secure and would hopefully in turn promote longer and less disturbed sleeping bouts (www.Tengwood.com).

The drill is a striking and captivating species, whose intelligence, social complexity and emotional capabilities have been an honour to witness while carrying out this thesis study. It is hoped the information curated in this study can help improve the captive environment for this endangered species and promote more successful breeding events in the future.

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