ECOLOGY OF THE ADERS' DUIKER (*Cephalophus adersi*) ON MNEMBA ISLAND, ZANZIBAR

By

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DEDICATION

In loving memory of my dear oupa, Danie Coetzee (1923 – 2019), ouma Hester Coetzee (1928 – 2007), ouma Anna Bronkhorst (1920 – 2009) and oupa Hendrik Bronkhorst (1918 – 1986).

But by the grace (the unmerited favour and blessing) of God I am what I am, and His grace toward me was not [found to be] for nothing (fruitless and without effect). In fact, I worked harder than all of them [the apostles], though it was not really I, but the grace (the unmerited favour and blessing) of God which was with me. 1 Corinthians 15:10

(Amplified Bible, Classic Edition)

DECLARATION

I **Lorraine Raby Bronkhorst** hereby declare that the dissertation/thesis, which I hereby submit for the degree of **Doctor of Philosophy in Environmental Science** at the University of South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

I declare that the dissertation /thesis does not contain any written work presented by other persons whether written, pictures, graphs or data or any other information without acknowledging the source.

I declare that where words from a written source have been used the words have been paraphrased and referenced and where exact words from a source have been used the words have been placed inside quotation marks and referenced.

I declare that I have not copied and pasted any information from the Internet, without specifically acknowledging the source and have inserted appropriate references to these sources in the reference section of the dissertation or thesis.

I declare that during my study I adhered to the Research Ethics Policy of the University of South Africa, received ethics approval for the duration of my study prior to the commencement of data gathering, and have not acted outside the approval conditions.

I declare that the content of my dissertation/thesis has been submitted through an electronic plagiarism detection program before the final submission for examination.

Student signature: L Bronkhorst Date: 18 November 2020

SUMMARY

Mnemba Island has been housing a population of the vulnerable Aders' duiker (*Cephalophus adersi*) since 2005, sharing the small, forested area with a prolific population of Suni antelope (*Neotragus moschatus*) (both species re-introduced). Despite government attempts to control the population size of Suni antelope, the tiny antelope proliferates at a seemingly high rate. Additionally, no Aders' duiker has been removed since introduction to the island. Together, the two antelope species have been negatively impacted the island's natural forest condition over time. Due to the Aders' duiker's endangered status, this natural habitat is essential to the survival of the species. For the first time, a study was initiated to investigate the ecology of the Aders' duiker on Mnemba island to aid in determining a feasible carrying capacity to better manage the protected species on this Island. The outcomes of the study would be instrumental in managing the sub population and creating more suitable conditions to provide a sustainable harvest for reintroduction of offspring into other conservation sites (to be identified by the Government) in the rest of the Zanzibar Archipelago.

A variety of inquiries were planned and performed to obtain an overview of the natural habitat, interactions of the Aders' duiker with its environment, each other, and with the Suni antelope. A lack of weather data for the north-eastern side of Unguja, Zanzibar also promted an onsite weather station to gather baseline data for a better understanding of the island's climate conditions.

A comprehensive vegetation assessment confirmed suitable species diversity and phenology for the maintenance of the duiker population. A mark-recapture population survey using an adjusted Lincoln Peterson estimate was undertaken to infer the current population density. Then the collection of birth and death data over twelve months provided an instantaneous growth rate which was necessary for modelling a logistic population growth curve. From the population survey and the growth rate, an estimated 25 Aders' duiker were estimated to be inhabiting the island and it was projected that a maximum sustainable harvesting density of 13 duikers would maintain an ecological carrying capacity for the island. An adjusted growth model suggested that the maintenance of the proposed ecological carrying capacity would result in a sustainable harvest rate of 40%, which aligns with the suggested rate for other antelope of this size.

All behaviour activities for the Mnemba Aders’ duiker population was observed over twelve months, using a stratified purposeful focal sample survey methodology, and pooling data for all daylight hours for 300 focal observations. Theoretically, each of the 25 duikers had an equal opportunity to be observed 12 times over 12 months. The pooled data provided a time-activity budget that indicated that the general Aders’ duiker population on Mnemba island foraged for 39% of daylight hours. Seasonal comparisons further indicated that males foraged 12% more in the dry season, while females foraged 10% less in the dry season. The species’ diel pattern was also confirmed as loosely crepuscular, with significant differences between male and female duiker activity patterns. Males presented a more matutinal pattern while females followed a more vespertine pattern.

Further to the capacity assessment, a twelve-month GPS tracking survey of one male and one female duiker provided spatial data for estimating annual and seasonal home and core range sizes, using a kernel density estimation. The two pairs of duikers implicated in the tracking inquiry were found to use half the indigenous forest on the island as their combied home ranges, and based on the average core range sizes, the natural forest would have spatially housed 25 individuals with no core overlap, which happened to be the same number as the population estimate derived from the growth model. Comparisons between the population survey results and the spatial carrying capacity proposed that maximum density had been reached.

KEY TERMS

Ecology; Aders’ duiker; Zanzibar; Mnemba Island; Carrying capacity; Home range; Activity budget; Vegetation survey; Climate; Conservation.

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No man is an Island, entire of itself; every man is a piece of the Continent, a part of the main; if a clod be washed away by the sea, Europe is the less, as well as if a promontory were, as well as if a manor of thy friends or of thine own were; any man's death diminishes me, because I am involved in Mankind; And therefore never send to know for whom the bell tolls; It tolls for thee.

John Donne, Meditation XVII
(Donne, c.1623)

I am thankful to God, my creator and saviour, for taking me on an incredible journey that has changed my life forever. Humbled by His mercy, I have come through this a much stronger person.

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CHAPTER 1

INTRODUCTION

The Eastern Arc and Coastal Forest region of Africa constitute two biodiversity hotspots as appraised by the Critical Ecosystem Partnership Fund (CEPF, 2005). The CEPF reports that coastal forests have been reduced to an intermittent patchwork with only one percent of this unique eco-region covered by closed canopy forest. The forested areas boast 400 endemic plant species (n > 3 000 total species identified). A further 500 endemic plant species can be found in the remaining mixed habitat farms, thickets, bush and savannah woodlands (CEPF, 2005). Forest areas that have not yet been degraded are under threat from expanding agricultural practices, firewood collection and timber extraction. Habitat loss also causes concern for dependent fauna, especially threatened and endemic species (CEPF, 2011). Much work has been done to assess the region’s status and the nature of these pressures, while many efforts have been made to devise sustainable conservation solutions through scientific inquiry. Details about research and solutions can be found in the historical work of writers such as Burgess (1990), Burgess et al. (1992), Burgess and Muir (1994), Clarke (1995), Clarke and Burgess (2000), Rogers and Burgess (2000), Finnie (2001), Younge et al. (2002), and more recent work of MacFarlane et al. (2015) and Bonnell et al. (2011).

Finnie (2001) suggested that over and above the obvious pressures placed on forest resources, an absence of suitable management practices exists in these areas. These can be ascribed to a combination of political and human resource challenges faced by government institutions. Yet, some successful attempts at reviving the conservation of coastal forest areas have been made (Younge et al., 2002). The National Coastal Forest Strategic Action Plans have been put in place to conserve the high number of endemic species along the East coast of Africa. The need for intensive conservation programs is based on the high endemism and biodiversity potential of coastal forests and are in response to a decline of the number and size of forest areas in the eco-region. In 1992 a total of 66 forest areas (~700 km^2 total size) were recorded in Tanzania. By 2002, the East African Coastal forest Programme reported that these areas had splintered into 179 smaller areas (~692 km^2 total size) (Younge et al., 2002). Although the total sizes of the areas show no significant difference, fragmentation of forest areas is of ecological concern. The increasing threats to biodiversity in these areas have thus received much attention in the field of environmental science (Clarke and Burgess, 2000). The CEPF report released in 2012 claimed that in the coastal forests of Tanzania alone, ±139 km^2 of deforestation took place over seven years prior to the report.

In the early 1980's, the Tanzanian government realised the urgency for protection of endemic species, which resulted in the implementation of the Tanzania Forestry Action Plan (THE UNITED REPUBLIC OF TANZANIA, 1990), the Tropical Forest Action Plan (TFAP) of 1988 and the New National Forest Policy (THE UNITED REPUBLIC OF TANZANIA, 1998), as cited by Younge et al. (2002). These plans were instituted to trigger conservation actions across Tanzania. Although recent reports suggest continued habitat degradation (Ahrends, 2005; Griffin, 2012), attention has been given by researchers and conservation organisations to preserve the area for purposes of global biodiversity (Burgess et al., 2003).

The Swahili coastal forest forms part of the Eastern Arc and Coastal Forest region, stretching along the Kenyan and Tanzanian coastline, including Unguja, Pemba and a host of smaller islands (collectively known as Zanzibar). Zanzibar, even though removed from the continent, does not escape the threats to its forest ecosystems. In his report on "Biodiversity, climate change and energy crisis", Kombo (2010) reviews the state of biodiversity and natural resource degradation for Zanzibar and concludes that forests are especially at risk from increased human activities. The once rich biodiversity of this area is dwindling at a rapid rate. Endemic mammalian species that depend on coastal forests for survival, such as the Red Colobus (*Piliocolobus kirkii*), Suni antelope (*Neotragus moschatus*), Aders' duiker (*Cephalophus adersi*) and blue duikers (*Philantomba monticola*) are negatively impacted by the decline in forest cover and diversity. Zanzibar, including Jozani Forest, has been listed as a high-priority site for long-term conservation (Rodgers and Burgess, 2000). In 2006, the WWF Eastern Africa Regional Programme published a Strategic Framework for Conservation for the period of 2005 to 2025, outlying very specific goals for individual species and habitat preservation targets in the region. Target three focusses on coastal forest endemic and threatened species, aiming to reversing population decline trends for many Pemba and Zanzibar bird species, the red colobus monkey, blue duiker and Aders' duiker. Target six aims to restrict human pressure placed on these species with a particular focus on preventing hunting of Aders' duiker in Kenya (Arabuko Sokoke) and Zanzibar (Jozani Forest) so that populations can become stable.

Aders’ duiker, a member of the red duiker family and one of 18 species of *Cephalophus*, is one of the most threatened antelope species in the world and was once quoted to be Africa’s most threatened antelope (Baldus, 2004). With ~600 individuals estimated to be left in Zanzibar by 1999, and with an international Red data listing in 2008 of Critically Endangered (IUCN, 2008a), the decline of the Aders’ Duiker population is a major cause for concern. According to Kanga (1999), an 87% decline in numbers over a 17-year period (from n = 5 000 in 1983 to n = 640 in 1999) in Zanzibar, resulted in a shift of the IUCN rating from Vulnerable to Critically Endangered. Habitat loss and hunting are listed as the main causes for declining numbers of Aders’ Duiker, and if not sufficiently addressed will lead to the species becoming extinct (IUCN, 2018a). Until 2008 it was believed that other than a small population left in Arabuko Sokoke, Kenya, no significant population of Aders’ existed outside of Zanzibar. Subsequently, a camera trap study in the Boni-Dodori forest in northern Kenya discovered an existing population in this area (Andanje et al., 2011b). Given the new discovery, the most recent IUCN rating for Aders’ duiker was listed as Vulnerable by the SSC Antelope Specialist Group (IUCN, 2017). The need to address habitat and human pressures in Zanzibar remains critical for the survival of the local duiker population. Concentrated research efforts on habitat ecology and behaviour of Aders’ Duiker are needed to provide necessary baseline data for critical conservation decisions (Finnie, 2001).

The extinction of the Zanzibar leopard (Rogers and Swai, 1988) is an example of a recent loss of a mammal species due to anthropogenic pressures. Mammal conservation priorities on Unguja Island include the protection of forest habitats, core populations of Colobus and Sykes monkeys, and three antelope species, as well as educating communities about the protection of species and habitats (Finnie, 2001; Williams et al., 1996). These programs are managed and implemented by conservation officials from the Department of Forestry and Non-Renewable resources (DFNRR) and enforced in the 12 local villages through wildlife bylaws, Village Hunter Associations and Community Forest Management Agreements (Williams et al., 1999). Previous research efforts suggested a captive breeding initiative for Aders’ duiker in Jozani or Kiwengwa forests (Williams et al., 1999; Finnie, 2001, 2002) as an effort to reverse the Aders’ duiker population decline and preserve the gene pool. After many years of planning, this program has recently been implemented in Jozani Forest as part of the newly established Biosphere reserve. Finnie (2001) suggested that the main barrier to establishing a breeding center earlier had been the lack of financial support, which was confirmed in a personal meeting with a representative from the DFNRR (Mr. Ali Mwinyi, on 16 April 2016). Meanwhile, the overall population of Aders’ duiker is rapidly declining (Ochieng et al., 2017), and little information exists about this species. With captive breeding programs being proposed as a solution (Payne and Bro-Jørgensen, 2016), husbandry data are needed for tailored breeding programs.

Smaller islands forming part of the archipelago of Zanzibar vary in size, density and diversity of coastal vegetation. These isolated habitats often provide unique opportunities to preserve and study threatened species. In the case of Aders' duiker, two such natural habitat sanctuaries are operational. In 1998, Chumbe Island, off the west coast of Unguja became the first islet sanctuary for Aders' duiker. In 2005 Mnemba Island, off the north-eastern coast of Unguja followed suit. Reports (Lanshammar, 2009; Mwinyi et al., 2012) indicate that the initial Aders' duiker population introduced to Chumbe Island has not increased significantly, whereas Mnemba's population seems to be growing steadily (Mwinyi and Hija, 2008; Mwinyi et al., 2012). The number of Aders' duiker on Mnemba has not been surveyed since inception of the breeding project. The population of Aders' duiker on Mnemba offers the only opportunity to study the species in-depth and describe the ecology of the species in its natural environment. With Zanzibar's population trends indicating that further decline could lead to local extinction (IUCN, 2018a), collecting baseline ecological data for this species becomes a matter of urgency.

1.1 Aim of the study

Mnemba Island plays a critical role in the repopulation of Aders' duiker back onto Unguja. Previous short-term distribution studies done in Kenya and Unguja (Finnie 2002; Schrodt 2005; Andanje et al., 2011a), and on Mnemba Island (Fiske 2011; Rivers 2012) advise that further investigation into the habitat requirements of Aders' duiker be done.

Information provided by the Department of Forestry and Non-renewable Resources (DFNRR, 20 November 2015) and Mnemba's management (Mike Kelly, 16 June 2015), along with recommendations made by Fiske (2011) and Rivers (2012), led to the assertion that Mnemba Island had been overpopulated with Suni antelope and Aders' duiker, and required an in-depth study to assess the island's vegetation diversity and potential carrying capacity for these species. In 2004, the Suni population appeared to be growing very fast and a capture exercise was deployed to remove a large portion of the Suni population. From the capture data, an estimated 155 Suni were found on Mnemba at the time. Suni have been removed multiple times since then. Since the time Aders' duiker was introduced to the island in 2005, no offspring have been removed.

Research into the Aders' duiker sub-population on Mnemba aligns with the Zanzibar Research Agenda (ZRA) for 2015 – 2020. The agenda was produced by the Revolutionary Government of Zanzibar in collaboration with the Swedish International Development Agency (Sida) through the Tanzania Commission for Science and Technology (COSTECH). Upon a COSTECH request for a detailed investigation into the Aders' duiker population on Mnemba, AndBeyond Safaris in collaboration with the University of South Africa proposed a baseline inquiry to answer fundamental questions about the ecology of the species on the island, and to gauge the overall success of the sanctuary.

Considering the lack of data for the species, the current study contributes to a better understanding of the species' resource use. If the findings on Mnemba reflect the general activity patterns suggested in previous studies, it would be assumed that the detailed findings of the current study could serve as a baseline for future captive and re-introduction projects. Research findings could be extrapolated to other areas in and around Zanzibar, specifically when identifying additional natural habitat sanctuaries. The aim of the inquiry into multiple aspects of the Aders' duiker's ecology on the island was to investigate potential trends which can be used to raise hypotheses for further indepth research for this species. The specific objectives that guided this inquiry were to determine:

- The status of the island's vegetation by describing the various plant communities and abundance of forest plant species found on Mnemba Island.
- Mnemba's weather conditions over an annual cycle, at the time of the vegetation survey.
- The current population size of Aders' duiker on Mnemba Island.
- Detailed description of Aders' duiker behaviour and seasonal activity patterns for the species on this island.
- If there is interaction between the Suni and Aders' duiker and if so when?
- The diet of Aders' duiker on the island.
- Seasonal home range sizes and daily distances travelled for male and female Aders' duiker on the island.
- Whether a carrying capacity can be deducted from the available information.

The current study was thus designed to establish a cticical baseline for ongoing research into the ecology of Aders' duiker on Mnemba Island, and to suggest a sustainable carrying capacity for the island (PC: L. Carlisle, 2015 and M. Kelly, 2015) (Fiske 2011; Rivers 2012).

1.2 Hypotheses

Considering the limited amount of ecological data available for Aders' duiker, coupled with the absence of a reference point for Mnemba Island's vegetation, the current study serves to collect as much baseline data as possible. Where possible, hypotheses were developed from available literature to be tested against the data collected in this study:

- Vegetation analyses would indicate a higher species diversity in the natural forest compared to the areas where the alien *Casuarina cunninghamiana* forest occur (Potgieter et al., 2014);
- Aders' duiker is more active in the morning and the evening (bimodal diel activity pattern) (Amin et al., 2015);
- No significant difference between Aders' duiker male and female foraging activity patterns is expected (Neuhaus and Ruckstuhl, 2004);
- Seasonal differences in Home range size can be observed for Aders' duiker with some overlap between social groups (Dubost 1980; Newing 2001; Johnson et al., 2002);
- Mnemba's Aders' duiker population is increasing annually and serves as a breeding population for re-supplying Unguja with Aders' duiker offspring (Own prediction).

1.3 Thesis Structure

Chapter two provides a necessary background for the study and the need for baseline information in context of regional conservation efforts, characteristics of the region in which the Aders' duiker ranges and the socio-ecological environment in which the study was initiated. The chapter specifically explores literature related to: the formation of the islands off the coast of Tanzania; the climate and natural diversity; history of Aders' duiker research in the region and the species' IUCN status; limited data on the species' ecology and how it relates to similar species; as well as range data for a few Aders' duiker surveys.

Chapter three describes Mnemba Island as a marine based terrestrial environment, an atoll and enclosed sanctuary. The chapter focuses on morphological, ecological, regional and site-specific climatic components. An onsite weather station was deployed for a year during the study period. This chapter contains the results from the local weather data collected on Mnemba Island. For context, Mnemba's conservation history is also briefly reviewed.

Chapter four summarises the methodological considerations that formed part of the study design process which led to the final selection of research methods and tools.

Chapter five focuses on the outcome of a Braun-Blanquet vegetation assessment for the Island, as well as a phenology table collated over an annual cycle.

Chapter six includes population density estimates obtained from a drive survey and growth rate data, which is presented as a range of carrying capacity scenarios, suggested maximum sustainable harvesting density, and a harvesting schedule. The chapter also summarises the differences in male and female body measurements, as well as related anatomical and physiological notes taken throughout the study.

Chapter seven describes Aders' duiker ecology in terms of detailed behaviour, complete day-time-activity budget, and a description of foraging behaviour and food selection. Seasonal comparisons, gender differences and diel patterns are compared for main ethogram behavioural states.

Chapter eight illustrates the spatial use of the island by two adult Aders' duikers (one male and one female). The data are used to understand the spatial capacity of the island in the context of social and foraging observations made during focal observations, as well as the differences in male and female home ranges and diel activity patterns. Seasonal comparisons are also presented.

Chapter nine contains the overall discussion and sets out to address the research objectives posed in the beginning of the study. Management recommendations and ongoing research priorities are presented.

Chapter ten concludes the study and presents the outcomes from the study.

Each chapter includes information about the study site that is relevant to the chapter’s research focus, as well as an outline of the research methodology for the current chapter. To ensure that the reader has context to each data chapter, some repetition between the data chapters, the literature and methodology chapters can be expected.

CHAPTER 2

LITERATURE REVIEW

Tanzania administrates four main islands under the Zanzibar Archipelago, known as 1) Mafia (in the Pwani Mainland Region across the Mafia channel), 2) Unguja (often referred to as Zanzibar Island), 3) Pemba, (Figure 2-1), 4) Latham Island (a bird breeding islet south of Unguja) and a host of other smaller islets and cays of which 25 of these contain forests.

Figure 2-1: Map of the Islands of Tanzania (Perry-Castañeda Map Collection FAQ., 2006).

The administration of Unguja and Pemba joined Tanganyika in 1964 to form the United Republic of Tanzania (Figure 2-2), but the semi-autonomous Revolutionary Government of Zanzibar is still responsible for the non-Union government matters of both "Spice Islands" (Unguja and Pemba) (Finke, 2006). Whenever the term Zanzibar is used in this study, it refers to Unguja, unless it is specified that the reference is to the group of islands in the Zanzibar Archipelago.

Figure 2-2: Location map of Zanzibar Archipelago in relation to the East Coast of Africa.

2.1 Regional context of the Zanzibar Archipelago

Unguja (Zanzibar Island) is situated, at the closest point, 36.5 km from the coastline of Tanzania, measuring 85 km from north to south (and 39 km across). Unguja is the largest of the islands of the Zanzibar Archipelago at 1 554 km^2 (Finke, 2006). The highest point is found at Masingini at 120 m above sea level, and the lowest point in Jozani Forest – Chwaka Bay Reserve, 1.75 m above sea level (Salum, 2009).

As with the coastal region of Tanzania, Zanzibar has high population densities all along the coast (Booth et al., 2003). Coastal zones are important as an economic driving force for the country and contribute to a third of the country's GDP (Zavala-Garay et al., 2015); yet high levels of poverty continue to exist among coastal populations. Conservation of coastal areas is as important as poverty reduction and food stability for a growing population. A fine balance between extracting resources for current developments and reserving resources for future generations must be ensured through sustainable resource use. A growing population of 3% per annum by 1998 attracted the attention of many researchers, who aimed to predict and mitigate the increase in resource pressures in Zanzibar, of which marine resources were most affected. Johnstone et al. (1998) explained how the growth in population and the concomitant pressures on the environment were compounded by the exponential and simultaneous growth of the tourism industry. Over and above local inhabitants and mainland migrants, Zanzibar attracts numerous tourists to its attractive sandy beaches and rich marine life.

Many factors have led to the overuse of Unguja's natural resources, placing stress on the Island's ability to keep providing livelihoods to the myriad of tourist operators, job hunters from the mainland, and the local population who must continually change their way of life to survive. Not only has complex socio-political eras shaped the way the local people live and operate but increasing demands on marine resources has had ripple effects on both terrestrial and marine landscapes (Ali and Sulaiman, 2006; Sherman et al., 2009; Javaid et al., 2016). Burgoyne (2018) summarised the history of the island by referring to the work of Longair (2016), Sharpley and Ussi (2014). In his summary Burgoyne (2018) highlights how the main economy of the island has changed its course from exporting crops to local tourism, citing the difference in tourism figures for 2016 (162 242) and 2017 (376 000) to indicate the magnitude of growth in the tourist sector. Tourism has subsequently become the most prominent source of jobs for local Zanzibaris. This trend will most likely continue as the Government of Zanzibar is planning largescale increases in the number of hotels and tourist establishments for job creation and as a tax pool for local government treasury (Revolutionary Government of Zanzibar, 2012). An increase in establishments could also bring about further drastic changes to the natural environment. Although an estimated 50% of locals could be employed in or depend on the tourism industry by 2020 (Burgoyne, 2018), the remaining 50% of the population might not benefit from the development of the industry. More hotels will lead to an increasing demand for fish on the menus and diving activities for guests.

These demands would not only directly reduce fish populations and marine diversity but could negatively impact the way local communities sustain themselves.

A review of the morphology of Zanzibar Archipelago (Section 2.2) reveals that it forms an integral part of the East African coastland, to which it was once connected (Booth et al., 2003; Prendergast, 2016). All the islands that form part of the Zanzibar Archipelago cover 0.27% (2 400 km^2) of the total land mass within the administrative borders of Tanzania.

2.2 Formation of Zanzibar Archipelago

As part of the investigation into the diversity of vegetation species on Mnemba Island, it is important to have a basic understanding of the way Zanzibar and its surrounding islands came about. Both Unguja and Pemba used to be part of the mainland. Pemba is believed to have separated during the Miocene Epoch and possibly due to dislocation via the Pemba Rift, as opposed to the Unguja separation at a later stage through rising sea levels (Stockley, 1941). Unguja reportedly only lost its land bridge during the Pliocene Epoch or later (Prendergast, 2016). The continental shelf ranges from 4 to 60 km from the Tanzanian shore at a depth contour of 200 m according to Booth et al. (n.d.). Vestiges of the Archaean Complex of ‘Tanganyika’, Pemba and Unguja are based mainly on uneven limestone with some sandstone strata and various deposits which support the formation of caves and sinkholes, loam, clay, sand and red earth substrates (Stockley, 1941; Prendergast, 2016).

More recent investigations into the timeline and the way Unguja separated from the mainland include the prominent work of Prendergast (2016). In a comprehensive study of fossil records from a cave in the South east of Unguja, Prendergast (2016) developed a model to illustrate the systematic isolation of Unguja from the coastal mainland. His model and findings support the notion that the rising sea levels towards the end of the Pliocene Epoch flooded Unguja’s land bridge that previously provided an easy passage between the area and mainland Tanzania. Fossil records revealed a reduction in the occurrence of large mammals on Unguja over time as the natural migration of these species became impossible. Sedimentation timeline simulations provide a clear indication of the gradual segregation of the island from the continent, with periodic connection and disconnection after which the Last Glacial Maximum caused an increase in sea levels to the point where Mafia Island and Unguja became separate land units (Figure 2-3).

Findings from the Prendergast study (2016) compares favourably to other studies in the South-western Indian Ocean, Mozambique and South Africa, suggesting that after many fluctuations, the rapid sea level rise stabilised at its current level around 3 ka (kilo annum is the number of thousands of years before the present time), leaving Unguja as a separate island with a new set of ecological dynamics to play out (Compton, 2001).

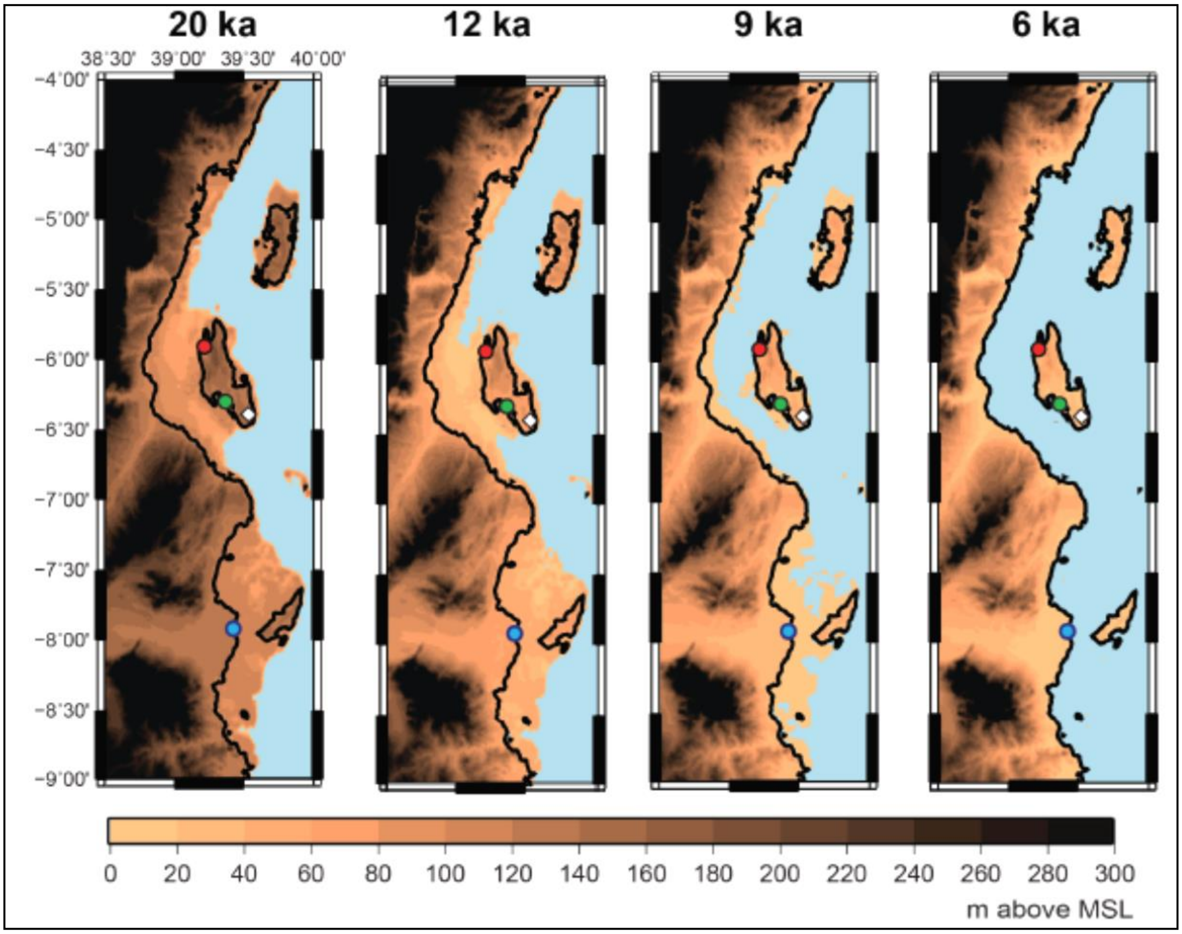


Figure 2-3: Pendergrast (2016) reconstruction of the Tanzanian Coastline, illustrating the separation of Unguja (after 10 ka) and Mafia (after 9 ka) Islands from the Mainland.

Critical evidence was discovered in the Kuumbi Cave fossil matter. The only record of large mammals on any of the Islands off the East coast of Africa (apart from Madagascar) was found, demonstrating a rapid defaunation of some of the large mammals (including Reedbuck (*Redunca arundinum*), Zebra (*Equus quagga*) and Leopard (*Panthera pardus*) after isolation. The series of images (Figure 2-4) from Prendergast's (2016) simulation, illustrates how Unguja's isolation started around 12 ka and by 10 ka a narrow strait remained as the only means of replenishing the island with fauna from the mainland. During this time species requiring larger home ranges, such as buffalo (*Syncerus caffer*), waterbuck (*Kobus ellipsiprymnus*) and zebra (*Equus quagga*) would dissipate in what is called a Species Relaxation. However, evidence showed that the biggest reduction in faunal diversity occurred at the time when cultivation took place by increasing human populations. Climatic impacts were not considered as causal to the sharp decline in species diversity but cannot be ruled out as compounding factors contributing to the local extinction of species.

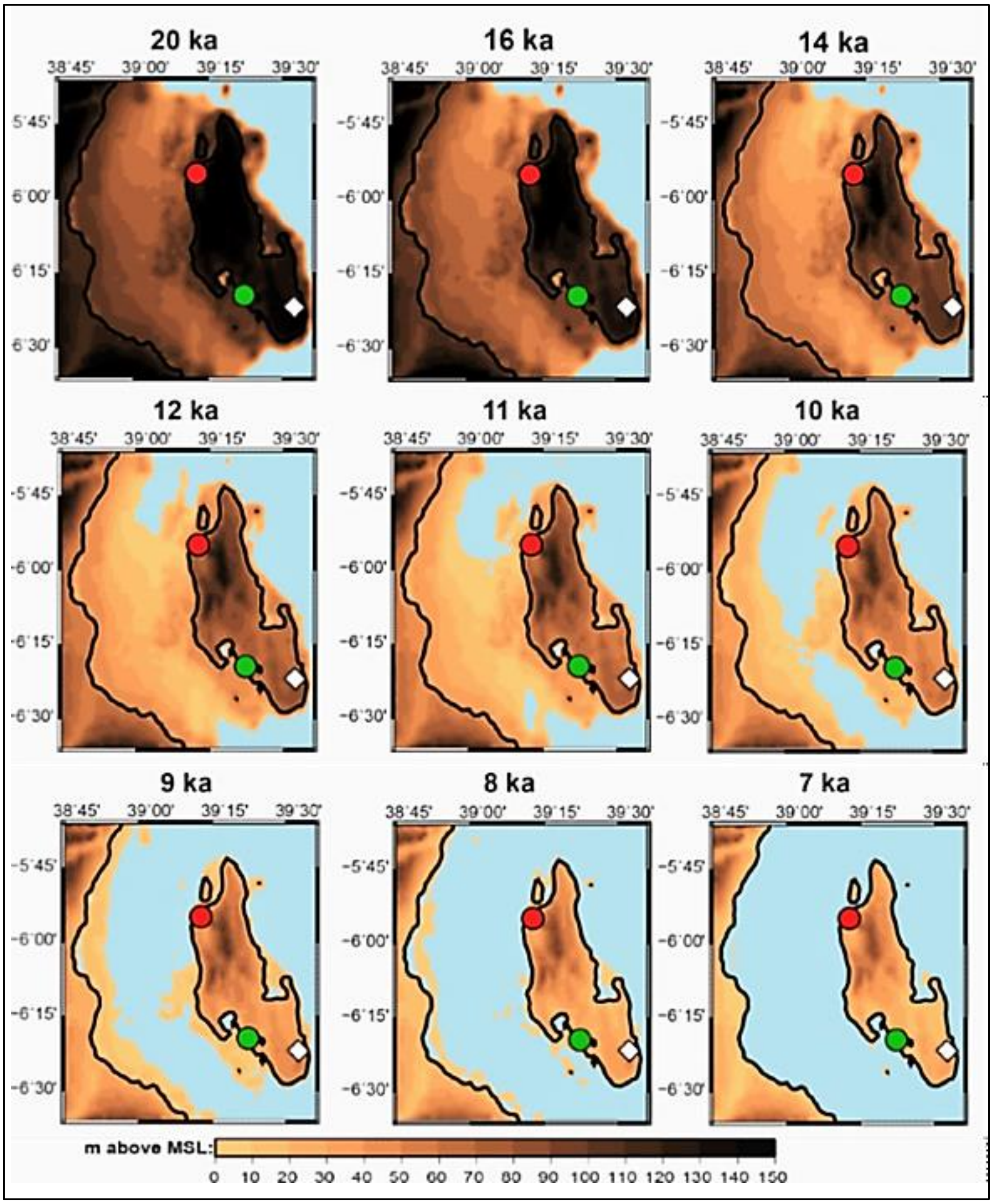


Figure 2-4: Prendergast (2016) topographical reconstruction of the island formation of Unguja, Zanzibar.

After 10 000 to 15 000 years and the local extinction of large mammals on Unguja (and no recorded adaptation of these species to accommodate the change), a few smaller endemic mammals remained on the island. Species found in the fragmented forest habitats included the Zanzibar leopard (recently extinct), Red Colobus Monkey (*Piliocolobus kirkii*), Aders' duiker, Suni antelope (*Neotragus moschatus*), Blue duiker *(Philantomba monticola)* and Sykes monkey (*Cercopithecus albogularis*). The work of Prendergast (2016) puts Zanzibar at the forefront of Island formation and biogeography research based on paleontological evidence, furthering our understanding of the important dynamics of this region. The Zanzibar channel which separates Zanzibar from mainland Tanzania has an average depth of between 30 and 60 m, with deeper entrances in the north and south of ~120 m (Prendergast et al., 2016). Today, a total of 19 Islands surrounding Unguja, including four of which are settled by humans to various degrees. The four are Chumbe Island, Mnemba Island, Tumbatu Island and Uzi Island. The other 15 islands include, Bawe, Changuu, Chapwani, Daloni, Kwale, Miwi, Murogo Sand Banks, Nyange, Pange, Popo, Pungume, Sume, Tele, Ukombe and Vundwe.

2.3 Atoll formation and dynamics

Atolls and the formation of coral reefs started receiving attention in the early to mid-1800 with some of the earliest theories and investigations published by Charles Darwin (Darwin, 1842). Woodroffe and Biribo (2011) describe the various definitions that have been developed by researchers thus far (Shepard, 1948; Newell and Rigby, 1957; Tayama, 1952; Kuenen, 1933; and Wiens, 1962) to clarify the shared attributes of different types of atolls. Although some differences can be found in the range of definitions (especially related to the lagoon reef) (Goldberg, 2016), for the purpose of this study a conjugation of common aspects from the various definitions in the literature cited above include: a calcareous (or coral) reef surrounding a lagoon or table reef; including some emerged reefs, small sandy cays or reef top islands; separated from other islands.

Atoll reefs are divided into zones, with each zone consisting of a unique aquatic environment. During low tide, the retraction of change over the Reef flat zone creates an intertidal environment unique to the location of the Atoll (Fonseca et al., 2012). The Reef crest and reef flat serves as a type of "brake" for wave energy (wave attenuation), which protects the island from the full force of waves. Woodroffe and Biribo, (2011) describes how waves are instrumental in the architecture of reef islands through wave and reef flat interaction, producing building and corroding interchange. Recent studies have shown that reef islands can form at different stages of sea level rise and fall, and do not depend on a lower sea level for formation (Kench et.al. 2014, 2015, 2018) Figure 2-5 illustrates the different theoretical zones associated with reef islands.

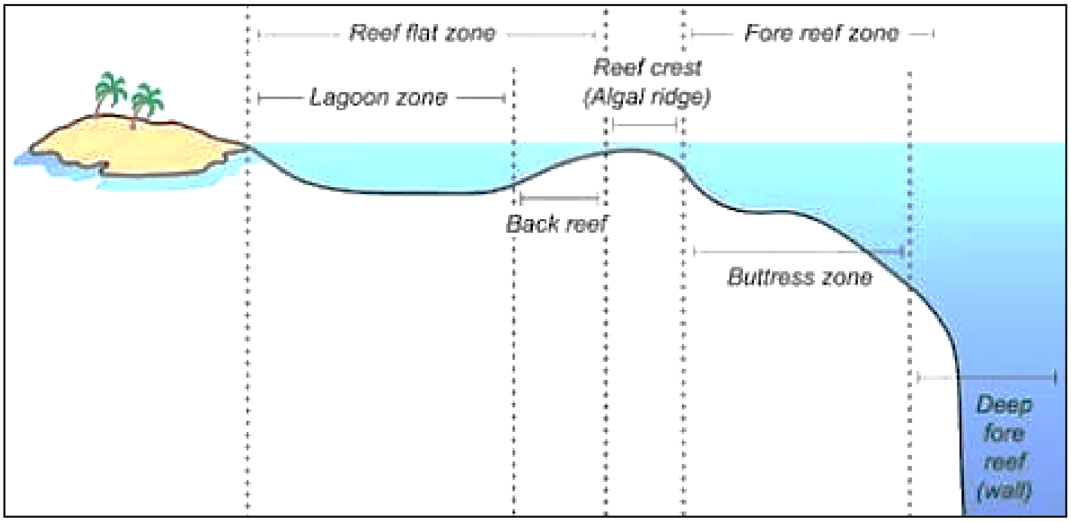


Figure 2-5: Reef structure of a tropical Atoll (US Government, 2018).

Sandy cays and atoll reefs are highly dynamic; shaped by waves and wind, resulting in ever changing sedimentation and vegetation conditions over time (Wingate, 2000; Yamano et al., 2005). Calcareous deposits initially provide poor soil conditions, after which the establishment of salt-spray-tolerant pioneer plant species alter the soil conditions as humus and bird droppings enrich the substrate. Eventually, some cays have phosphate-rich soil conditions attributed to fine scale conditions such as the occurrence of *Pisonia grandis* (or catch-bird-tree) stands that attract large numbers of birds, which further result in high concentrations of bird guano. Studies of low-lying atoll islands provide evidence of poor vegetation diversity, with a few dominant species dominating (Gwynne and Wood (1969); Barnes et al., 2008; Woodroffe and Biribo, 2011). Typical species found on atolls include beach creepers like *Vigna marina* and *Ipomoea pes-caprae*; shrubs and trees like *Suriana maritime*, *Scaevola taccada, Cordia subcordata, Hernandia peltata, Guettarda speciosa* and *Pisonia grandis*. Depending on the size of the island, succession rates and climax patterns, as well as the presence of anthropogenic influences, vegetation in the center of the island could take on various dynamics. Atoll vegetation ranges from mature vegetation and rich soil conditions to sandy soils and stands of planted species (Woodroffe and Biribo, 2011).

Mnemba Island is one of four forested islets around Unguja (Figure 2-6). It is noted that Mnemba, although not located in mid-ocean and once connected to Unguja (Prendergast, 2016), now holds a distinct morphology with all the intricacies of a sandy cay mounted on a sub tidal (shelf or bank) atoll reef (Woodroffe and Biribo, 2011; Goldberg, 2016). Mnemba, for unknown reasons, did not make the list of atolls of the world by Goldberg (2016) recently.

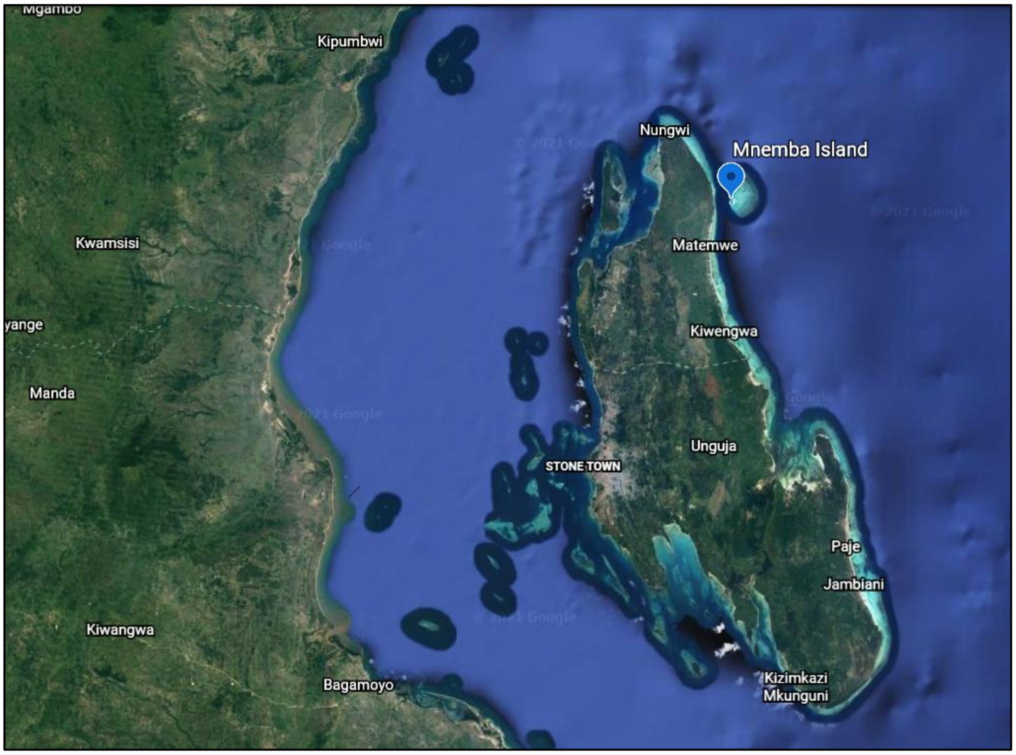


Figure 2-6: Mnemba Island, an Atol off the north-eastern coast Unguja, Zanzibar. (Google Earth, 2021).

2.4 Island vegetation dynamics and surveys

Biogeography of an island is concerned with the island's climate, location, topography, and morphology that give rise to the resulting patterns and trends of species diversity. According to Yu and Lei (2001), equilibrium theory consists of four components: the way species spread between areas; the nature of the relationship between an island's size and requirements for each species; the nature of the connection between islands and mainland; and the turnover of species (introduction and extinction). These factors interact to form a unique habitat and island ecology where vegetation diversity and composition are dynamic (Hnatiuk and Merton, 1979; Losos et al., 2010). Atoll structures are also dynamic by nature (section 2.3), adding complex conditions that can amplify environmental and climate related changes to island vegetation.

Small sandy cays have been studied by island bio geographers (Yu and Lei, 2001; Losos et al., 2010) to understand the way species reach remote locations across the ocean, and to recognise events that lead to extinction of species in isolation. When human activities are included in the dynamics of small islands, disturbance and introduction of non-indigenous species can be expected. Islands that are close to the mainland or other populated islands will likely display fragmented natural vegetation patterns, interspersed with alien vegetation (crop and wind breaking species) (Hnatiuk and Merton, 1979; Wickens, 1979). Seed dispersal is mostly by means of drifting matter washing out onto the beach. Researchers (Hnatiuk and Merton, 1979) suspect that success rates are not expected to be very high with sea dispersal. It is commonly understood that seed eating animals like birds and bats play an important role in dispersing vegetation to and on islands (Wickens, 1979).

Island vegetation distribution and diversity is also significantly influenced by rainfall (Stoddart and Walsh, 1979; Yamano et al., 2005), and plays a major role in fruiting and flowering of plant species. Changes in rainfall affect vegetation conditions, leading to fluctuations in species composition and fruiting patterns on islands. Yamano et al. (2005) refers to *Pemphis* sp*.* as an indicator species that can be found on islands where the annual rainfall exceeds 1000 mm. Various sandy cays thus exhibit different vegetative conditions that are directly linked to the environmental and biogeographical factors surrounding each island. Interestingly, local conditions of atoll islands (as shown in the case of Aldabra, Seychelles) can have an impact on its own climate expression and vegetation (Hnatiuk and Merton, 1979). For example, surface temperature increases in an exposed atoll ring or shallow lagoon can alter the temperature of the island. This heated island phenomenon could either encourage mid-day rain showers or result in evaporation of forest moisture that ultimately leads to dryer conditions compared to larger atolls or islands with no lagoon (Hnatiuk and Merton, 1979).

Low-lying atolls have been described as habitats with a low degree of endemism and fluctuating periods of species colonisation and extinction (Taylor et al., 1979). Understory vegetation is often not well developed due to the underlying sandy substrate as well as the lack of moisture (Hnatiuk and Merton, 1979). Additionally, low densities of herbaceous perennials have been noted while higher ratios of low growing and subsurface buddying perennials can be found on some atolls. Life forms are indicative of climatic and substrate conditions at the time of classification, provided that disturbance is accounted for.

A species that has been studied extensively on low-lying Indian-ocean-islands, and around the world, is the *Casuarina species*. Potgieter et al. (2014) summarises the results of various studies, indicating that *Casuarina* sp*.* are regarded as detrimental to beach and coastal vegetation health. Erosion has been reported as one of the major negative impacts from *Casuarina* sp. plantations in coastal zones. Dense needle beds below *Casuarina* sp*.* trees cause various changes in the ecosystem, including soil condition deterioration and smothering of natural vegetation. Compound effects on entire ecosystems have also been noted, with concern, where terrestrial and marine reptile, bird and mammal species diversity reduces drastically in established *Casuarina* sp*.* stands. De Vos et al. (2019) and other researchers reported that *Casuarina sp*. can change the beach dynamic and interference with the nesting of sea turtles and crocodiles. However, apart from detrimental ecological reports, *Casuarina* sp. is typical of Indo-Pacific beach flora, with *C. equisetifolia* being indigenous to the Seychelles and Madagascar (Wickens, 1979), and possibly native to Pemba (Beentje, 1990). In locations such as Aldabra, large stands of *Casuarina* trees were reported as early as 1815 by European sea captains. On islands where no destruction of old trees had taken place, diameters of the largest specimens can be used to estimate the age of initial introduction (Wickens, 1979; Devaranavadgi et al., 2013).

In Australia the native *Casuarina equisetifolia* trees often form a buffer between the beach zone and the inland forest (Australian Government, 2017). Unlike *C. cunninghamiana*, *C. equisetifolia* does not form pure stands, and allows for a variety of species to colonise the zone. The Department of Environment and Heritage Protection in Australia (2017) reported that the *Casuarina* zone can play a role in signifying beach conditions by looking at the absence or presence of herb land plants in this zone.

Casuarina cunninghamiana are mostly dioecious, with flowering taking place once a season during the most favourable time according to the local climate (Clemson, 1985; Blake and Roff, 1988). Wind pollination between male and female trees is aided by certain insects and birds. A cone matures over twelve months, turns brown and could remain on the tree for up to six more months before dropping (Boland et al., 1996). *Casuarina* as a genus is generally fast growing, but the *C. cunninghamiana* is reported to be a slower grower, with a highly affective root system (Merwin, 1989). Due to its ability to fix atmospheric nitrogen, as well as its capacity to withstand a range of environmental factors such as droughts and waterlogging, the *Casuarina cunninghamiana* is a natural choice for use as wind breaks in tropical and sub-tropical islands (Elfers, 1988). This species is found to tolerate saline conditions; however, it could become chlorotic when exposed to calcareous soils, and is often substituted with *C. glauca* in brackish areas (Weinstein, *1983*). Because of the partnerships with *Frankia genus* bacteria (the actinomycete that fixes nitrogen) and mycorrhizal fungi, *C. cunninghamiana* can grow in soils with a low fertility (Pinyopusarerk et al., 1996). *Frankia genus* is also salt-tolerant and plays a critical role in the establishment of *Casuarina* trees in areas where the soil and water are exposed to salt (Marcar, 1996). Mycorrhizal fungi form symbiotic relationships with the roots of *Casuarina* spp. ensuring phosphorus uptake, which in turn leads to an effective symbiosis between the *Frankia genus* and *Casuarina* roots (Reddell et al., 1986; Khan, 1993).

Inquiry into important regional indigenous coastal forest shrubs and trees revealed that *Sideroxylon, Mimusops, Suregada* and *Pandanus* occur regularly along the coast of East Africa (Pakia, 2005). *Sideroxylon inerme* is a keystone species and provides a critical function in the ecology of coastal vegetation. Cadman et al. (2016) explains that *S. inerme* has the ability to link and support various food chains for both animals and plants. This evergreen milkwood tree does well on the coast and in sandy soil. *Mimusops obtusifolia*, also known as *Mimusops fructicosa* (Kamundi, 2018) among other synonyms, is a species native to east Africa, and of least concern (IUCN). In Southern Africa, *Mimusops caffra* plays a very important role in sand dune reclamation (Grubben, 2008), and although no literature could be found for *M. obtusifolia* in this regard, reasoning would lead us to imagine that the *M. obtusifolia* species could offer similar benefits to eroding sandy cays (Drummond, 1975). One significant difference between the two species is that *M. obtusifolia* is typically found in Coastal scrub, while *M. caffra* is reported as a dunes species (Ekblom, 2002). *Suregada zanzibariensis* is known for its significant role in soil conservation and stability in coastal zones, and can be found growing naturally on sandy soils, salt marshes and coastal forests. Leaves are reported to contain steroids and tannins, as well as alkaloids and flavonoids and serves as valuable browse species. *Pandanus kirkii* is a well-known mangrove species which can often be found on island beach dune crests (Fosberg, 1949; Beeckman et al., 1990). Various *Ficus* spp. are also found in the Swahili center of endemism coastal forests.

Historical vegetation classification of islands in the Indian ocean resulted in various publications about sandy coral cays in the Seychelles, of which Desroches Island (±20 times bigger than Mnemba Island) was surveyed in 2006 (Barnes et al., 2008). Very low species diversity was recorded, with clear distribution dominance by *Scaevola taccada.* Eight additional species were identified and are listed here in order of frequency (Barnes et al., 2008): *Cocos nucifera, Heliotropium foertherianum, Suriana maritima, Guettarda speciosa, Casuarina equisetifolia, Hibiscus tiliaceus, Hernandia nymphaeifolia* and *Ipomoea pes-caprae.* In earlier surveys (Stoddart and Poore, 1970), species such as *Cordia subcordata, Ochrosia oppositifolia* and *Pipturus argenteus* were listed, but were not found in the survey conducted 33 years later, which confirms the dynamic nature of small island vegetation. Barnes et al. (2008) infers that the vegetation structure of Desroches is typical of the islands in the Indian and even Pacific oceans.

The islands in the Kingdom of Tonga, in the Tasmian sea was surveyed using methods such as Braun-Blanquet to estimate cover-abundance, and modified TWINSPAN algorithm (two-way indicator analysis) to identify plant communities (Drake et al., 1996). Six major plant communities were identified on these islands, and species such as *Morinda citrifolia, Clerodendrum inerme, Scaevola sericea, Hernandia nymphaeifolia, Terminalia catappa, Guettarda speciose, Pisonia grandis, Cocos nucifera, Cordia subcordata, Grewia crenata, Pandanus tectorius, Psychotria carnea,* to name a few, were found across the different communities on the islands. Additional species identified included *Pemphis acidula, Cassytha filiformis*, *Ipomoea pes-caprae* and *Ficus obliqua.* Drake et al. (1996) describes various vegetation survey findings of islands across the Indo-Pacific and concludes that each island with its unique substrate and climatic conditions, such as Tonga’s ‘Eua island with its very high elevation and a number of biogeographic elements (such as volcanic core and deep soils), will have a specific floral composition. However, in reviewing the species diversity and composition from different literature sources, a comparable species composition is noticed. In comparison, describing the floral composition and distribution of Mnemba Island’s vegetation is of key concern in the continual conservation of the island’s forest habitat and the ecology of the Aders’ duiker on the island.

2.5 Zanzibar – Climate and Natural Resources

2.5.1 Tropical East Africa

Zanzibar, like Tanzania and the rest of the East African coastline, is subject to monsoon winds that dictate the climate of the area. These monsoonal changes bring both opportunity and sometimes disaster to the people living along this coastline. Two monsoons, the southeast (kusi) monsoon between March and September and the northeast (kaskazi) monsoon from December to March are distinguished. The onset of the southeast monsoon brings the long rains (ending in May), followed by a dry season, and then again a (short) rainy season between October and December. Cyclones are known to occur at certain times during the year. During the southeast monsoon, temperatures can drop to 23˚C and wind speed increase dramatically. North-east monsoon brings about much hotter temperatures followed by a calm to wind-still conditions (Jiddawi and Öhman, 2002; Zavala-Garay et al., 2015).

Climate statistics for Zanzibar is commonly published for tourism purposes, indicating which times are best for visiting the island. AM Online Projects collected weather data from 1982 to 2012 and modelled monthly averages for places across the globe (available on their website at Climate-data.org). For this study, monthly average temperatures and rainfall data for Zanzibar Island and Zanzibar City (Stone Town) are illustrated in Figure 2-7 and Figure 2-8 (Climate-data, 2018). Differences in annual rainfall occur between the western and eastern sides of Unguja (Siex, 2011; Watkiss, 2012). A higher rainfall in the west produces fertile limestone soils with no sediment (Prendergast, 2016). This area is perfectly conditioned for high tropical forests, whereas the drier eastern side of Unguja supports coral-thicket on red sandy soils (Siex, 2011). These differences can be ascribed to prevailing seasonal winds, sea currents and associated climatic conditions (Watkiss, 2012).

The East African Coastal Current (EACC) flows northward along the east coast and influences Zanzibar seasonally (Garcia-Reyes et al., 2009). Garcia-Reyes et al. (2009) reports that this major current does not enter the Zanzibar channel from the South in January but passes by Unguja on the eastern side and flows directly through the Pemba channel and deflects to enter the Zanzibar channel from the North instead. By February and March, the Zanzibar channel is completely cut off from the EACC which causes a significant rise in sea temperature in the channel between Unguja and Tanzania. A stronger EACC current between April and August reverts to funneling through the Zanzibar channel, bringing back cooler conditions. For illustration, the image produced by Garcia-Reyes et al. (2009) is reproduced in Figure 2-9.

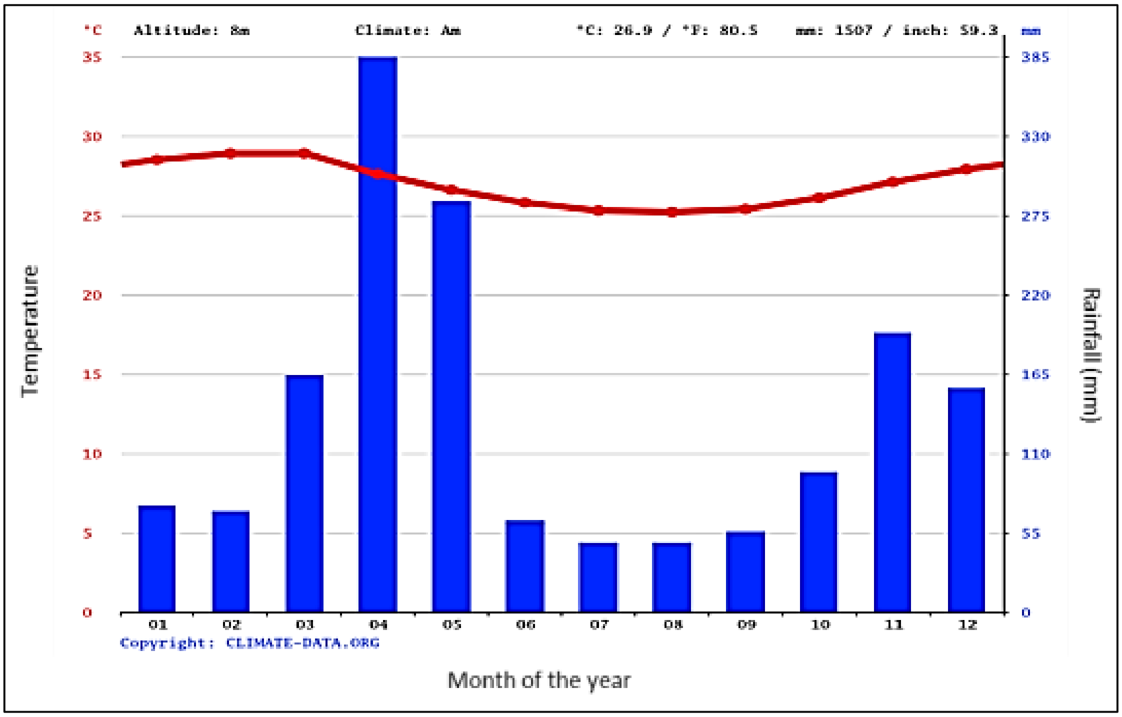


Figure 2-7: Climate Graph – Zanzibar City, including average monthly temperature and rainfall, modelled from data between 1982 and 2012 (Climate-data, 2018).

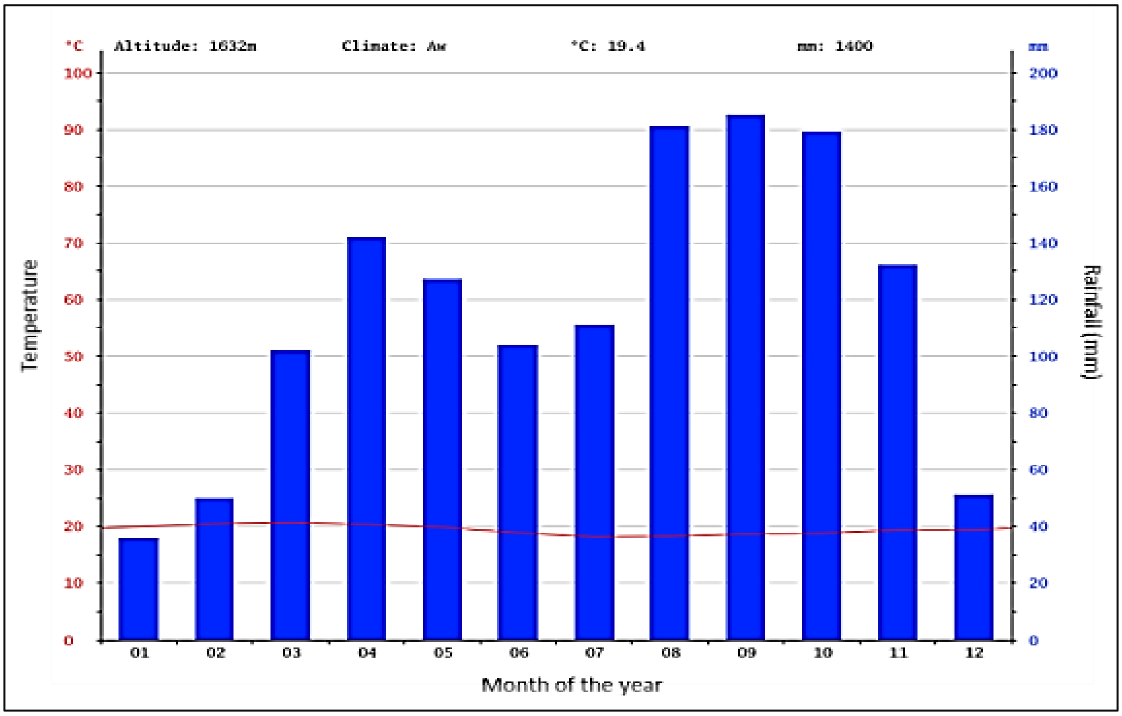


Figure 2-8: Climate Graph – Unguja Island, including average monthly temperature and rainfall, modelled from data between 1982 and 2012 (Climate-data, 2018).

The model developed by Garcia-Reyes et al. (2009) confirms that seasons in Zanzibar are largely centered on the effects of the EACC and monsoon winds. Winds augment the north flowing current, during the kusi monsoon, and reduce (or even reverse) surface current speeds and direction during the kaskazi monsoon (working against the North flowing EACC below the surface layer) (Zavala-Garay et al., 2015). This effect causes climatic differences between the two sides of Unguja (Yu and Lei (2001). Mnemba Atoll, on the east of Unguja, experiences a strong north flowing surface current from March to November, while a weak south flowing surface current is typical during December through February. The north flowing current continues flowing (in the oposing direction to the surface current) below the surface current in December to February (Zavala-Garay et al., 2015; Swanepoel, 2017).

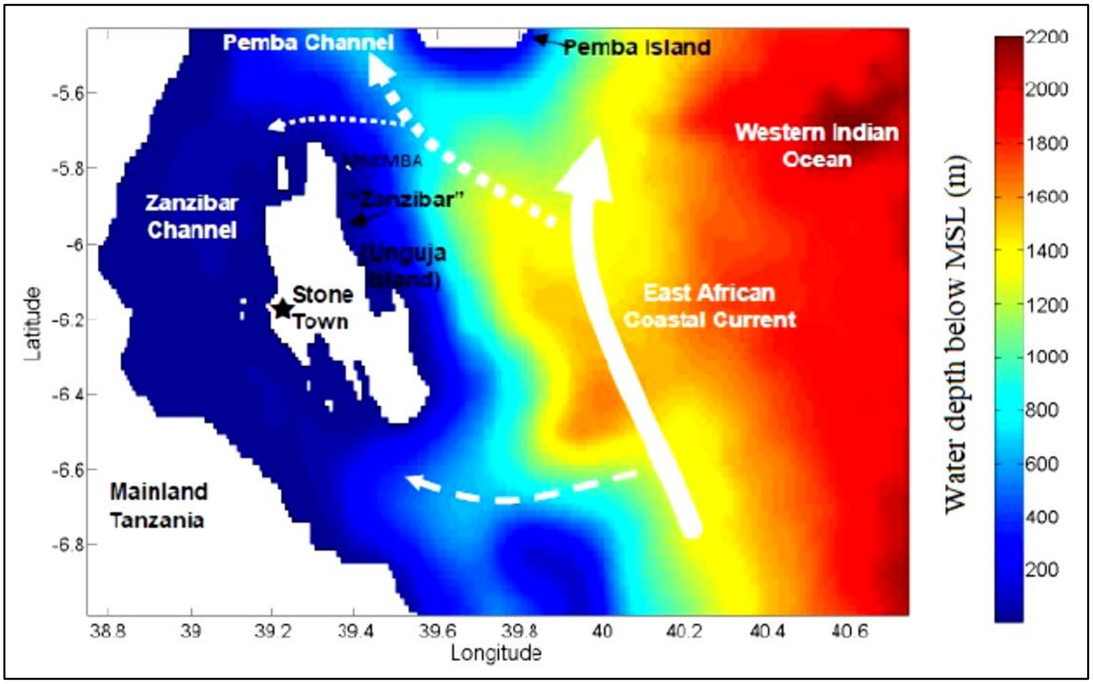


Figure 2-9: The East African Coastal Current Flow directions. Colour coded water depth below Mean Sea Level in meters (Garcia-Reyes et al., 2009).

2.5.2 Climate change in the region

Changes in climate (wind, rainfall and temperature) and resulting impacts have been documented in East Africa for many years (Jarso, 2012). Droughts and floods have proved to have devastating effects on overall economic development in the area. Rapid changes in weather patterns is not only a regional, but a global concern, urging governments and intergovernmental organisations to monitor and prepare for extreme and new weather conditions. The Intergovernmental Panel on Climate Change (IPCC) produces periodic Synthesis Reports, wherein climate monitoring data are summarised, and forecasted changes and impacts are quantified for areas around the globe. These reports are aimed at disseminating recommendations for mitigation and prevention strategies related to extreme climatic events, to governments who take a proactive stance in protecting the environment and security of people and food supplies. According to the Fourth (IPPC, 2007) and Fifth (IPPC, 2014) synthesis reports, island biodiversity is particularly at risk due to climate change. A higher rate of influx of invasive plant species is predicted from the effects of rising temperatures. Coastal erosion from a rise in sea level has also been reported. Managing the environment in a time of drastic climatic change poses new challenges for conservation of small islands due to the direct effect that changes in the weather and sea conditions have on coral reefs and island ecosystems (Ocean Policy Research Foundation, 2014).

Rising sea levels are one of the most visible changes in recent times. The IPCC (2007) suggests that impacts from rising ocean levels will cause loss of land and in some cases entire islands. A rise in sea level is directly linked to ocean and ambient temperature increases. Reports (IPPC, 2007; IPPC, 2014) warn that degraded shores will be impacted more by an increase in sea level and flash flood storms than will intact beaches.

Rising sea levels are not the only concern with increased ocean temperatures. According to the most recent Synthesis Report, the IPCC5 (2014), coral reefs in warm-water zones have already reacted to an increase in temperature. Responses to increased temperatures are detected through surveys of fish, crustacean and coral species composition, as well as through measuring the rates of bleached coral and diminished coral cover. Additionally, acidification of the sea also affects coral growth rate and most likely causes shells of gastropods to thin down (especially shells which contain the same soluble aragonite and calcite as coral does). Increased acidity levels could spell great difficulty for organisms including foraminifera, pteropods, corals, echinoderms, and molluscs (IPCC5, 2014). So far, Synthesis reports indicate a low confidence linked to overall declining of coral growth by climate change, but ignoring site specific evidence of decline in growth, could have dire outcomes for marine ecology in the near future. A decline in fish breeding habitats has positively been linked to climate change (IPCC5, 2014).

It is important to monitor climate related changes in affected areas to anticipate possible impacts on biodiversity and human activities. Shorelines and coral reefs are classified as vulnerable ecosystems. Changes in these ecosystems serve as indicators that climate deviations are underway and could alert us to other possible impacts that might not have been foreseen (Ocean Policy Research Foundation, 2014). Baseline data for vulnerable areas serve to compare current and future conditions and thus aids in measuring the rate and magnitude of change. Without comparable data we might not know to what extent our environments change and thus we will not be able to prepare ourselves for such change. It is also important to understand how human impacts on sensitive marine environments will have a pronounced effect on these vulnerable ecosystems during unpredictable climatic conditions (Ocean Policy Research Foundation, 2014; IPCC5, 2014).

Historically, rainfall in Zanzibar was known for its reliable and wide distribution, with an average of 1 500 to 2 000 mm per annum (Mkumbukwa, 2014; Climate-data, 2018). Personal communication (2016) with residents and recent research reports such as the Global Climate Adaptation Partnership (Watkiss, 2012) indicate that weather patterns are changing in the region. Watakiss et al. (2012) and Swanepoel (2017) provide evidence that Zanzibar has already undergone major changes in climate conditions such as increases in ambient and sea temperature and increases in wind velocity. Mustelin et al. (2009) also indicates that extreme weather has been recorded in the form of stronger winds, floods and unreliable rainfall. Kombo (2010) suggest that continual climate changes can be expected on the East coast of Tanzania. Most coastal communities do not possess the means to protect themselves if ocean levels rise by 1 m from the current MSL (Mean Sea Level). In many locations the 50-year flood line has already expanded. In extreme cases, such as the disappearance of Maziwi Island off the coast of Tanzania near Pangani (Shaghude, 2004), and Fungu la Nyani in Rufiji (Shemsanga et al., 2010) in the 1970s, the warning of changes associated with the rise in ocean levels is very clear (Afrodad, 2011). Other low-lying islands in the region are also threatened by rising sea levels, including large sections of Zanzibar and Mafia Islands (Woodroffe, 2008; Urama and Ozor, 2010).

2.5.3 Fauna and Flora of Zanzibar

Tanzania boasts more than 600 endemic plant species. It has been reported that most of these species are contained in the eastern arc forests and coastal forests, and that more species are yet to be discovered in these areas, especially on the islands of Zanzibar. Nahonyo et al. (2002) points out that both Unguja and Pemba are very important locations within the biodiversity hotspot off the coast of East Africa. Like mainland Tanzania, Zanzibar’s natural resources are under pressure from habitat degradation and species loss.

Natural resources in and around Zanzibar (Unguja) have been severely stressed by human activities (Nahonyo et al., 2002). Based on Prendergast's (2016) simulations and archaeological findings, we know that Zanzibar's natural environment used to resemble the coastal forests of East Africa, before separation by the Zanzibar channel between 10 ka and 15 ka. Unguja's forests and grassy plains once supported larger mammals such as Buffalo (*Syncerus caffer*), Zebra (*Equus quagga*), and Waterbuck (*Kobus ellipsiprymnus*) etc. (Prendergast, 2016). Today the faunal composition of the Island looks very different to the once coastal extension of Tanganyika. Monsoon seasons and winds create unique local conditions for natural and planted vegetation biodiversity. Optimum conditions for the cultivation of spices are well documented and have led to the export trade of black pepper, cloves, cinnamon, and nutmeg, which have altered the face of this once lush, forested island into the patchy landscape of today. Plains on the island are typically grassy with clay soil as substrate (Prendergast, 2016). Deeper soil can be found on the western front of Unguja, compared to the east and a large area in the south where coral karst is the norm. The deeper soil once supported lush coastal forest but with an increase in the human population over the past 200 years these forests have made way for human habitation and agroforestry. In the east the degraded shrubbery dominates the once thicket-forested landscape. The oldest forest areas and only National Park on the island is the Jozani Forest Reserve (Williams et al., 1999) in the east.

Floristically, Zanzibar forms part of the Zanzibar-Inhambane coastal forest mosaic, now called the Swahili coastal forest, sharing a similar composition and structure to forests of similar latitude on the Tanzanian coast (Nahonyo et al, 2002; Kindt et al., 2015; van Breugel et al., 2015a; van Breugel et al., 2015b). Appendix A Illustrates the spatial distribution of vegetation types in East Africa. Zanzibar-Inhambane coastal forest mosaic is known for its assortment of wet and dry forest species, shrubs, and grasses (Prendergast, 2016). It is believed that the propinquity to the mainland permits some distribution of species to the island (Moreau and Pakenham, 1941). On Unguja, the natural forest types range from closed forests with tall vegetation (deep fertile soil areas), to shorter coral bush and thickets. Species richness and evenness differs between forest patches that form part of the evergreen canopy habitat dominated by *Scorodophloeus fishcheri, Cynometra webberi, Milletia stuhlmani, Manilkara sulcata*, and thicket woodland typically characterised by *Acacia zanzibarica, Pteleopsis myrtifolioa, Spirostachys africana*, and *Brachylaena huillensis* (Burgess and Clarke, 2000).

Jozani Forest is the most sizable remaining natural forest allotted to preserving indigenous vegetation and currently has the highest diversity of fauna on Unguja Island. This high faunal diversity is the main reason that most diversity studies and conservation efforts undertaken since the 1800's are centered in this area (Williams et al., 1999). Nahonyo et al. (2002), in a biodiversity study of the Jozani Forest and Chwaka bay National Park, stressed the importance of a zoned approach to ensure protection of different habitats within the reserve. In the survey conducted by Nahonyo et al. (2002), a total of 291 vascular plant species were recorded for the Jozani and Chwaka Bay, of which 28 species were listed as endemic or near endemic. Twenty-one species of vascular plants were found to be threatened or endangered. The forest was divided into ten vegetation 'categories' with distinct species composition and structure, including a marine ecosystem for Chwaka Bay. The other nine vegetation categories include degraded and altered areas, natural vegetation, and original forests i.e., swamp forests, salt marsh grassland, cotton soil grassland, evergreen mixed dry forest, Albizia forests, dry bush land thicket, shrub land, forest plantations and derived vegetation. Exotic species such as *Areca catechu* (Palmae) and *Casuarina equisetifolia* were found to suppress natural vegetation growth.

Although Jozani Forest is the only National Park in Unguja, there are other smaller forested areas of importance. Sumbi (2002) listed threatened forest areas (Appendix B) equating up to 81 100 ha. Jozani Forest, Kiwengwa Forest, Tumbatu Island and Muyuni, each make up around 5 000 ha (collectively spanning 20 500 ha of the threatened forested area). The rest of the threatened areas form part of fragmented public forests, general and public land or community-based forest areas. To combat degradation and fragmentation of forests in Zanzibar, a protected area spatial plan was prepared for Unguja and Pemba by the Wildlife Conservation Society (WCS) (Siex, 2011). A network of linked forests and recommended corridors were identified for habitat conservation and wildlife protection. In total, five existing areas and one proposed area were identified and mapped, with six wildlife corridors linking the forest areas (Siex, 2011) (Appendix B). Siex (2011) claimed that with careful planning and consultation with communities, "best habitat" areas could be linked to form an extended network of natural wildlife sanctuaries and corridors. Siex (2011), however, warned that measures and monitoring had to be implemented immediately to ensure timeous protection of species biodiversity.

Fauna species found in Jozani Forest have escaped increasing anthropogenic pressures by congregating in this area (Williams et al., 1999). By 2002 forty-eight mammal species had been recorded for Unguja. Three bovid species, Suni antelope (*Neotragus moschatus*), Aders' Duiker (*Cephalophus adersi*), Zanzibar Blue Duiker (*Philantomba monticola*) and other animals including bush pigs, the endemic Red Colobus, the Sykes Monkey as well as two squirrel species, three mongoose species, six shrew species and three galagoes (*Galago senegalensis*, *Galagoides zanzibaricus* and *Otolemur garnettii*) frequent the forests of Jozani-Chwaka Bay area.

Smaller mammal species are also abundant and widely distributed across community and private forested areas in Unguja (Nahonyo et al., 2002). The diversity of shrew species is significantly high when compared to Tanzanian coastal forests and there is particular interest in two species of Elephant shrew, *Petrodomus tetradactylus* and *Rhynchocyon petersi adersi*. A total of 20 bat species are found in Unguja of which the Decken's Horse-shoe Bat (*Rhinolophus deckeni*) and the Heart-nose Big eared Bat (*Cardioderma cor*) are threatened.

Nahonyo et al. (2002) reports that 24 animal species are classified as either endangered or threatened, of which fourteen species are from the class Mammalia. Seven of the mammal species on Unguja are endemic or near endemic, such as the Zanzibar and Greater galagos, the Aders'duiker and the Red Colobus. Perhaps the Red Colobus is the most well-known endemic species on Zanzibar, and one of the many species described by and named after Sir John Kirk in the late 1800's. Suni antelope have a wide distribution along the East coast of Africa, including many forested and degraded areas in Zanzibar, whereas the Blue duiker is the most widely distributed duiker in all of Africa. The blue duiker on Zanzibar is a different race to that of Pemba and both differ to the race on the mainland.

By the year 2002 it was believed that five mammalian species were brought onto the island by humans, which are the Javan Civet (*Viverricula indica*), the House rat (*Rattus rattus*), Common rat (*Rattus norvegicus*), the Wild boar (also known as the Black pig – *Sus scrofa*) and the Musk-shrew (*Suncus caeruleus*). So far, no contraindicative effects have been reported with regards to the indigenous African civet having to share space with its introduced counterpart. Conversely, rats have brought diseases with them and became pests.

A total of 44 reptile species are listed for Zanzibar (10 species are threatened) and 27 species of Amphibians of which six are endemic/near endemic (two are locally endemic to

Zanzibar). The Flowerpot snake (*Ramphotyphlops braminus)* has been brought from outside Zanzibar archipelago, but little is known about its subsequent effects on the island's ecology.

Nahonyo et al.'s study (2002) of fish species in the Chwaka Bay area, just over 30 km south of Mnemba Island, produced a total of 157 species, including ~24 that are threatened. He also reported that no endemic fish species were recorded. As marine resources are the lifeblood of the people of Zanzibar, the Department of Environment (Revolutionary Government of Zanzibar, 1999) have produced many documents and proposals with regards to marine species diversity and the optimum use of natural marine resources. A complete list of resident fauna (indigenous, endemic, and introduced) from Unguja can be found in Nahonyo et al. (2002).

Hassan (2011) warns that strain is put on the natural environment from human population expansion. Resulting cultivation and habitat destruction, the incrementing demand for water and waste disposal along with the lack of planned development, will not have good results for Zanzibar's biodiversity. The need for construction of homes and tourist destinations has added extra pressure on the environment for wood (poles), sand and lime. Due to the sensitivity of coral rag vegetation, it would take a very long time to rehabilitate the natural vegetation. Hassan (2011) points out that the only way to prevent further destruction to the natural environment amidst a population and tourism explosion is to tighten the control and management of development. The need for integrated development following sound environmental principles and mitigation is long overdue. Hassan (2011) pleads for the establishment of environmental authorities and updated legislation. Relevant Acts that have been enacted since the 1980s are: The Commission for Lands and Environment Act 1981, The Environmental Management for Sustainable Development Act no.2 of 1992; The Zanzibar Nature Conservation Areas Management Act 1993 and The Forest and Resources Management and Conservation Act no. 10 of 1994 (Hassan, 2011).

2.6 Duiker Phylogeny and Genealogy

In 2011, Groves and Grubb revised the classification of hoofed animal species, which lead to over 450 distinct species being recognised. The family *Bovidae* (order *Cetartiodactyla,* suborder *Ruminantia*) is classified as one of the "even-toed" ruminant families and branches out to various subfamilies, including *Antilopinae* (antelope) and *Cephalophinae* (duiker). *Antilopinae* is further divided into 43 genera and 239 recognized species (Wilson and Reeder, 2005). Two tribes of antelope can be distinguished, i.e., gazelles (*Antilopini*) and dwarf antelope (*Neotragini*). Suni antelope (*Neotragus moshcatus*) are dwarf antelopes that frequent a range of forest habitats up to 2 700 m in altitude, and dry deciduous thickets along the East coast of Africa.

Extensive genetic classification studies have been undertaken to classify the subfamily *Cephalophinae* according to phylogenetic lineages (Janse van Vuuren and Robinson, 2001; Johnston and Anthony, 2012). Three distinct genera are recognised from genetic investigative studies: *Sylvicapra* (specialising in savannah habitat), *Philantoba* (dwarf species), and the diverse forest specialists, *Cephalophus* (Johnston, 2011).

The word duiker stems from the Afrikaans word that means “diver” and was chosen to describe the distinct ducking and diving behaviour of the genus when they flee from an observer or predator (Huffman 2016a). Among the 22 *Cephalophinae* spp. some sister species have not been classified with certainty, but recent studies place all duikers within five broad mitochondrial lineages: Giant duikers, Dwarf duikers, East African Red duikers, West African Red duikers and the Savannah duiker. Table 2-1 summarises the species according to genealogical groupings and indicates the conservation status of each species. A multi-locus species phylogeny study done by Johnston and Anthony (2012), following on from the single mitochondrial work by Jansen van Vuuren and Robinson (2001), was based on four gene sequences (MGF, a stem cell factor; PRKCI, a protein-kinase-CI; SPTBN, the B-spectrin non-erythrocytic and THY, thyrotropin) and results confirmed the monophyly of the genera *Philantomba*. Johnston and Anthony’s (2012) nuclear and mitochondrial combined results resolved that the *Sylvicapra* sp is a sister species to the giant duiker group and validated the monophyly of the West African Red duiker lineage. Support was found for *Cephalophus zebra* to find its position in the genealogy as sister to the clade of Giant duikers.

Although Kingdon (1982, 1997) believes that *Cephalophus adersi* does not associate strongly with the red forest duiker group, Johnson and Anthony (2012) positions *Cephalophus adersi* as sister taxa to the Red duiker group (east and west), supported through the THY and MGF genealogy. Some support is found for the radiation of both *Cephalophus zebra* and *Cephalophus adersi* as part of the earliest radiation in the group (Kingdon 2015). Due to declining populations and pressures, both these species are under pressure. The Zebra duiker has a small distribution area, and the population size is estimated to be less than 10 000.

Table 2-1: All species of the Family *Cephalophinae* listed according to genealogy groups – Clades, Taxonomy and Conservation Status (Jansen van Vuuren and Robinson 2001, Johnston and Anthony 2012, Kingdon 2015).

Genealogy group	**Scientific name**	**Common name**	**IUCN status (v3.1)**
Dwarf red duiker (Sister to East African Red Duikers)	*Cephalophus adersi*	Aders' duiker	Vulnerable
Dwarf duikers	*Philantomba monticola*	Blue duiker	Least Concern
	Philantomba maxwellii	Maxwell's duiker	Least Concern
	Philantomba walteri	Walter's duiker (Colyn, 2010)	Data deficient
East African red duikers	*Cephalophus nigrifrons*	Black-fronted duiker	Least Concern
	Cephalophus harveyi	Harvey's duiker	Least Concern
	Cephalophus rufilatus	Red-flanked duiker	Least Concern
	Cephalophus natalensis	Red forest duiker	Least Concern
	Cephalophus leucogaster	White-bellied duiker	Near threatened
West African red duikers	*Cephalophus ogilbyi*	Ogilby's duiker	Least Concern
	Cephalophus callipygus	Peters's duiker	Least Concern
	Cephalophus niger	Black duiker	Least Concern
	Cephalophus callipygus weynsi	Weyns's duiker	Least Concern
	Cephalophus brookei	Brooke's duiker (Grubb, 2005)	Not assessed
	Cephalophus rubidus	Ruwenzori duiker (Jansen van Vuuren and Robinson, 2001)	Endangered
	Cephalophus crusalbum	White-legged duiker (Groves and Grubb, 2011)	Near threatened
Sister to giant duikers	*Cephalophus zebra*	Zebra duiker	Vulnerable
Giant duikers	*Cephalophus silvicultor*	Yellow-backed duiker	Near threatened
	Cephalophus spadix	Abbott's duiker	Endangered
	Cephalophus dorsalis	Bay duiker	Near threatened
	Cephalophus jentinki	Jentink's duiker	Endangered
Savannah duiker	*Sylvicapra grimmia*	Common duiker	Least Concern

The International Union of Conservation (IUCN) provides a classification of the status of each of these duiker species (where data are available) and makes recommendations about priority conservation actions, evaluating species recovery where plans have been devised. Classification of Species by the IUCN Red List considers nine distinct categories (Appendix

C) based on key factors such as distribution, population size and fragmentation, and population growth trends. Both Zebra duiker and Aders' duiker are listed as Vulnerable and distributed in small areas on the West and East coasts of Africa respectively. The relatively small habitat and continual population decline, as well as the lack of data, contributes to their classification as vulnerable. Aders' duiker is found in three isolated locations along the coast of Kenya and Tanzania (Figure 2-10): Arabuko-Sokoke and Boni-Dodori in Kenya, and the eastern forest reserves in Zanzibar (off the coast of Tanzania). Records of smaller islands' housing populations of Aders' duiker in the past are limited. The case of Tumbatu island (north west of Unguja) has been promoted by Archer and Mwinyi (1995) as reliable. Due to an increase in human population, and subsequently an increase in th epresence of dogs, along with deforestation, no Aders' duiker is found on Tumbatu island anymore.

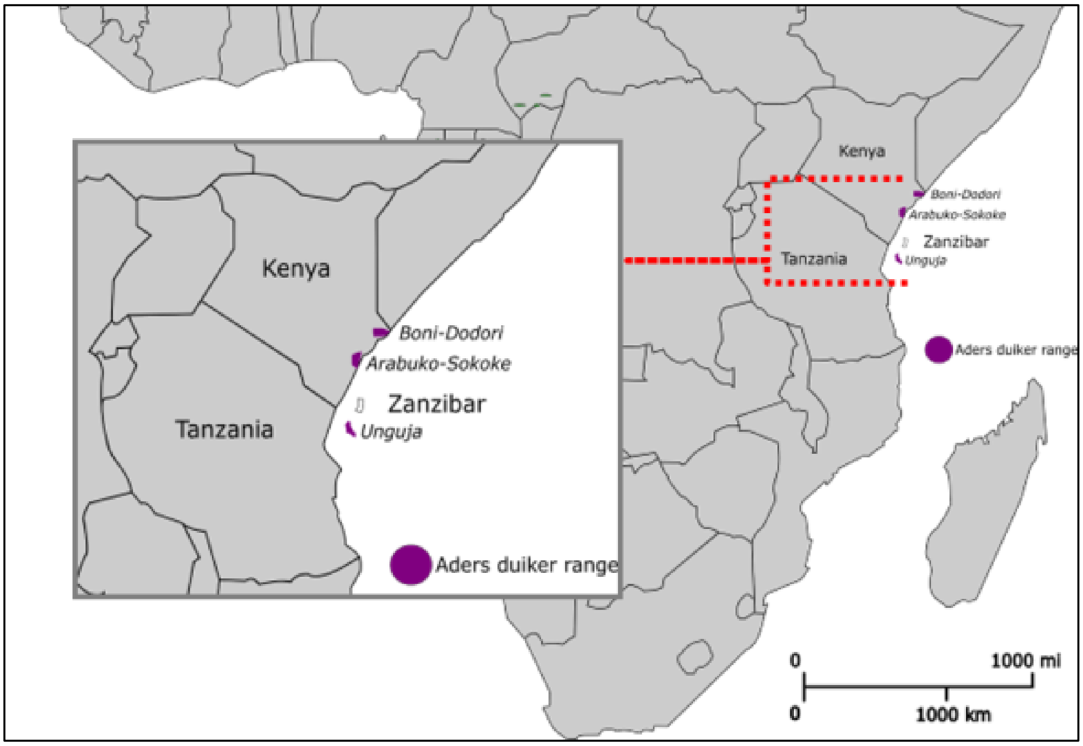


Figure 2-10: Distribution map of Aders'duiker (Cephalophus adersi) on the East Coast of Africa, in Kenya and off Tanzania (Unguja, Zanzibar) (Huffman, 2016a; Wilson, 2001; Finnie, 2008; Andanje et al., 2011a).

2.7 Aders' duiker Conservation History

The first description of the Aders' duiker was made by Oldfield Thomas in 1918 when he reviewed the specimen from Zanzibar which Dr. W.M. Aders' provided to the British Museum

(Thomas, 1918). At the time, speculative associations were made with *Cephalophus wyensi* (Thomas, 1918) as well as *Cephalophus natalensis* and *Cephalophus callipygus.* Aders' duiker in Zanzibar is colloquially known as 'Paa nunga' (kiSwhaili) and according to literature has always had a small distribution, which is now limited to the three areas mentioned in section 2.6. According to Finnie (2002) there used to be other pockets of Aders' duiker around Pemba Island, but none can be found there today. It can be assumed that more islands around Zanzibar once housed isolated populations. Chumbe Island for example, still had a population until the 1980's, which were eventually hunted out (MacPherson et al., 2002). Another reference was made about a once thriving population on Funzi Island, which was decimated by feral dogs (Kingdon, 1997).

2.7.1 Conservation efforts and Species recovery

Aders' duiker has been under official protection in Zanzibar since 1919 (Finnie, 2002). A review of various reports, including but not limited to Archer and Mwinyi (1995), Finnie (2001) and Lanshammar (2007), leads to the supposition that although many efforts have been made to reverse the devastating effects that human encroachment has had on this species and its habitat, no single significant breakthrough has yet been found. Zanzibar is currently losing an estimated 1.2 percent of its forest habitat each year (Siex, 2011) through shrinking forest portions and fragmentation. The protection of Aders' duiker and its habitat has been recognised as a national and international priority, and all efforts to learn more about this antelope should be prioritized (East, 1999).

2.7.2 Zanzibar Government efforts

The Zanzibar Government Forestry website summarizes their official attitude towards conservation of forests and habitats as follows: "*According the Long-Term Forest Resources Management Plan, there are ten Forest Conservation Areas, covering a total area of 36 824 hectares. The Forest Conservation Areas (FCAs) of Zanzibar are endowed with quality ecosystems of high and unique biodiversity values illustrating the natural and cultural heritage of Zanzibar. These Forest Conservation Areas contain unique ecosystems such as coral rag thickets, mangrove areas and mash lands. This particular operation target addresses seven (7) objectives, eleven (11) strategies and a total of fifty-eight (58) activities*" (Department of Forestry and Non-Renewable Resources, 2018a).

Understanding the complexity of conservation of a resource is critically linked to understanding the underlying socio-cultural and socio-economic environment in which the resource is located. The movement towards participation and collaboration between Governmental, International and Local community groups in Zanzibar, in the quest to protect diversity, was documented by Williams et al. (1999).

As a result of the concern for the decline in habitat and duiker populations, Williams and his team performed a detailed survey in 1994/1995 to evaluate the level of population decline and distribution across Unguja. Compared to the previous census in 1983, it was estimated that 65% of the Aders' duiker population had disappeared by 1995. A year before the Williams' census, the government Commission for Natural Resources (Now the Department of Forestry and Non-renewable Resources, or DFNRR) implemented an experiment involving village communities in the conservation of antelope resources through a system of record keeping for hunts that take place in their area of influence. It was a valid attempt to try and gather critical information about harvesting rates and population implications, but unfortunately the system only worked for two years. In a report compiled by Williams et al. (1999), the Village Community-based conservation effort was examined through a series of interviews and inquiries into grass-roots perceptions and causes for the failed program. Many important lessons were documented from this inquiry providing insight into the cultural-specific environment as well as the complex nature of community-government relationships.

One of the main failures of the program was linked to the hunters perceiving hunting registers as a form of government control. Lack of ownership of the antelopes as a resource impacted the motivation of village communities to take responsibility for the protection of local antelope populations. A comparison of the attitudes of people in Williams et al. (1999) report, contrasts strongly to the attitudes of local staff working on Mnemba Island, where the wellbeing of the Aders' duiker population is seen by most staff as their responsibility, and as part of their conservation work on the island. Lack of ownership plays an important role in failed conservation projects, as Williams et al. (1999) found in the mid-1990s. Failure to take part in a project to protect a resource is associated with feelings of not having legal ownership over such resources.

After the failure of the hunting registers, and through further government consultation with village hunters and leaders, an open-closed hunting season was enforced in 1996, following years of inactive enforcement. Hunters reportedly recognized the benefit of allowing antelope populations to breed during a closed season (Williams et al., 1999). Consultation with communities revealed that although hunters were aware of the decline in duiker populations, they did not perceive it as a limited resource, and did not see the need to personally be involved in the conservation of these animals. Non-hunting members of the communities were unaware of the decline in antelope populations and were unfamiliar with ways to implement local enforcement through Village by-laws. Unrealistic expectations with regards to the kind of revenue that could be gained through managing hunting on a local level were also found to be potential sources of failure of local conservation programs (Williams et al., 1999). Small material gains did not motivate communities to enforce hunting logbooks and the accountability of local hunters. It was found that the overall success of community-based conservation was hampered by bureaucracy, inadequate resources, lack of community support and severe pressure on duiker habitats. The DFNRR concluded that at least seven main requirements would have to be met to effectively implement Community-based conservation in Unguja, Zanzibar (Williams et al., 1999):

- Officially permit long-term custodianship promoting a positive perception of local oversight.
- Develop favourable policies to enable communities to enforce the law on a local level.
- Build institutional capacity which compliments policies on national and especially local level.
- Ensure adequate communication channels and coordination between different levels of enforcement.
- Educate and disseminate information about environmental matters and conservation strategies.
- Formal partnerships that strengthen communication between parties.
- Generation of proceeds from hunting activities and the investment of these proceeds into the communities where the funds are generated.

In 1995 the 5 000 ha Jozani Forest and Chwaka Bay Conservation area (JCBCA) was established as a community-based conservation solution, which constituted a combined effort between the Government, CARE-Tanzania (an NGO) and the nine surrounding communities. The aim of the JCBCA was to protect and promote the Jozani Forest reserve and to ensure the conservation of biological diversity in Unguja (Kombo et al., 2013). Unsustainable harvesting of natural resources in and around the park received particular attention and the government ensured that policy and legislation amendments served as legal support for conservation efforts on the ground. Although community involvement was envisaged and practical measures were implemented in the agreement that encouraged villagers to refrain from uncontrolled harvesting of resources, by 2006 Jozani Forest area and park surroundings experienced significant degradation. Consultation with communities revealed shortcomings in the program that caused the failure of the program, these included a lack of understanding the mandate of the community conservation committees; lack of integration of the committees into the communities; and difficulty for members of the community to report illegal harvesting when perpetrators were from among their own communities. Kombo's (2013) analysis of the community-based conservation programs around Jozani and Chwaka Bay also confirmed (Uwemajo, 2013) that micro-financing efforts implement in an attempt to eradicate poverty and relieve pressure on natural resources, did not succeed.

Various efforts to keep the Jozani-Chwaka Bay Conservation Project focused are documented (Hartley and Rijali, 2003), and much work has been done on the ground by various stakeholders to ensure habitat and biodiversity conservation takes priority. The latest development in the protection of the Jozani – Chwaka Bay area is the establishment of a Biosphere Reserve in 2016 (UNESCO, 2016). With the area containing the only national park on the island, the urgency to escalate conservation efforts was recognised on an International level and has been driven as a partnership between local government and UNESCO. The UNESCO website states that 7% of plant species are endangered and 30 bird species are of importance in the 21 274-ha reserve (marine and land area). The establishment of Jozani – Chwaka Bay Biosphere Reserve increases the chances of this critically important conservation and biodiversity hotspot to maintain its role in preserving the natural habitat on the island, especially in favour of species such as the Aders' duiker. The core, buffer and transition area method of conservation has been implemented effectively in many hot spots around the world and allows for sustainable harvesting and community involvement. In addition to the establishment of conservation areas and efforts, the DFNRR also restructured itself in 2017 to ensure effective management and improved monitoring of all conservation and environmental mandates (Department of Forestry and Non-renewable Resources Zanzibar, 2017).

The impact of conservation initiatives is yet to provide a significant turn-around for Aders' duiker numbers in Unguja (Finnie, 2002). In 2003, some positive feedback from communities around Jozani Forest indicated that Aders' duiker populations were suspected to be increasing, but no concrete evidence could be linked to these claims. It is suspected that whatever positive effects on local populations had been forthcoming around Jozani Forest are countered through overharvesting and habitat destruction in other parts of the island, continuing to reduce the overall population. To accelerate efforts to increase the Aders' duiker population, and to test the feasibility of smaller island sanctuaries as a long-term approach to save the species, the DFNRR relocated small groups of Aders' duikers to Chumbe Island in 1998 (Carter 1998; Carter 1999; Daniels et al., 2004; Lanshammar 2007; Mwinyi et al., 2012) and to Mnemba Island in 2005 (Mwinyi, 2006). This proactive approach earned the Government much fulfilment ten years after the introduction onto Mnemba Island, when the need arose to plan a take-off from the duiker offspring that bred from the core population. Before take-off was to be initiated, the DFNRR commissioned a population survey and an in-depth study of the ecology of this Aders' duiker sub-population.

2.7.3 IUCN and species recovery

The most recent assessment of the Aders' duiker's species conservation status by the International Union for Conservation of Nature and Natural Resources (IUCN) was based on the IUCN Species Survival Commission (SSC) Antelope Specialist Group Report from 2017. Aders' duiker was listed as a "Threatened Species" in the 2017 IUCN Red List (IUCN, 2017). The historical IUCN listing of the species indicates two trends: A clear decrease in the overall population of the species and an increase in knowledge of range and distribution. Figure 2-11 illustrates the two sets of information on a timeline. The Specialist report in 2017 predicts a more than 30% reduction in this population by 2027 if pressures and threats in and around the Boni-Dodori forest sections continue unabated. In as much as the discovery of a new population leads to the reclassification of this species as Vulnerable (as opposed to Critically endangered), the Aders' duiker population in Zanzibar is still considered to be locally 'Critically Endangered'. Overall population decline is continuous in all the areas where the antelope species occurs.

Three major threats to Aders' duiker listed in the latest IUCN report are intentional hunting of the species, pressure from small-scale livestock farming, and demands on their habitat from small-scale crop farming. Further threats include a lack of conservation and civil unrest in Boni-Dodori. Feral dogs also pose an immediate risk to populations living near human activity, where packs of dogs move freely through the reserves. Conservation and research direction for the Aders' duiker is to be prioritised around the conditions of the locations where they occur. A lack of management for both Boni and Dodori is raised as a major concern. Given the sheer size of the population in this area makes it the most sustainable gene pool for the species (Amin et al., 2015, IUCN, 2017) and provides an opportunity to implement management programs before the population declines further. Arabuko-Sokoke has its own unique challenges with timber and wood carving demands, as well as hunting. In Zanzibar some headway has been made to secure areas of significance such as Jozani-Chwaka and Kiwengwa-Pongwe for conservation of habitat and duiker populations, but the same pressures with resource extraction and hunting persists on the island, making conservation efforts difficult. Figure 2-11 illustrates the timeline of Aders' duiker population surveys that supported the rating by the IUCN as vulnerable, then critically endangered and again as vulnerable in 2017.

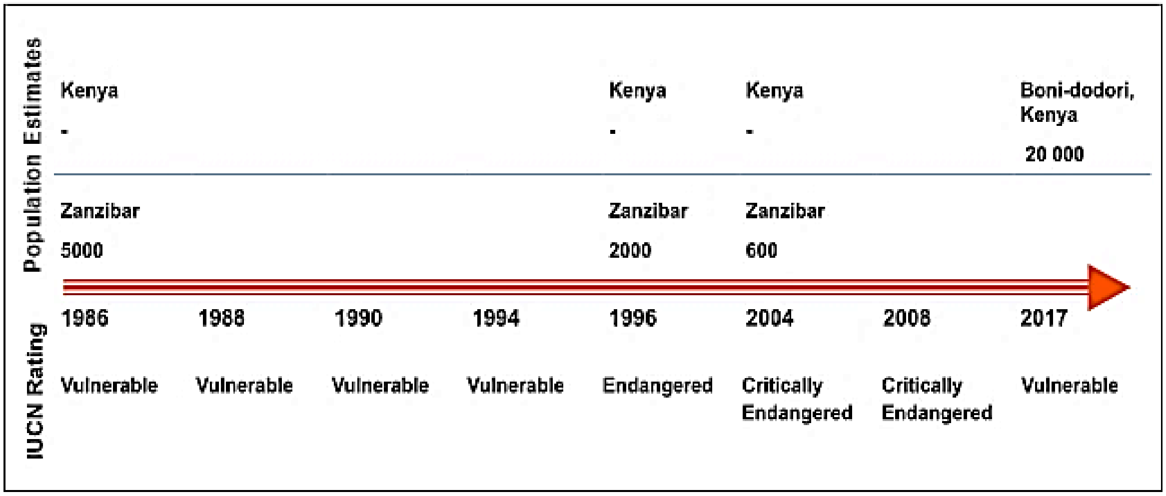


Figure 2-11: Timeline of Aders' duiker population estimates and related IUCN ratings from 1986 to 2017 (IUCN, 2017).

The IUCN recognises the following ongoing conservation actions for Aders' duiker:

- Ongoing in-situ research, monitoring, and planning in the form of an action recovery plan and systematic monitoring of the species conservation status.
- Habitat protection and management for conservation priority sites.
- Education of communities about status and need for protection of the species.

Further conservation requirements identified by the IUCN include:

- Additional protection of habitat.
- Increased management effectiveness of habitat.
- Sustainable resource extraction and control.

- Updating and implementing species recovery program.
- Captive breeding/artificial propagation in both Kenya and Zanzibar.
- Lasting educational programs.
- Increased law enforcement on National levels.
- Increased law enforcement on Local levels.

Important Research needs identified by the IUCN:

- Research into population size, range, and distribution over time.
- Monitoring of populations more closely.
- Monitoring of hunting and the impacts of hunting.

The most comprehensive work to date aimed at steering Aders' duiker conservation forward in Zanzibar, is the Revised Species Recovery Plan compiled by Finnie in 2002. Although somewhat outdated now, the ten action points are still relevant and should be expanded to include new developments in research and conservation initiatives. The action points from the Revised Species Recovery plan are presented in Table 2-2.

The purpose of this review is not to evaluate the Species recovery plan's progress, but to understand the conservation initiatives from 2002 (Finnie, 2002) and how these have influenced current conservation efforts and activities. Point 7 'Captive breeding', and point 10 'Further research', particularly informs the scope of this current study. All behavioural data obtained through this study would contribute to the establishment of a captive breeding program. Detailed behavioural research is a further requirement for effective conservation decision making (Finnie, 2002). The DFNRR continuously endeavours to promote and expand efforts within the ten action points in the Recovery plan. For the period of 2016/2017, the Department of Forestry and Non-Renewable Resources Zanzibar (2018a) states that an Operational Target under the department's mandate of Conservation of Wild Animals, includes the following seven action points, of which four points are aligned with that of the Aders' Duiker Species recovery plan:

- Education of public on wildlife conservation (Finnie, 2002 – Action Point five);
- Managing ecological research (Finnie, 2002 – Action Point ten);
- Managing trophy hunting (Finnie, 2002 – Action Point eight);
- CITES regulation (Finnie, 2002 – Action Point one).

Table 2-2: Action points from the Revised Species Recovery Plan compiled by Finnie in 2002.

	Action point	Description
1	Protection under international law	Aders' duiker has been protected under Zanzibar law since 1919. The appropriate laws must be publicised and enforced.
2	Development of an Effective Protected Areas System	A new, larger conservation area has been identified that will secure part of the Aders' duiker range, in which a strict anti-hunting policy will be enforced.
3	Community Wildlife Management Program	A community wildlife management program commenced in 1995 to reduce antelope hunting to a more sustainable level. This will be continued and expanded.
4	Community Forest Management Program	Community Forest Management Agreements will be in place for the eight villages surrounding Jozani Forest, and the program has been extended to cover most of southern Unguja.
5	Conservation Education	In rural areas, people's awareness of conservation education is relatively high. However, in urban areas, a lot of work is still required.
6	Translocation	In February 2000, five Aders' duikers were translocated to Chumbe Island where a female was already in place. The success of this translocation needs to be monitored before future translocation programs can be investigated.
7	Captive Breeding	An investigation into the feasibility and efficacy of a captive breeding program was undertaken in December 2001.
8	Trophy Hunting	Trophy hunting has been suggested as a conservation tool. However, for such a rare species the likely success of this program must be investigated thoroughly.
9	Monitoring	The status of Aders' duiker needs to be monitored closely so the efficacy of the SRP can be judged and, if necessary, altered.
10	Further Research	A simple research program to understand more about the behavioural and population ecology of Aders' duiker is necessary.

2.7.4 Kenya efforts - Arabuko-Sokoke and Boni-dodori

In the mid 1990's the Aders' duiker on Zanzibar were thought to be the only viable population left, but subsequent sightings reconfirmed that Arabuko-Sokoke and Boni-dodori in Kenya support existing populations (Kingdon, 1982; Kanga, 2002; Neelakantan and Jackson, 2007; Andanje and Wacher, 2004; Schrodt, 2005). Forest duikers and the Arabuko-Sokoke Forest (ASF) have attracted attention among the international conservation community.

Kenyan law aims to protect the Aders' duiker from any form of hunting, through the Wildlife Conservation and Management Chapter 376, yet studies provide evidence of persistent hunting of the species in the Arabuko-Sokoke Forest (Kanga, 2002). Fitzgibbon et.al. (1995) claimed that harvesting of the species in Arabuko-Sokoke Forest used to be sustainable, but Kanga (2003) raised concerns about the devastating effects of the bush meat trade, as well as habitat pressures and encroachment. Along with other threatened and endangered duikers, the Aders' duiker came under the spotlight in the Animal Keepers' Forum in November 2000. The importance of all duiker species as a source of protein is recognised by the American Association of Zookeepers and practical suggestions are made to counter the impact of the bush meat trade on the overall duiker population in Africa (Eaves, 2000). Eaves (2000) firmly recommended breeding programs for all species in need, specifically explaining that creating in-situ programs are vital to the survival of the Aders' duiker.

Kanga (2002) produced a conservation and recovery plan for the ASF. As part of the conservation plan, Kanga, like Eaves (2000), suggested in-situ breeding programs as a means to recover from the rapid population decline. Kanga also suggested further research into the ecology of the species, which he personally pursued. In 2003, Kanga produced the 'Ecological aspects and conservation of Duikers in Arabuko-Sokoke Forest' in which he determined that Aders' duiker occurred at a density of 2.8 duikers per km^2. Eight years before Kanga's recovery plan, Fitzgibbon et.al. (1995) in their survey on subsistence hunting in the ASF, grouped all duiker species together and reported a duiker density of 63 per km2. This combined density for the duikers and the resulting harvesting rate they calculated, potentially skewed the deduction that a species such as the Aders' duiker was existing and harvested at a sustainable density and rate. Reports from other studies provided a more negative picture of the decline of the Aders' duiker population in the area (Kingdon, 1982; Kanga, 2002; Andanje and Wacher, 2004; Neelakantan and Jackson, 2007).

Practical conservation solutions are needed to counter threats and pressures on the Aders' duiker population, which researchers encourage through, amongst others, urgent ecological studies. Schrodt (2005) published a report on habitat characteristics for Aders' duiker in the ASF. Although sample sizes were small, results indicated that dense thicket (low visibility and high food abundance) and limited disturbance by elephant activity were favoured by the Aders' duiker. In describing the challenges and shortcomings of the study, she reiterates the necessity for ecological research to ensure that conservation decisions and methods are in line with empirical behavioural data. A year before Schrodt's (2005) study, the first recorded sighting of an Aders' duiker in Boni-Dodori reserve made headlines in the conservation community, and confirmation of a larger distribution range for this species raised hope for the overall survival of this species (Andanje et al., 2011a). Following the discovery in Boni-Dodori, three camera trap studies elevated Aders' duiker research to the next level in Kenya. In 2006, a digital camera trap pilot study in Arabuko-Sokoke, performed by Neelakantan and Jackson (2007), captured the first image of the species in the wild. Neelekantan and Jackson (2007) produced a summary of the increase in sightings over different investigative studies which can be interpreted as the result of more dedicated research efforts which lead to improved knowledge about the species and its distribution.

Following on from Neelakantan and Jackson's (2007) study, Tollington and Edwards (2008) set up a second camera trap study in six areas of Kenya's coastal forest reserves that had not previously been surveyed, using similar habitat parameters to those used by Schrodt (2005) in ASF a few years prior. These parameters included diversity of plant species, the level of disturbance in test relevés, as well as the overall structure of the vegetation. The mean number of trap days only amounted to 10.3, which yielded no images of Aders' duiker in any of the 6 test sites. Trap rates for other antelope were also low, indicating that the small number of trap days could play a role in the results as concluded by the researchers themselves. Although no favourable results were forthcoming, this study contributed to the larger body of knowledge regarding the need for apt research design and conditions for studying rare and elusive species such as *Cephalophus adersi*.

The most striking efforts in camera trap surveys that revolutionised the knowledge of the species' range and distribution, were published by Andanje et al. (2011a) and Amin et al. (2015), in which comparative studies between Arabuko-Sokoke and Boni-Dodori Forest reserves were undertaken in 2008 and 2010/11 respectively, producing updated population figures. These studies were initiated following the sighting of the Aders' duiker individual in Boni-Dodori in 2004. Andanje et al.'s (2011a) systematic approach to compare the density distribution of the species in both the reserves provided positive sightings of a considerable population of Aders' duiker. Results from the first survey suggest that Boni-Dodori housed a significantly larger population of Aders' duiker than Arabuko-Sokoke, and the largest sub-population of this species in its entire range. The survey confirmed a thriving population in the northern forest reserves of Kenya with an estimated 7.3 Aders' duiker per km^2, in stark contrast with Kanga's 2.8 individuals per km^2 for Arabuko-Sokoke (ASF) in 2003. Amin et at.

(2015) compared trap rates from surveys of the two areas, resulting in an Aders' duiker occupancy rate in Boni-Dodori being up to eight times that of the Arabuko Sokoke Forest.

2.7.5 Chumbe Island efforts

The Chumbe Island Aders' duiker project started in 1995. Collaboration between the Chumbe island conservation officials and the DFNRR served as preparation for a series of relocations to the island. A single female duiker arrived on Chumbe in November 1997 and another in February 1998. The second relocated duiker died after three days on the island. Further investigation into the feasibility of the island as suitable habitat included a food species study, which confirmed that Chumbe's coral rag forest provided suitable and sufficient food for the duikers (Aplin, 1998; Williams et al., 1996). Monitoring of the first relocated duiker proved to be troublesome due to impenetrable vegetation cover and irregular coral substrate. Eventual confirmation of the animal's continual existence served as confirmation to go ahead with more duiker relocations to Chumbe (Carter, 1998). Despite using a temporary holding pen in Jozani Forest to break up the long journey to the island, during the following capture early in 1999, the animal died within two hours of its release in Jozani. An expert in chemical capture was then added to the team (Carter, 1999) and in February 2000, five Aders' duikers (three males and two females) were successfully released onto Chumbe Island (Daniels, 2004).

Four out of the six Chumbe Aders' duikers were fitted with coloured ear tags for identification during monitoring. A monitoring system using trail cameras was implemented to keep track of the population and to study behaviour (MacPherson et al., 2002). Problems with non-significant trappings, heat sensor malfunctions and low yields of duiker images ended the trail camera monitoring (Daniels, 2004). To keep a record of the population on Chumbe Island, a series of surveys were carried out by rangers and teams of hunters and conservation staff over the years following the absence of cameras in the field. A summary of the results (Table 2-3) from drive surveys indicates that there was a period from 2000 to 2003 when the core population seemingly increased. However, territory surveys conducted in 2003 indicated a decline in scent marks on trees after 2001. Post 2003 only adults were sighted during drive surveys and it was assumed from the drive results that some of the initial six Aders' duiker had died (Daniels et al., 2004). Continuous monitoring in the form of ranger sightings is used to trace the population trend and regular sighting data are plotted from 2005 onwards.

Table 2-3: Summary of Aders' duiker drive survey results on Chumbe Island from 2000 to 2012.

Year	Estimated population	Ages	Evaluation of results	Source report
2000	6	Initial adult core population	n/a	Daniels et.al. 2004
2003	3-6	Mixed group of ages	Young animals indicate breeding. Decrease in scent marking indicates possibility of fewer adults being present.	Daniels et.al. 2004
2007	6	Adults only	More individuals are suspected to have passed survey unnoticed. Younger animals could be hiding.	Lanshammar, 2007
2009	4-6	Adults only	Two males identified. Possible recount of two individuals. Suspected population stagnation due to too few females on the island.	Lanshammar, 2009
2012	5	Mostly adults with one juvenile	No sexes identified. Improved methodology, yet habituation to capture method suspected to cause low number of duikers spotted.	Mwinyi et.al. 2012

A report by Mwinyi et al. (2012) summarizes sighting data (not population estimates) from 2005 to 2012 in graph form (Figure 2-12). The data indicates a higher rate of sightings in 2007 and a drastic drop during 2009. This data supports the suspected stagnation of population growth from the 2009 survey results (Lanshammar, 2009). These surveys and reports are rudimentary population estimates. From perusal of the drive survey reports, data were not collected using mark-recapture models, transect line models or results analysed using calculations such as Lincoln-Pearson (or similar) estimates. Nonetheless, from the sightings data collected between 2005 and 2011, and drive surveys results between 2000 and 2012, the population growth appears low (Lanshammar, 2009).

A second attempt to monitor the Chumbe duikers using trail cameras (this time digital cameras as opposed to the initial analogue cameras) was implemented in 2008. Unfortunately, the images failed to produce individual identification which was hoped for (Lanshammer, 2008) and water damage eventually rendered cameras ineffective by 2009 (Mwinyi et.al, 2012). The last drive survey to date was conducted in 2012 and yielded a population estimate of five Aders' duikers, of which one juvenile was identified, indicating that at least one female was part of the population at the time.

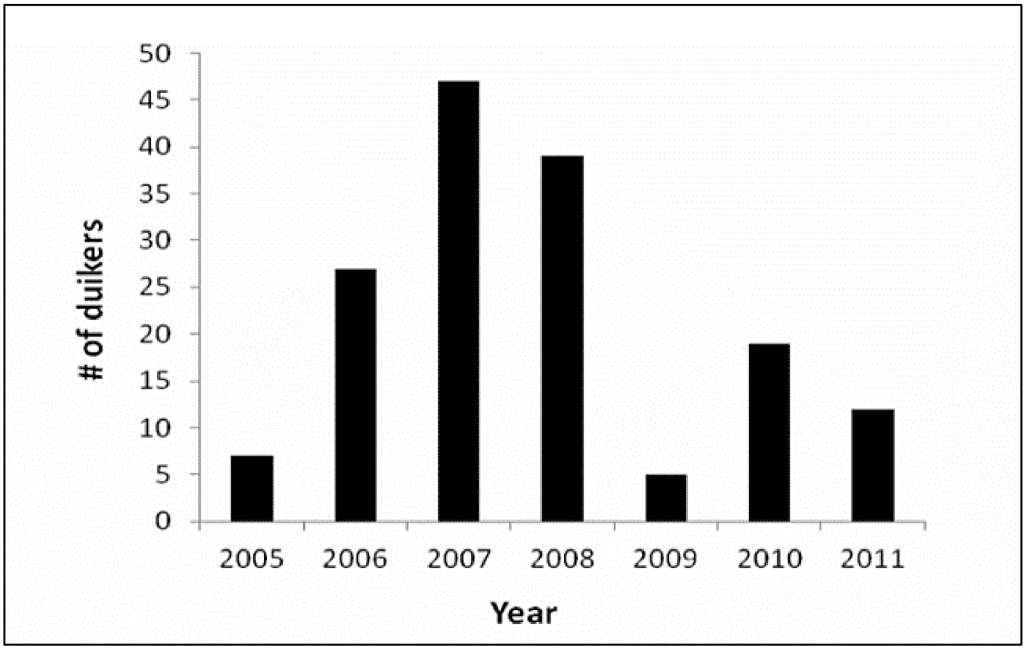


Figure 2-12: Number of sightings of Aders' duiker on Chumbe Island from 2005 to 2011 (Mwinyi et al., 2012).

Survey conditions on Chumbe Island are challenging and although every survey drive is improved, it seems that the drive method is only able to account for a portion of the population. The percentage of this portion is yet to be verified. Various other reasons are proposed for the low counts during these drive surveys, including the habituation of the duikers to the drive methodology – standard behavior includes hiding away and escaping the line, especially in dense forest cover. It is also suggested that breeding has been hampered by an unfavourable sex ratio due to the death of one of the initial females. Overall, results from all the different monitoring efforts are inconclusive and definitive population trends are not clear. A review of drive reports and consultation with the Conservation Manager on Chumbe Island, Ms. Kloiber (2016), revealed that the island's Aders' population is not easy to monitor, and staff are not confident that the rough coral rock habitat supports a large population or is conducive to prolific growth of this species in this type of habitat.

Much is still to be discovered about the ecology and behaviour of this species to successfully plan and execute species recovery programs such as the one on Chumbe Island. Mnemba

Island on the other hand has provided much more favourable conditions for the rare Aders' duiker to breed and thrive in a safe environment.

2.7.6 Mnemba Island efforts

Due to the favourable vegetation and isolated environment, the Department of Forestry and Non-renewable resources have introduced two of the three ungulate species from Unguja onto Mnemba Island as a pilot study. Suni antelope were first introduced in 1993 and the first introduction of *Cephalophus adersi* to the Mnemba cay took place in September 2005 (Mwinyi and Hija, 2008). As reported by Mwinyi (2016), six individuals, consisting of three pairs, were captured in the Mtende/Kitogani area in the South of Unguja, and relocated to Mnemba Island. Only two pregnant females survived this relocation, the other four dying within two weeks of their arrival on the islet. A second relocation took place a year later (September 2006), during which four individuals (two pairs) from the Mtende, Kitogani and Kibuteni forests were successfully transferred to Mnemba Island without any known mortalities during or after the relocation. Both females from the second relocation were pregnant at the time they arrived at Mnemba. It is thus accepted that a core population of eight (four females, two males and two offspring of unknown gender) started the Mnemba Aders' duiker sub-population in 2006. No additional Aders' duiker had been introduced or any offspring removed since the initial introduction until the time when the current study was completed in April 2017. The only antelope removed from the island in the past were Suni.

Suni antelope have found the island to be a breeding mecca and have overpopulated the island to the point of over-browsing (Mwinyi and Hija, 2008). Until the current research project, more than 300 Suni antelope have been removed from the island since introduction and reintroduced back to Unguja. Through personal communication the Head Conservation Officer for AndBeyond (Mr Les Carlisle, 2015) indicated that overpopulation of the island became a concern for the sustainability of the Aders' duiker breeding program, as well as for the island's overall vegetation condition. Ever since the introduction of the Suni antelope and Aders' duiker onto the small Island, no long-term impact studies have been done to evaluate the antelope's utilisation of resources. The short-term studies mentioned before, estimated from density counts in small parts of the island, that a population of 16 Aders' duiker and 67 Suni antelope were present on the island in 2012 (Rivers, 2012).

Mnemba Island forms part of the ‘Oceans without Borders’ Conservation initiative which includes key terrestrial conservation projects on the island. Under this banner, ecological research on the Aders’ duiker has been prioritised and starting in 2018, ongoing research efforts are monitored and scored annually to ensure overall conservation goals are met.

2.8 Aders’ duiker Ecology

A workable amount of quantitative information on the ecology of the Aders’ duiker can be found in literature (Finnie, 2001; Amin et al., 2015). A summary of available information serves as a starting point for further research.

2.8.1 Anatomy and physiology

Contrary to behavioural observations, little information exists regarding the biology and reproduction of Aders’ duiker. In section 2.6, Duiker Phylogeny and Genealogy information for the genus *Cephalophus* explicates how *Cephalophus adersi* is proposed to fall somewhere between the West and East African Red duiker cades. This red forest duiker, first described by Oldfield Thomas in 1918 (Thomas, 1918) and later by Kingdon (1982), Swai (1983), Nowak (1991), Wilson (2001), and MacDonald (2006), bears a signatory white band across the side of the belly from behind the front legs to across the buttocks (Figure 2-14), and white asymmetric mottles from the knees down (especially on the front legs) (Figure 2-13). Slight variations in the shades of their coats exist, ranging from shiny red with a dark brown hew on the back and neck, to lighter shades of red and tan, with a grey hew on the back and neck. A noticeable dark red tuft crowns the head, covering the base of the horns in both male and female specimens. Recorded dimensions for this species from previous studies are summarised in Table 2-4. Inopportunely, these dimensions are not adequately comparable due to unknown measurement methodologies and the lack of age and gender data for the specimens involved.

Aders’ duiker body size can differ greatly between sites (Table 2-4), but due to a lack of specimen age data, these differences cannot be generalised (Wilson, 2001). As with other duiker species, the Aders’ duiker also displays a squat body posture with thin, pointy legs. Typical duiker tail-fanning is present, which Aders’ duiker performs with its short almost hairless tail shaft ending in a bushier white tuft. Extending and arching of the spine is clearly visible when Aders’ duiker walks with vigilance anticipating possible danger and the need to accelerate.

Table 2-4: Summary of existing dimensions for Aders' duiker (m = male; f = female) (Huffman, 2016a).

Source	Adult Weight	Head and Body Length	Shoulder Height	Tail Length	Horn length
Kingdon (1982; 1997)	6.5-12 kg	66-72 cm	30-32 cm	9-12 cm	3 – 6 cm
Wilson (1987)	6-12 kg	66-62 cm	-	9-12 cm	-
Kanga and Mwinyi (1999) (n = 9)	8.7-10.2 kg ♂ 6.8-10.1 kg ♀	63-78 cm	37.5-44.0 cm	6.0-13.8 cm	3.5 – 5.3 cm
Wilson (2001) (n = 4)	8.5-12.4 kg	67.0-73.0 cm	40.0-43.5 cm	10.0-13.1 cm	2.9 – 4.8 cm

Figure 2-14a and Figure 2-12b illustrate the distinct white band (15 cm wide) across the rump, that forms the signature of this duiker species' pelt, as well as the matching white tuft at the end of the fanning tail (Kingdon and Hoffman, 2013; Kingdon, 2015). Another significant feature of the Aders' duiker is the white leg markings on the lower leg. Leg markings (Figure 2-13) are unique and could be used for identification of individuals (Amin et al., 2015).

Figure 2-13: Aders' duiker leg markings - white spots on lower legs and above hoofs.

Figure 2-14: a) Red colour overall, with darker hew on neck and back; b) Signatory white band across back legs and buttocks, merging with lighter under belly; tail ending in white tuft.

No significant body size difference has yet been recorded between female and male individuals (Finnie, 2002), but from preliminary observations on Mnemba Island individuals' horn length in males tend to be longer (Figure 2-15). Orbital glands are found below the eyes in the middle of the cheek, two thirds up from the nose toward the eye socket. A somewhat pronounced snout ends the kite shaped face, balancing out the large ears and conspicuous eyes (Figure 2-15). Ears are pronounced for acute hearing, forming the most important sense for defense (Archer, 1994).

It has been suggested that year-round breeding takes place, but most sightings of pregnant and lactating females have been recorded in the latter half of the year (East, 1988; Huffman, 2016a). Only one pregnancy per female per year is common according to local hunters (Lanshammer, 2007). One young is born at a time and reportedly stays concealed for a couple of weeks after birth (Macdonald, 2006). Local knowledge on Unguja also revealed that once male and female duikers have paired, they do not separate, even during threats and pressures from the environment (Lanshammer, 2007). Competitive and often fatal rutting incidents have been observed between young, single males and older pair-bonded males.

a) b)

Figure 2-15: a) Horns on male Aders' duikers are often longer than on Females (this is a male); b) Kite shaped face of Aders' duiker, with red crown, pronounced snout, large ears and conspicuous eyes (this is a female).

2.8.2 Habitat

The notoriously shy Aders' duiker is known for its affinity to coral rag thicket, coastal woodlands (Wilson, 1987; Archer, 1994) and *Cyanometra* forests in Arabuko-Sokoke, Kenya (Kanga, 2002). Habitat association studies done by Schrodt (2005) revealed that there are significant correlations between the presence of Aders' duiker and good visibility, availability of food, low disturbance by larger species such as elephants, and specific forest types. Supporting evidence by Williams et al. (1996) and Kanga (1999) places the species in secondary forest from time to time. Limitations in defendable data due to logistical constraints in the Arabuko-Sokoke forest (Kanga, 2002) triggered further attempts to find out more about the species’ habitat requirements. Andanje et al. (2011a) for example proposed that suitable habitat stretches exist into Somalia as well as between Boni-Dodori and the Arabuko-Sokoke forest areas. Investigation confirmed that one of the largest surviving populations of Aders’ duiker lives in Boni-Dodori (Amin et al., 2015). Ongoing pressures from civil unrest between Al-Shabaab in Somalia and the Kenyan military creates difficult conditions for research in the area (Bocha, 2017; Kazungu, 2018). If pressures continue, hunting parties from these groups could have additional negative effects on population numbers and conditions of duiker habitat.

2.8.3 **Activity patterns**

Antelope species’ use of habitat and resources are dependent on the quality and diversity of the thickets they frequentPressures on their natural habitat in unprotected forests and reserves could force these small forest frugivores to adjust their foraging behavior, resulting in them venturing beyond the protection of forest cover into man’s ‘domain’. The last pockets of forest where Aders’ duiker occur, surviving deforestation and habitat destruction, provide food and shelter for the time-being. To pre-empt how changes in the protection of these natural areas could affect the way the species interacts with its environment, we need to understand in detail how they use their time and available resources. It is thus important to understand how much time is spent on foraging activities and how foraging is expressed on average in a typical time budget.

Aders’ duiker’s choice of undisturbed habitats adds to the difficulty of observing and recording their full array of behaviour. Due to the history of daytime sightings, the Aders’ duiker is described as mainly diurnal (Willimas et al., 1996; Kingdon, 1997) with peak activity early in the morning and late afternoon, known as a crepuscular activity pattern (Estes, 1991; Kingdon, 1997; Bowman and Plowman, 2002; Amin et al., 2015). The rest of the time the duiker eludes most observation efforts. Finnie (2002) also points out that more activity is noted during cool and wet weather. No comprehensive Ethogram or activity budget has been developed for the species but some observations from four individuals on Mnemba Island was made from which ten behavioural states and one event was identified (Fiske, 2011). Detailed quantitative information about behavioural activities and resource use for the species could not be found in the literature.

A 24-hour study of two other species of captive duikers (*P. monticola* - blue and *S. grimmia* - common) produced a rudimentary Ethogram containing seven main and 28 sub-behavioural categories (Bowman and Plowman, 2002). Although the sample population used were captive, behavioural categories are believed to be closely related to the behaviour of a wild population, since activity patterns analysed for the two species correspond with patterns of duiker observations in the wild (Dubost 1980; Smithers 1983). Main activity categories include: Rest; Maintenance; Ruminate; Travel; Investigate; Groom and Interact. Another example which can be used to inform the development of an Ethogram for the Aders' duiker, is that of *Aepyceros melampus,* or commonly known as the Impala, which was used by Muposhi et.al. (2013) to quantify the activity budget of the species in a natural environment. In their study, Muposhi et al. (2013) included nine categories in the Ethogram: Rest; Forage; Excrete; Ruminate; Move; Vigilant; Groom; Flight; and Other. Depending on the purpose of the investigation, ethograms are either detailed or broad. Bowman and Plowman (2002) grouped all foraging, drinking and excreting behaviour together as maintenance, whereas Muposhi et al. (2013) separated Foraging and Excretion. In the former, "Travel" included all forms of movement, while the latter study distinguished between Moving and Fleeing. When choosing the level of detail for an Ethogram, it is thus imperative to clearly formulate the questions one wishes to address with the time-activity data that is collected (Braude et al., 2002).

Due to the lack of behaviour research for the Aders' duiker, this study set out to collect as much detail as possible. From a wider scope of behavioural repertoires, future focused research questions can be prioritised. Once an Ethogram has been developed, it can be used for management of wild populations of Aders', as well as in captive conditions (Guerrero, 2000; Altmann, 1974; Ransom and Cade, 2009).

2.8.4 **Diet and foraging**

Foraging observations indicate that Aders' duiker is a frugivorous browser that consumes fruits and buds, sprouts, and seeds, as well as dicotyledonous leaves (Swai, 1983). These food items are often obtained by following animals such as monkeys and birds that drop items from the canopy to the forest floor. Kingdon (1997) and Wilson (2001) in turn found that Aders' duiker depends on flowers and berries that fall to the ground, sniffing out these items at dawn and dusk when individuals, pairs or family groups actively feed. Kingdon (1997) and Wilson (2001) listed food species consumed by Aders' duiker as *Euclea schimperi* (guarri bush), *Polyspheria* spp*., Diospyros. consolataei* (Ebony tree)*, Cassine aethiopica* (chasmanthe or cobra lily) and *Canthium* spp*.* (turkey berry bush). Food species found in stomach content and faecal material included *Diospryros consolatae* (fruit), *Tetracella littoralis*, *Mystroxylon ethipicum*, and *Ficus sur.* Aders' duikers are particularly interested in fresh growth such as buds and sprouts, allowing them to purportedly meet their daily moisture requirements through diet alone (Kingdon, 1997). Additional reports all claim that these duikers don't really drink to maintain moisture levels in their diet (Fitzsimons, 1920; Blarney and Jackson, 1956; Kingdon, 1982; Smithers, 1983; Hart, 2001).

The importance of producing a list of selected food plants is critical to aid in the identification of suitable relocation sites for conservation and breeding programs. Aplin (1998) investigated the suitability of Chumbe Island as Aders' duiker habitat and consulted with local hunters from Jozani forest. The list of plant species identified on Chumbe Island supported the notion that Chumbe would provide adequate food resources for an in-situ conservation initiative. The list of species (14) identified were: *Ancylobotrys petersiana, Canavalia rosea, Cassia occidentalis, Clerodendrum* spp*., Diospyros consolatae, Fluggea virosa, Jasminum fluminense, Mystroxylon aethiopicum, Phymatodes scalopendria, Polysphaeria multiflora, Pyrostria bibracteata, Sideroxylon inerme, Suregada zanzibariensis,* and *Uvariodendron kirkii.* A preliminary food species list from two short studies identified 11 plant species for Suni and Aders' duiker on Mnemba Island (Fiske, 2011; Rivers, 2012): *Bouganivillea glabra, Cassytha filifomis, Eugenia capensis, Ficus lutea, Grewia glandulosa, Guettarda speciosa, Mimusops obtusifolia, Pandanus kirkii, Suregada zanzibariensis, Tetraceara boivaniana, and Todalia asiatica.* Only four of the plant species (*Diospyros consolatae, Mystroxylon aethiopicum, Polysphaeria species* and *Suregada zanzibariensis*) overlap with the cited literature.

Along with the need to understand which food species are consumed, food type selection in context with foraging activity patterns provides insight into a species' metabolic requirements (Dubost, 1980; Barrett, 2009; Barrett et al., 2010). To guide ecologists in designing empirical energy studies for a species, behavioural data are collected to provide supporting evidence for a particular foraging strategy that best describes the ungulate: time minimizers, energy intake maximizers and net energy maximizers (Kohli et al., 2014). Studies on certain monomorphic ungulates found that no significant difference in foraging strategies between males and females exist (Ruckstuhl and Neuhaus, 2009). Considering the high variability of food items in the duiker diet (fruit, flowers, browse, fungi, insects) and extreme changes in weather conditions on Mnemba Island, it is possible that the combination of available food and duiker biological cycles could lead to males and females optimizing their foraging through one of the strategies described above (Bergman et al., 2001). For example, females could employ a time minimizing strategy by increasing feeding time during lactation when energy requirements are high, and male duikers could minimize time and maximize energy intake during rutting (Shipley et al., 1994). It is expected that females spend less time socializing or resting at this time (Bergman et al., 2001). However, with duiker breeding taking place throughout the year, a general sample of female activity budget across twelve months might not sufficiently demonstrate individual differences. If seasonal and gender differences are detected in an activity budget, one could begin to develop a hypothesis for the species. Additional information from social behaviour could also help form an understanding of the species' foraging strategies, as Ruckstuhl (1999) has noted that social cohesion plays a significant role in foraging rates and activity budgets, than reproduction activities and requirements do.

2.8.5 Social structure

Duikers and other small antelope are often territorial, occurring in pairs, small family groups or roaming solitary (Newing, 1994). Short term studies on Mnemba Island revealed different group combinations including pairs, adults socialising with sub adults, and small groups of three Aders' duikers foraging together (Huffman, 2016a; Fiske, 2011). Fiske (2011) observed grooming of sub-adult offspring by the mother, as well as mutual grooming between males and females, especially through licking and facial rubbing.

2.8.6 Range, sympatry and resource competition

Previous studies and sightings have yielded limited information on the interaction of *C. adersi* with its environment. Initial thoughts were that the species holds a similar home range to that of the *C. natalensis* (the Natal red duiker), which ranges between 2 and 15 ha (Hoffmann and Bowland, 2013; Amin et al., 2015). A larger duiker species such as the near-threatened *C. leucogaster* (White-bellied duiker) extends its home range to 63 ha (Hart, 2013a). Two of the dwarf duiker species, *Cephalophus maxwelli* and *Philantomba monticola* (at half the body size of the Aders' duiker) traverse home ranges of 5 – 6 ha and 2.5 – 4 ha respectively (Dubost, 1983; Newing, 1994; Hoffmann and Bowland, 2013). Differences in home range size are widely accepted to be related with body size (Seton, 1909; Harestad and Bunnell, 1979). A perfect linear relationship between home range and individual and group size has not yet been described, but it has been reported that frugivores in general utilise larger areas for foraging compared to folivores (leaf eaters) (Downs et al., 2012). A recent study of different grazers and browsers across their habitat ranges claimed a weak correlation between body size and home range (Kiffner and Lee, 2019). Quality of habitat is a more relevant indication of the area size that an ungulate would cover during foraging activities (Harestad and Bunnell, 1997; Newing, 1994; Amin et al., 2015; Kiffner and Lee, 2019).

A survey done by Williams et al. (1996), estimated the density of Aders' duikers in the forest habitat on Unguja Island as 4.5 individuals per 100 ha, also expressed as 22 ha/duiker. Although William et al.'s (1996) results did not serve to measure the average home range size, but population density, when converted to ha/individual it correlated closely with the estimated range of 19.2 ha per individual according to the body-weight-range theory (Amin et.al. 2015). In Arabuko-Sokoke forest (ASF) Kenya, 2.8 duikers have been surveyed per 100 ha (Kanga, 2003), while in the north of Kenya in Boni-Dodori forest (BDF) density results indicate 7.3 Aders' duiker per 100 ha (Amin et al., 2015). Given the antelope's habit of wandering into secondary thickets when it is safe to do so (Kanga, 1999), their traversing range could be affected by vegetation structure and habitat conditions. In addition to resource condition and body size, territoriality also influences the sizes of species and individual ranges.

Duikers are territorial antelope that mark their territories and home ranges with faecal piles (middens) and by rubbing secretions from facial glands onto parts of the vegetation (Swai, 1983). Kingdon (1982) supports the notion that the Aders' duiker is positively territorial. According to Wilson (2001), the less pronounced facial glands imply that territorial marking behaviour for this duiker species is of reduced significance. However, local hunters and trackers on Unguja described scent marking as an important part of communication between multiple individuals when demarcating territorial ranges (Lanshammar, 2007). These hunters reported personal sightings of violent clashes by male duikers, in what they believe are bouts to protect the monogamous relationships with their females (Lanshammar, 2007). Several individuals scent marking the same tree could be interpreted as covering the scent of another individual when competing for the same area, or as a threat to the core inhabitant's relationship with his female. Similar findings have been recorded for other territorial antelope species (Brashares and Arcese, 1999). A study of territorial marking by male Oribis (*Ourebia ourebi*) in the Serengeti found that marking was mainly driven by intra-sexual competition in males as an attempt to maintain territorial boundaries. The rate of such marking strongly corresponded to the number of other males adjacent to the focal male’s territory and was not affected by territory size or number of available females (Brashares and Arcese 1999). An increase in male presence would thus increase the rate of territorial marking and other territorial behaviour in antelope species who share the Oribi’s territorial repertoire. It can also be expected that a dominant or resident male, in the case of overlapping territories, would demonstrate increased marking rates when the population increases, as was found among Maxwell’s duiker males (Rails, 1969).

Many researchers have been intrigued by interspecific competition among sympatric forest antelope species. Across Western, Central and Eastern Africa, a variety of duiker species can be found in sympatry with each other, where recordings of up to seven species have been made in the same area, consuming similar vegetation types. These forest specialists along with other antelope species (such as the Suni, *Neotragus moschatus*) are masters at niche development and separation through differences in body size and activity patterns (Kraresh et al., 1995; Newing, 2001; Prins et al., 2006; Van Vliet and Nasi, 2008; Nakashima et al., 2013). Advancement in trail camera technology has made it possible to capture information on the relationship between sympatric antelope species over time. For example, in the Boni-Dodori forests in Kenya, imagery provided evidence that Aders’ duiker shared its habitat with Suni antelope, Harvey’s duiker and Blue duiker (Andanje et al., 2011a; Amin et al., 2015). Amin et al. (2015) suggested that competition for resources between forest antelope species potentially have effects on Aders’ duiker in areas where high levels of sympatry together with comparable activity patterns between species occur. A study in the Udzungwa Mountains in Tanzania indicated that sympatry existed between small forest antelope species, but instead of Aders’ duiker, the Abbott’s duiker (*Cephalophus spadix*) frequented these habitats (Bowkett et al., 2014). An understanding of how these antelope species coexist and share resources sheds light on the intricate dynamic of resource competition. More detailed research is needed to fully comprehend the degree of resource sharing among forest antelope species. Due to habitat fragmentation and pressures from human activities, certain species could be forced to coexist as they retreat into the last viable forested areas.

Amin et al. (2015) found that in the Kenyan coastal forests, Suni were particularly more nocturnal than the Aders’ duiker. The results were more pronounced in the ASF, compared to the BDF study areas. Significant associations between the trapping rates of sympatric antelope species in the study in Kenya suggested that competition for resources took place, but the authors did not rule out an unknown form of niche separation (Amin et al., 2015). To date, no direct interspecies aggression has been recorded between Aders' duiker and Suni antelope, supporting the notion that competition takes place on a non-confrontational (ecological) level (Wilson, 2001; Huffman 2016c). The Blue duiker and Suni antelope also seem to be thriving in comparable conditions and niches where their ranges overlap. Both species are mainly nocturnal and share a section of their range across East Africa, including the island of Zanzibar (East, 1988).

Suni are exceptionally territorial with both genders protecting their home ranges (Huffman, 2016c) - male territory sizes measure 3 ha in size on average. Audible and olfactory communication between Sunis is typically observed (Estes, 1991). Although shy and small, Suni ecology has been described comprehensively due to the species being widely spread and a popular antelope for captivity (IUCN, 2008b). Males are known to select more than one female, but no record of more than two has been recorded (Kingdon, 1997; Estes, 1991). Female offspring remain with the parents for longer compared to male offspring, possibly due to male offspring exhibiting stronger territoriality. Along with small ranges and strong territoriality, Suni antelope will forage in the same area for extended periods of time (Heinichen, 1972). Existing information about the ecology of the Suni antelope provided context when the current study of Aders' duiker on Mnemba Island was designed. Observations of sympatry between the antelope species on Mnemba Island provide information that can be used to design further studies in other forest habitats in Tanzania and Kenya. The context of sympatry between the two species is known from a few studies that focused on either one or both species.

As is believed about Aders' duiker, the Suni's diet provides for most of their daily moisture requirements. Very little evidence exists to suggest that grass forms part of the Suni's regular diet. However, compared to Aders' duiker, Sunis frequent a wider variety of habitats (Lawson, 1989) resulting in them having a more catholic diet. Prins et al. (2006) suggested, and Rivers (2012) confirmed that the diet of these two antelope species overlap due to similarities in foraging patterns and dietary requirements. Both ruminants have similar foraging preferences, browsing in coral rag forests, consuming foliage (leaves, buds and sprouts), herbs, seeds, fruit, pods, shoots and fungi. In Kenya's natural forests, Suni were found to forage during the day and night, while Aders' duiker only foraged in the day (Amin et al., 2015). The fact that Suni included a nocturnal feeding regime as opposed to the duiker's diurnal feeding patterns, could play a role in reducing direct competition for food resources between the species. However, both species showed crepuscular peaks, which would put them directly in each other's feeding paths at these times of the day (Amin et al., 2015).

Suni antelope are about half the size of Aders' duiker, weighing 4 to 6 kg compared to the duiker's 6 to 12 kg. Newing (2001) found that the size of food selected by different frugivorous antelopes (particularly that of fruits and seeds), was linked to body size, adding to the intricacies of niche separation of these sympatric species. A density map from East (1988) shows the distribution of Blue duiker, Aders' duiker and Suni antelope across Unguja Island in the Zanzibar Archipelago (Figure 2-16). Due to habitat constraints and focused conservation efforts, the areas of protection for all three antelope species in Zanzibar overlap greatly.

When Aders' duiker was introduced to Mnemba Island in 2005, Suni antelope had already been thriving in the small forest reserve. One of the main questions that have been raised about Mnemba's introduced antelope population is the extent to which Suni and Aders' duiker compete for the same fallen fruits, flowers and leaves (Rivers 2012; Fiske 2011).

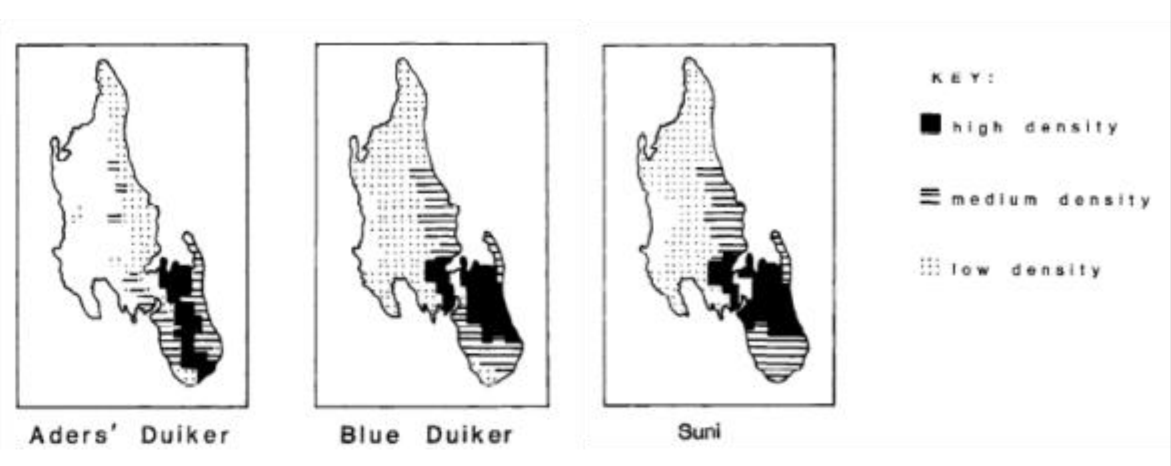


Figure 2-16: Blue duiker, Aders' duiker, and Suni Antelope distribution on Unguja, Zanzibar (East, 1988).

Observations of the interactions between Suni and Aders' duiker have been limited to two short studies on Mnemba Island. Rivers (2012) recorded a range of behavioural interactions when Suni and Aders' duikers were near one another, yet no aggressive behaviour was noted during these encounters. Unlike suggested findings based on the comprehensive trap rate study by Amin et al. (2015), Rivers (2012) proposed that even though there were dietary overlaps between the two species, no major competition for habitat was apparent. However, Rivers (2012) envisaged that if Suni population numbers increase to the point where the duiker species faced severe competition for resources, rivalry could manifest. Competition is a complex phenomenon and unless the ecology of each species is understood, it is difficult to make assumptions based on single facetted studies. Among other antelope species, it has been found that competition for resources is tolerated if a certain benefit is derived from communal feeding. For example, by sharing time and space during foraging, increased safety and security for the more vulnerable species could outweigh the loss of food resources (Sullivan, 1984; Giraldeau and Caraco, 2000). Fiske (2011) reported that Suni and Aders' duiker responded to alarm calls from each other. The likelihood that the presence of the one species is beneficial to the other species in evading danger is a reasonable concept.

To increase our knowledge of the lesser-known Aders' duiker, it is necessary to understand the species' intricate movements and activities in and around its habitat, i.e., the spatial ecology of the species.

2.9 Conclusion

Detailed information pertaining to the ecology of *Cephalophus adersi* is critical to save the species from extinction (Ochieng et al., 2017; Andanje et al., 2011a). The lack of ecological data and using arbitrary information for conservation decisions causes slow and unmeasurable progress in conservation efforts (Schrodt, 2005). Studies that look at detailed information about food selection and seasonal activity changes are lacking as a foundation to understanding niche habitat selection by Aders' duiker (Fiske, 2011).

The Mnemba Island Aders' duiker program (2005) provides unique opportunities for conservation research. Although the island has proven to be a successful small antelope sanctuary, challenges from over population and resource degradation have created the need for a scientific management plan. The current study affords the opportunity to add to the body of knowledge for the species and provides relevant data for managing the sub-population on the island.

CHAPTER 3

RESEARCH SITE

The previous chapter established the plight of the Aders' duiker and their conservation status as vulnerable. Should conservation efforts fail to increase the population and secure habitat locations on the island of Zanzibar, the potential for local extinction in the near future seems probable. The focus of this study is on Mnemba Island, a small atoll off the north-east coast of Unguja, Zanzibar. Although Mnemba Island is marketed as one of the most exclusive tourist getaways in the world, this little islet is by no means isolated from the impacts of surrounding anthropological pressures. No comprehensive flora and terrestrial fauna diversity baseline studies have been done for the island and little information exists with regards to the terrestrial ecology. This chapter aims to provide an overview of selected research findings from available literature that describes the atoll's location within the region, highlighting its physical aspects and summarizing onsite information collected during the current study.

Detailed climate data for the north eastern side of Unguja was not available. Mnemba Island's size and location in relation to Unguja, and the ocean currents and trade winds that affect the area, indicate that the island most likely experiences unique climatic conditions, dissimilar to that of Unguja (Stone Town Airport). It was anticipated that Mnemba's weather would differ from that of Unguja resulting in a decision to erect an impromptu weather station on the atoll for the duration of the current study. The purpose of this weather station was to collect the first microclimate baseline data for this island, and to informally compare collected data for the 2016 calendar year with that of Stone Town's weather data for the same year. Any inferences about weather effects on the vegetation of the island were thus made with local weather patterns collected from the weather station as reference, as opposed to using irrelevant data from the west coast of Zanzibar.

3.1 Location, Morphology and Biogeography

Mnemba Island is a sandy cay of 18 ha including a vegetation area of 11 ha. The island forms part of Mnemba atoll, a coral reef complex with a shallow lagoon – refer to section 2.3 for more details about atoll morphology – and located 2.7 km off the north-eastern shore of Zanzibar (S 05 49.219, E 039 22.959’) (Figure 3-1). The closest villages, Muyuni, Kijini and Matemwe, are on Unguja, across the 75 m deep channel from Mnemba (Swanepoel, 2017). The island has a triangular shape and is positioned on the western edge of the atoll reef, at about 8 o’clock (with north being 12 o’clock). The entire atoll area is approximately 150 ha in size, with the distance from the northern reef to southern reef edge measuring 7 km along a very shallow reef flat (Revolutionary Government of Zanzibar, 2005; Swanepoel, 2017). The fringing coral reef complex has a circumference of about 3 km. In section 2.3 it was explained why Mnemba’s reef complex can be classified as a sub-tidal shelf-atoll.

Figure 3-1: Mnemba Island - located 2.7 km off the north-eastern coast of Unguja, Zanzibar (Expert Africa, 2018).

Mnemba’s tidal range was measured as 4m between low and high tides, while at low tide the lagoon (or reef flat) is completely drained (Swanepoel, 2017). Figure 3-2 shows an aerial view of the atoll from a western direction, looking toward the east. The shallow reef flat is clearly visible, as well as the semi-submerged reef crest beyond it along the eastern edge of the atoll.

Figure 3-2: Mnemba Atoll – Aerial view, looking east (St John and St John, 2017).

The reef is composed of hard corals with a high diversity of reef habitats created by the different depths at which the coral is exposed. When diving along the reef face, the different structures can be observed as terraces, shelves and inclines. A high diversity of coral species has been recorded on the reef, hence Mnemba Atoll's reputation for having the highest coral diversity of any reef in Northern Unguja (Revolutionary Government of Zanzibar, 2005). Species from *Favites*, *Pocillopora*, *Porites*, *Stylophora* and *Acropora* are found on the outer slopes of the reef. The Department of Fisheries and Marine Resources (Revolutionary Government of Zanzibar, 2005) recorded 36 genera of hard coral from a survey done around the island. On the northern side of the cay, a smaller reef of 0.25 km^2 (locally called the house reef) is situated close to the shore and only reaches 7 m in total depth (Grellman, 2018). The reef flat, consisting of sediments of fine carbonates borders the island's eastern and southern shores (Swanepoel, 2017). The shallow lagoon fills up during high tide and serves as wave attenuation, protecting the fine sandy beaches from excessive wave impacts (Swanepoel, 2017; Grellman, 2018). In addition to the rich coral network, the seabed on the southern side of the cay supports a sea-grass marine ecosystem (Grellman, 2018).

The East African Coastal Current (EACC) described in Section 2.5.1 approaches Mnemba from the south and flows around the island to meet up again at the north eastern corner of the cay. Due to wave attenuation on the reef flat to the east of the island, the surface current on the eastern side is weaker (0.22 ms^{-1}) compared to the surface current speed of the channel in the west (0.47 ms^{-1}) (Swanepoel, 2017). Swanepoel (2017) found that waves originate primarily from the south-east, carrying sediment towards the island's north-eastern lip (Figure 3-3). Sand is currently being deposited on the North western side of the island and the shore is being eroded on the southern and eastern sides of the island by the predominant currents (Grellman, 2018).

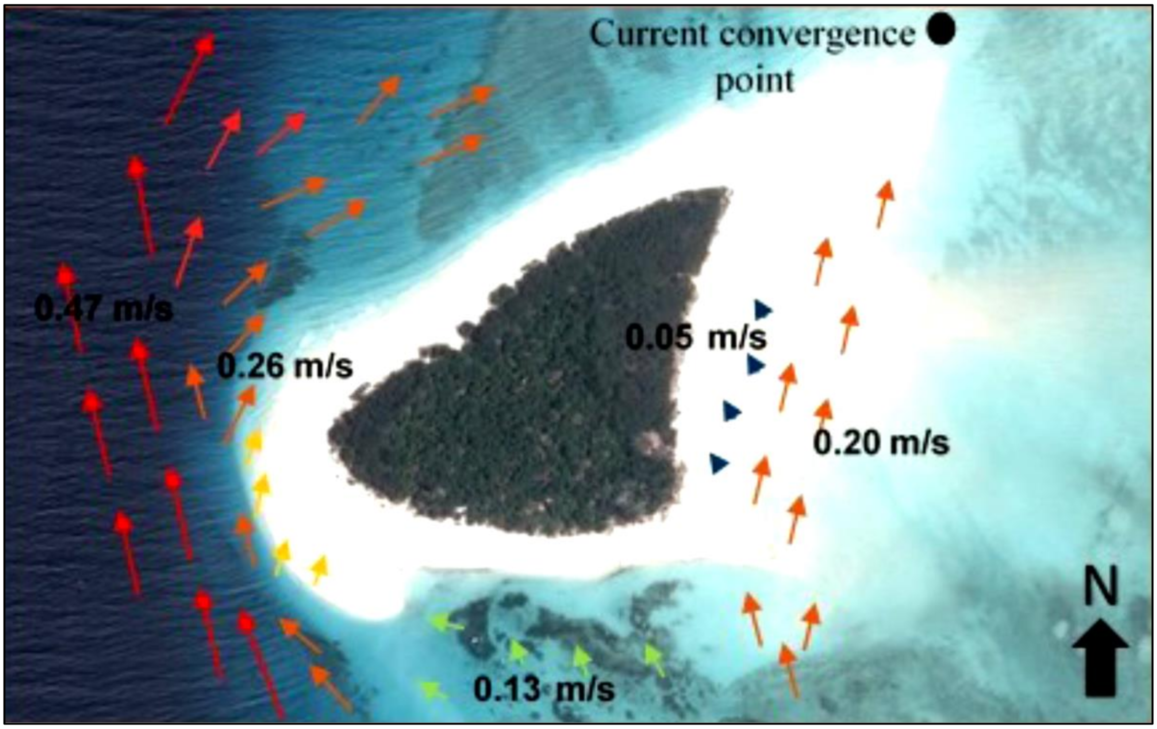


Figure 3-3: Surface current directions and the north-eastern convergence point for Mnemba Island, measured on 28 and 29 May 2016 (Swanepoel, 2017; Google Earth, 2017).

A study by Ngoile (1990) 27 years prior to Swanepoel's (2017) investigation, reported opposite current directions, as well as erosion on the south-western and north-eastern shores, as opposed to the south-eastern and eastern beach (Figure 3-4). The implications of tide and current directions on an atoll are related to beach stability and vegetation dynamics (Woodroffe and Biribo, 2011). The current study aims to establish the condition of the island's vegetation, as well as possible factors influencing the ecology of the island.

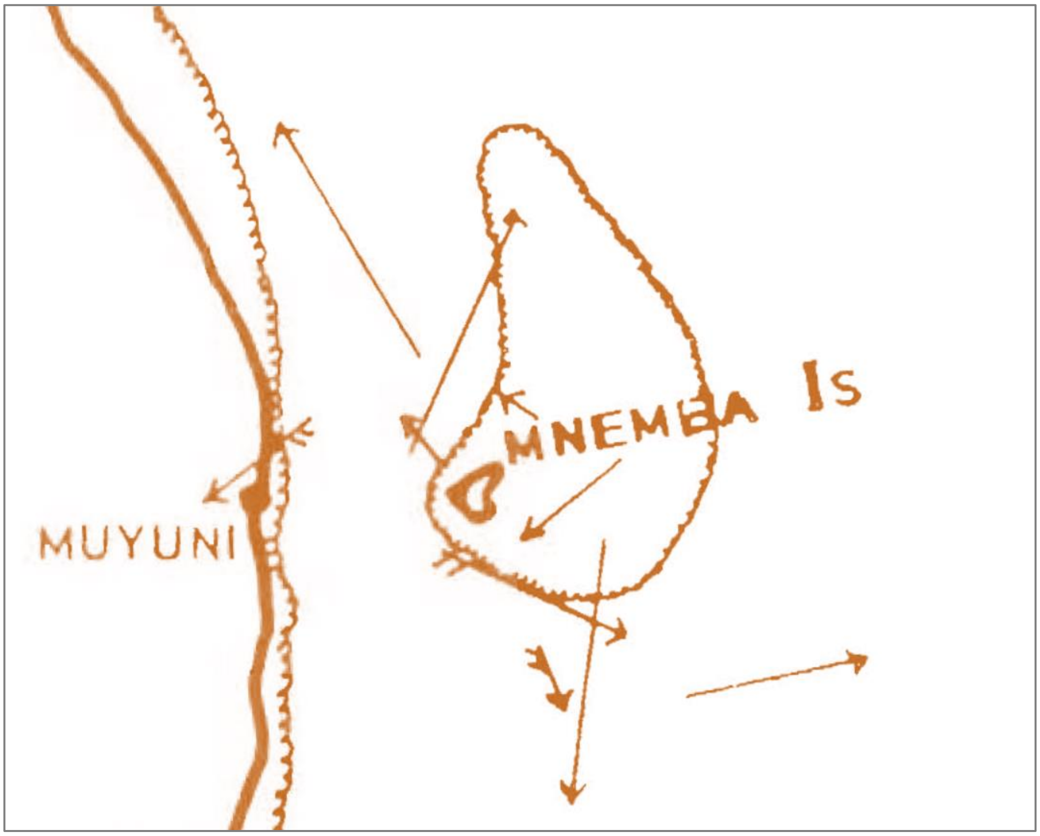


Figure 3-4: Surface current directions for Mnemba Island, taken on 21 December 1989 (Ngoile, 1990).

3.2 History of Mnemba Island lodge

Mnemba Island Lodge is operated by AndBeyond Safaris. A government lease includes the sole right of the use of Mnemba Island and a 200 m exclusive zone around the island (measured from the high-water mark). The first owners of the Island's lease operated a small hotel from 1989 until the late 1990's when AndBeyond Safaris took over the lease for the island and renewed it for an additional 33 years (Burgoyne et al., 2017). The new lease agreement was made between AndBeyond and the Revolutionary Government of Zanzibar.

Before Mnemba Island was first leased for tourism, fishermen from surrounding villages would use the unoccupied island as an overnight stop-over from which they would access the surrounding reef for fishing. Fishermen came from the villages of Pwani Mchangani, Kiwengwa, Kigomani, Mbuutunde, Matemwe, Muyuni and Nungwi (Burgoyne, 2018), of which the first five are commonly viewed as the historical beneficiaries of the island. Burgoyne (2018) found that inadequate communication and consultation processes with beneficiary communities regarding the initial lease conditions in the 1989 caused complex conflict between the new lease owners, the government and local village members. Conservation and management of the coral reef and instituted fish breeding zones have been affected by this conflict.

As a natural resource, Mnemba Island and its surrounding coral reef complex have been providing sustenance to local fishermen and a pristine diving environment to tourists for a long time. Regrettably, the anthropological pressures on the coral reef resulting from overfishing, damaging fishing practices and uncontrolled tourist activities have been documented by researchers such as Mbije et al. (2002), Nangle and Sheng (2010), Swanepoel (2017), Burgoyne (2018) and Grellman, (2018).

3.3 Terrestrial environment

Comprehensive diversity or ecological baseline data are not available for the terrestrial environment on Mnemba Island. Apart from two short-term studies (one on the Aders' duiker and one on the Suni antelope), and a brief terrestrial survey in 1990 (Ngoile, 1990), no other references were found. The major features of Mnemba's terrestrial ecosystem include the sandy substrate, the natural and planted vegetation, the introduced ungulates, resident and migratory birds, and the island's microclimate. The current study aims to understand the ecology of the Aders' duiker within the Mnemba Forest ecosystem. This study does not aim to conduct a full terrestrial survey or to compile comprehensive lists of the fauna. The focus is on vegetation diversity and the behaviour and resource use of the Aders' duiker.

3.3.1 Soil

In line with typical atoll island morphology (section 2.3) the sandy cay would have been formed from coralline and reef limestone as parent material, which would have led to dominant Sandy Loam conditions, with a high drainage index (Haij, 2010). Initially the calcareous deposits would result in poor soil conditions, but with the establishment and succession of island vegetation, soil conditions would potentially improve. Due to the absence of clay soils on coral cays, water retention is only possible when humus and other organic material form in the soil (Batianoff et al., 2010). Batianoff et al. (2010) explains that fertile soil is commonly found in the established woody vegetation where biomass contributes to higher levels of organic material and nutrients.

The sandy substrates of cays are often transformed to phosphate-rich soil due to the occurrence of a particular niche species, *Pisonia grandis* (or catch-bird-tree). This tree has been studied concerning island soil transformations and was found to have a significant part in the evolution of coral island ecology (Walker, 1991; Burger, 2005; Batianoff et al., 2010). Mycorrhizae on the roots of the *Pisonia grandis* further contribute to nutrient rich soils (Sharples and Cairney, 1998). Humus from this species has been described as an acidic form of peat (Fosberg, 1957).

Bird droppings are another critical contributor towards soil nutrition, especially in remote island ecosystems. With increased woody vegetation, birds start to occupy islands as permanent or breeding sites, consequently contributing to succession and maintenance of plants by depositing nutrient rich (such as potassium) guano in the soil (Woodroffe and Morrison, 2001).

3.3.2 **Vegetation**

Mnemba's sandy substrate is protected by a variety of vegetation species. Well established natural vegetation has settled on the island concentrically, which is typical of atoll succession (Batianoff et al., 2010). The vegetation is made up of many shrubs, small and large trees and one genus of the *Pandanus* spp. (screw pines) surrounded by stands of introduced *Casuarina cunninghamiana*. The only vegetation survey found as reference for the island is a report by Ngoile (1990), listing 32 plant species for the island. Ngoile (1990) described the overall structure of the forest as having three zones (Figure 3-5) distinguished by the species: *Casuarina cunninghamiana, Pandanus kirkii* and *Pemphis acedula*. He also recorded that the zones were separated by noticeable ridges in the sandy substrate that had built up over the years. A complete list of plants identified in the current study and by Ngoile (1990) is available in Appendix D.

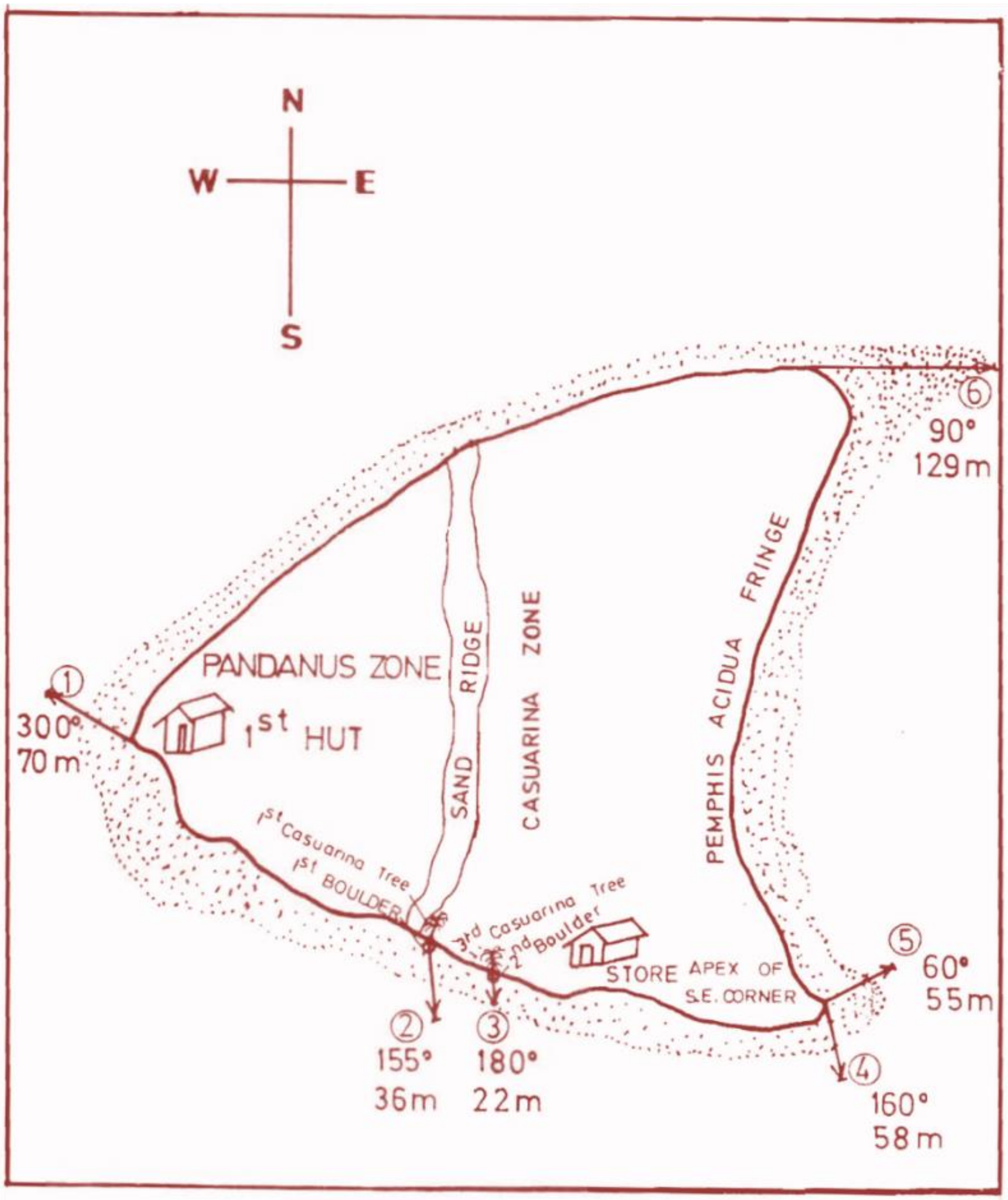


Figure 3-5: Map of Mnemba Island - terrestrial and beach survey (Ngoile, 1990).

The outer vegetated areas along the beach serve as a wind break from waves and current generated winds. The forest floor in the natural forest is mostly sandy with leaf and twig debris, while the *C. cunninghamia* forest floor is littered with a thick layer of pine needles. A comprehensive analysis of the vegetation diversity and condition is detailed in Chapter 5.

Mnemba Island Management contracted a botanist from South Africa to assist with an erosion combating plan to stabilise the beach on the eastern side of the island through planting hundreds of saplings of species that occur on the island, including: *Scaevola sericea, Ipomoea pes-caprae, Suriana maritime, Launaea sarmentosa, Eugenia capensis, Mimusops* *obtusifolia, Sideroxylon inerme, Grewia glandulosa, Ficus* sp. and *Pandanus kirkii* (Personal communication with Starke in 2016). The re-vegetation of the understory beneath the *Casuarina cunninghamiana* canopy is expected to avert the sea from claiming more land on this side of the island. During his reef sedimentation research in 2018, Grellman witnessed the re-vegetation project and reported that over 600 new plants had been established and another 1000 saplings were being prepared in the on-site nursery. Grellman (2018) claims that the Department of Forestry's restriction on the species for re-vegetation could delay the erosion protection plan. No details are available with regards to the restrictions he referred to.

During a visit from a consulting botanist John Ndege in 2016, it was suggested that various species of trees and shrubs can be introduced from Unguja that will do well in the *Casuarina cunninghamiana* stands. Preliminarily two species were suggested, *Apodytes dimidiata* and *Trichilia emetica* which the botanist claimed suits the environment and could ultimately take over the planted forest, creating a more natural habitat on the eastern side of the island.

According to the regulations of the Forestry Department, no removal of *Casuarina cunninghamiana* trees are permitted without prior inspection and issuing of necessary permits. The Island's in-house conservation team suspect that the planted forest might be contributing to the erosion problem on the eastern shore. Swanepoel (2017) also explained how the dead pine trees lying on the beach added to the instability of the beach when waves churn the massive trunks during high tide. During a site visit from the department of Forestry (DFNRR), Mr Haji in 2016, a concern was shared with regards to *Casuarina cunninghamiana* trees on Zanzibar's coastlines. It was explained that during fieldwork on Unguja, communities complained that *Casuarina cunninghamiana* trees contributed towards beach instability and erosion. Community members reportedly observed the trees uprooting and falling over, which loosens the sand that is washed away during high tide. The forest canopy, both natural and planted, houses many different bird species throughout the year.

3.3.3 **Birds and bats**

A database of bird species for the world lists 326 species for Zanzibar Island (Lepage, 2018) of which nine are rated as globally threatened and another nine as introduced species. Birdlife International monitors three Important Bird Areas on Unguja (Figure 3-6) with a checklist of 217 species: Jozani Chwaka Bay National Park (556 ha), Zanzibar Island East-coast (10 000 ha) and Zanzibar Island South-coast (4 000 ha) (Figure 3-6) (Birdlife

International, 2019). Birdlife International identifies (and monitors) Important Bird Areas (IBA) as site fit at least one of four criteria: A1 – the site is home to a globally threatened bird species; A2 – the site is home to a species with a normally restricted range such as an endemic species; A3 – the site is part of a Biome that houses a certain species exclusively; A4 – the site regularly houses a number of birds from one or more species that constitutes 1% or more of the global population for the species. Species that meet the criteria for an IBA are called trigger species (BirdLife International, 2019). Jozani Forest is home to all the forest bird species on the island, including three endemic species: *Nectarinia veroxii zanzibarica, Andropadus virens zanzibaricus* and *Tauraco fischeri zanzibaricus,* making it an IBA*.* The *Nectarinia olivacea granti* is regionally endemic with this species also occurring on Pemba. Mafia Island shares a regional endemic species with Jozani: the *Cercotrichas quadrivrigata greenwayi* (a subspecies of the Bearded scrub robin) (Birdlife International, 2018).

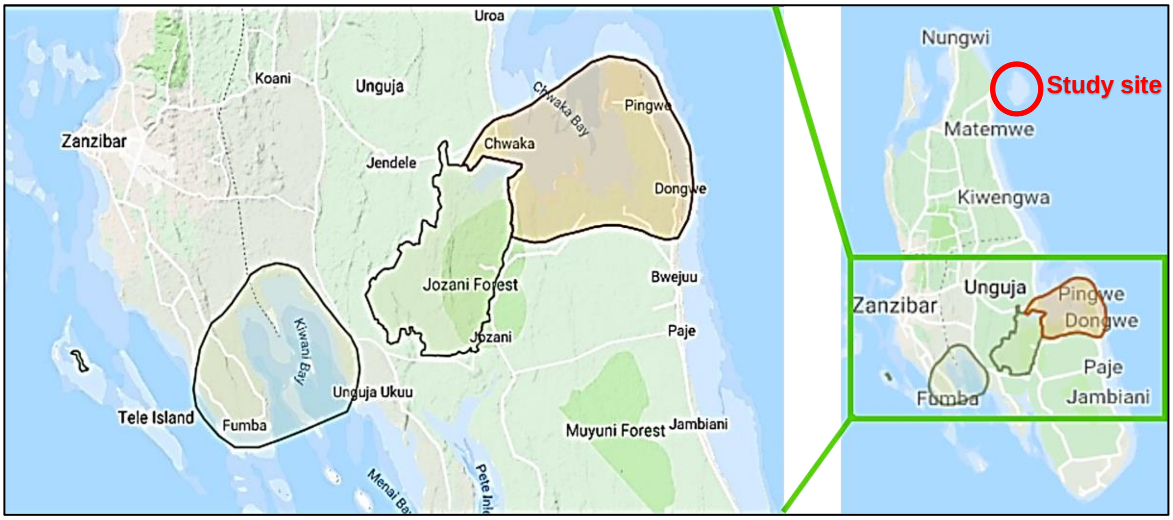


Figure 3-6: Map of Important Bird Areas on Unguja, Zanzibar, as monitored by Birdlife International (2019), in relation to the location of the Mnemba atoll study site.

Due to the absence of avian research on Mnemba Island, regional data such as the Birdlife International sites are important starting points for further investigation into bird diversity studies. On the East coast of Unguja, the Jozani Chwaka Bay National Park is the largest monitoring site with Mangrove forests being a key part of this area’s ecological concern. Shorebirds come here to feed, such as *Sternula saundersi*, occasional *Morus capensis*, *Charadrius leschenaultia*, *Arenaria interpres* and *Dromas ardeola*. These species also occasionally occur on Mnemba Island. Approximately 50 species of birds have been officially recorded on Mnemba Island according to Eyes on Africa (2016), but the species list was not found in a literature search. All birds identified during the current research study are listed in Table 3-1.

Table 3-1: Twenty bird species identified in the current research study for Mnemba Island (* = Near Threatened).

Scientific name	**English Name**
Accipiter melanoleucus	Black Goshawk/Sparrow hawk
Acrocephalus baeticatus	African Reed Warbler
Anus spp.	Noddy
Arenaria interpres	Ruddy Turnstone
Calidris alba	Sanderling
*Calidris ferruginea**	Curlew Sandpiper
Charadrius mongolus	Lesser Sand-Plover
Cinnyris bifasciatus	Purple-banded Sunbird
Corvus splendens	Black Crow
Coturnix delegorguei	Harlequin Quail
Dromas ardeola	Crab-Plover
Egretta gularis	Western Reef-Heron
Gypohierax angolensis	Palm-nut Vulture
Halcyon senegaloides	Mangrove Kingfisher
Ichthyaetus hemprichii	Sooty Gull
Numenius phaeopus	Whimbrel
Pluvialis squatarola	Black-bellied Plover
Polyboroides typus	African Harrier-Hawk
Sterna repressa	White-cheeked Tern
Streptopelia semitorquata	Red-eyed Dove
Terpsiphone viridis	African Paradise-Flycatcher
Thalasseus bergii	Great Crested Tern

Breeding activity of red-eyed doves was particularly noticeable on the island. Many occupied nests were found during the vegetation survey and empty shells were scattered across the forest floor during June, July, and August. Young doves were very active in the lower canopy around September, October, and November. Crows and raptors were seen hunting young doves and other birds, while crabs were scavenging on bird carcasses on the forest floor.

The West Reef-heron also breeds in the forest, especially in the Southern half of the island. Heron nests (platforms made with sticks) with chicks and empty pale blue shells were encountered in June. A few chicks were found dead on the forest floor (being eaten by crabs) or hanging from branches below the nests.

Mnemba Island is home to a variety of fig tree species and other fruit trees, making the island a suitable habitat for fruit bats. Unguja is home to over 20 species of bats but no references were found concerning the species of bats occurring on Mnemba. During the current research study two bat species were seen roosting in fig trees and consuming on figs: *Eidolon helvum* and *Epomophorus wahlbergi*. The role that bats play in seed dispersal and pollination should not be underestimated (Hodgkison et al., 2003; Lopez and Vaughan, 2004). Future studies on bat ecology at Mnemba Island would provide more details about the intricate relationship between bats and the spread/introduction of fruiting plant species. The likelihood that bats contribute towards the regeneration of Aders' duiker food plant diversity is high.

3.3.4 **Coconut crabs and other crustaceans**

According to the Department of Fisheries (Revolutionary Government of Zanzibar, 2005), Mnemba Island beaches are not high in crustacean diversity. There are three known species of Ghost crabs, *Ocypode ceratophthalma* and *Ocypode ryderi* (identified in the current study), and *Ocypode kuhlii* (identified by Ngoile in 1990). The forest is home to the renowned Coconut crab from Zanzibar, *Birgus latro*, which is also sometimes called the Robber crab. Another species of land hermit crab, *Coenobita* spp. and the circumequatorial land crab *Geograpsus grayi* were also identified. Dead wood on the forest floor provides shelter and food for one yet unidentified species from the *Armadillidiidae* family.

3.3.5 **Reptiles, Nematodes, Insects and Arachnids**

No snakes have ever been found on Mnemba Island and the diversity of reptiles is low. Geckos such as *Hemidactylus mabouia* and an unidentified species of dwarf gecko are mentioned in a report by the Department of Fisheries and Marine Resources (Revolutionary Government of Zanzibar, 2005). During the current study the *Hemidactylus platycephalus* and the *Mabuya striata* were observed.

During vegetation relevés surveys, an unidentified species of millipede was observed living in the *Casuarina cunninghamiana* litter. Millipedes play a vital role in the development of secondary forest and plant diversity amidst *Casuarina spp*. stands and have the ability to digest 'needle' litter which aids in the formation of a humus layer and increased fertility of the otherwise 'dead' soil (Werner and Newton, 2005).

A few types of caterpillar (of which *Datana major* was identified) were seen eating green leaves from *Grewia glandulosa*, *Suregada zanzibariensis*, and *Sideroxylon inerme*. The damage that caterpillars did to *Grewia glandulosa* foliage came at a time when the short rains failed to deliver. Food shortages for both Suni and Aders' duikers were evident during this time. A few worms and beetles were noticed in the forest litter, dead wood and fruit remains. Earthworms were only found in April during the long rain season. Arachnids and insects observed frequently during field work included *Gasteracantha falcicornis, Oxypleura lenihani*, *Oecophylla longinoda,* an unconfirmed species from the Araneidae family, large black ants and at least five different unidentified species of butterflies.

3.3.6 **Mammals**

Mice were found on the island. Supplies are brought to the island on a weekly basis from Unguja and it can be expected that mice could easily travel with supplies. Both Suni and Aders' duiker were reintroduced to the island.

3.3.7 **Water sources**

An old dry water well (age not confirmed) is situated on the island, which indicates that there was once a source of fresh water. It is unconfirmed, but the well was most likely constructed by the first lessees of the island in the late 1980's. Currently all water used by the hotel is derived from desalinating sea water onsite. A large desalination plant has been constructed that runs on diesel.

3.3.8 **Built environment**

Mnemba Island Lodge is self-sufficient in that all permanent staff members live in wooden structures with Makuti (leaf) roofs on the island. Twelve (12) guest rooms are also made of wood with Makuti walls and roofs and other biodegradable materials. Bathroom structures for staff and guest accommodation are built from stone and whitewashed with crushed limestone. Additional guest facilities include two dive centres (built with stone, wood and makuti roofs), and an open plan dining area (with short rock walls, Makuti floors and roof). Operational facilities include a built kitchen, cold room, waiter room, washroom, storeroom, staff dining area, generator and desalination plant, mosque and the ruins of the previous generator room and storeroom (which were damaged by the sea reclaiming a section of the island). At the time of data collection, the built infrastructure made up 5% of the vegetated area.

3.3.9 Tourist impact on the terrestrial island

Various studies have been undertaken to estimate coral health and the impact of large scale tourism on the Mnemba reef - these are important concerning the future of the reef's ecology (Mbije et al. (2002), Nangle and Sheng (2010), Swanepoel (2017), Burgoyne (2018) and Grellman, (2018). Impact of tourist activities on Mnemba's forest ecology has not been undertaken, but Breedt et al. (2016) published a report on the evaluation of Mnemba Island Lodge's waste production and made recommendations on waste management and improvements on recycling, which were subsequently implemented by the Lodge. The researchers found that staff members had a good understanding of waste management.

3.4 Climate

Mnemba Island conforms to the seasons of Zanzibar and the Tropical East Coast of Tanzania (Section 2.5.1), in that it experiences a dry season, a short rain season and a long rain season. Nangle and Sheng (2010) reported an average sea temperature of 27°C including diving visibility of 20 to 60 m at Mnemba reefs. Atolls have their own localised marine climates (Fonseca et al., 2012; Section 2.3) based on the structure of the reef, wave attenuation, sea currents and location. Yu and Lei (2001) also explained how an island's overall climate is particular to its topography, shape and size, in addition to outside factors which include sea and atmospheric flow. Mnemba's proximity to Unguja and the dynamics of the separating channel and the currents that pass by the atoll contribute to the unique climatic conditions for the island. When searching for climate data, the only values that were available for the time of the current study were for Stone Town, on the east coast of Unguja. Instead of taking weather data for Stone Town as relevant, it was decided that local data would be collected to make more accurate inferences about ecological processes on the island. It was doubtful that a low-lying atoll would have the same rainfall values (Yu and Lei, 2001) as the higher areas of Unguja and Stone Town.

An impromptu weather station was erected on Mnemba for the duration of the current study (Appendix E). To compare datasets for the two sites, the same online weather portal (Weather Underground) that was used for uploading data collected on Mnemba Island, was used to extract data collected at the Stone Town Airport (for the same twelve-month period). Hourly readings of Temperature (°C), Dew Point (°C), Wind Chill (°C), Humidity (%), Barometric pressure (mmHg), Wind speed (km/h), Wind Direction (°), Rainfall (mm), and Solar Radiation (uW/cm^2) were communicated from the sensory array to the internal memory of the Wi-Fi connected console in the weather station.

The purpose of this weather station was to collect the first baseline data for this island and to informally compare collected data for the 2016 calendar year with that of Stone Town's weather data for the same year. Basic graphic comparisons between the two sites were made for Average Monthly Temperature (°C), Average Monthly Humidity (%), Average Monthly Dew Point (°C), Average Monthly Relative Barometric Pressure (mmHg), Aggregate Monthly Rainfall (mm) and Average Monthly Wind Speed (km/h). The results of the weather data and rudimentary comparisons between the two sites are discussed below.

3.4.1 Mnemba Weather data

Temperature

Temperatures on Mnemba Island averaged between 25°C and 31°C from January to September 2016. From October to December 2016, the average temperature rose sharply from 31°C to 38°C. The highest daily average temperatures were recorded in October (31°C), November (34°C) and December (39°C), and the lowest average temperatures were logged in June (26 °C), July (26 °C) and August (27 °C). Temperature spikes of over 40 °C were recorded during July, November, and December 2016. The upward trend from August 2016 was not as pronounced for Stone Town (Figure 3-7). Instead, the average temperature dropped to 25°C in September 2016 and only steadily rose to an average of 27°C in December.

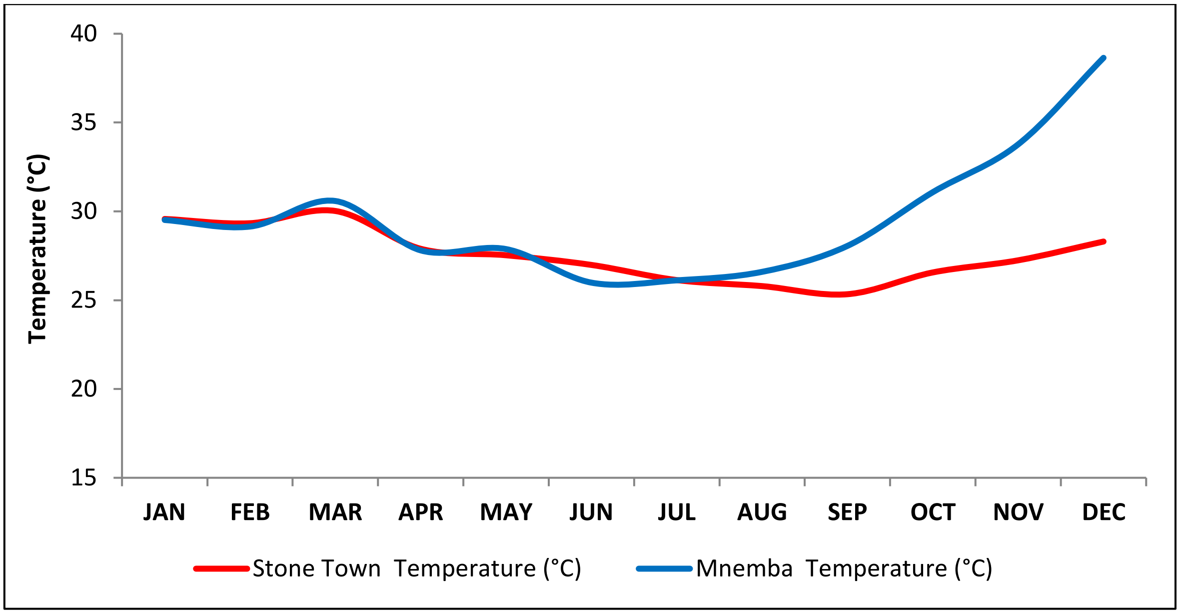


Figure 3-7: Monthly Average Temperature Data (°C) for Stone Town and Mnemba Island (Zanzibar) - January to December 2016 (Weather Underground, 2016a, 2016b).

Humidity

Humidity data for Mnemba Island averaged between 79% and 89% from January to November 2016 (peaking in April 2016 at 89%), after which it gradually decreased and then suddenly dropped to 74% in December 2016. Stone Town data showed a wider fluctuation of humidity (66% to 83%) as is shown in Figure 3-8, with a peak of 83% in April 2016, followed by a drastic drop in July (66%) and a gradual rise to 74% in November and December 2016.The graph illustrates how the shape of the curve is similar for both sites up to June 2016, but then Mnemba's humidity consistently remains higher than Stone Town's humidity (on average Mnemba humidity was 10.6% higher than that of Stone Town) until November and December when the difference decreased. The biggest difference in humidity between the two sites was in July (17%) and the smallest difference was in December (1%).

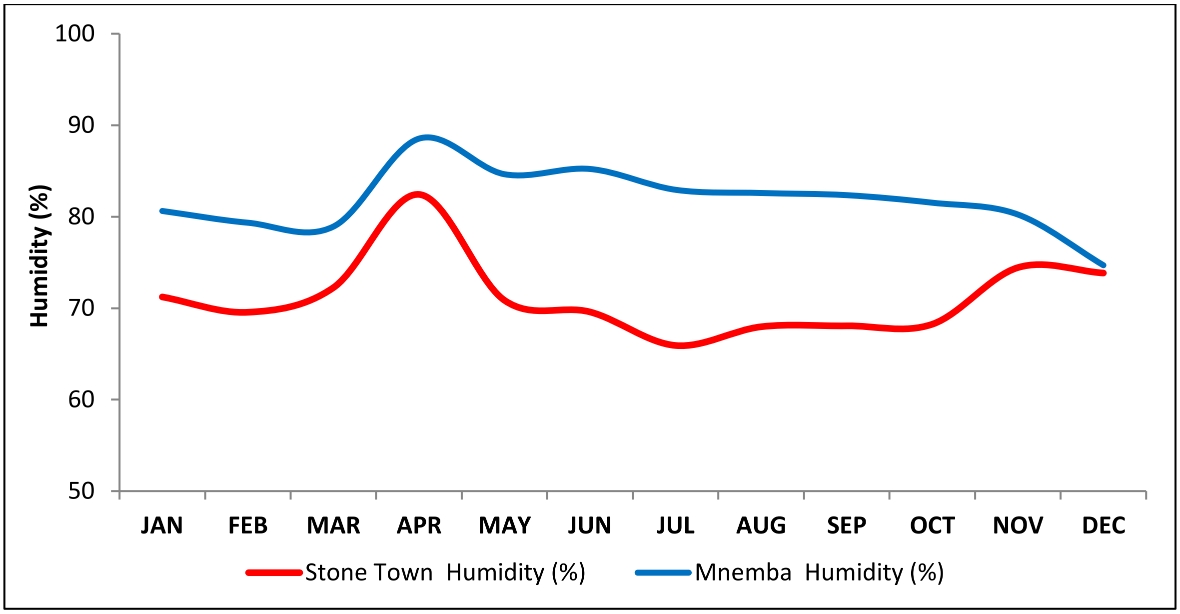


Figure 3-8: Monthly Average Humidity Data (%) for Stone Town and Mnemba Island (Zanzibar) - January to December 2016 (Weather Underground, 2016a, 2016b).

Barometric pressure

Average Relative Barometric pressure was the highest during June and at its lowest in January 2016 for Mnemba Island. In Figure 3-9, both Stone Town and Mnemba have a similar annual trend. Stone Town also experienced the highest average pressure in June, as well as in August 2016 (same value), while the lowest pressure was reported in March and January 2016 (same rounded values). Differences in pressure between the two sites varied slightly from month to month, but Mnemba generally maintained a higher average pressure than Stone Town, except for the month of May. The anomaly in May could be related to the sudden drop in humidity at Stone Town, while Mnemba only experienced a slight drop in humidity (refer back to Figure 3-8).

The biggest difference between the two sites occurred in December (Mnemba's pressure was 2 mmHg lower than that of Stone Town), while the smallest difference was reported for September 2016 (no difference in this month).

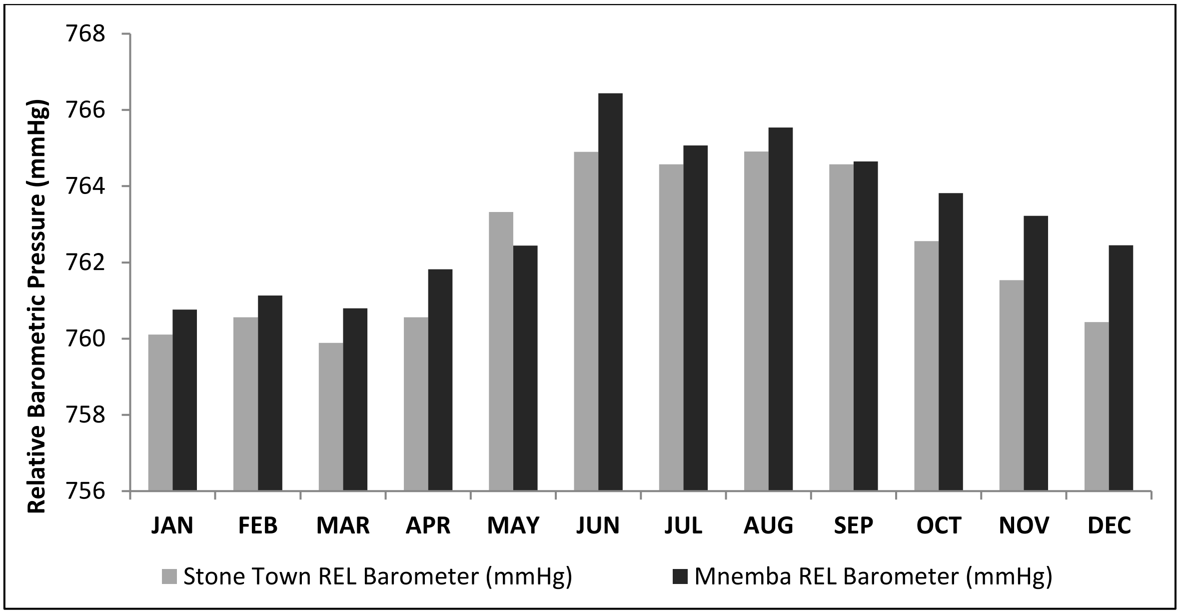


Figure 3-9: Average Relative Barometric Pressure Data (mmHg) for Stone Town and Mnemba Island (Zanzibar) - January to December 2016 (Weather Underground, 2016a, 2016b).

Dew Point

Figure 3-10 illustrates average monthly Dew Point Temperatures for the two sites. The dew point at Mnemba is higher than that of Stone Town at all times, but follows the same curve, with an increase in the difference between the two sites from September to December 2016, and a difference of 10°C in the latter month. The smallest difference was recorded in April 2016 when the dew point for both sites was 25°C. For Mnemba Island, on average, the dew point was 3.6°C below the average daily temperature, with the biggest difference recorded during February, March, November and December. For Stone Town the average difference between Dew Point and Temperature is 4.9°C. Dew point is influenced by pressure and humidity, thus with the higher humidity and pressure recorded for Mnemba, in comparison with data for Stone Town, the higher Dew point values for Mnemba makes sense.

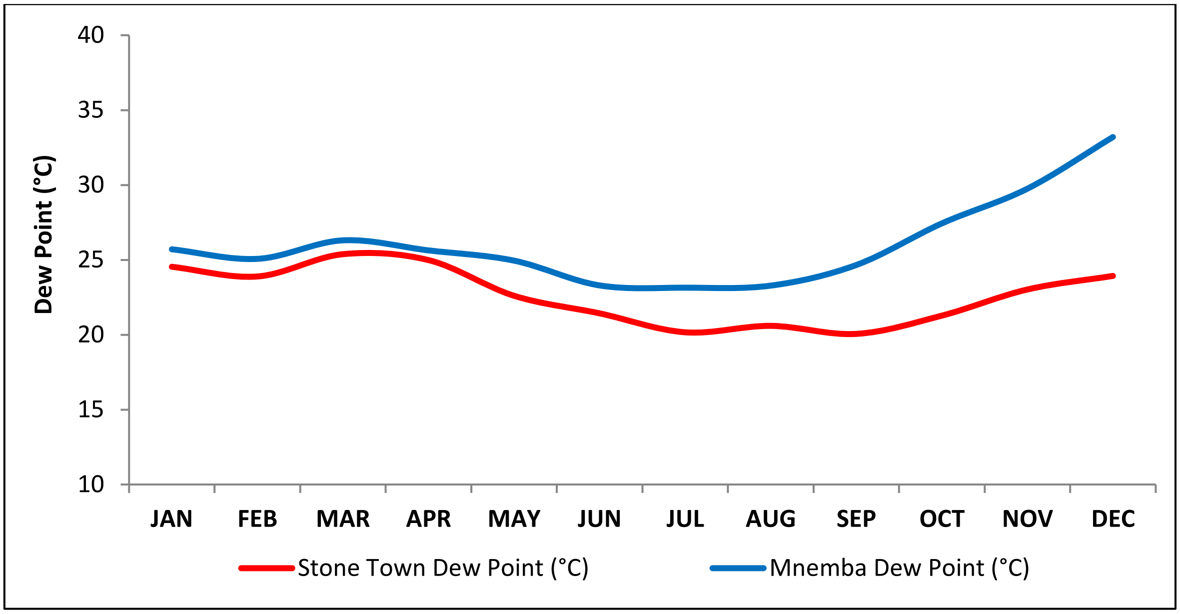


Figure 3-10: Dew Point Data (°C) for Stone Town and Mnemba Island (Zanzibar) - January to December 2016 (Weather Underground, 2016a, 2016b).

Rainfall

A monsoonal pattern in March and April and again during October and November was found in the 2016 data for Stone Town (Figure 3-11). This pattern was not as definite for Mnemba during the short rain season in October and November 2016. Based on informal discussions with long-term Mnemba Staff members, 2016 experienced a much dryer year than normal and was following a downward annual rainfall trend. Unfortunately, there is no historical data on site to quantify this trend. In Figure 3-11 we see that from March - May 2016, Mnemba received slightly more (490 mm) rain than Stone Town (472 mm), but during the October - December 2016 short rains, Mnemba received very little rain (70 mm) while Stone Town received half its annual rainfall in this time (500 mm). Stone Town experienced its highest daily and monthly rainfall for the year during the November short rains. In total, Stone Town received almost double the annual rainfall (1070 mm) than did Mnemba Island in that year (591 mm). A dryer climate on the east of Unguja is commonly quoted in the literature (Yu and Lei, 2001; Haij, 2010). The particularly low rainfall for Mnemba during the short rain period in 2016 could be related to the sharp increase in the island’s temperatures and higher barometric pressure (Figure 3-9) during the latter part of the year.

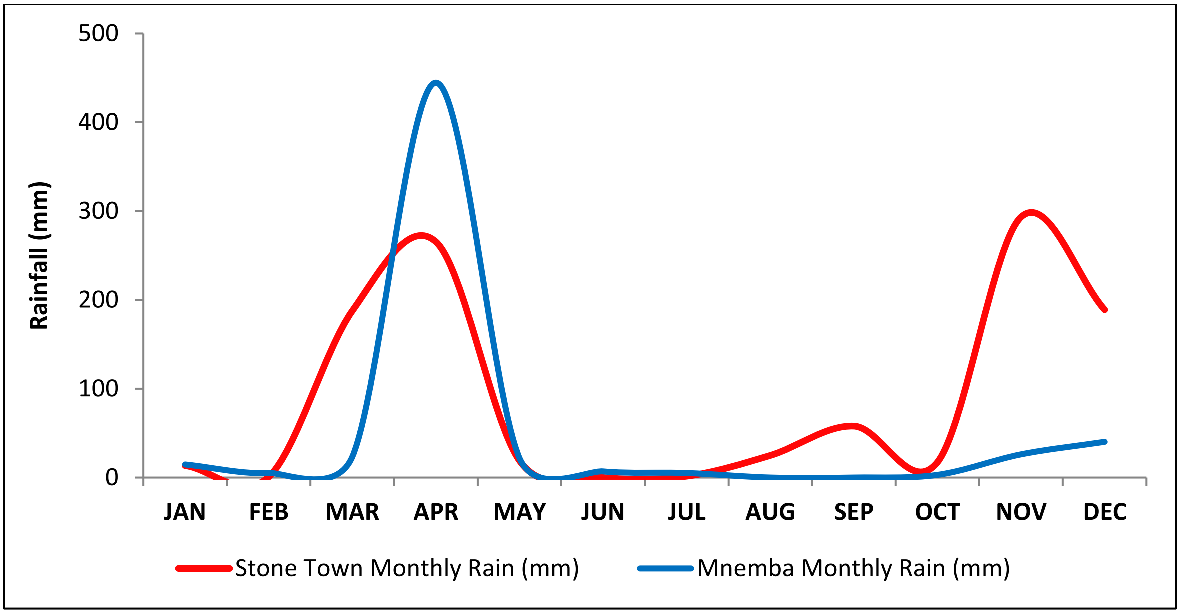


Figure 3-11: Aggregate Monthly Rain Data (mm) for Stone Town and Mnemba Island (Zanzibar) - January to December 2016 (Weather Underground, 2016a, 2016b).

Wind speed

Figure 3-12 illustrates maximum wind speed (km/h) differences between Stone Town and Mnemba Island for 2016. The beginning of 2016 showed similar trends for the two sites until May 2016, after which Mnemba's wind speeds drastically dropped to the lowest average maximum speeds in August (20 km/h). In September 2016, Mnemba's maximum wind speeds started rising until it reached the highest wind speeds (average maximum of almost 50 km/h) during December. Stone Town experienced its highest average maximum speed of 45 km/h in June and lower wind speeds from September onwards, reaching the lowest average in December (25 km/h). Differences between the sites are ascribed to seasonal winds, sea currents and associated climatic conditions (Watkiss et al., 2012) (section 2.5.1). Readings from the weather station on Mnemba Island was also potentially influenced by its close proximity to the open seas. Limited wind data for Mnemba in June, August, September and October 2016 diminished the comparison between Stone Town and the research site. No wind chill effect was observed for Mnemba Island – average wind chill temperature and average temperature was recorded as the same values. Wind chill data were not available for Stone Town.

Wind direction

A radar Wind Rose was created from the onsite wind direction data for Mnemba Island from January to December 2016. The onboard wind monitor collected wind data at a height of 10 m above the ground on the Eastern side of the Island, and produced a slight bias due to its location, but the baseline data still proves valuable in understanding the unique weather conditions that persists on the atoll.

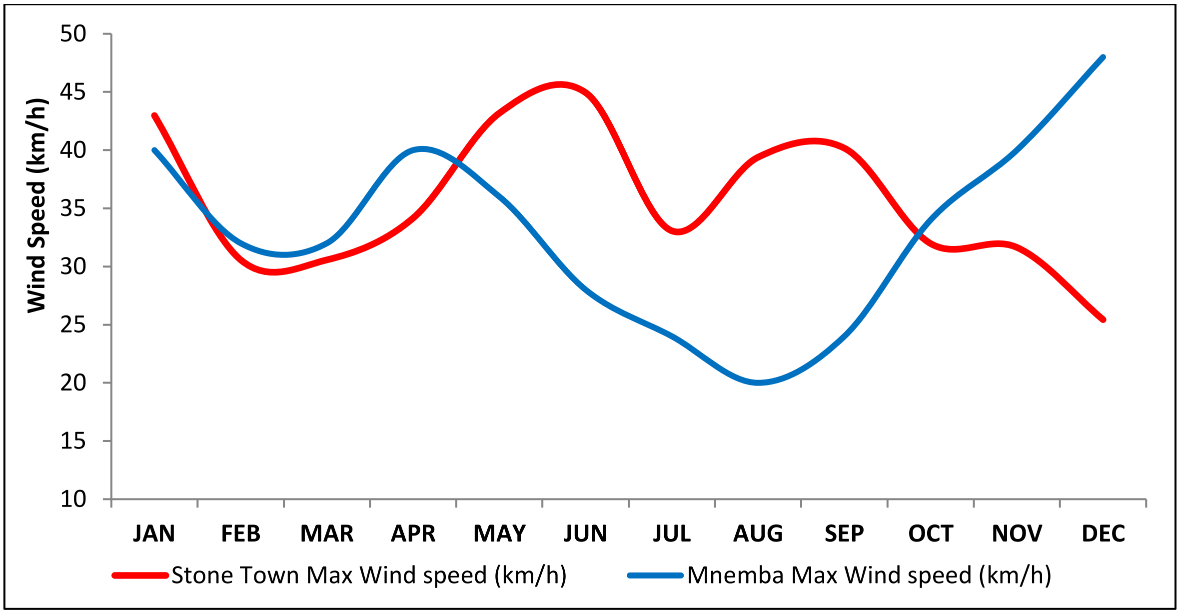


Figure 3-12: Wind Speed Data (km/h) for Stone Town and Mnemba Island (Zanzibar) - January to December 2016 (Weather Underground, 2016a, 2016b).

The Wind Rose in Figure 3-13 indicates that the trade winds from the South East reach the island at a consistent speed, while a stronger wind from the North West was prominent in 2016. Data indicated that the North West winds were most frequent during November and December. Due to battery failure and Wi-Fi disconnection, wind data were limited during June, August, September, and October 2016. The wind rose is thus more representative of the first five months of 2016 and the last two months.

Wind direction data for Stone Town during the same time indicated that the majority of the wind came from the South-east and then from the North-east (Swanepoel, 2017). Long-term data are needed to understand the dynamics of the trade winds and the effects it has on Mnemba Island's microclimate.

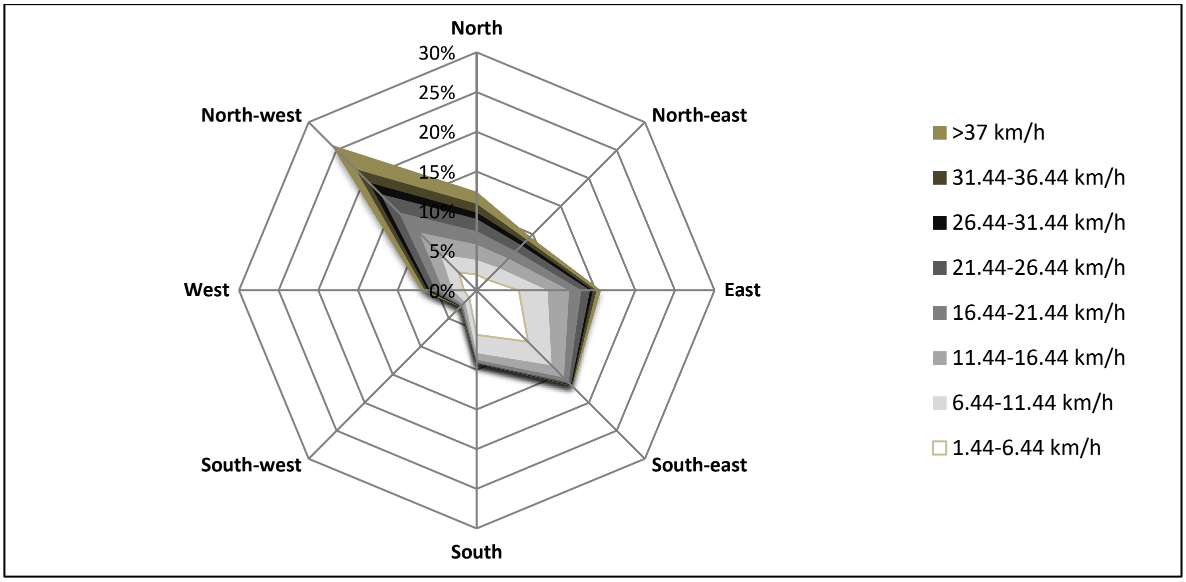


Figure 3-13: Mnemba Wind Rose for 2016 (January to December).

Solar Radiation and UV Index

Solar radiation was also recorded for Mnemba Island in 2016. Radiation was collected as microWatts per cm^2 (uW/cm^2) and a UV Index calculated by the Weather Underground portal. The UV index is directly proportional to the radiation data. In Figure 3-14 we can see the highest radiation in January 2016 of 495 uW/cm^2 (UVI of 1.3), which then drops gradually from February to May. In June, the lowest radiation was recorded for the site (300 uW/cm^2 or UVI of 0.6), after which it steadily climbs again to around 450 uW/cm^2 (UVI of 1.2) in November and December. The average solar radiation was below dangerous levels according to the World Health Organization (2002), however, throughout the year, UVI values reached up to 6, 7 and sometimes 8 around midday (which are considered to be dangerous levels of radiation). No UVI data were available for Stone Town for this period of time.

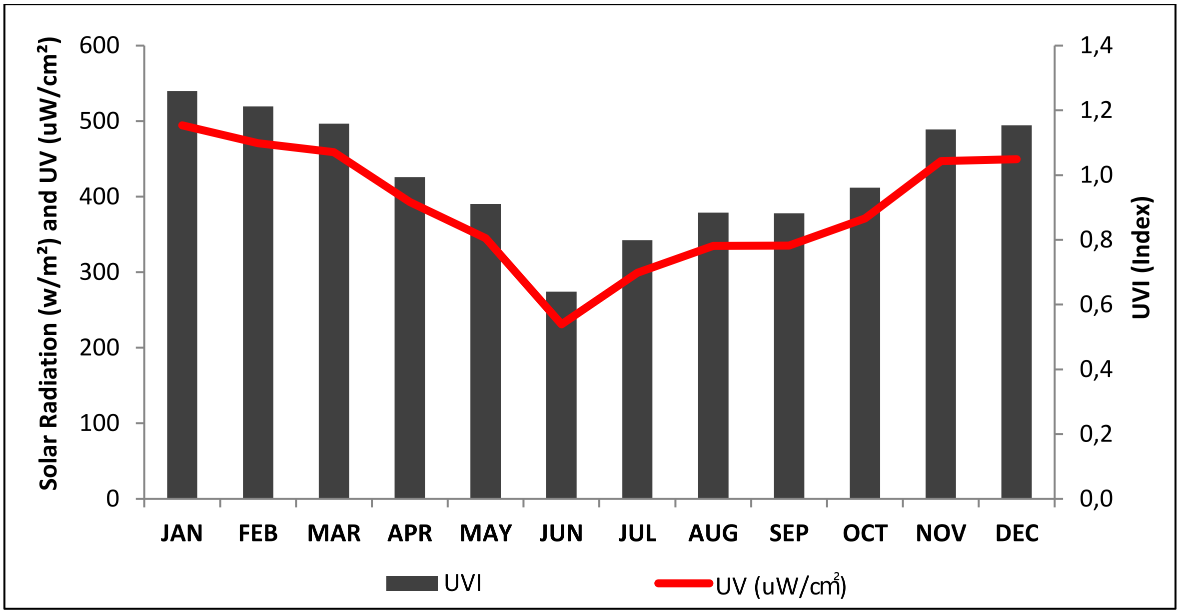


Figure 3-14: Mnemba Island Solar Radiation, Ultraviolet Readings and Ultraviolet Index measure on site: Monthly averages for 2016.

3.4.2 Climate Implications

Zanzibar forms part of the Paleotropics region comprising of Southeast Asia, some parts of Australia, Madagascar, Africa, and New Guinea. Midday solar radiation is experienced at 90° or near it, throughout the year. This phenomenon is the cause of the stable annual average temperature for low lying areas in this region, and indistinct seasonal fluctuations. Rainfall in the paleotropics is largely affected by the intertropical convergence zone and evaporation at high radiation levels, but geographic location (especially elevation) adds its own specific precipitation patterns. Variations between tropical regions are also expected based on cold and warm ocean current movements and the proximity of areas in relation to these ocean currents. Winds linked to ocean currents can change the climate of an area drastically at times, as is evident from the cyclic El Niño effect (Beck, 2008). Far reaching climate variation is caused by this effect and brings about extremes in temperature and rainfall. Droughts and heatwaves are attributed to El Nin˜o in some areas while in other areas flash floods are experienced at the same time. Although these extreme climate conditions can cause great damage to areas and human lives, studies have also produced interesting results of positive effects on tropical ecosystems. For example, a surge in dry and sunny conditions has caused increases in fruit production in some areas during El Niño. Unfortunately, the benefits are often short-lived and followed by droughts and scarcities for certain species (Beck, 2008). Frugivores are affected greatly by irregular fruit production during climate oscillations. In certain instances, increased rates of mortality have been recorded due to the lack of food caused by sudden changes in food availability. Alternatively, in other areas, mass migrations have been observed when fruiting and flowering reacts favourably directly following an El Niño event. Climate patterns are thus complex ecological catalysts that require more research to unravel both negative and positive patterns over long-term cycles. Seasonal changes affect the production of food plants in forests which then have significant impacts on species being supported by these forest ecosystems. Extensive long-term studies in the Amazon forest proved that a lack of rainfall caused overall underdevelopment of all aspects (leaf production, trunk size photosynthesis, transpiration) of forest tree species (Beck, 2008).

The importance of understanding climate patterns and cyclic changes in an ecologically sensitive area is important for the management and conservation of vegetation and fauna found in the area. From in-situ climate data collected on Mnemba Island, substantially higher average temperatures in November and December combined with a very dry 'short rainy' season, is interpreted as a localised drought. Personal communication with long-term staff members confirmed that a lower rainfall had been experienced for a few years in a row. Staff also conveyed that the forest is less dense than it once used to be. This dryer and hotter trend towards the end of the year was not seen in the data from Stone Town.

Although the eastern side of Unguja is known as the drier side of the island (Siex, 2011), implications of a lack of North-east (kaskazi) monsoon can be expected to have effects on leaf retention, fruiting and flowering in the next cycle. From the wind direction data for Mnemba, a predominant North-westerly wind, as opposed to the North-east monsoon wind, was recorded towards the end of 2016, which could potentially be the cause for the low rainfall at the time of the study. Contrary to the findings for Mnemba, data for Stone Town indicated that both the North-east winds (Swanepoel, 2017) and monsoon did occur in 2016 rains (Weather Underground, 2016a, 2016b). Data collected during the current study took place shortly after an extreme El Niño Southern Oscillation (ENSO), similar in magnitude to the extreme event in 1997 (Hu and Fedorov, 2017). Fer et al. (2017) alerts us to the "Predicted increased ENSO intensity" that can be expected in the future. East Africa's precipitation is more specifically affected by the Indian Ocean Dipole (IOD) (Black et al., 2003), and in combination with the intensification of the ENSO in future, Fer et al. (2017) estimates that vegetation growth will be affected by climate change in the region. This complex interaction between the two systems (ENSO from the Pacific Ocean and the IOD) has not been quantified (Lim and Hendon, 2017), leaving climatologist unsure about the exact impact of the convergence of extreme conditions in the future.

Mnemba Island as a small low lying (11 ha) island located on the dry side of Unguja, could potentially face drastic climate conditions in the future. Being fully exposed to ocean currents, winds and rising sea levels, the atoll's natural vegetation could serve as a significant early warning system for ensuing climate change (Keener et al., 2012). Extrapolated from Beck's (2008) description of effects, depending on the phenological reactions of resident plant species, changes in the climatic conditions of Mnemba Island might have either positive or negative effects on plant production. In turn, resident Aders' duiker (and Suni antelope) would have to adjust their energy budgets to accommodate this fluctuation (compensate during lower production of food items, or take advantage of higher production of leaf litter, fruits and flowers if that is the case) (Beck, 2008). Compound effects could also impact breeding rates and competition for food (Baker and Hobbs, 1982; Cook et al., 2001). Population control of fast breeding antelope in enclosed areas is critical during climate extremes (El Niño). Population growth records could provide the necessary data to plan and manage the impacts that ungulates would have on the island's vegetation during adverse climate phenomena, and vice versa.

In-situ weather data compared to that of Stone Town thus suggests that Mnemba Island's microclimate is specific to its location and conditions. In addition to supporting Mnemba Island's forest management as prime habitat for the resident Aders' duiker population, weather data serves as an important starting point for further research into climate trends in the region and the effects on the ecology of fauna species that depend on fruit, flowers and forested habitats.

CHAPTER 4

METHODOLOGY

4.1 Introduction

This chapter provides an overview of the methodological approaches considered to fulfil the research objectives for the study. Subsequent data chapters elaborate further on the details of selected methodologies.

Before commencement of research activities, a four-day reconnaissance visit took place in June 2015, followed by testing of equipment and finalization of methodological design. Equipment, tools, and support were brought from South Africa during a temporary (one year) relocation by the researcher to Unguja. Proximity to the study site was important for monitoring the various aspects of the study on a regular basis. Site setup commenced in October 2015 and data collection was simulated by the end of November 2015. Careful planning of data collection ensured that no inconvenience was caused to Mnemba Island Lodge staff, and guest activities/privacy. Field work sessions incorporated the following:

- Installing an onsite weather station (WS-1001-WiFi Observer) and maintaining the equipment (details of the outcome was discussed in Chapter 3),
- Conducting a comprehensive vegetation survey by sampling 24 relevés (Chapter 5),
- Performing a drive capture survey of the Aders' duiker population on Mnemba Island (Chapter 6),
- Habituation of Aders' duiker and Suni antelope during site setup and finalising methodology for behavioural observations (Chapter 7),
- Executing focal observations of Aders' duiker behaviour across all seasons (Chapter 7),
- Installing a satellite base station and fitting radio-frequency collars with GPS tags to four Aders' duikers to collect movement data over a one-year period (Chapter 8),
- Mapping the various physical components of the island using geospatial positioning technology (outcome used in all chapters).

The project's components were executed during nine site visit sessions over a total period of 18 months, between October 2015 and April 2017 (amounting to 100 days in the field). Ten days made up the site reconnaissance; five days were spent setting up and maintaining the weather station and other equipment; three days were used for onsite administration; focal observations was done over 55 days; 24 days were dedicated to the vegetation survey; and another three days were spent on equipment troubleshooting and unforeseen activities. The focal observations were stratified into dry and wet seasons with dry season focal data collected over 26 days and wet season data obtained over 29 days. All activities were cleared with the relevant authorities before commencement.

4.2 **Ethics clearance**

All research projects and initiatives in Tanzania must be registered with the Tanzania Commission for Science and Technology (COSTECH). This study was registered with the commission as an official research project on 29 July 2015. Prior to commencement of research activities in 2015, communication with the Department of Forestry and Non-renewable Resources (DFNNR) in Zanzibar took place via email, and the research concept was approved and welcomed by the Head of the Department, Mr. Hamdan in 2015. Upon arrival in Zanzibar, a presentation to relevant Departments took place, during which the proposed methodology was explained and questions from local experts were addressed. Mr. Ali Mwinyi, an African mini-antelope specialist-group member and officer of the Forestry Department (DFNNR) was assigned as technical assistant to the project. Additionally, according to legal requirements, the research project was registered with the Second Vice Presidents Office and a research permit obtained from the Zanzibar Research committee.

No major ethical concerns were raised, and data collection was done using minimally invasive techniques. The Department of Forestry (DFNNR) undertakes a bi-annual dive survey on Mnemba during which they capture Suni as part of their take-off plan for the species. This undertaking is initiated by DFNNR with Mnemba Island staff participating in the event. As a student on the island, participation in the April 2016 drive survey was allowed for population data collection purposes, and to fit radio-frequency collars to four Aders' duiker adults. In April 2017 the radio collars were removed using chemical capture methods. Collars were designed to fit the collared animals comfortably and securely. Although care is taken to ensure that collars do not obstruct movement or cause entanglement, there is never a 100% guarantee that it would not interfere with the collared animal. Whenever fatalities do occur, collar designers go to great lengths to ensure that the next prototypes are improved upon, with safety features such as anti-snare collars and emergency signals being the result of such improvements. Accelerometers form part of the hardware in the tracking devices and can be programmed to raise alarm if an animal’s head is down for too long. Tranquilisers were administered by a private veterinarian, Dr. Dave Cooper, while Dr. Ramadan (State Veterinarian for Zanzibar) and an official from the DFNNR assisted in capture recovery. Ethical clearance from the University of South Africa was registered under the reference 2015_CAES_095 (Appendix F - Ethics clearance, Research permit and Immigration legalities contains a copy of the ethics documents and research permits).

4.3 Vegetation survey

Quantifiable surveys of vegetation remain the foundation of scientific inquiry into species ecology and habitat management and would also form the basis for understanding the ecology of Aders’ duiker on Mnemba Island. From the reconnaissance visit in June 2015 it was clear that an uncomplicated approach would suit the small triangular shaped islet. Thus, to quantify food species availability and electivity from foraging observations of the resident Aders’ duiker population, it was deemed necessary to conduct a comprehensive vegetation survey (Schrodt, 2005; Andanje and Wacher, 2004; Tollington and Edwards, 2008). The outcome of the vegetation survey would also form a baseline for future management of the island’s terrestrial ecosystem.

In a comprehensive interpretation of the application of vegetation surveys, Brown et al. (2013) provides “*guidelines for phytosociological classifications and descriptions of vegetation in southern Africa*”, giving preference to the Braun-Blanquet approach. This survey method aims to identify different ecosystems by categorising plant species and ranking the categories based on decreasing heterogeneity. Although the guidelines were written for a southern African context, the international standard which it was based on makes it a suitable approach for the current study. With long-term monitoring as a key focus, the Braun-Blanquet method was selected as a phytosociological survey methodology (Vačkář et al., 2012). The method can be easily repeated in future research, monitoring and comparisons (Barrett et al., 2006; Barrett 2009; Brown et al., 2013).

Through communication with Mr. Starke in 2016, a list of plant species that were identified for an Mnemba Island during an anti-erosion project was obtained (Section 3.3.2). This list of plants was used as a starting point for identifying plants during the current vegetation survey. Additional collaboration and consultation with government botanists, Mr. Haji and Mr. Ndege, and longtime local staff members ensured identification of most plant species during field sessions. Supporting photographs were taken of fruiting and flowering plants throughout the study to allow positive identification of plant species that would otherwise have been missed. All *Casuarina cunninghamiana* relevés were surveyed over May, June and August 2016, and natural forest relevés over May, June, August and November 2016. Survey forms were designed in TerraFlex Survey Software and accessed on a Trimble GeoExplorer (6 000 series) handheld computer. Field data were uploaded to the InSphere Online data portal for later retrieval. One researcher collected all the data for this study, negating the need for inter-observer variability assessments. A total of 24 selected relevés at 20 x 20 m each. All plants species present within the sample plot were identified and recorded and a cover-abundance value assigned using the modified Braun-Blanquet cover-abundance scale.

At the time of the study Mr. Ndege was compiling an updated species list for Zanzibar and other East African islands on behalf of the Missouri Botanical Garden. Since no voucher samples existed for Mnemba Island, Mr. Ndege advised that voucher samples be collected for as many of the species as possible and filed at the local herbarium in the Zanzibar Natural History Museum in Stone Town. A total of 52 voucher samples (from 44 plant species) were collected on Mnemba Island in November 2016 as part of the current study. Standard herbarium mounting procedures were followed. In April 2017, all specimens were filed at the herbarium and received by the curator, Madam Maneno. Mr. Ndege returned to the herbarium in July 2017 to peer review the voucher samples and communicated the relevant corrections that were needed. For a complete list of herbarium voucher specimens filed at the herbarium in Zanzibar, refer to Appendix G.

Before the vegetation survey commenced, the island's two main physiognomic areas (natural vegetation and *C. cunninghamiana* plantation) were mapped using a Garmin eTrex GPS. Polygons were created in ArcGIS for size determination and mapping of plant communities once classification was done. The data were analysed by applying the modified TWINSPAN classification algorithm (Roleček et al., 2009).

4.4 Duiker population survey

At the onset of the current study the exact number of Aders’ duiker on Mnemba Island was unknown. Based on a rudimentary approximation of 3.1 individuals per hectare of natural vegetation, Fiske (2011) suggested a population count of sixteen in April 2011. No annual birth or death records have been kept for the island’s antelope population before the current study, but the initial population size was known as 8 individuals (refer to Chapter 6 for details on the initial population).

A drive method with multiple mark-recapture samples was selected as the survey method for estimating the population figure. This method is proven to be the most suitable for forest duiker species (Newing, 2001; Kanga, 2002; Viquerat et al., 2012). It is commonly quoted in literature that duikers, including Aders’ duikers, breed year-round (Huffman, 2016a, 2016b; Finnie, 2002). With no further information regarding breeding times, a population survey could be scheduled at any time of the year. The Department of Forestry (DFNRR) planned a capture operation of Suni antelope for April 2016, during which Suni would be removed to reduce the browsing impact on the island. This was identified as an opportunity to also mark and release all Aders’ duikers caught in the drive nets. A best practice capture protocol was followed to ensure experienced personnel were on site during the capture. A briefing session took place with members of the Department of Forestry and Non-renewable Resources, during which the capture and other research components were discussed and approved.

The AndBeyond Mnemba Island Lodge was closed during the capture period, allowing the entire island to be surveyed. The capture operation was executed by Mr. Ali Mwinyi. A total of four capture days took place with each day recorded as a new survey sample event. The entire island was surveyed during each capture day to account for territoriality and movement of animals and to satisfy the assumption that all animals had an equal chance of being captured on each capture day.

On a capture day, entire sections of the forest were enclosed with capture netting. Once the netted wall was up and enclosed (Figure 4-1), the capture team walked from one side of the netted area to the other side making noise and chasing antelope forward until they were entangled in the nets. When an antelope was caught, a second team moved in to disentangle it. All Suni antelope that were captured were removed from the island and placed in capture crates for transport to Unguja. Aders’ duikers were blindfolded, measured, marked with gentian violet and released. Care was taken when pregnant females were caught in the nets by limiting the handling time and releasing them quicker to reduce stress. To keep track of captured animals for the mark-recapture methodology (Table 4-1), different sides and areas of the duikers were marked with gentian violet wound spray during different days. This procedure was repeated until the entire island was surveyed on each survey day.

Figure 4-1: Nets used during capture operation in April 2016 (Carlisle, 2016).

Mnemba Island is a closed site, and the drive net survey serves as a suitable method to fulfil the assumptions for a Lincoln-Peterson model (Krebs, 2014). The Lincoln-Petersen assumptions and fulfilment criteria for this specific study are summarised in Table 4-1. As demonstrated in point 7, the possibility of overestimating the population size was based on the relatively small population on the 11-ha island. Consequently, the Multiple Lincoln-Peterson (MLP) model, using the Schnabel index variation to calculate N, provided a method for treating the small population size (Krebs, 2014) by grouping data from multiple captures and reducing heterogeneity between captures. Due to the enclosed site, small area size and complete coverage on all capture days, the assumption that any individual had an equal probability of being captured (Borchers et al., 2002) remained stable over all four capture days. Ccapture probability (p) was independent of marking conditions for the individuals.

The Lincoln-Petersen model uses input data from a ‘no replacement’ point of view. Careful record keeping of recaptures and unique marks from specific days allowed for a ‘no replacement’ calculation with the Schnabel index variation, resulting in a weighted average of the Petersen estimate (Schnabel, 1938). For additional accuracy, the Schumacher-Eschmeyer estimate calculation was done, but using data with the premise that marked animals can be replaced into the sample pool.

Table 4-1: Assumptions of the Lincoln-Peterson model (Krebs, 2014) and the fulfillment of assumptions during the Aders’ duiker drive net survey on Mnemba Island.

Assumption	Fulfilment and Reason
1. Survival probability of each member is the same	Yes. Gentian violet wound spray was used to mark each captured animal. No predators exist on the island. Marks did not harm or interfere with individual survival.
2. No Births and deaths between release and recapture.	Yes. Recapture days were consecutive. No births or deaths took place during the four days.
3. Immigration and emigration between release and recapture.	Yes. The island is 2.7 km off the north-eastern shore of Zanzibar, which makes immigration and emigration impossible.
4. Mixing of marked animals among the population.	Yes. The island is only 12 hectares in size. When animals were released back onto the island they could move freely among the rest of the population. Each day the entire island was surveyed - marked and non-marked animals had equal opportunities for capture on any of the days.
5. Re-capturing marked animals are not more difficult or easier.	Yes. Gentian violet markings did not affect catchability.
6. Marks remain fixed on the animals for the duration of the capture.	Yes. Gentian violet has been used successfully in mark-recapture studies of this nature (Silvy et al., 2005). The dye marks were still visible on day four of the capture.
7. Prevent an overestimation of population size by ensuring that a high enough recapture rate is obtained.	Yes. The 11-hectare island is a small enclosed system with a relatively small Aders’ duiker population. To prevent overestimation, the multiple Lincoln-Peterson model using the Schnabel index variation and the Schumacher and Eschmeyer Methods were used to obtain more accurate results.

Chapter 6 summarises the analyses of capture and population results. Fecundity (births or ‘b’) and mortality (deaths or “d”) data were also collected for the duration of the current research study, which was then used to calculate the instantaneous population growth rate r (r = b – d). Intrinsic growth rate (r_m or maximum growth rate per capita) was deduced and plotted along with the start and end population to create a rudimentary growth curve based on the logistic model. It is widely accepted that as a renewable resource, antelope and other stock animals reach equilibrium in their population growth as habitat pressures and overpopulation controls population size (Russel, 1931; Milner-Gulland and Mace, 1998). Since the duiker population had been left to produce without interference, it was accepted that by the time of the survey, the population had reached equilibrium. The results of the population survey results were integral for expressing the island's carrying capacity (see section 4.10).

4.5 Anatomy and physiology

During the mark-recapture survey, as many Aders' duiker as possible were measured, using standard methods (Ansell, 1965), to obtain anatomical dimensions. A total of seven males and six females were measured to varying degrees (dependent on stress levels during net capture). Figure 4-2 illustrates standard measurements taken using a flexible measuring tape.

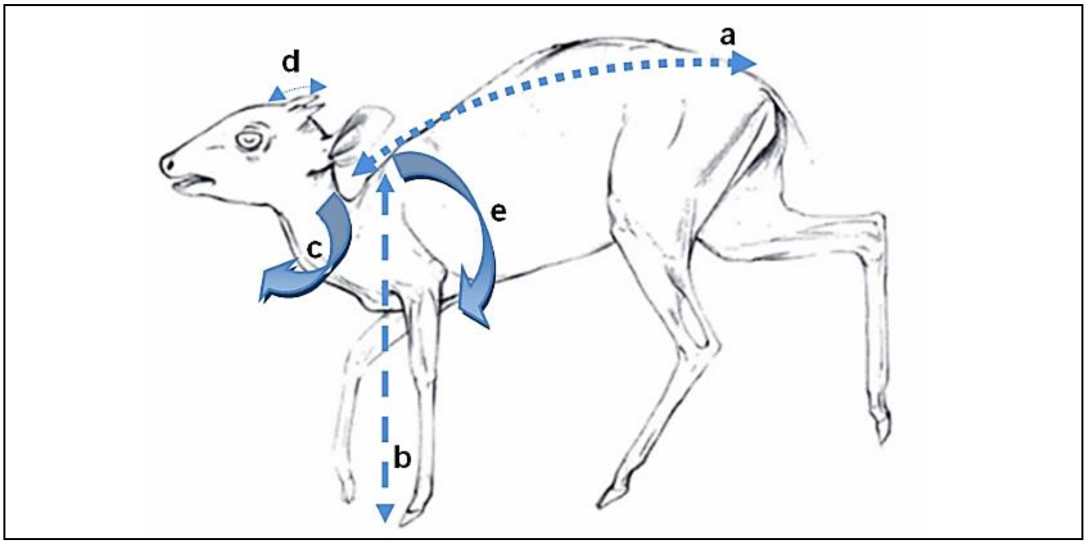


Figure 4-2: Standard measurements taken for the Aders' duiker.

a) Body length: Measured from tail root (where coccygeal vertebrae meet the sacrum) to the atlas joint behind the head, along the spine, following the shape of the back.

b) Shoulder height: Measured from the tip of the foreleg hoof along the straight foreleg to the top of the shoulder. The stretch of the leg was not standardised, and some variation was experienced.

c) Neck girth: Measured around the base of the neck.

d) Horn length: Measured from the base of the horn where visibly exposed from the skin, to the tip of the horn along the lateral side.

e) Chest girth: Measured directly behind the front leg, around the curvature of the chest with the measuring tape meeting at the spine.

Measurements for ecological studies typically include total body length, shoulder height, chest girth, horn length, and tail length (Ansell, 1965). To minimize animal handling time and capture-related stress, the length of the head (from the atlas joint to the nose tip) was estimated without the measuring tape, and tail length was not collected. The total body length including the head estimate was calculated afterwards. This study served to evaluate the feasibility of collecting routine measurements for the sub-population of Aders' duiker on the island and to make suggestions for biological data collection and monitoring. Qualitative notes on any biological observations were collected during focal sessions to serve as ancillary information for making research recommendations. Where duiker age was reported as young (or juvenile) or adults (including sub adults), young duikers were classified as such when their coats had not yet turned colour or smoothed out like in the adults and sub adults. This method was consistent and reliable throughout the study, even at a distance using the binoculars. This method was also used by Ruckstuhl and Neihaus (2009) for *Oryx gazella*.

Hair samples were collected for genetic analyses, but laboratory tests revealed contamination of the samples, which caused the genetic component of the study to be disregarded. Further research is strongly recommended.

Text box 1

4.6 **Activity budget**

Time-activity studies have proven to be a reliable method to help answer important questions about the behaviour and ecology of a species (Rugg and Buech, 1990). To determine the Aders' duiker's time-activity budget on Mnemba Island, focal samples were collected over a period of 16 months between December 2015 and April 2017. Two broad seasons were covered: a wet / rainy season (a short rain period from October to December, and the monsoon from March to May) with alternating dry season in-between. A predetermined site visit schedule was agreed upon with the hotel management, and focal observation days divided between the wet and dry season.

Aders' duikers were habituated in October 2015 for two weeks before official behavioural observations started. Habituation constituted test sessions of focal observations during which time the handheld data logger was activated and tested for GNSS (Global Navigation Satellite System) reception and accuracy, as well as finalising data collection sheets according to preliminary behavioural repertoires. The focal observation methodology was finalised, and sampling schedule tested for site and species suitability. The Aders' duiker's tolerance for focal observation was established at a minimum distance of five meters, provided that the researcher remained on the foot path and did not pursue animals into the forest interior. Duikers especially appeared relaxed when a layer of vegetation cover separated them from the researcher. Aders' duiker could be observed from between 5 - 30 meters using a pair of DCF 10 x 25 FIELD 5.5 96M/1 000M pocket binoculars, when necessary and depending on forest density. A minimum following distance of ± 20 m was maintained when focal animals were mobile during observation sessions.

TerraFlex Survey software was used for data capture and linked to the InSphere Online data portal, which received data in real time over the island's Wi-Fi connection. The focal observation track was standardised (mapped in ArcGIS 10.2.1) and adhered to during each focal session. The track covered a large area of the island and natural forest, without interfering with guest activities. Observations were possible up to 30 m into the interior of the forest on either side of the focal observation track. Figure 4-3 illustrates the sampling track with a 30 m buffer on either side (Using ArcToolbox Analysis tools – Proximity (Buffer)). With the natural vegetation of the island measuring 53 251 m^2, the buffered area of the sampling track that overlapped with the natural vegetation was calculated as 41 197 m^2, (Using the clipping feature in ArcGIS), which means that 77% of the natural vegetation was covered during each tracking session. The length of the track was calculated in ArcGIS as approximately 1 140 m. During a one-hour tracking session the track was walked entirely in both directions, giving an opportunity for a maximum of 3 x 20 minutes back-to-back observation sessions in that hour. Study conditions and research aims determined that continual focal observations would be the best way to gather as much behavioural data for Aders' duiker as possible. Continous focal observation in this instance refers to focal observations that record sequential behaviour, with all occurences captured, for anlyses of rates - frequency per unit time (see Altmann, 1974), and not based on the count of predescribed events.

Anticipating difficulty in consistently finding animals for observation, potential territorial use of the island, along with the aim to remove sampling or pick-up bias (Altman, 1974; Rugg and Beuch, 1990), it prompted the use of a Combination or Mixed Purposeful Sampling (Johnson and Christensen, 2014; Garamszegi, 2016). This sampling methodology was set out to collect comparable amounts of time (frequency) for focal observation across two seasons (du Toit and Yetman, 2005; Fennessy, 2004). More detail with regards to the scheduling of sessions, onset and termination, is given in Chapter 7, section 7.2.2.

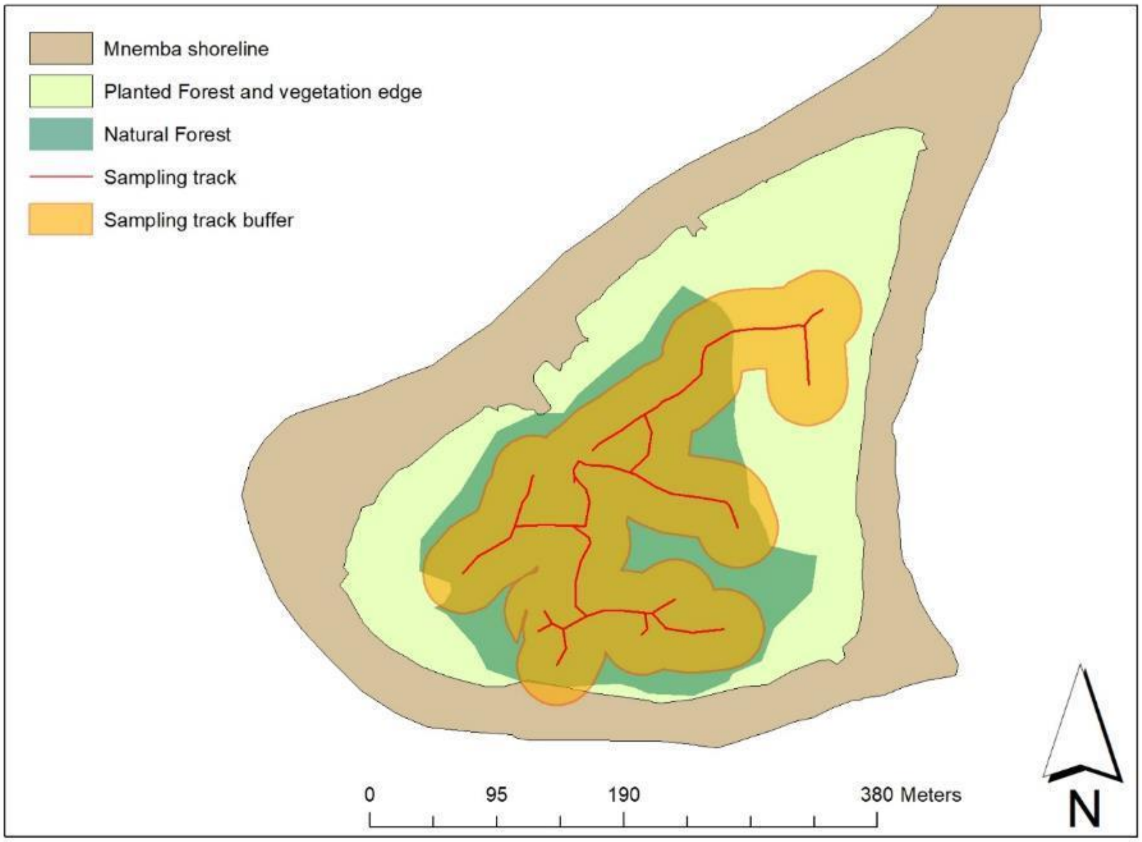


Figure 4-3: Focal observation sampling track with 30 m visibility buffer.

Nocturnal focal observation was not possible due to poor visibility at night, especially during moonless nights. Based on camera trap rates for Aders' duiker activity in Kenya (Amin et al., 2015), limited activity was to be anticipated before 6:00 and after 19:00. Due to the inherently small population size and small closed environment, each duiker had an equal chance of being observed multiple times over the 16-month study period

During focal observations, behavioural activities were selected from a list of pre-coded behaviours based on an all-inclusive ethogram (Appendix J), which was developed from literature studies (Innis, 1958; Leuthold and Leuthold, 1978; Dagg and Foster, 1982; Pellew, 1984; Le Pendu et al., 2001; van der Jeugd and Prins, 2000; Bowman and Plowman, 2002; Rivers, 2012), and preliminary observations during habituation sessions. The final ethogram included a complete inventory of repertoires exhibited by the sub-population, grouped as thirteen main behavioural states and 34 sub-behavioural states.

A state was defined as a main state based on the main activity being observed and was named after the most durable part of the activity. For example, travelling is a main state which refers to the movement of the animal, during which no additional behaviour was observed. Travelling could be classified as one of three main state/sub-state pairs: travelling-walking, travelling-trotting and travelling-fast-walking. Another example of a main state such as foraging includes the sub-state, forage-walking, which entails walking as a movement (in addition to alternating feeding repertoires), with a major function of walking being that of finding food. For each classification of an activity, an exclusive main state/sub-state pair category was assigned.

Auxiliary variables were captured during focal observations, including general weather conditions, focal animal details (gender, age group, unique identification, behavioural events not captured as behavioural states) and social parameters (group size, notes on intra- and inter-species interactions). During a random sample of observations, the speed of a slow walking and fast walking Aders' duiker was measured as meters per second (using a stopwatch and measuring distance after the focal observation). The complete focal observation survey is available in Appendix J.

Since only one researcher consistently applied the sampling and surveying methodology, there was no inter-observer bias. Validity and external reliability were ensured by applying a stratified sampling design. By pooling (Braude et al., 2002) activity data from each observation session, activity budget objectives for this study were met.

4.7 Food selection

Foraging data were collected during focal observation sessions. Opportunistic sampling was used to collect information on food species selected and the part of a food plant (food type) that was consumed. Comparison of food species consumed between seasons was not possible due to limited amounts of data collected on each food species. However, the type of food selected, and rate of consumption was comparable between the dry and wet seasons. An inventory of food species was collated from focal observations and opportunistic foraging observations.

Food species electivity was evaluated using the Ivlev electivity index (Krebs, 1999). Food type (part of the plant or non-plant items selected) was recorded for all items consumed during the 50 focal foraging observation sessions (27 dry season sessions and 23 wet season sessions). A seasonal electivity index for food types was compiled using the relative abundance values of the various food types.

A flowering and fruiting chart of food plant species for Aders' duiker on Mnemba Island was compiled using photographic records from surveyed relevés, voucher sample collection and opportunistic recording over a period of 18 months. Each observed food species was listed on a new row in the chart and all potential food related phenophases listed in a new column: New leaves, Sprouts and Seedlings; Fallen leaves - green; Fallen leaves - yellow; Green fruits; Green fruits - fallen; Ripe fruits; Ripe fruits - fallen; Fresh fungus; Flowers and Buds; and Fallen Flowers. When a species presented a particular phenophase, this was recorded. Once all data were collected, notes were pooled for dry and wet seasons (Braude et al., 2002) and if an item occurred in the wet season, a 'W' was recorded for that species under the correct column. The same was repeated for the dry season (with a 'D' marked for the species under the relevant phenophase).

4.8 Spatial Ecology

The field of spatial ecology developed rapidly alongside advances in spatial data collection (hardware), data analyses (software) and theoretical deductions, adding value at fine scale levels (Cooke et al., 2004; Gregory, 2017; Lyons et al., 2018). In the past, small quantities of space-time information often led to contrasting inferences between studies with no means to test the accuracy of the interpretations. McCullough et al. (2000) highlighted the value of collecting suitable quantities of spatial data on an elusive antelope species such as the Reeves' Muntjac in Taiwan, by refuting earlier assumptions about the species' territoriality and resource use. Similarly, to understand how a species such as the Aders' duiker utilises its resources across dry and wet seasons in its immediate environment, it is of interest to collect space-time data on the individual level over an annual cycle (Gregory, 2017). Space-time data can be analysed to provide concrete evidence of where and when the duiker moves about in its habitat. This type of delineation was first described by Burt (1943) as an animal's home range, the spatial pattern specifically associated with foraging activities and social events.

4.8.1 GPS tracking and home range analyses

Preceding the current-day Global Positioning system (GPS) enabled tracking collars, researchers used Radio Frequency (RF) collars to locate animals manually and record spatial locations to analyse movement patterns. In the case of a tropical deer, the Thamin (*Cervus eldi thamin*), researchers tracked collared animals on foot and recorded locations in grid blocks, which were then used to estimate average home range for males and females (Aung et al., 2001). The use of RF collars is particularly feasible when larger mammals are tracked over vast areas. For smaller areas and smaller research animals, RF collars do not have the fine scale accuracy compared to GPS tags. Current day GPS tracking devices include the facility to select a range of custom settings and measurements, such as time intervals between readings, battery use intensity, animal travel speed, and 'changes to the animals head angle' (accelerometer). An increase in the number of location points and the number of variables that can be measured have made it possible to describe fine scale behaviour and movements that take place outside of human view. Successful deployment of GPS tags produced detailed spatial utilisation and movement data for many different species including large ungulates such as the Tsessebe (*Damaliscus lunatus lunatus*) (Göpper, 2012) and the Greater Kudu (Tragelaphus strepciceros) (Butler, 2017), various duiker species (Bowland and Perrin, 1995; Newing, 2001) and for highly mobile predators such as the Spotted hyena (*Crocutta crocutta*) (Cagnacci et al., 2010; Stratford and Stratford, 2011). GPS technology has made it possible to collect previously inaccessible data providing researchers with the opportunity to describe animal ecology and evaluate the use of natural resources in much more detail (Cooke et al., 2004).

Many researchers have used spatial ecology to create resource use models and predictions to inform research design and conservation decisions (Lyons et al., 2018). Although there is consensus that developments in the field of location data collection provide opportunities to study more species and in-situ scenarios, large amounts of data present new challenges in data analyses (Downs et al., 2012). Along with the development in GPS hardware, progression in data analyses software (GIS) was needed to correctly explain the data. One such method of analysis, the non-parametric Kernel density estimator (KDE), often referred to by wildlife biologists as the most suitable method to measure home ranges and spatial utilisation (Larkin and Halkin, 1994; Mitchell and Powell, 2003; Kie et al., 2010; Downs et al., 2012), uses input points obtained directly from GPS tracking tags. KDE tools are available in a variety of software packages, of which the ArcGIS (10.4.1) KDE extension is a popular and proven choice (Locher and Lindenberg, 2016; Laver, 2005; Quinton, 2016; Gregory, 2017).

Spatial algorithms and input parameters have been greatly refined since the incorporation of tools such as KDE in software packages. One of the key parameters for a KDE calculation is bandwidth: the value that defines the relationship between input points, and the assumption about the way points are aggregated to represent a form of density - similar to a histogram (Hemson et al., 2005; Quinton, 2016). Bandwidth also represents the search radius – all points within this radius will add to the total weight of points. Setting the bandwidth at a suitable level can be problematic as it assumes the spatial arrangement of data before analyses. In selected software applications that perform automated KDE's, researchers can either choose to calculate the bandwidth manually or opt for automatic calculation from the input data. In the latest version of ArcGIS, the bandwidth (also called cell size), if not provided, is calculated using the number of input points and the spatial configuration of the points. Outliers are corrected for; thus, bandwidth is not increased drastically by extreme points. The two-dimensional output of the KDE is a 'flat' representation of a three-dimensional hill (or kernel) which is derived by assigning density values (from the height value of the kernel) to each cell and presenting it as a "smoothed" raster output. Cells with the same density value are linked with contour lines called isopleths to indicate which areas are being used more frequently or for longer than other areas. Thus, the KDE is more than just a boundary around a collection of GPS points. Each point is assigned a probability (weighted) value which is transformed into a smoothed-out probability surface map. Using a weighted density probability method allows biologists to accurately predict if an area is likely to be frequented (Quinton, 2016). The output is a 'hot spot' map that indicates where an individual animal has a 0.95 probability of spending its time (home range). The 'hot spot' map is also often produced with the median weighted value per cell to derive a core range. Home range maps are helpful when evaluating resource needs within a given area, for example they can be used to estimate the impact that an individual animal has on the vegetation in its surroundings (Girard et al., 2002). The current study is concerned with a small, enclosed area and a small population. The KDE with automatic bandwidth calculation is deemed the best fit for determining home range size for the collared individuals.

Companies such as African Wildlife Tracking (AWT) build custom RF collars with onboard GPS tags according to target species' anatomy, mobility, terrain, and the duration that the tag would need to be fitted to the animal for. Input data for KDE home range analysis is directly obtained from the GPS tags. The duration of collecting tracking data is linked to the research question/s and the aim/s of the investigation. On a small island such as Mnemba where resources and space are limited, movement data for at least an annual cycle, for a male and a female Aders' duiker would provide the information needed to be able to make accurate inferences about home range size and carrying capacity on the island (Quinton, 2016).

4.8.2 Resource use, Home range size and Carrying capacity

Spatial ecology is thus concerned with the relationship between the location of resources and the distribution of consumers around it (Burt, 1943). This field of ecology adds tremendous value to decision making and managing wildlife areas. Underlying assumptions and theories have been devised within the field of spatial ecology, especially with regards to resource distribution, to explain complex dynamics of range size and overlapping ranges. For example, the robust Resource Dispersion Hypothesis indicates that range size does not relate directly to the size of the group sharing the area (population density), but to the spatial arrangement of the surrounding resources. It is suggested that group size is related to habitat heterogeneity and the richness of resources in a habitat. The theory assumes that in a heterogeneous environment the minimum social unit (for example a pair of duiker antelope) will never utilise all the resources in their range, and that the range can be shared with additional individuals without resources being depleted (Johnson et al., 2002). The same food patches can form part of more than one home range according to the Resource Dispersion Hypothesis, not only in space but also in time. The random distribution of fruit trees on an island would thus allow various pairs and groups to utilise the same resources as food patches, provided that the population is small enough to allow sufficient spacing in a feeding cycle where the food source is accessed at different times by the different groups. Observation of widespread overlap in home ranges of the solitary Natal red duiker suggest that spatial separation among duikers does exist, but within the parameters of the social interaction of each species (Jarman, 1974; Bowland and Perrin, 1995).

In addition to the heterogeneity of resource distribution, phenological changes during wet and dry seasons create variation in home range size, feeding times and routines, which lead to further overlap. The Resource Dispersion Hypothesis states that at times when resource patches are richer than in other seasons (or displaying a patchier distribution), larger ranges are observed with greater overlap among groups (Johnson et al., 2002). Various studies agree that poor resource quality and extreme patchiness contribute towards larger home range sizes (Downs et al., 2012).

Downs et al. (2012) cautions however against wrongful conclusions about home range size, since the association between individuals, groups and resources is a complex dynamic not to be simplified for the sake of theoretical assumptions. Cooper (1978), Gittleman and Harvey (1982), Lindstedt et al. (1986) and Litvaitis and Sherburne (1986) have documented the effects of population size, energy requirements, forage availability and individual size as influences on home range extent, indicating that home range sizes are adapted to accommodate changes in these variables.

The balance between resource management and optimum breeding, which includes of rare and endangered species (Plotz et al., 2016), is known as the Ecological Carrying Capacity (ECC) (Rachlow, 2008; McLachlan and Defeo, 2018). Thus far the advancement in spatial ecology tools have proven invaluable in understanding resource electivity, estimating carrying capacity and developing harvesting schedules (Fagan and Lutscher, 2006; Mitchell and Powell, 2007; Downs et al., 2008; Rayfield et al., 2009; Plotz et al., 2016). Like home range size, carrying capacity is not static, but varies with time, over cycles of resource productivity, changing predation levels and human influences (Rachlow, 2008; Kuzyk et al., 2009; McLachlan and Defeo, 2018). Within the scope of ECC, the objective of a specific project or area, further guides the desired carrying capacity (K) or density. Recent literature points out that domestic stocking estimates using Browsing Units (BU) or Grazing Units (GU) for calculating carrying capacity is not accurate when applied to ungulates in the wild. To avoid the potential error of overestimating the capacity of the already fragile forest habitat, the scope of the current study ruled out the typical ECC approach (Kuzyk et al., 2009).

Four alternative objectives of an ECC are: Maximum Sustainable harvest Density (MSD), Minimum Impact Density (MID), Maintenance Density (MD) and Tolerance Density (TD). At MSD, the population would continue to yield a positive growth rate while placing no extra pressure on the habit and resources (Wildlife Campus, n.d.). This is also called the Maximum

Sustainable Yield for a population in a specific environment (Russel, 1931). Takeoff (live harvesting) would be focused on younger animals that are not yet producing offspring, or old animals that are not contributing to population growth. Breeding pairs are not disturbed and minimum interference with the social structure of the reproductive population is ensured during harvesting. The second objective of MSD is to prevent the population from reaching a density level that would put pressure on habitat resources, especially during unexpected ecological changes. The importance of habitat preservation is recognised by the maximum harvest density objectives, without compromising the conservation goal of increasing the animal population. If the vegetative habitat is the main resource to protect, the MID approach would provide a better strategy by keeping the population at minimum sustainable yield (Wildlife Campus, n.d.). However, minimum sustainable yield would not benefit the declining population plight of the Aders' duiker in Zanzibar. The last two ECC objectives mentioned above are MD and TD. The former is concerned with the number of individuals that the habitat would support without considering pressures on resources, for example, the population number that is reached when no population management or intervention exists. This population objective is in contrast with the MID approach (Wildlife Campus, n.d.). The latter, TD, refers to the resulting population density when territorial and behavioural factors play a predominant role in controlling the spatial capacity of a given area. TD requires that animals have the freedom to move in and out of the study area (or a bounded area), and being killed off due to territorial bouts and physical competition.

Many different approaches have been used by wildlife managers and commercial fisheries to calculate sustained stocking rates (Kuzyk et al., 2009; Bobo et al., 2015; Barua and Panhwar, 2017), but in practice, carrying capacity is not always measureable from raw input data (Milner-Gulland and Mace 1998; Morris and Mukherjee, 2000). Researchers have however indicated the usefulness of density surveys of undisturbed populations (Russel, 1931; Robinson and Redford 1991; Bodmer and Robinson 2004; Tobler et al., 2013) and population growth models (Jensen, 1975; Milner-Gulland and Mace 1998) in simulating sustainable harvesting programs. The current study, a baseline of ecological conditions of the Aders' duiker population, was concerned with estimating a maximum sustainable harvest density based on the current conditions on the island. Current population density from survey results would be equivalent to the Maintenance density as per the definitions mentioned above. Using the Maintenance density figure, a more sustainable density, i.e. Maximum harvest density could be derived.

Maximum Sustainable harvest Density as an expression of ECC assumes that the resource in question is independently renewable without intervention. It also assumes that takeoff stimulates growth, which leads to a total population figure that supersedes the MD population if no harvesting took place (Russel, 1931). The sustainable harvesting approach is further informed by logistic population growth models, which advocate that the resource does not grow indeterminately, but based on the intrinsic growth rate and resource availability, a plateau is reached when the supporting environment reaches its maximum carrying capacity (Milner-Gulland and Mace, 1998). The logistic growth model has proven particularly useful in populations that are bound to a specific area when the assumptions mentioned above are met (Jensen, 1975). The practical application of MSD as the desired density figure is thus rooted in the logistic growth model's assumption that a sexually mature population at half the carrying capacity of an area would increase at maximum rate and at no detriment to the population or the environment. Harvesting an unsustainable number of animals leads to population decline, while allowing the population to increase to full capacity leads to a zero-growth rate due to density dependent limitations (Morris and Mukherjee 2000; Kuzyk et al., 2009; Tobler et al., 2013, Bobo et al., 2015).

Using population density estimates in predicting carrying capacity in heterogeneous habitats have some limitations. The dynamic role that spatial factors play in the carrying capacity of wild ungulates was demonstrated by Iijima and Mayumi (2016). Interpretation of carrying capacity should thus be informed by the spatial use of the environment, which considers resource dispersion, quality and population density, and the effect it has on home range size across seasons (Trewhella et al., 1988; Newing, 1994; Bowland and Perrin, 1995; Johnson et al., 2002; Amin et al., 2015).

4.8.3 Home Range analyses on Mnemba Island

As explained in the preceding section, home range (HR) is the area traversed by an individual (or by the core social unit) during its daily activities of food gathering, and seasonal activities including mating and caring for offspring. Territorial species (or genders) often patrol areas that are larger than their routine home ranges (Burt, 1943) and this should thus not be mistaken for a larger home range.

Due to Mnemba Island's restricted size and isolation from Unguja or any other forest habitat, it was assumed that home ranges would not be exclusive, but that some overlap would occur.

This assumption did not compromise the results since the Resource Dispersion Hypothesis (Johnson et al., 2002), which underlies home range theories for frugivores, states that home range overlap does not interfere with resource availability for the primary social unit in a given home range. The most accurate method to collect home range data were identified as GPS tags fitted to Ultra High Frequency (UHF) collars. Tracking collars have been successfully fitted to a variety of small antelope and other small animals, proving to be a feasible technique for assessing spatial utilisation of habitat (Tucker et al., 2014). It was decided to deploy four custom-built GPS enabled radio frequency collars, developed by Africa Wildlife Tracking (AWT) (weighing 130 gms each), fitted to two male and two female Aders' duikers. In addition to the mark-recapture survey of Aders' duiker during the Suni capture in April 2016, the four tracking collars were fitted to selected animals for the commencement of home range investigations. Low powered UHF (Ultra-High Frequency) transceivers with long range capability were used to send and receive data through the dense forest cover. The time interval for logging location readings was set to two hours and 55 minutes, with GPS co-ordinates stored onboard the non-volatile memory of the GPS tags. The storage capacity of the onboard memory was 8 176 readings. Data were downloaded to a handheld transceiver over UHF every six weeks, after which the tag memory was cleared. Each GPS log included the tag ID, date/timestamp, a waypoint, 3-axis accelerometer data (x, y, z), movement since last reading (Y/N), temperature, and speed if the tag was moving. GPS accuracy, DOP (dillution of position) was 10 meters, and location points were not truncated (Walter et al., 2011). An on-site IM-SAT Tower was erected to communicate new settings with Tags through the AWT (Africa Wildlife Tracking) server if necessary, and to monitor movement from off-site (as an early warning system in the event of animals getting stuck).

Collars were fitted to four Aders' duiker (Figure 4-4) in April 2016 during the Suni capture and Aders' duiker mark-recapture survey. Only two of the four GPS tags, one male and one female were successful in collecting data over the full twelve-month cycle. One of the male collars failed to download GPS points to the handheld RF receiver from deployment. When the collar was removed along with the others after a year, it was found that no data were stored on the onboard memory. The second female that was fitted with a collar suffered from capture myopathy and died a few days after capture. To prevent complications and possible further deaths, a decision was made to not deploy any more collars, but to supplement the two working collars data with observationional data from non-collared animals. Observational data would be collected during field trips. The remaining two collars successfully collected location data from the end of April 2016 to April 2017, after which the collars were removed.

For the current study, an annual cycle of location point data was necessary to calculate an average and seasonal home range for selected animals. Collared animals formed part of separate breeding pairs. Rudimentary deductions could thus be made about the extent to which the two individuals as part of their pair bonds utilised island resources.

As discussed in the ethics clearance section (Section 4.2), the removal of the collars was done by immobilising the duikers. The chemical capture was performed by a highly experienced wildlife veterinarian, Dr. Cooper, in collaboration with Dr. Ramadan from the State Veterinary Department in Zanzibar. A cocktail of immobilisation chemicals consisting of 0.5 mg Thiofenatanyl, 20 mg Ketamine, 4 mg Azaperone and 2.5 mg Butorphenol, was administered as an adult dose, using a 1 cc Pneudart with a half-inch barbed needle, launched from a gas-powered Dan-Inject dart gun. Butorphenol is a mixed antagonist/agonist which countered the respiratory depression of the opiods, withouth waking the duiker up completely. Naltrexone was given at the end, which reversed the effects of all the substances. This combination of chemicals allowed for a quick recovery after administration of the antidote, allowing for a shorter down time and less risk of fatalities to the animals during immobilisation.

Figure 4-4: Collared Aders' duiker female, Tag number 1625 (Shephard, 2016).

GPS location points were collected every two hours and 55 minutes when conditions were favourable. Using the GPS fixes from both animals, home range was estimated using kernel density estimation (KDE). Two other home range analyses were also considered - the Minimum Convex Polygon (MCP) and the Elliptical Time-Density (ETD) model. All methods use GPS coordinates as input data to generate space utilization patterns (Lichti and Swihart, 2011). Although the kernel method has come under much scrutiny in the past (Fieberg, 2007), as a home range estimator the KDE has proven to be more accurate than the MCP (Seaman et al., 1999). The MCP tends to overestimate the size of home ranges in small areas and was thus not considered as a suitable method for the current study. The ETD model was contemplated as a more recently developed approach to estimating utilization distributions for wildlife (Wall et al., 2014). The strengths of this trajectory-based model lie in its ability to draw on speed and direction between fixes and preserving connectivity between subsequent points. However, in the context of a very small site area (and an even smaller range for the duikers tagged in this study), the need for assessing movement corridors and considering direction and speed in mapping the home and core ranges, was negated. Also, a very small and homogenous terrain, in combination with regular location fix intervals, a long study period, and very small ranges with no possibility to migrate, the use of independent location points in the KDE was not necessary, and technically not possible in this study (Swihart and Slade, 1997). The use of the nonparametric KDE in ArcGIS for the purpose of this study was suitable for describing density probability with parameters set for the highest level of accuracy possible (more details in section 8.2.2) (Swihart and Slade, 1997; Lichti and Swihart, 2011; Fleming and Calabrese, 2017; Winner et al., 2018; Fleming et al., 2018).

ArcGIS 10.3 was used to calculate the KDE for the Aders' duikers' GPS collar data. From the KDE output file, a 95% KDE was extracted as the average Home Range, and 50% KDE as the average Core Range (Plotz et al., 2016; Quinton, 2016; Fleming and Calabrese, 2017) for the two sampled duikers. Analyses of the spatial data obtained from the GPS collars are described in more detail in the methods section (8.2) of Chapter 8.

4.9 Diel patterns

Data sources for the assessment of diel patterns can include camera trap images (Amin et al., 2015; Ikeda et al., 2016; Frey et. Al. 2017; Vazquez et. al. 2019), manual observations (Boman and Plowman, 2002), and spatial data collected from GPS tracking devices (Ensing et al., 2014). Chapter 2 referred to focal observations of *P. monticola* - blue duiker and *S.*

grimmia - common duikers (Boman and Plowman, 2002) that confirmed crepuscular activity patterns for these forest antelope, even in captivity. The focal observation component of the current study was limited to daylight hours by poor visibility directly after sun set until just before sunrise. The use of night vision equipment did not prove successful which restricted direct observation of behaviour to daylight hours (Section 4.6). From evidence presented by Amin et al. (2015), daylight hours cover all the activity incidents needed to confirm the main activity patterns for Aders' duiker. However, it was necessary to investigate the degree to which the sub-population on Mnemba followed a similar diel pattern in the absence of predators and under high population density conditions. Gathering nocturnal activity data were thus very important to gauge the degree of nocturnal activity. To address the nocturnal activity gap, 12 months of temporal-spatial data were extracted from the GPS collars fitted to two duikers, as 'distance travelled' in meters and annual data pooled, by 'hour of the day'. This included nocturnal movement and related data that were stored on the tags.

A very detailed diel pattern for the two duikers could be compared with information from existing literature, as well as with focal observations in the current study. It was however anticipated that average daily distances would be underestimated due to the two-hour 55-minute gap between successive points. The difference between average distances travelled in the different time categories of the day (see Chapter 8) were also compared for seasonal differences. This way it could be postulated that diel pattern was different for the two duikers between the two seasons.

All spatial analyses were done using the Geographic Projected Coordinate System: Arc_1960_UTM_Zone_37S, Projection: Transverse_Mercator; Linear unit: Meter, and a Geographic Coordinate System: GCS_Arc_1960, Datum: D_Arc_1960, Prime Meridian: Greenwich, Angular Unit: Degree. Chapter 8 describes the methods and calculations in more detail.

4.10 Carrying Capacity

As stated in section 4.4, the results from the survey were integral in estimating the carrying capacity for the island. Combined with desired habitat quality and conservation aims, population counts are often used to guide decisions about ecological carrying capacity and harvesting schedules in a closed environment (Jensen, 1975; Tobler et al., 2013; Plotz et al., 2016; Lyons et al., 2018).

An ecological carrying capacity approach was followed with the density objective set at Maximum Sustainable Density (MSD). Since carrying capacity, as described in section 4.8.2, is not a static ecological condition, and is mainly linked to the management objectives of an area, the estimate of MSD from population results would be a starting point for further monitoring and should be adjusted as the breeding project continues (Jensen, 1975; Milner-Gulland and Mace, 1998; Morris and Mukherjee, 2000; Rachlow, 2008; Kuzyk et al., 2009; McLachlan and Defeo, 2018; Wildlife Campus, n.d.).

The key assumption was that the carrying capacity (k) at the time was equal to the population (D_{est}) of duikers on the island. This approach was taken due to the lack of any previous survey or population growth data for the duiker population on Mnemba (Bobo et al., 2015). The method of estimating carrying capacity from population density ($k = D_{est}$) for duiker species has been performed for undisturbed and disturbed habitats, using the Robinson and Redford (1991) model to calculate the maximum utilizable surplus (P_{max}) based on the maximum growth rate (r_{max}) (Robinson and Redford, 1991; Bodmer et al., 1994; Fa et al., 1995; Feer, 1996; Delvingt et al., 1997; Dethier and Ghuirgui, 1999; Noss,1998; Muchaal and Ngandjui, 1999; Ngandjui and Blanc, 2000). The logistic population growth model was used to simulate Maximum sustainable density (MSD) at various levels of k, as guided by population (D_{est}) figures from the survey results. Chapter 6, section 6.2.3 elaborates on the equations used, while section 6.3.2 presents results and provides options for harvesting schedules.

The practical application of Maximum sustainable density (MSD) as the desired density figure is rooted in the logistic growth model’s assumption that a sexually mature population at half the carrying capacity of an area would increase at maximum rate and with no detriment to the population or the environment. Harvesting an unsustainable amount would lead to population decline, while allowing the population to increase to full capacity leads to a zero-growth rate due to density dependent limitations (Morris and Mukherjee 2000; Kuzyk et al., 2009; Tobler et al., 2013, Bobo et al., 2015).

Population density estimates have limitations in predicting carrying capacity in heterogeneous habitats. The dynamic role that spatial factors play in the carrying capacity of wild ungulates was demonstrated by Iijima and Mayumi (2016). Home range data collected in the current study provided a key spatial element to the ecology of the duikers in light of spatial capacity of the island. As with the population survey, home range data were collected at a time when the duiker population had reached a maintenance density on the island. Home range results would thus be directly related to the effects of population density, habitat heterogeneity and consequently carrying capacity. The size of the two measured home ranges was extrapolated to the rest of the island to compare the spatial carrying capacity with population density estimates (Ryan and Jammieson, 1998; Adcock, 2001a, 2001b; Downs et al., 2008; Downs et al., 2012; Iijima and Mayumi, 2016).

This study did not aim to provide a carrying capacity for the Suni antelope as a co-existing antelope on Mnemba island. From the onset of the research, it was clear that the island was not big enough for both these species. Aders' duiker population figures are plummeting in Zanzibar, while Suni are thriving and more versatile in its' habitat.

CHAPTER 5

VEGETATION ANALYSES OF MNEMBA ISLAND

5.1 Introduction

Due to the small size and close proximity to Zanzibar, species richness on Mnemba Island was anticipated to fall between the high and low ranges of Unguja's diversity, and possibly at the lower end of the ranges for evenness. Smaller habitats can reflect a lower evenness, while richness and diversity could still be relatively high. Low evenness is also an indicator of fragmentation or isolation of forest patches (Mligo, 2015). As explained by Hnatiuk and Merton (1979), major disturbances can cause the vegetation of an island to change completely over time. For this study, the classification of the current vegetation of Mnemba Island was to enable better habitat management, as well as to understand the ecology of the forested area on the island. The compilation of a food species database further assisted in understanding how the island served as suitable habitat for the endangered Aders' duiker. Continual management of the island's vegetation is necessary to ensure sustainability and preservation of the endangered duiker population. Fiske (2011) noticed that the large section of *Casuarina cunninghamiana* on the island might hinder propagation of the natural habitat and associated food species. She recommended regular vegetation surveys of Mnemba Island for management purposes. This study will be the first quantitative vegetation survey for the island.

Suni antelope and the endangered Aders duiker were introduced to Mnemba Island in 1993 and 2005 respectively (Mwinyi and Hija, 2008). Since introduction to the island, the Suni antelope have bred prolifically and placed pressure on the vegetation of the island (Mwinyi and Hija, 2008). AndBeyond raised a concern that overpopulation of the island could have long-term consequences on vegetation health and influence the sustainability of the Aders' duiker breeding program. Although Suni offspring had been captured and removed twice before the current study, the island's vegetation was still visibly over-browsed (a clear browse line could be observed) up to a height of 1.2 m above ground level. No studies have yet been done to evaluate the health and biodiversity of the island's vegetation, exept for a brief investigation into the terrestrial landscape in 1989, which revealed that among others, the Giant Fig (*Ficus lutea*), Milk wood (*Sideroxylon inerme*), Rubber Fig (*Ficus scassellati*) and Dune cross berry (*Grewia glandulosa*) were important indigenous plant species occurring on

Mnemba Island. At that time, Ngoile (1990) described the overall structure of the forest as having three zones distinguished by *Casuarina cunninghamiana, Pandanus kirkii* and *Pemphis acedula*. He also recorded that the zones were separated by noticeable ridges in the sandy substrate that had built up over the years. The list published by Ngoile (1990) included only 32 plant species and did not constitute a comprehensive vegetation survey or classification of the plant communities.

Considering recent climatic changes in the region and the rise in sea level, the compounding effects of Suni overpopulation might change the island's future landscape and suitability as an antelope sanctuary, highlighting the need to monitor and manage the island's vegetation. Without baseline data of the terrestrial environment, monitoring of changes and impacts are impossible. It is thus imperative to establish a foundation from which to monitor biodiversity and vegetation health as part of a conservation management plan on the island. Given the current study's concern with the ecology of the rare and locally endangered Aders' duiker, with particular interest in foraging behaviour, a vegetation survey is important to provide context to the duikers' foraging behaviour (Kent and Coker, 1997). This vegetation study provides the baseline data for food species identification, calculating electivity of food items, and phenological analyses from in-situ foraging observations of the Aders' duiker (Chapter 7). Of particular interest for management planning, are the differences in plant species diversity and composition between the two main physiognomic-physiographic areas that are distinguished from aerial and on-site investigations: The "planted" *Casuarina cunninghamiana* section and the natural or original atoll vegetation.

5.2 Chapter objectives

This chapter contains the findings from the current vegetation survey done on Mnemba Island, describing the plant communities that were identified from data collected during fieldwork in 2016 and 2017. The structural breakdown of the plant communities and their spatial location within the study area are provided. Floristic and environmental results are compared for the various plant communities.

5.3 Methods

5.3.1 Study area

Mnemba Island is a sandy cay mounted on a sub tidal (shelf) atoll reef (Woodroffe and Biribo 2011; Goldberg, 2016), located within the Swahili coastal forest region. Waves are instrumental in the building of reef islands through wave and reef flat interaction, creating a building and corroding interchange which contributes to the dynamic nature of these islands (Fonseca et al., 2012; Woodroffe and Biribo, 2011). Mnemba's sandy beaches are protected from wave impact by various species of adaptive vegetation. Well established vegetation has settled on the island since the formation of the atoll (Woodroffe and Biribo, 2011; Goldberg, 2016). The natural vegetation consists of shrubs, trees, mangrove species (screw pines), lianas and creepers. The *Casuarina cunninghamiana* plantation was initially introduced to the island as a wind break from wave and ocean-current generated winds before the 1970s, and now almost surrounds the natural vegetation on the island. Mnemba has a homogenous sandy substrate throughout, unlike the shallow coral substrate found on Unguja and islands such as Chumbe, Tumbatu and Pemba. Shallow sandy soils are typical of coral rag forests and contributes to low plant diversity (Beentje, 1990). Although Mnemba Island falls within a biodiversity hot spot, the size of the island and its sandy nature are potential limitations to its species diversity (Samoilys et al., 2015).

The island's vegetation plays a significant role in bird ecology throughout the year (section 3.3.3) and stabilization of the sandy cay. Amidst the forest, Mnemba Island also houses the AndBeyond Mnemba Island lodge with supporting infrastructure (Figure 5-1).

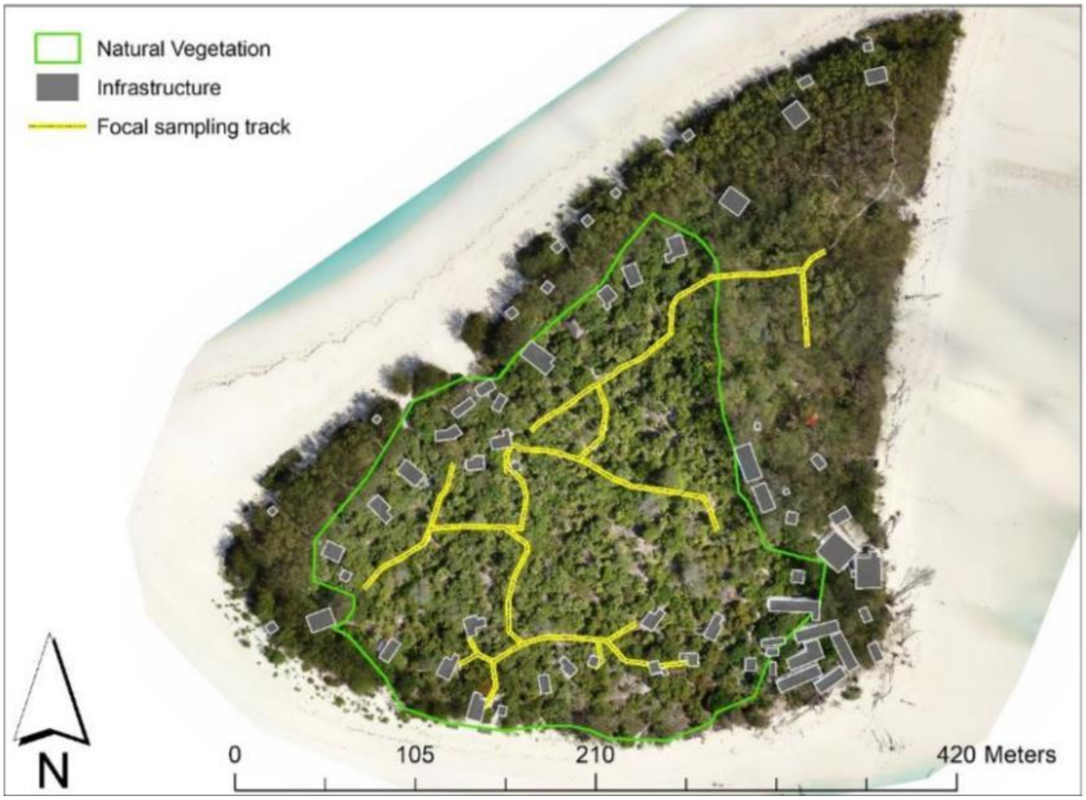


Figure 5-1: Aerial view of Mnemba Island's foot path and infrastructure in November 2016.

The sandy soil ranges from white beach sand on the outer fringes of the forest, to dark brown sand in the interior of the island and is well drained throughout. No coral karst is visible, but small amounts of coral-rich limestone and pumice stone are scattered in isolated patches on top of the sandy substrate (Ngoile, 1990; Arthurton et al., 1999; Pickford, 2008). Fossilised molluscs and coral conglomerates were also found in isolated areas. Coral rock from Unguja had been transported to the island when the lodge was constructed in the 1970s, and much of the coral rock scattered around the built areas are remnants of these building materials.

Sandy foot paths form a basic trail network, connecting the different ends of the island through the forest (Figure 5-1). Foot paths were mainly constructed for tourist activities. The island is further characterised by scattered AndBeyond Lodge buildings, staff accommodation, a store and workshop, desalination plant, small mosque and a water tower placed in the forest vegetation. In total, 113 300 m^2 of the vegetated part of the island consists of 106 746 m^2 of forest and footpaths, and 6 554 m^2 of building footprints (excluding any other man-made footprints or impacts affecting vegetation growth) (Figure 5-1). In Table 5-3 the size of the vegetation cover and built infrastructure for each plant community is quantified in square meters and percentage footprint.

The closest point from Mnemba Island to Unguja is Muyuni beach, 2.7 km across the 75 m deep channel between the two islands. It is assumed that the closest source for species introductions to Mnemba Island is from Muyuni area. However, the vegetation on Muyuni beach is greatly affected by fuel wood farming (Sumbi, 2002) and over the last 50 years the natural coral rag vegetation has been completely altered by human activities (Burgoyne, 2018). Informal communication with long-term staff and community members working on Mnemba Island confirms that Muyuni used to be characterised by various large tree and shrub species. Large-scale road construction and tourism development activities recently caused significant deforestation in Muyuni and neighbouring areas. The anthropogenic impacts on the area around Muyuni beach has resulted in drastic changes in vegetation over the years (Sumbi, 2002; Burgoyne, 2018). At the time of the current investigation, a large area of vegetation around and including Muyuni was burnt by property developers. The lack of intact vegetation prevented comparative studies of vegetation composition and structure between Mnemba Island and Muyuni.

5.3.2 Phytosociology

Mnemba Island is part of the Swahili coastal forest region and hosts mature coastal forest tree species, suggesting that the minimum sample relevé area for sampling the islands vegetation should be between 400 m^2 and 1 000 m^2 (Brown et al., 2013). Since relevés for the current study had to fit into narrow sections of the small triangular floristically homogeneous forest, a relevé size of 400 m^2 was selected for doing the vegetation surveys. A vector grid was created in ArcGIS (specifications set at 20 x 20 m blocks) and overlaid onto the island’s vegetation map (Figure 5-2).

The centre coordinates of each grid cell were listed as a location attribute (Latitude and Longitude, DMS) (Brown et al., 2013), along with a unique number for each cell. Based on a cell’s location within one of the two physiognomic-physiographic areas, each cell was assigned to either “planted” or “natural” vegetation (Barrett, 2009). Cells that were located only partly within either planted or natural vegetation were omitted from the list of potential cells for random selection of sample relevés. A total of 87 possible relevés were located in the planted forest and 110 relevés within the natural forest, totalling 78 800 m^2 of sampleable vegetation. Since the planted forest was visibly more homogenous compared to the natural vegetation and did not provide the main habitat for the resident antelope species, it was decided to base one third of the relevés in the planted vegetation and two thirds in the natural vegetation.

Using the random selection function in MS Excel, eight relevés in the planted area and sixteen relevés in the natural forest were selected. The combined size of the 24 selected relevés was 9 600 m^2, which translated to 12% of the suitable area. For classification of the island's plant communities, eight relevés in the homogenous planted forest (Weber et al., 2000), and sixteen relevés (exceeded the minimum of ten recommended by Brown et al., 2013) in the natural forest were sufficient.

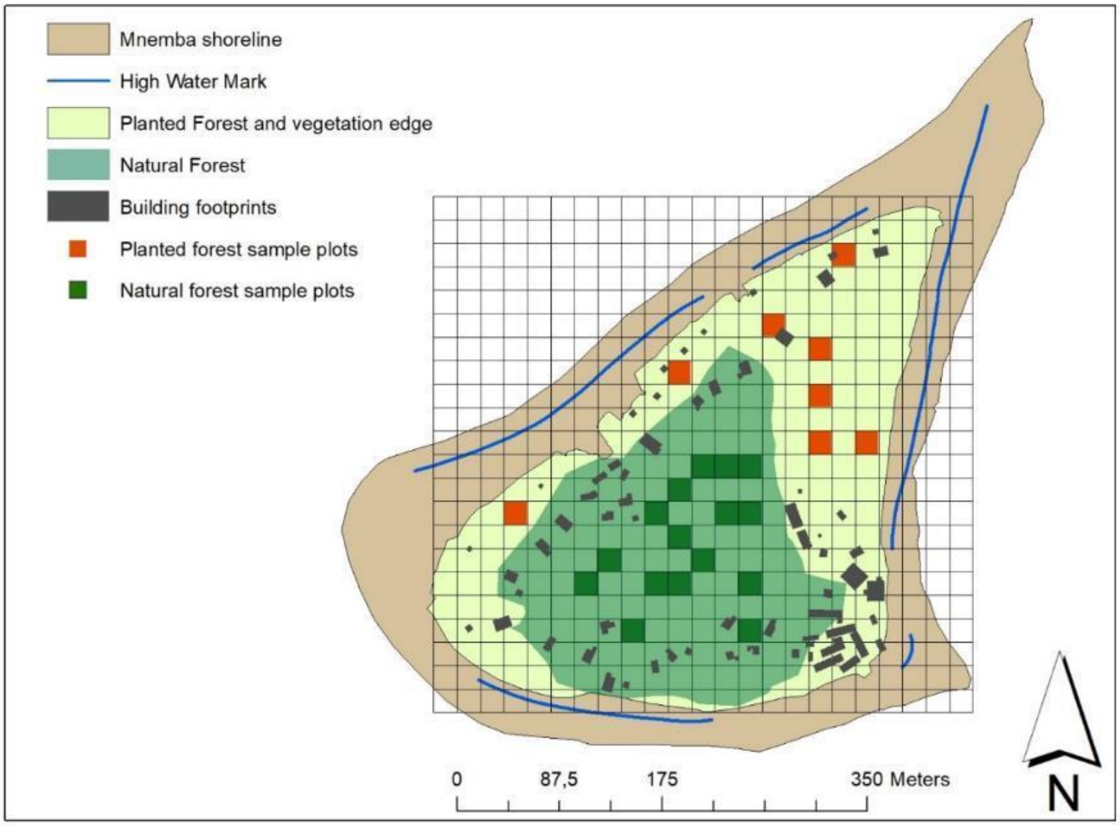


Figure 5-2: Reconnaissance map of Mnemba Island, with vegetation survey sampling grid overlaid. Red grid cells indicate random sample relevés in the planted areas while dark green grid cells indicate sample relevés in the natural forest.

In the field, random relevés were further assessed for suitability based on homogeneity (Zurich–Montpellier sampling method) and proximity to guest rooms and infrastructure (Kent 2012). Vegetation surveys near guest rooms could only be conducted if the rooms were not occupied. Relevé's that contained infrastructure, or that would impose on guest privacy while being sampled, were replaced with the first suitable neighbouring relevé, starting at the top right corner of the initial random selected grid cell and moving clockwise (Figure 5-3). If none of the neighbouring cells were suitable, the process was repeated with the neighbouring cells one "layer" removed. In Figure 5-3 randomly selected relevé number 263 is used as example. In-field conditions revealed that the relevé was too close to a guest room. Starting at the NE corner, the next available neighbouring relevé, grid number 287, was also too close to a guest room. Again, the next available neighbouring relevé, grid number 264, was not suitable due to guest activities. The fourth available neighbouring relevé, number 241, was suitable and thus replaced the random relevé number 263 in the sample relevé list for Natural forest relevés. This process was applied consistently to ensure repeatability of the study.

The presence of sandy paths in a relevé did not discount it from being surveyed. A path was categorised and quantified as the percentage of 'nonvegetated' area of a relevé. Random sample relevés were located using a Garmin eTrex GPS and an Android digital field compass from Chartcross Limited (available on Google App store - installed on a Samsung Note 10.1). During fieldwork sessions, cloudy weather and magnetic interference resulted in the researcher using two separate devices to ensure accuracy of GPS locations. The latitude and longitude from the central point of each relevé was first located, followed by the four corners of each relevé. Corners and halfway marks (between the four corners) were marked out for better visibility of relevé boundaries in the dense forest before survey activities commenced.

Sample relevés were documented by taking a photo from the centre point towards eight directions (North; North-east; East; South-East; South; South-west; West; North-west). A diagram of shrub and tree cover was drawn by hand to aid in calculating species cover-abundance and cover classes for growth forms. All plant species from survey relevés were assigned a cover–abundance class using the modified Braun-Blanquet cover-abundance (BBCA) scale - Table 5-1 (Brown et al., 2013). Survey forms were designed in TerraFlex software and loaded onto the Trimble GeoExplorer (6 000 series) handheld computer. Field data were captured and uploaded directly to the InSphere Online data portal over Wi-Fi.

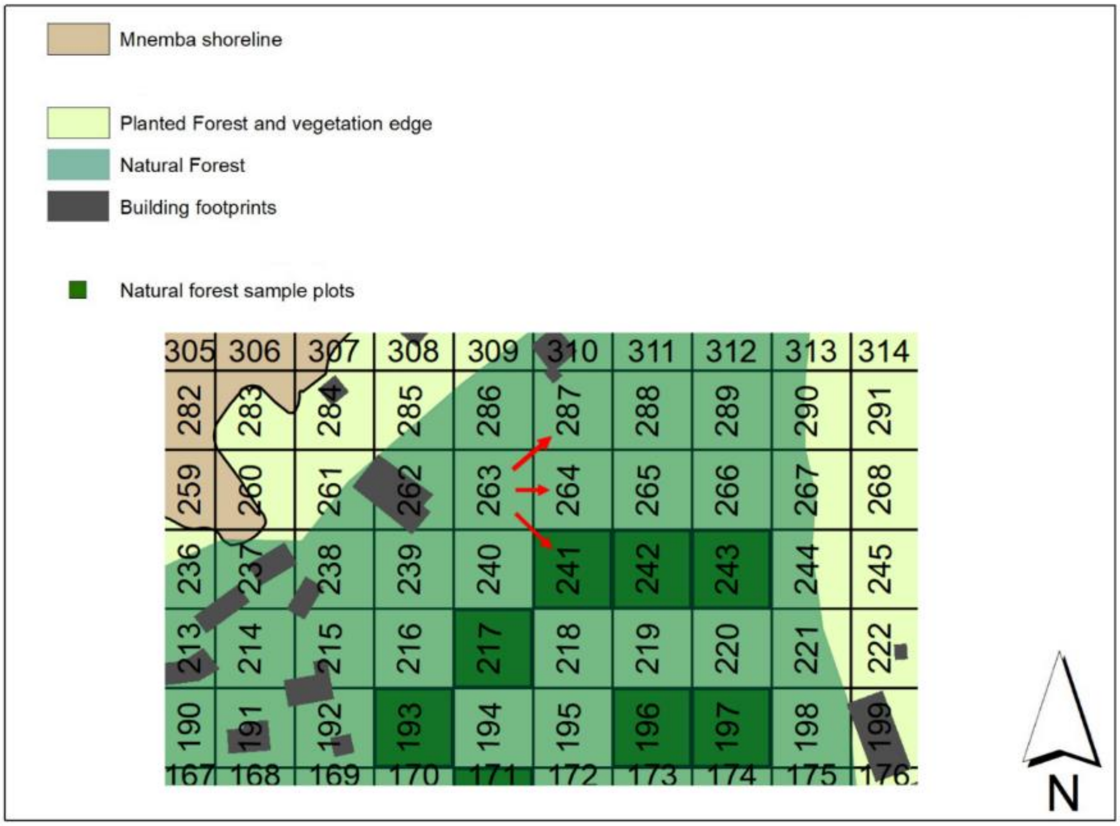


Figure 5-3: Sample grid methodology.

Braun-Blanquet data were then manually prepared for importation into the vegetation program JUICE. Plant communities were derived using the modified TWINSPAN algorithm through clustering vegetation according to similar internal heterogeneity (Kent and Coker, 1997; Roleček et al., 2009). A phytosociological table was then constructed and refined according to the methods set out in Brown et al. (2013). Plant community names were assigned according to the International Code of Phytosociological Nomenclature (Weber et al., 2000; Brown et al., 2013). Braun-Blanquet ordinal classes were converted to continuous nominal cover percentages by using the predicted mean (PM) values for each ordinal category as published by McNellie et al. (2019). McNellie et al. (2019) found that smaller species tended to be over-estimated when transformed to averages, but since Mnemba Island's vegetation was primarily dominated by shrub and tree forms, the PM values were considered suitable for the purpose of the current study. Table 5-1 includes the PM cover-abundance values for each Braun-Blanquet Cover-Abundance (BBCA) class.

Table 5-1: Modified Braun-Blanquet cover abundance scale and the predicted mean (PM) value for each class, as calculated by McNellie et al. (2019).

Scale	**Description**	**Predicted Mean (PM) (McNellie et al., 2019)**
r	One or few individuals with less than 1% cover of the total sample relevés area.	0.01*
+	Occasional and less than 1% cover of the total sample relevés area.	0.49
1	Abundant with low cover or less abundant but with higher cover, 1 - 5% cover of the total sample relevés area.	0.74
2	Abundant with 6-25% cover of the total sample relevés area, irrespective of the number of individuals.	17.5
2a	6 - 12.5% cover.	8.95
2b	12.6 - 25% cover.	17.5
3	26 - 50% cover of the total sample relevés area, irrespective of the number of individuals.	38.77
4	51 - 75% cover of the total sample relevés area, irrespective of the number of individuals.	62.43
5	76 - 100% cover of the total sample relevés area, irrespective of the number of individuals.	81.24

The mean value for class 2a in the modified BBCA scale was covered by McNellie et al.'s (2019) table. PM values for 2a were adapted by using the mean cover value for class 2 proposed by Braun Blanquet (1964), and the PM published by McNellie et al.'s (2019) was used for 2b. These two values represented the calculated means for the two sub-classes. Class r was also not represented in the PM table. A PM value of 0.01 – above 0 but less than 0.49 (PM for +) – was assigned to Class r in the BBCA.

Characteristic species were identified for each plant community by simplifying parameters from similar studies (Westhoff and van der Maarel, 1978; Grobler et al., 2006; Barrett, 2009):

- Between 11% and 100% constancy in the plant community, with a combined constancy value for the rest of the communities that are half the constancy value for the species in the characteristic community.

Cover percentages were calculated for each species in each plant community, by adding the PM values for each species per relevé in the community and dividing the summed PM value by the total number of relevés in the community:

- Dominant species were identified as species with a cover percentage of over 50% for any of the relevés in a characteristic community, or as the species with the highest total cover percentage in that community (Westhoff and van der Maarel, 1978; Van der Maarel, 2009; Wikum and Shanholtzer,1978, Barrett, 2009).

Species diversity was calculated for the characteristic species from each plant community, using the Shannon-Wiener index formula. The index value "H" accounts for evenness and abundance and range from 0 to 5, where a higher Index value indicastes a higher species diversity. Calculating evenness gives us an idea of the homogeneity of each community, where a value closer to 1 represents a high level of homogeneity. The diverstity index and evenenss valuea can be compared to understand the difference in diversity between the plant communities. The formulae are as follows:

$$1.\ \ H = -\sum[(pi) * ln(pi)]$$

$$2.\ \ E = \frac{H}{H\ max}$$

Where, $\sum$ = Summation
p_i = Number of individuals of species i / total number of samples
S = Number of species or species richness
H_{max} = Maximum diversity possible
E = Evenness, where H = Shannon Wiener Index

Additional data collected in each relevé included:

- Tree allometric measurements: Breast height diameter (BHD) at 1.4 m for each tree with a diameter bigger than 6 cm. The height of the lowest and highest individual for each species was also recorded.
- Percentage tree cover for each layer in the canopy was calculated
- Number of fallen and standing dead trees as well as species of such trees.
- Degree of (%) cover of rockiness.
- Degree of (%) cover of erosion and nonvegetated areas.
- Litter type, litter depth, humus type and humus depth.
- Signs of earth worms and other fauna.
- Basic soil type was recorded using the ribbon method (FAO, 2020) (see method in the Text box 2 below).

Mix 25 grams, wet the soil until it has a moldable consistency. Form a ball in your hand. If no ball is formed, the soil consists of sand only. Once in a ball, squeeze between index finger and thumb to form a ribbon of soil. If no ribbon forms, the soil is classified as loamy sand. If ribbons are formed but breaks before it reaches 2.5 cm, the soil is classified as loam. If the ribbons are longer than 2.5 cm but breaks at 5 cm, it can be confirmed as clay loam soil. Any ribbons over 5 cm is tipically classified as clay soil.

Text box 2

Tree density for each tree species was calculated by counting the trees with a diameter larger than 6 cm in each relevé (Dillis et al., 2015) and dividing this by the number of relevé samples in each community (n = 8 planted and n = 16 natural forest), this was then multiplied by the number of sampleable relevés from each community (n = 87 planted and n = 110 natural forest) (Orban, 1995). The advanced stick method was used where the height of the tree was calculated as (length of stick x distance to the tree) / (distance to eye), which worked for almost all trees on the island. Where stick method was not possible, tree height was estimated based on a nearby tree of similar canopy height. Once data was collected, tree height ranges were assigned to all trees with a diameter above 6cm: Low range = 4 to 9 m; mid-range = 10 to 14 m; High range = 15 m and higher (Adjusted from Dansereau, 1951).

Environmental characteristic differences between the main plant communities were tested for significance using the Mann-Whitney U test. Sub-communities were also compared for significant differences using the Kruskal Wallis test (all *P* values used were for 2 tailed tests and α was set at 0.05). Results are summarised in section 5.4.4.

5.4 Results

5.4.1 Classification of Mnemba Island plant communities

The results of the modified TWINSPAN classification differentiated two major plant communities, each consisting of two sub communities:

1 Casuarina cunninghamiana–Suriana maritima Open to Closed Sandy Dry Coastal Forest

  1.1 Casuarina cunninghamiana–Suriana maritima–Enteropogon macrostachyus Sandy Dry Coastal Forest Community

1.2 *Casuarina cunninghamiana–Suriana maritima–Chrysothrix* sp. *Open Sandy Dry Coastal Forest*

2 *Eugenia capensis–Mimusops obtusifolia Coastal Forest*

2.1 *Eugenia capensis–Mimusops obtusifolia–Scutia myrtina Coastal Forest*

2.2 *Eugenia capensis–Mimusops obtusifolia–Clerodendrum glabrum Coastal Scrub*

Figure 5-4 illustrates the spatial orientation of the different plant communities on Mnemba Island.

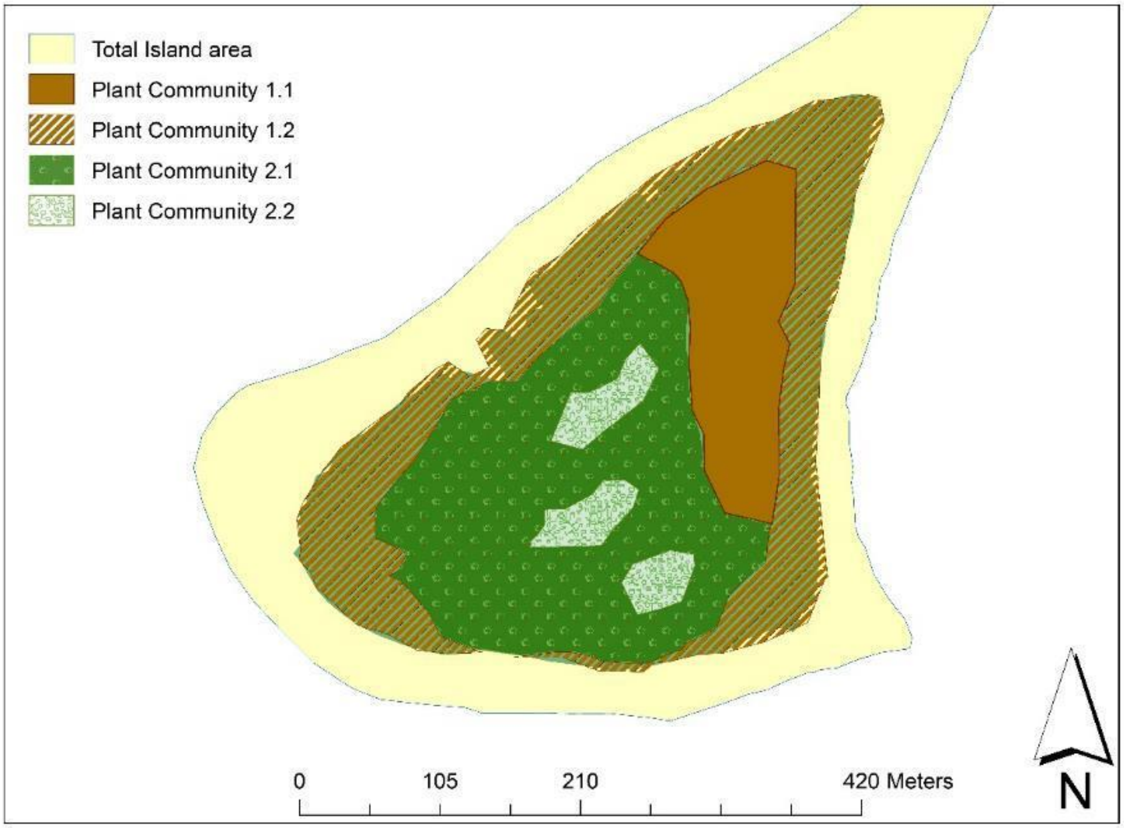


Figure 5-4: Plant communities identified on Mnemba Island.

The phytosociological table (Table 5-2) reflects the above mentioned major and sub communities through the grouping of dominant species for each plant community according to relevés (columns) and species (rows).

The constancy values for each species in their respective characteristic plant communities, compared to the rest of the island, are further illustrated in Figure 5-5.

Table 5-2: Phytosociological table with Modified Braun-Blanquet cover abundance scale values for each species as presented in the final plant communities for Mnemba Island. Maytenus hytrophylla (in species group B) is now *Gymnosporia heterophylla*

Community Number	**1**								**2**																	
	1.1				1.2				2.1									2.2							**% Constancy**	
Releve numbers	1	1					1		1	2	2	2	2	1	1	1	2			1	1		1		**Main**	**Other**
	3	4	7	6	3	2	5	1	7	0	2	4	1	6	8	9	3	9	5	2	1	4	0	8	**Community**	**Communities**
Species group A																										
Casuarina cunninghamiana	5	4	1	2b	1	5	4	5	.	.	.	.	r	.	.	.	r	.	.	.	.	.	.	.	100%	13%
Suriana maritima	+	+	+	r	2b	3	2a	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100%	0%
Enteropogon macrostachyus	+	2a	1	+	+	+	+	.	.	.	.	.	.	.	r	.	.	.	.	r	.	.	.	.	88%	13%
Evernia prunastri	+	+	+	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	63%	6%
Brachiaria leersioides	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25%	0%
Ricinus communis	r	r	+	1	+	.	r	+	.	.	.	.	.	.	.	.	.	+	.	.	+	+	.	+	88%	25%
Rhynchosia sublobata	+	.	+	+	+	r	.	r	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	75%	19%
Aneilema indehiscence	+	+	.	.	.	+	.	r	.	+	.	.	.	.	.	.	.	r	.	+	.	+	.	.	50%	25%
Dactyloctenium aegyptium	+	+	+	.	.	.	.	.	.	.	r	.	.	.	.	.	.	+	.	+	.	+	.	r	38%	31%
Polyporus tubaeformis	+	+	+	+	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	63%	13%
Species group B																										
Melanthera biflora	.	.	1	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	50%	0%
Panicum repens	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	75%	0%
Ipomoea pes-caprae	r	r	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	50%	5%
Scaevola sericea	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25%	0%
Kyllinga erecta	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25%	0%
Sesbania bispinosa	.	.	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25%	0%
Maytenus heterophylla	r	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	50%	5%
Species group C																										
Bougainvillea spectabilis	.	.	.	.	r	r	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	75%	0%
Chrysothrix sp	.	.	.	.	.	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	50%	5%
Fomitopsis pinicola	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25%	0%
Bidens pilosa	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25%	0%
Panicum maximum	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	25%	5%

Continue/

Species group D																										
Eugenia capensis	.	.	.	.	.	.	.	+	2a	3	2b	2a	2a	1	3	2b	3	2a	4	4	2b	2b	2a	2a	100%	13%
Mimusops obtusifolia	+	.	.	.	+	.	.	.	3	3	2a	1	+	+	+	2b	2b	+	1	2a	2b	1	1	1	100%	25%
Pandanus kirkii	r	2a	2a	.	.	.	.	.	2b	2b	1	+	2a	+	2b	1	2a	1	1	+	+	+	+	1	100%	38%
Secamone punctulata	.	.	.	.	r	.	.	.	+	1	2a	+	2a	+	1	1	1	+	+	1	1	+	+	1	100%	13%
Cassytha filiformis	.	.	.	.	.	.	.	.	.	+	1	1	+	1	+	1	1	+	2a	.	+	.	+	+	81%	0%
*Grewia glandulosa**	r	r	.	.	r	.	.	r	+	+	.	r	+	.	+	+	+	2a	1	2a	.	1	1	1	81%	50%
Maerua triphylla	r	.	.	.	.	.	.	.	+	+	+	+	+	+	+	.	1	.	.	r	.	r	+	+	75%	13%
Synaptolepis kirkii	r	+	.	.	.	.	.	.	+	.	+	r	+	.	+	+	1	+	+	.	+	+	.	1	75%	25%
*Pisonia grandis**	.	r	r	.	.	.	.	.	.	.	+	3	.	+	.	.	2a	.	.	+	.	r	+	.	44%	25%
Ecbolium ligustrinum	.	1	.	.	+	.	.	.	.	.	+	+	+	1	r	r	+	.	.	.	+	.	2b	1	63%	25%
*Suregada zanzibariensis**	r	+	.	+	.	.	.	.	r	.	+	+	+	.	.	.	+	+	.	+	+	+	.	+	63%	38%
Ficus scassellati	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	19%	0%
Afroligusticum linderi	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	r	.	.	13%	0%
Cocos nucifera	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	r	.	.	.	.	13%	0%
Adenia gummifera	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	r	13%	0%
Species group E																										
Scutia myrtina	.	.	.	.	.	.	.	.	.	.	2b	+	.	+	.	.	+	.	.	.	+	.	.	.	44%	7%
Pavetta stenosepala	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+	.	+	.	.	.	.	+	.	.	44%	7%
Bourreria petiolaris	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	+	r	.	.	.	.	.	.	33%	7%
Ficus lutea	.	.	.	.	.	.	.	.	.	.	r	.	+	.	r	r	.	.	r	.	.	.	.	.	44%	7%
Psychotria psychotrioides	.	.	.	.	.	.	.	.	.	r	+	+	.	.	.	.	.	.	.	.	r	.	.	.	33%	7%
Ficus polita	+	.	.	.	.	.	.	.	.	r	+	.	.	.	.	.	.	.	.	.	.	.	.	.	22%	7%
Conyza newii	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	11%	0%
Justicia capensis	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	11%	0%
Auricularia auricular-judae	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	11%	0%
Xanthoria sp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	11%	0%
Ludia mauritiana	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	11%	0%
Phaeotrametes decipiens	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	11%	20%
Daldinia concentrica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	11%	0%
Solanum viarum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	11%	0%

Continue/

Species group F

Clerodendrum glabrum	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	1	+	+	+	+	+	1	100%	6%
Daedaleopsis confragosa	.	.	.	.	.	.	.	.	.	.	r	.	.	+	.	.	.	+	+	r	+	+	+	+	100%	12%
Pavonia species	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	+	+	.	.	57%	6%
Phyllanthus amarus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	r	.	+	57%	0%
Polysphaeria parvifolia	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	+	+	+	.	.	.	+	57%	12%
Abutilon spp	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	r	.	.	.	+	+	+	57%	6%
Ipomoea spp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	r	.	.	29%	0%
Boerhavia diffusia	r	.	.	+	r	.	+	.	.	.	.	.	.	.	.	.	.	.	+	.	r	r	.	.	43%	24%
Kyllinga platyphylla	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	29%	12%
Acacia auriculiformis	.	.	r	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	r	.	.	29%	12%
Ehretia amoena	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	14%	0%
Parmelia sulcata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	14%	0%
Pycnoporus sp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	14%	0%
Trametes hirsuta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	14%	0%
Boerhavia spp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	14%	0%
Morinda citrifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	14%	0%
Coccinia grandis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	14%	0%
Pupalia lappacea	.	r	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	r	.	29%	12%

Species group G

Sideroxylon inerme	+	2a	1	.	.	+	+	r	+	2b	+	1	+	+	2a	1	+	1	r	+	+	r	+	+	92%	n/a
Capparis viminea var orthacantha	+	.	1	+	+	+	+	+	.	+	+	+	r	.	+	+	+	+	r	+	r	+	+	+	88%	n/a
Cyphostemma adenocaula	+	1	1	1	+	+	+	+	r	.	r	.	r	.	.	+	+	+	+	+	+	+	1	1	83%	n/a
Eragrostis ciliaris	+	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	+	r	r	.	.	.	21%	n/a
Terminalia catappa	.	.	r	.	r	.	.	.	.	r	.	.	r	.	.	.	.	.	.	.	.	r	.	.	21%	n/a
Dalechampia scandens	+	+	1	2a	2a	1	1	+	.	+	+	.	+	+	+	+	+	+	1	+	+	+	.	+	88%	n/a

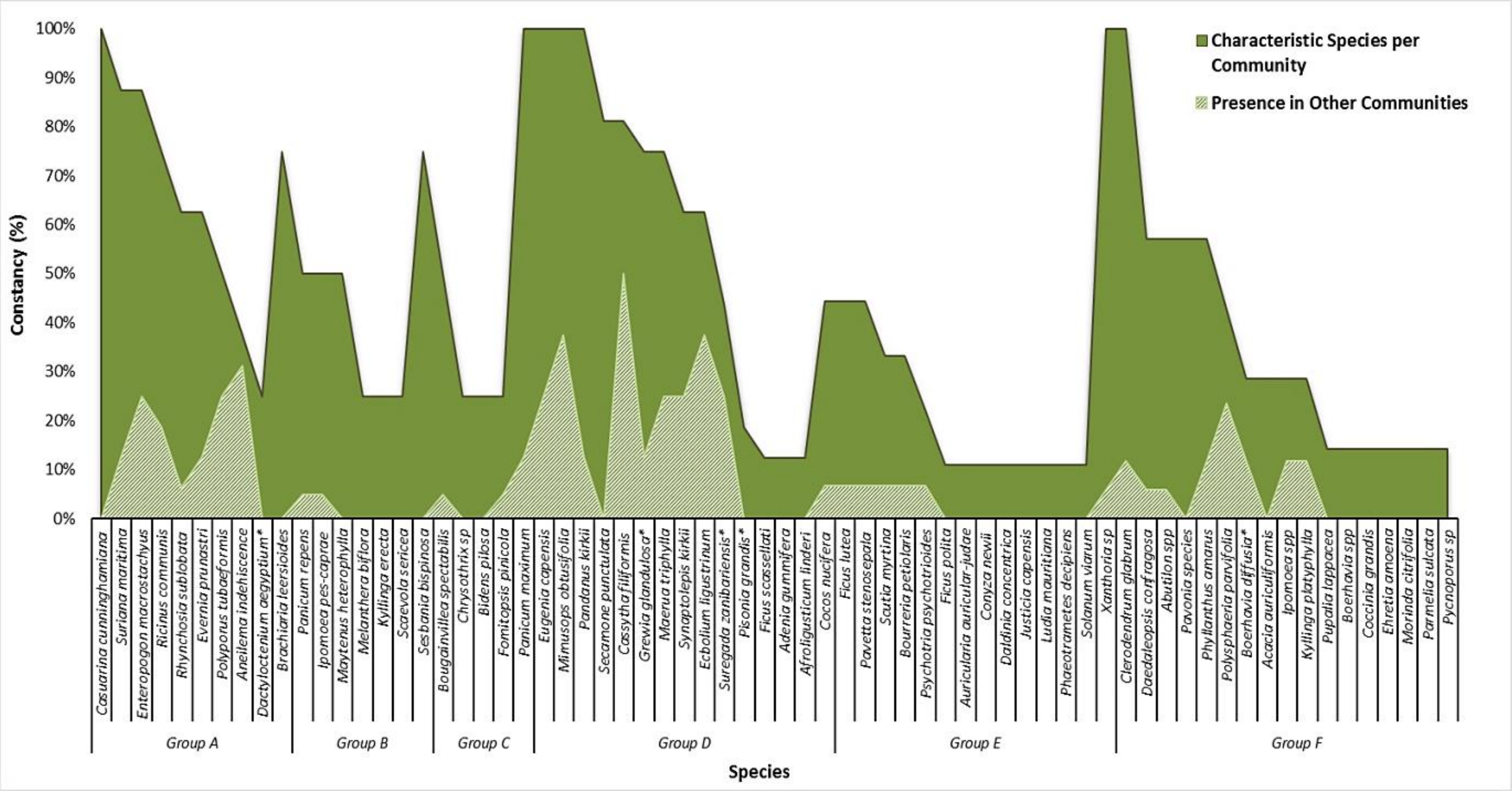


Figure 5-5: Constancy values for characteristic species within each plant community, excluding species from Group G.

5.4.2 Description of Mnemba Island habitat and plant communities

Due to morphological homogeneity of the terrestrial environment, parameters such as geology, land type, terrain form, altitude, aspect and slope were similar across sampled relevés and were not used in analyses or comparisons. The island's forested area is fundamentally level / flat, with a total change in altitude of 1 m across the entire vegetated area. Contours were mapped by a survey company in 2016 and the data provided to AndBeyond, Mnemba Island. The contours were overlaid with the current study data (Figure 5-6), which shows that vegetation occur between 4 and 5 m above Mean Sea Level (MSL), with the highest elevation of the island being 5 m above MSL.

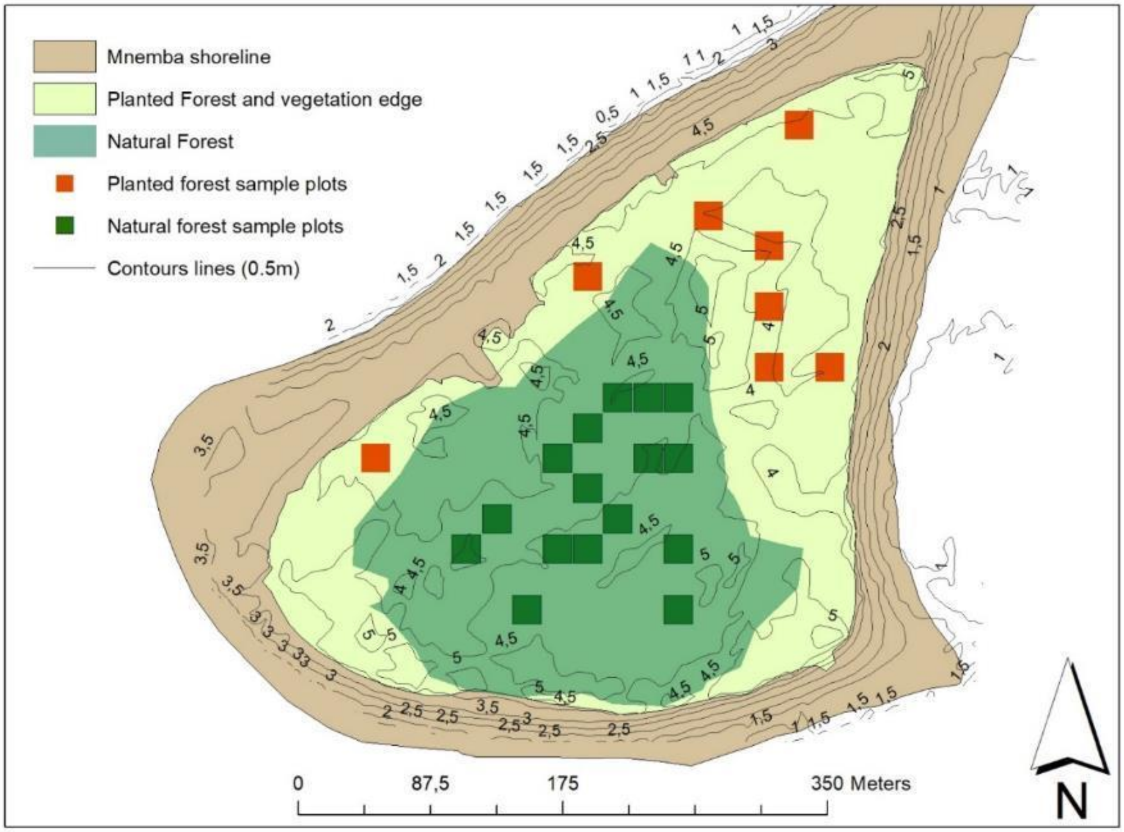


Figure 5-6: Elevation contours at Mean Sea Level (MSL) for Mnemba Island.

Table 5-3: Size delineation of Mnemba Island vegetation, plant communities and built infrastructure.

Major Plant Community / Sub-community	Area (m^2)	Area (% of surface cover)	Built up (m^2) *	Built up (%) *	Vegetation and sandy paths (m^2)	Vegetation and sandy paths (%)
Island Veg area	113 300	100	6 554	6 **	106 746	94 ***
1.	59 500	53	3 943	60 ∧	55 557	52 ^ ^
1.1	18 700	17	1 115	17 ∧	17 585	16 ^ ^
1.2	40 800	36	2 828	43 ∧	37 972	36 ^ ^
2.	53 800	47	2 611	40 ∧	51 189	48 ^ ^
2.1	46 800	41	2 307	35 ∧	44 493	42 ^ ^
2.2	7 000	6	304	5 ∧	6 696	6 ^ ^

*Only walled structures. Other infrastructure like water tanks etc. is not included in this measurement.

**Built up percentage for the total island as a percentage of the surface cover area, thus excluding the beach.

∧ Built up percentage for plant communities is expressed as a percentage of the total built up area.

***Vegetation and Sandy paths area and% for the island's surface cover is calculated by deducting the total built-up area from the total vegetated area of the island.

∧ ∧ The% Vegetation and sandy paths for plant communities is calculated as a percentage of the total Vegetation and sandy paths area, not the% of Surface cover.

1 ***Casuarina cunninghamiana – Suriana maritime Open to Closed Sandy Dry Coastal Forest***

The coastal forest community dominated by *Casuarina cunninghamiana* is mainly situated on the outer edge of the island's vegetation. Apart from a 40 m stretch of natural vegetation along the southern vegetation edge, this plant community is entirely surrounded plant community 2, creating a buffer between the frontal dune zone and the interior forest of the island (Figure 5-7 and Figure 5-8). On the eastern side of the island, the *C. cunninghamiana* buffer extended deeper into the interior of the island. Table 5-3 showed that this community made up 53% of the island's vegetated area.

Figure 5-7: *Casuarina cunninghamiana–Suriana maritime Open to Closed Sandy Dry Coastal Forest.* This plant community forms a buffer between the interior natural forest and the frontal dune zone.

A litter bed of pine needles, typical to this type of vegetation was observed for this community, with an average depth range between 2.5 cm and 3 cm deep. The fermentation layer below the litter ranged from 6 to 7 cm. Sandy soils with good drainage prevailed throughout. Rock cover was less than 0.1% with a pile of crystallised pumice found on top of an elevated area. Evidence of very moist conditions in the past could be seen on the eastern side of the island, where remnants of very large bracket fungi, *Fomitopsis pinicola*, were found at the base of two large pine trees. Disturbance to vegetation mainly resulted from infrastructure construction projects, as well as the uprooting of *Casuarina cunninghamiana* trees due to high tide interaction on the eastern shore. This community housed 60% of all building structures on the island at the time of the survey (Table 5-3). Nonvegetated areas were identified as sandy paths and indents from the beach.

Figure 5-8: The outer ring of vegetation on the island which is classified as Community 1 forms a buffer between the interior natural forest (Community 2) and the frontal dune zone. The difference in tree height between the two communities is conspicuous.

There were signs of young birds hatching, including doves sitting in their nests, other bird species' nests with eggs in low shrubs, as well as empty eggshells scattered on the forest floor. Fresh carcasses from doves and other birds were also noted. Very few crabs and crab holes were detected. Insects were noted opportunistically during the vegetation survey and included wood pill bugs and two unidentified butterfly species. Suni dung piles were found in this plant community, but no Aders duiker middens were noted.

Species from group A (Table 5-2) were characteristic for community 1 and included: the Australian she-oak, *Casuarina cunninghamiana,* the evergreen shrub, *Suriana maritima* (Figure 5-9), the castor oil plant, *Ricinus communis*, perennial grasses *Enteropogon macrostachyus* and pioneering *Dactyloctenium aegyptium,* the climbing perennial herb, *Rhynchosia sublobata,* creeping herb*, Aneilema indehiscens* and the pioneer grass species, *Dactyloctenium aegyptium.* Fungi and lichen included *Evernia prunastri, Brachiaria leersioides,* and *Polyporus tubaeformis.*

The upper tree layer dominated the woody vegetation with *Casuarina cunninghamiana* estimated at 350 trees per ha. *Suriana maritima* (Group A)*, Sideroxylon inerme* (Group G) and *Pandanus kirkii* (Group D) was also prominent. The herb-like *Melanthera biflora* (Figure 5-10) (Group B) was prominent in the herb layer, while *Dalechampia scandens* (Group G) was conspicuous in certain areas. The grass layer was dominated by the perennial grass *Enteropogon macrostachyus* (Group A), while *Dactyloctenium aegyptium* (Group A) and *Panicum repens* (Group B*)* were also conspicuous*.*

Figure 5-9: *Suriana martima,* a characteristic species for Community 1.

Figure 5-10: *Melanthera biflora*, a prominent species in the herb layer for Community 1.

Two sub-communities were classified:

1.1 Casuarina cunninghamiana – Suriana maritima – Enteropogon macrostachyus Sandy Dry Coastal Forest Community

The *Casuarina cunninghamiana* – *Suriana maritima* – *Enteropogon macrostachyus* community was situated between the outer "rim" of Community 1 and the interior forest on the eastern side of the island, as illustrated in Figure 5-4, between sub-communities 2.1 and 1.2. Sub-community 1.1 made up less than a third of major plant community 1 (31.4%) and 17% of the total vegetated area of the island. An average of 87% of this community contained litter cover consisting of mostly pine needles and seeds, small twigs and branches, with an average depth of 2.5 cm. The fermentation layer beneath the litter had an average depth of 6 cm (Figure 5-11). The number of fallen trees (or large sections of trees) amounted to 11 trees per ha, with an average of 2 dead trees per ha remaining upright.

Sandy soils with good drainage prevailed throughout this sub-community. Rock cover was less than 0.01%. Nonvegetated areas included small footpaths and a water pipe trench covered with litter, as well as wide sandy footpaths which are maintained by the hotel staff, at an average of 11%. Disturbance to vegetation was mainly due to this community housing 17% of the island's hotel support infrastructure and operational functions such as desalination and power generation, covering at least 1 150 m^2.

Figure 5-11: Pine needle and seed litter with fermentation layer below, from sub-community 1.1.

Characteristic species for sub-community 1.1 were represented by species group B in Table 5-2 and included the herbaceous scrub *Melanthera biflora,* the perennial grass species *Panicum repens*, an evergreen shrub *Gymnosporia heterophylla, a* pioneer dune creeper *Ipomoea pes-caprae,* the beach stabilising pioneer shrubs *Scaevola sericea* and *S. taccada*, a pike *sedge Kyllinga erecta* and the legumous shrub *Sesbania bispinosa*.

The woody layer was dominated by *Casuarina cunninghamiana* (group A). The broadleaf evergreen coastal species *Sideroxylon inerme* (group G) in its shrub growth form, and screw pine *Pandanus kirkii* (group D) displayed dominance in scattered areas of this community, while the erect shrub *Suregada zanzibariensis* (group D) was prominent. The catch-bird tree *Pisonia grandis* (group D) had a cover-abundance of less than 1%. Scamper climbers were prominent in the understory, including *Cyphostemma dysocarpum* and *Dalechampia scandens* (both species from group G) while *Melanthera biflora* (group B) was locally dominant in this community. The grass layer was dominated by *Enteropogon macrostachyus* (group A) (Figure 5-12). Grass species *Dactyloctenium aegyptium* (group A) and *Panicum repens* (group B) were also locally prominent. The herb and forb layer were represented only by *Boerhavia diffusa* (group F). A locally prominent lichen *Evernia prunastri* (group A) and two fungi species *Phaeotrametes decipiens* (group E) and *Polyporus tubaeformis* (group A) were identified.

Figure 5-12: The grass layer in sub-community 1.1 was dominated by *Enteropogon macrostachyus* (group A).

The overall vegetation cover for this community was 79% with an average number of 21 plant species per 400 m^2 relevé. In total, 37 plant species were recorded for this plant community, which translated to 49% of all species identified during the relevé sampling process.

Tree cover ranged from 54% to 92% across sample relevés, with an average of 74%. The average percentage of trees with a diameter above 6 cm at a low level in the forest canopy was 29%, and at high level, 71%. There was no percentage density at the mid-level range in this sub-community. The average minimum tree height was 12.1 m, and the average maximum height was 16.7 m, with an average range of 8.4 m between the lowest and highest trees. The shortest tree was 3 m high and the tallest tree 28 m. On average, trees in this community had a diameter of 27.4 cm. The number of *Pisonia grandis* trees per ha was calculated as 100 individuals, with an average BHD of 23.5 cm and an average height of 12.0 m. The number of *Casuarina cunninghamiana* trees per ha totaled 419, reached an average height of 22.5 m, and an average BHD of 29.4 cm.

The shrub cover in this community ranged from 25% to 75% between sample relevés, with an average shrub cover of 46%. The average minimum shrub height was 0.4 m while the average maximum shrub height was 1.37 m for sample relevés, with an average range between lowest and highest shrubs of 1.0 m. The highest shrub species was measured at 9 m. The average cover for grass/sedge species was 10%. The average climber / creepers height was 1.7 m, with the highest climber reaching 8 m above the ground. The herb / forb layer cover abundance was 24%.

1.2 *Casuarina cunninghamiana–Suriana maritime–Chrysothrix Open Sandy Dry Coastal Forest*

The *Casuarina cunninghamiana–Suriana maritime–Chrysothrix* community was situated on the outer edge of the island, bordering the sandy beaches and encompassing almost the entire island. This sub-community housed the salt spray zone and frontal dune vegetation, except for along a 40 m section of the beach on the South side of the island where the interior plant community extended onto the beach (Figure 5-4). Sub-community 1.2 made up more than two thirds of major plant community 1 (68.6%) and 36% of the total vegetated area of the island.

An average of 96% of this community contained litter cover made up of mostly pine needles and seeds, small twigs and branches, with an average depth of 3.0 cm (Figure 5-13). The fermentation layer beneath the litter had an average depth of 7 cm. The number of fallen trees (or large sections of trees/shrubs) amounted to 53 trees/shrubs/branches per ha, with an average of 61 dead trees/shrubs/branches per ha remaining upright.

Figure 5-13: Fermented litter (or humus) below the intact litter layer in sub-community 1.2.

Sandy soils with good drainage prevailed throughout sub-community 1.2 and rock cover was absent. Nonvegetated areas covered ~8% of the sampled areas and included small footpaths and sections of the beach that extended into the vegetation’s edge. This community housed 43% of the island’s hotel support infrastructure and operational functions such as laundry services and staff and guest facilities, causing 2 828 m^2 (2% of the island’s vegetation) to be displaced and disturbed. Additional disturbance was caused by the uprooting of *C. cunninghamiana* trees due to high tide wave interaction on the eastern side of the island – see Figure 5-14 and Figure 5-15 below:

Figure 5-14: Fallen *C. cunninghamiana* trees in sub-community 1.2

Figure 5-15: Uprooting of *C. cunninghamiana* trees due to high tide wave action on the Eastern side of the island in sub-community 1.2.

Characteristic species for sub-community 1.2 were represented by group C in Table 5-2, and included the exotic woody scrambling shrub *Bougainvillea spectabilis* (Figure 5-16), gold dust lichen *Chrysothrix* sp., stem decaying bracket fungus *Fomitopsis pinicola*, the perennial herb *Bidens pilosa* and perennial tufted grass *Panicum maximum.*

Figure 5-16: *Bougainvillea spectabilis* is native to South America. In sub-community 1.2 this species was a characteristic species and locally prominent.

The woody layer was dominated by *Casuarina cunninghamiana* (group A) and *Suriana maritima* (group A; Figure 5-17). Locally prominent in the woody vegetation were the broadleaf evergreen coastal species *Sideroxylon inerme* and the evergreen shrub *Capparis viminea* (both from group G). *Dalechampia scandens* dominated as a climber in the understory, while *Cyphostemma dysocarpum* (Figure 5-18) was prominent (both from group G). The grass layer was dominated by *Enteropogon macrostachyus* (group A) with local prominence of *Panicum maximum* (group C). The herb and forb layer were represented by *Bidens pilosa* (group C), *Boerhavia diffusa* (group F), the creeping herb *Aneilema indehiscence* and the climbing perennial herb *Rhynchosia sublobata* (all group A). Locally prominent lichen *Chrysothrix* sp. (group C) and fungus *Fomitopsis pinicola* (group C) were identified. The castor oil plant *Ricinus communis* was also locally prominent in the undergrowth.

Figure 5-17: The woody layer in sub-community 1.2 was dominated by *Casuarina cunninghamiana* and *Suriana maritima* (group A).

Figure 5-18: The creeper *Cyphostemma dysocarpum* (group G) was prominent in the understory of sub-community 1.2.

The overall vegetation cover for this community was 73%, with an average number of 15 plant species per 400 m^2 relevé. In total, 29 plant species were recorded for this plant community, which translated to 39% of all species identified during the relevé sampling process.

Tree cover ranged from 50% to 83% across sample relevés, with an average of 70%. The average percentage of trees with a diameter above 6 cm in the lower canopy averaged 38%, in the medium canopy 15% and in the upper canopy 30%. The average minimum tree height was 11.0 m and the average maximum height was 15.8 m, with an average range of 6.5 m between the lowest and highest trees. The shortest tree was 4 m high and the tallest tree 28 m. On average, trees in this community had a diameter of 14.8 cm. Only *Casuarina cunninghamiana* trees that had a diameter of 6 cm and more were counted, and BHD measured. The number of trees per ha was calculated as 538, reaching an average height of 15.9 m, and an average BHD of 14.8 cm.

The shrub cover in this community ranged from 5% to 35% between sample relevés, with an average shrub cover of 22%. The average minimum shrub height was 0.2 m while the average maximum shrub height was 10.8 m for sample relevés, with an average range between lowest and highest shrubs of 0.64 m. The tallest shrub species was measured at 3 m. The average cover for grass/sedge species was 0.3%. The average climber/creepers height was 1.4m, with the highest climber measured at 8 m. Herb cover was 3%.

2 *Eugenia capensis–Mimusops obtusifolia Coastal Forest*

Natural coastal forest community 2 was shaped in the form of a triangle and dominated by *Eugenia capensis* (Figure 5-19, Figure 5-20 and Figure 5-21). This community made up the interior vegetation of the island and was almost completely enclosed by plant community 1. On the southern side of the island, along 40 m of the vegetation edge, this plant community extended onto the beach (Figure 5-8). Table 5-3 showed that this community made up 47% of the island’s vegetated area.

Figure 5-19: The coastal forest community, dominated by *Eugenia capensis,* made up the interior vegetation of the island.

Figure 5-20: *Eugenia capensis* identified as the most abundant species in the indigenous forest on Mnemba Island. Fruit lacked stalks from the branches.

Figure 5-21: *Eugenia capensis* flowers on Mnemba Island.

Dry leaves, twigs and wood chips, seeds, dry fruit, fresh leaves, branches, pine needles, flowers (dry and fresh), bark, husks (coconut), bird nest material and dung made up the litter bed, with an average depth ranging between 2.1 cm and 5.8 cm. The ground was covered in litter for 82% of the surface area (Figure 5-22). The fermentation layer below the litter ranged from 4.1 to 4.7 cm (Figure 5-23). Sandy loam soils with good drainage prevailed throughout. Rock cover was 1.0% and resembled rock remnants from various building projects undertaken on the island in the past. Nonvegetated areas comprised of large sandy clearings, paths, antelope middens and nests, contributing to an average of 8% of community 2 (excluding the built infrastructure). Community 2 housed 40% of all building structures on the island (Table 5-3), which displaced 2 611 m^2 of the island's vegetation at the time of the survey. Additional disturbance to the vegetation included operational activities such as recycling of waste, discarding of coconut husks and raking of sandy paths for guest activities.

Figure 5-22: Dry leaves, twigs and wood chips, seeds, dry fruit, fresh leaves, branches, pine needles, flowers (dry and fresh), bark, husks (coconut), bird nest material and dung made up the litter bed in plant community 2.

Faunal activity included: ants and ant nests, termites, butterflies and caterpillars, cicadas and moulting castings, different species of beetles and spiders, millipedes, skins and geckos. Much bird activity included doves, dove nests, dove carcases, dove eggs, herons and heron nests, dead heron chicks and shells, guano deposits and crows. Duiker middens, paths and lairs as well as duiker scent posts were found throughout this community, while Suni middens were found mainly in the northern section of this community at the time of investigation. On two separate occasions the remains of antelope species were found in the undergrowth, one being a partial skeleton of a Suni antelope. The other incident included a skull of a duiker. Crabs were present during the rainy seasons and were observed eating the remains of birds and insects, while coconut crabs, *Birgus latro*, were observed throughout the year.

Figure 5-23: The fermentation layer below the litter ranged from 4.1 to 4.7 cm. Sandy loam soils with good drainage prevailed throughout plant community 2.

Species from group D (Table 5-2) were characteristic for major plant community 2: the evergreen dune myrtle shrub *Eugenia capensis;* evergreen milkwood tree *Mimusops obtusifolia;* screw pine *Pandanus kirkii* (Figure 5-25); woody vine *Secamone punctulate;* parasitic climber *Cassytha filiformis;* evergreen coastal shrub *Grewia glandulosa;* scrambling shrub *Maerua triphylla;* climbing shrub *Synaptolepis kirkii;* broadleaf evergreen “catch-bird” tree *Pisonia grandis;* small and semi-evergreen woody shrub *Ecbolium ligustrinum;* another evergreen coastal shrub *Suregada zanzibariensis;* the strangling fig species *Ficus scassellati*; hardy perennial herb *Afroligusticum linderi;* seedlings from the palm species *Cocos nucifera*, and perennial liana *Adenia gummifera.*

The woody vegetation was dominated by the multi-stemmed shrub *Eugenia capensis*, as well as four tree species, *Mimusops obtusifolia*, *Pandanus kirkii* (Figure 5-24), *Pisonia grandis*, (all group D) and *Sideroxylon inerme* (group G), and the lianas *Secamone punctulate* (group D) and *Capparis viminea var orthacantha* (group G). Group D shrubs *Suregada zanzibariensis, Grewia glandulosa, Ecbolium ligustrinum* *and Maerua triphylla*, as well as *Polysphaeria parvifolia* (group F) were prominent. The number of trees with a BHD larger than 6 cm for *Mimusops obtusifolia* were 87/ha, for *Pandanus kirkii* 56/ha, for *Pisonia grandis* 33/ha and for *Sideroxylon inerme* 15/ha.

Figure 5-24: *Mimusops obtusifolia* and *Pandanus kirkii* were amongst the dominant trees in the woody layer for plant community 2.

The strangling fig *Ficus scassellati* and exotic palm tree *Cocos nucifera* were locally prominent to plant community 2, as was the perennial liana *Adenia gummifera* (all group D). *Dalechampia scandens* (group G) dominated the climber/creeper layer in the understory while *Cyphostemma adenocaula* (group G) and the parasitic vine *Cassytha filiformis* (group D) were prominent, especially in the canopy layer. The herb layer was negligible, with the perennial herb *Afroligusticum linderi* (group D) being locally prominent. The grass layer was also negligible with *Dactyloctenium aegyptium* (group A) being locally prominent.

Figure 5-25: Pandanus kirkii seedling. This species is a characteristic species for plant community 2, and dominant in the woody layer, in shrub and tree form.

Two sub-communities were distinguished for community 2 and are described below:

2.1 Eugenia capensis–Mimusops obtusifolia–Scutia myrtina Coastal Forest

The *Eugenia capensis*–*Mimusops obtusifolia*–*Scutia myrtina* sub-community consisted of the largest part of community 2, located in the interior of the island. Sub-community 2.1 extends onto the beach and frontal dune zone (Figure 5-8). Table 5-3 showed that this sub-community made up 41% of the island's vegetated area.

On average, 86% of the forest floor was covered with litter consisting of dry and yellow leaves, twigs and branches, seeds, fruits (Figure 5-26) and flowers, coconut husks, tree bark and needles from *Casuarina cunninghamiana* trees, at an average depth of 5.8 cm. The average fermentation layer was measured as 4.1 cm thick. On average, 19 fallen trees (or large sections of trees/shrubs) per ha was calculated for this sub-community, as well an average of 5 standing dead trees/shrubs per ha.

Sandy loam soil was well drained, except for one month during the monsoon when certain areas were waterlogged. The average rock cover was calculated as 1.7%. Nonvegetated areas averaged 6% for sampled areas in this sub-community and included wide sandy foot paths, clearings in the forest and animal lairs. Infrastructure in this sub-community made up 35% of all the hotel infrastructure and operational functions, and included the kitchen, dining areas for guests and senior staff, as well as some of the staff accommodation. These buildings spanned 2 307 m^2 and was calculated as 2% of the island's forest area. Additional disturbance to the vegetation included operational activities such as recycling of waste, discarding of coconut husks and raking of sandy paths for guest activities.

Characteristic species for sub-community 2.1 were represented by group E in Table 5-2. Tree species included the two figs *Ficus lutea* and *F. polita*. Seven shrub species were identified, *Pavetta stenosepala, Bourreria petiolaris, Psychotria psychotrioides, Justicia capensis, Ludia mauritiana, Conyza newii*, and the perennial tropical soda apple *Solanum viarum* from Brazil, as well as one vine species *Scutia myrtina*. This community also had characteristic fungi including the jelly ear fungus *Auricularia auricular-judae*, lichenized fungus *Xanthoria* sp., polypore fungus *Phaeotrametes decipiens*, and the inedible fungus *Daldinia concentrica*.

The woody layer was dominated by the multi-stemmed shrub *Eugenia capensis*, as well as four species in the tree layer, *Mimusops obtusifolia, Pandanus kirkii* (Figure 5-27), *Pisonia grandis* (Figure 5-28) (all group D), and *Sideroxylon inerme* (group G), and the lianas *Scutia myrtina* (group E) and *Secamone punctulate* (group D). *Ficus lutea* (Figure 5-29) was locally prominent in the tree layer. *Capparis viminea* var*. orthacantha* (group G), *Pavetta stenosepala* (group E), *Ecbolium ligustrinum* (group D), *Suregada zanzibariensis, Maerua triphylla* and *Grewia glandulosa* (group D) were prominent in the shrub layer. *Dalechampia scandens* and *Cyphostemma adenocaula* (both group G) were prominent climbers/creepers in the understory, and the parasitic vine *Cassytha filiformis* (group D) in the canopy layer. *Phaeotrametes decipiens* was locally prominent in the grass layer but with a very low abundance. The herb layer was absent.

Figure 5-26: *Mimusops obtusifolia* fruits along with leaf and twig debris in the litter layer for sub-community 2.1: a) Green fruit, b) Ripe fruit.

Figure 5-27: *Pandanus kirkii,* a palm species. This species was dominant for sub-community 2.1 and occurred in both the shrub and tree layer.

The overall vegetation cover for this sub-community was 72% with an average number of 18 plant species per 400 m^2 relevé. In total, 44 plant species were recorded for this plant community, which translated to 59% of all species identified during the relevé sampling process. Tree cover ranged from 13% to 69% across sample relevés, with an average of 36%. The average percentage of trees in the lower canopy was 16%, in the medium canopy 56% and in the upper canopy 28%. The average minimum tree height was 9.9 m and the average maximum height was 13.5 m, with an average range of 7.5 m between the lowest and highest trees. The shortest tree was 1.5 m high and the tallest tree 38 m - an old dead (but standing) *C. cunninghamiana* with a trunk diameter of 42 cm and evidence of previous fire. On average, trees had a diameter of 22.9 cm. The number of trees with a BHD larger than 6 cm was calculated as 244 per ha.

Figure 5-28: *Pisonia grandis* was dominant for sub-community 2.1 and provided breeding habitats for birds that contributed towards soil mineral content through bird droppings, shells and carcasses.

Figure 5-29: *Ficus lutea* was prominent in plant community 2.1.

The shrub cover in this sub-community ranged from 30% to 75% between sample relevés, with an average shrub cover of 52%. The average minimum shrub height was 2.0 m while the average maximum shrub height was 4.1 m for sample relevés, with an average range between lowest and highest shrubs of 2.6 m. The tallest shrub species was measured at 12 m. There were no grasses, sedges or herbs. The average climbers/creepers height was 0.8 m, with the tallest climber measuring 18.0 m.

2.2 *Eugenia capensis–Mimusops obtusifolia–Clerodendrum glabrum Coastal Scrub*

This sub-community constituted three separate segments within community 2, staggered from north to south and being the smaller portion of community 2 (Figure 5-8). Table 5-3 showed that this sub-community made up 6% of the island’s vegetated area.

On average, 82% of the forest floor was covered with litter, consisting of dry and decaying leaves, twigs, and branches, as well as seeds and pods, wood chips, birds’ nets and guano, and antelope dung, at an average depth of 2.1 cm. The average fermentation layer was measured as 4.7 cm thick. On average, 34 fallen trees (or large sections of trees/shrubs) per ha was calculated for this community, as well as an average of 8 standing dead trees (or large sections of shrubs/branches) per ha.

Sandy loam soil was well drained, except during the monsoon when certain areas were waterlogged. The average rock cover was calculated as 0.3% and consisted of coral rock scattered on top of the sandy substrate (Figure 5-30). Nonvegetated areas accounted for an average of 9% of the sampled areas in this community. Nonvegetated areas consisted of sandy foot paths and clearings, middens and lairs. Infrastructure footprints for this sub-community were calculated as 304 m^2. Disturbance to the vegetation included staff accommodation and clearings for new staff facilities. An old well and a water trench were also located in this sub-community.

Figure 5-30: Scattered coral rock made up an average of 0.3% of the surface in sub-community 2.2.

Characteristic species for sub-community 2.2 were represented by group F in Table 5-2. Shrub species included *Morinda citrifolia*, a *Pavonia* sp., *Polysphaeria parvifolia*, *Acacia auriculiformis*, *Ehretia amoena*, and *Clerodendrum glabrum*. Herbaceous shrubs and herb species included *Abutilon* sp., *Ipomoea* sp., *Boerhavia* sp., *Pupalia lappacea, Phyllanthus amarus* and *Boerhavia diffusia*. The sedge species *Kyllinga platyphylla*, and the perennial vine *Coccinia grandis* were also characteristic. Fungi in group F included the polypores *Daedaleopsis confragosa* and *Pycnoporus* sp., foliose lichen *Parmelia sulcate* and hairy bracket *Trametes hirsute*.

The woody vegetation was dominated by the multi-stemmed *Eugenia capensis*, *Grewia glandulosa, Ecbolium ligustrinum* (all group D) in the shrub layer, as well as *Mimusops obtusifolia* in the tree layer. Prominent species in the woody layer included *Sideroxylon inerme* (group G), the vine *Capparis viminea* var*. orthacantha* (group G), *Pandanus kirkii*, the vine *Secamone punctulate* (group D), *Pisonia grandis* (group D), *Suregada zanzibariensis* (group D), *Ecbolium ligustrinum* (group D), *Maerua triphylla* (group D), and Synaptolepis kirkii (group D). Prominent species in the climber/creeper layer included *Dalechampia scandens* (group G), *Clerodendrum glabrum* (group F), and the parasitic vine *Cassytha filiformis* (group D), while locally prominent species were *Aneilema indehiscens* (group A) (Figure 5-33), and *Cyphostemma adenocaula* (group G). Shrubs and herbaceous shrubs that were identified as locally prominent were *Ricinus communis* (group A), *Rhynchosia sublobata* (group A), *Pavonia* sp. (group F) (Figure 5-31), Abutilon sp. (group F), *Polysphaeria parvifolia* (group F), *Phyllanthus amarus* (group F) (Figure 5-32), *Ipomoea* sp. (group F).

The grass layer was represented by local prominent species *Dactyloctenium aegyptium* (group A) and *Eragrostis ciliaris* (group F). A prominent fungus species was the *Daedaleopsis confragosa* (group F). In the herb layer *Boerhavia diffusia* (group F) was prominent. The overall vegetation cover for this community was 73% with an average number of 24 plant species per 400 m^2 relevé. In total, 53 plant species were recorded for this plant community, which translated to 71% of all species identified during the relevé sampling process.

Figure 5-31: *Pavonia* sp. - locally prominent in sub-community 2.2.

Figure 5-32: *Phyllanthus amarus* - locally prominent in sub-community 2.2.

Tree cover ranged from 8% to 71% across sample relevés, with an average of 31%. The percentage of trees in the lower canopy averaged 52%, in the medium canopy 42%, with no trees in the high-level range above 15 m. The average minimum tree height was 4.4 m, and the average maximum height was 9.1 m, with an average range of 5.9 m between the lowest and highest trees. The shortest tree was 1.5 m high and the tallest tree 12 m. On average, trees in this sub-community had a breast height diameter (BHD) of 14.4 cm and the number of trees with a BHD larger than 6 cm was calculated as 40 per ha.

The shrub cover in this sub-community ranged from 25% to 86% between sample relevés, with an average shrub cover of 54%. The average minimum shrub height was 0.8 m while the average maximum shrub height was 2.5 m for sampled relevés, with an average range between lowest and highest shrubs of 1.8 m. The tallest shrub species was measured at 9.0 m. No grasses or sedges were present. The average climber/creeper height was 2.2 m, with the tallest climber measuring 10.0 m.

5.4.3 Plant species outside of sample relevés

An old vegetation sample plot prevents Suni and Aders’ from browsing the vegetation inside it. A photo of the plot from a) the dry, and b) the wet season demonstrates the effect of the dry season on non-browsed *A. indehiscence* (Figure 5-33).

Figure 5-33: *Aneilema indehiscence* in a) the dry season, and b) wet season.

Due to the size and shape of the plant communities, plot placement sometimes excluded the fringes of the different plant communities, especially in the frontal dune beach zone. Species identified along the beach were the salt tolerant bush *Pemphis acidula*, the coastal grasses *Sporobolus virginicus* (Figure 5-34), *Halopyrum mucronatum, Paspalum virgatum*, the perennial beach shrub *Guettarda speciose* (Figure 5-35), and the beach shrub *Cordia subcordata* (Figure 5-36). Species occurring in the interior that were not in any of the sampled relevé's included the pioneer species *Trema orientalis,* the perennial twine *Parquetina nigrescens, Searsia natalensis* from the sumac family, a coastal shrub *Euclea natalensis*, the dry forest shrub *Fluggea virosa*, the liana *Caesalpinia bonduc* and the strangling fig *Ficus ingens*. The naturalised *Tacca leontopetaloide* was also present. Fruit and vegetable species introduced to the island by staff members for food gardens were not included in the survey.

A complete list of all plant species identified on Mnemba Island is available in Appendix D – Plant species identified on Mnemba in 1989 and in this current study (2016/2017)..

Figure 5-34: *Sporobolus virginicus* and *Ipomoea pes-caprea* on the frontal dune, beach zone.

Figure 5-35: *Guettarda speciosa* - also identified in the frontal beach zone.

Figure 5-36: *Cordia subcordata* - shrub in the frontal dune zone and interior of the island.

5.4.4 **Floristic and environmental characteristics**

The vegetation survey indicated that a total of 54 families were represented by 91 species on the island. A floristic analysis for plant community 1 and 2 was compiled for comparison from the releve' sample data. Plant community 1 constituted a total of 31 families - 61% of all the families identified on the island were present in this plant community. Plant community 1 was comprised of 45 species from 43 genera (51% of all species identified) (Table 5-4). Families with the most species in Plant community 1 were from the spurge family *Euphorbiaceae* (represented by a climber and two shrubs), the bean family *Fabaceae* (also one climber and two shrubs), four-o-clock family *Nyctaginaceae* (one herb species, a shrub, and a tree species) and the grass family *Poaceae* with five species. Together with *Asteraceae, Capparacea, Sapotaceae and Cyperaceae,* these families contributed 49% of all identified species in plant community 1.

Table 5-4: Families and number of genera and species for plant community 1.

Family	Genera	Species	Family	Genera	Species
ASCOMYCOTA			Fabaceae	3	3
Parmeliaceae	1	1	Goodeniaceae	1	1
BASIDIOMYCOTA			Malvaceae	1	1
Fomitopsidaceae	1	1	Moraceae	1	1
Polyporaceae	1	1	Myrtaceae	1	1
CHRYSOTHRICACEAE			Nyctaginacaea	3	3
Chrysothricaceae	1	1	Sapotaceae	2	2
DICOTYLEDONEAE			Surianaceae	1	1
Acanthaceae	1	1	Thymaleaeae	1	1
Amarnthaceae	1	1	Tiliaceae	1	1
Apocynaceae	1	1	Vitaceae	1	1
Asclepiadaceae	1	1			
Asteraceae	2	2	MONOCOTYLEDONEAE		
Capparacea	2	2	Amarnthaceae	1	1
Casuarinaceae	1	1	Commelinaceae	1	1
Celatraceae	1	1	Cyperaceae	1	2
Combretaceae	1	1	Gramnaecea	1	1
Convolvulaceae	1	1	Pandanaceae	1	1
Euphorbiaceae	3	3	Poaceae	4	5

Plant community 2 housed 42 plant families (82% of all plant families from the island were found in this plant community) - 64 species from 64 genera (72% of all species identified on the island) (Table 5-5). Thirteen families housed 56% of the species: *Parmeliaceae, Polyporaceae, Acanthaceae, Boraginaceae, Capparacea,* spurge family *Euphorbiaceae,* the bean family *Fabaceae, Malvaceae, Moraceae,* four-o-clock family *Nyctaginacaea, Rubiaceae, Sapotaceae,* and grass family *Poaceae.* This community shared the prominence of species from the *Nyctaginaceae* (two herbs and a tree species), a climber and two shrubs from *Euphorbiaceae*, and three grass species from *Poaceae* with plant community 1. Other families with multiple species in plant community 2 included five fungi from the *Polyporaceae* family, four shrub species from *Rubiaceae,* and three fig trees from the *Moraceae* family.

Table 5-5: Families and number of genera and species for plant community 2.

Family	Genera	Species	Family	Genera	Species
ASCOMYCOTA					
Parmeliaceae	2	2	Lauraceae	1	1
Teloschistaceae	1	1	Malvaceae	2	2
Xylariaceae	1	1	Moraceae	3	3
BASIDIOMYCOTA			Myrtaceae	1	1
Auriculariaceae	1	1	Nyctaginacaea	3	3
Polyporaceae	5	5	Passifloriacea	1	1
CHRYSOTHRICACEAE			Phyllanthaceae	1	1
Chrysothricaceae	1	1	Rhamnaceae	1	1
DICOTYLEDONEAE			Rubiaceae	4	4
Acanthaceae	2	2	Sapotaceae	2	2
Apiaceae	1	1	Solanaceae	1	1
Apocynaceae	1	1	Thymaleaeae	1	1
Asteraceae	1	1	Tiliaceae	1	1
Boraginaceae	2	2	Vebanaceae	1	1
Capparacea	2	2	Vitaceae	1	1
Casuarinaceae	1	1	MONOCOTYLEDONEAE		
Celatraceae	1	1	Amarnthaceae	1	1
Combretaceae	1	1	Commelinaceae	1	1
Convolvulaceae	1	1	Cyperaceae	1	1
Curbitaceae	1	1	Gramnaecea	1	1
Euphorbiaceae	3	3	Palmae	1	1
Fabaceae	2	2	Pandanaceae	1	1
Salicaceae	1	1	Poaceae	3	3

The two main plant communities on Mnemba Island had a minimum of 28 plant families in common. Plant community 1 housed three families not represented by plant community 2: the fungi family *Fomitopsidaceae,* and two pantropical flowering species from the families *Goodeniaceae* and *Surianaceae*. Fourteen of the families that were found in plant community 2 did not occur in plant community 1: flowering species from *Apiaceae, Vebanaceae, Phyllanthaceae* and *Lauraceae,* forget-me-not family *Boraginaceae,* willow family *Salicaceae,* palm family *Palmae,* passion-flower family *Passifloriacea,* the buckthorn family *Rhamnaceae,* coffee family *Rubiaceae* and nightshades *Solanaceae,* as well as fungi species from the *Auriculariaceae* and *Xylariaceae* families, and lichen-forming fungi *Teloschistaceae. Casuarinaceae* (one tree species) covered 41%, and *Asteraceae* (one shrub species) covered 21% of plant community 1 (Table 5-6). *Myrtaceae* (one shrub species) covered 23%, and *Sapotaceae* (two genera and two species) covered 12% of plant community 2. A cover-abundance table for all species from plant and sub communities is detailed in Appendix G.

Table 5-6: Plant families for plant community 1 and 2 with the highest cover-abundance percentages.

COMMUNITY 1		**COMMUNITY 2**	
Family	**Cover (%)**	**Family**	**Cover (%)**
Casuarinaceae	41%	Myrtaceae	23%
Asteraceae	21%	Sapotaceae	12%
Surianaceae	10%	Pandanaceae	5%
Euphorbiaceae	3%	Nyctaginaceae	3%
Pandanaceae	2%	Apocynaceae	8%
Fabaceae	2%	Acanthaceae	1%
		Rhamnaceae	1%

Species that were identified outside of the sample relevés constituted twelve families, of which six families were additional to families identified in the sample relevés (Table 5-7). One local endemic species, *Capparis viminea* var. *orthacantha* was prominent on the island. Ten species (11%) were introduced to the island, of which *Casuarina cunninghamiana* was the most significant. *Coco nucifera, Terminalia cattapa* and *Morinda citrifolia* has been naturalised in the region but was not significantly represented on Mnemba Island. *Bougainvillea spectabilis* was not abundant at the time of the survey and the island management was eradicating the specimens. The sporadic occurrence of *Acacia* *auriculiformis*, *Paspalum virgatum*, *Bidens pilosa, Phyllanthus amarus* and *Solanum viarum* did not raise any concern for invasion at the time. No threatened or rare species were identified, but the *Psychotria* genus could not be identified down to species level, and was thus not ruled out, since ten of the *Psychotria* species are globally vulnerable. One new species was identified for Zanzibar, namely *Pisonia grandis*. According to Mr. Gereau (Missouri Botanical Garden, pers. com. 2016), there are only two records for this species along the East coast of Africa. One report is for Kilifi District in Kenya on the coast between Kikambala and Kijangwani, and one report from Jambe Reef, Tanga District in Tanzania.

Table 5-7: Species identified outside sample relevés. Families that did not occur in the sample relevés are indicated with an (*).

	Family	**Genera**	**Species**
DICOTYLEDONEAE	Anacardiaceae*	1	1
	Asclepiadaceae*	1	1
	Boraginaceae	1	1
	Ebenaceae*	1	1
	Euphorbeaceae	1	1
	Fabaceae	1	1
	Lythracieae*	1	1
	Moraceae	1	1
	Rubiaceae	1	1
	Ulmaceae*	1	1
MONOCOTYLEDONEAE	Poaceae	1	3
	Taccaceae*	1	1

Figure 5-37 demonstrates the extent of the Island's vegetation cover that constituted plant community 1 and 2 (percentage of entire forested area), as well as the extent that each sub-community contributed to the plant cover of the main communities (1.1 and 1.2 as percentages of plant community 1; 2.1 and 2.2 as percentages of plant community 2). Figure 5-37 also illustrates the relation between the extent of the Island's built infrastructure contained within Plant community 1 and 2, and the extent of the built infrastructure from the relative sub communities within each main community (1.1 and 1.2 as a percentage of the built structures in plant community 1; 2.1 and 2.2 as a percentage of the built structures in plant community 2). Plant community 1 was 6% bigger than plant community 2 while Plant community 1 housed 60% of the island's infrastructure.

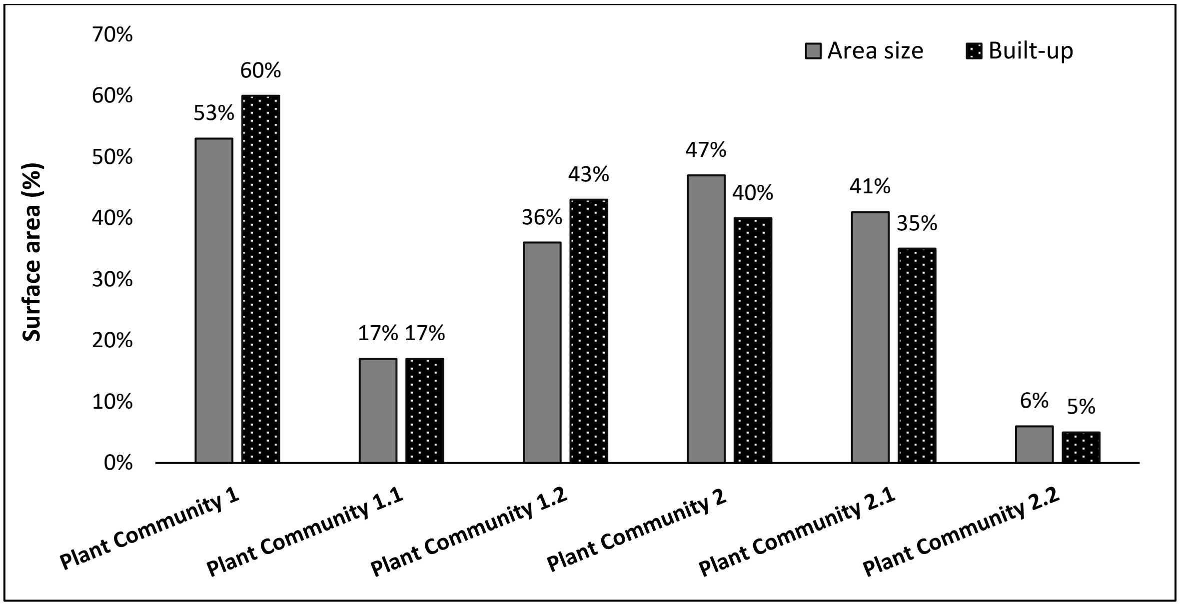


Figure 5-37: Percentage of the Island's vegetation and built infrastructure within the main and sub plant communities.

The differences in the overall characteristics of the two main plant communities are listed in

Table 5-8. Results for statistical analyses of differences between main and sub plant communities are summarised in Appendix H – Statistical analyses of differences between plant communities. Results indicated that plant community 1 housed double the number of trees with a BHD above 6 cm compared to plant community 2 *(U* = 32.5; n1 = 8; n2 = 16; *P* = 0.053). However, the higher number of species per relevé for plant community 2 did not test significant. Shrub cover was significantly higher in plant community 2 *(U* = 37; n1 = 8; n2 = 16; *P* = 0.027), with significantly higher grass cover *(U* = 32; n1 = 8; n2 = 16; *P* = 0.000) and tree canopy cover *(U* = 6; n1 = 8; n2 = 16; *P* = 0.003) in plant community 1. The average tallest trees were significantly taller *(U* = 20; n1 = 8; n2 = 16; *P* = 0.006) in plant community 1 as opposed to the average tallest trees in plant community 2. In contrast, the average tallest shrubs were significantly taller *(U* = 16.5; n1 = 8; n2 = 16; *P* = 0.003) in plant community 2 (Figure 5-39) than in plant community 1. The average depth of the fermentation layer was noticeably deeper for plant community 1 (6.5cm deep) than for plant community 2 (4.4cm deep) *(U* = 20; n1 = 8; n2 = 16; *P* = 0.048).

A Shannon-Weiner Index was calculated to determine species diversity and evenness for the main and sub communities. These differences are listed as separate calculations for each plant community in Table 5-9.

Table 5-8: Overall characteristics of Plant community 1 and 2 on Mnemba Island.

	Plant Communities					
	1	**1.1**	**1.2**	**2**	**2.1**	**2.2**
Nr families	31	26	27	42	38	35
Nr Genera	43	37	34	64	52	52
Nr Species	45	38	34	64	55	54
% of total species from all releve'	44%	49%	39%	65%	59%	71%
Average (mean) nr of species / relevé	17	21	14	20	17	23
Vegetation cover (%)	76%	79%	73%	73%	72%	73%
Tree cover (%)	72%	74%	70%	34%	36%	31%
Shrub cover (%)	34%	46%	22%	53%	52%	54%
Grass cover (%)	5.0%	10%	25%	0.0%	1%	0,3%
Herb cover (%)	0.1%	24%	3%	0.3%	0,4%	0,4%
Average BHD (over 6 cm)	21 cm	27 cm	15 cm	20 cm	23 cm	27 cm
Nr trees with BHD over 6 cm / ha	491	444	538	338	381	282

Table 5-9: Species diversity tested within each Plant and sub community – Shannon-Wiener Index.

	Shannon-Wiener Index (H)	**Evenness (E)**
Plant Community 1	2.24	0.97
Plant Community 1.1	1.84	0.95
Plant Community 1.2	1.06	0.96
Plant Community 2	2.54	0.94
Plant Community 2.1	2.53	0.96
Plant Community 2.2	2.53	0.88

A higher Shannon-Wiener Index is indicative of a higher richness and the evenness of the community. The evenness value indicates diversity, where a higher evenness value is related to more homogenous plant communities. The results table above shows highest diversity for Plant community 2, followed by sub communities in this main community, and the Plant community 1 followed by the sub communities within this main community. Plant community 1 is the most homogenous of all the communities, while sub community 2.2 is the least homogenous.

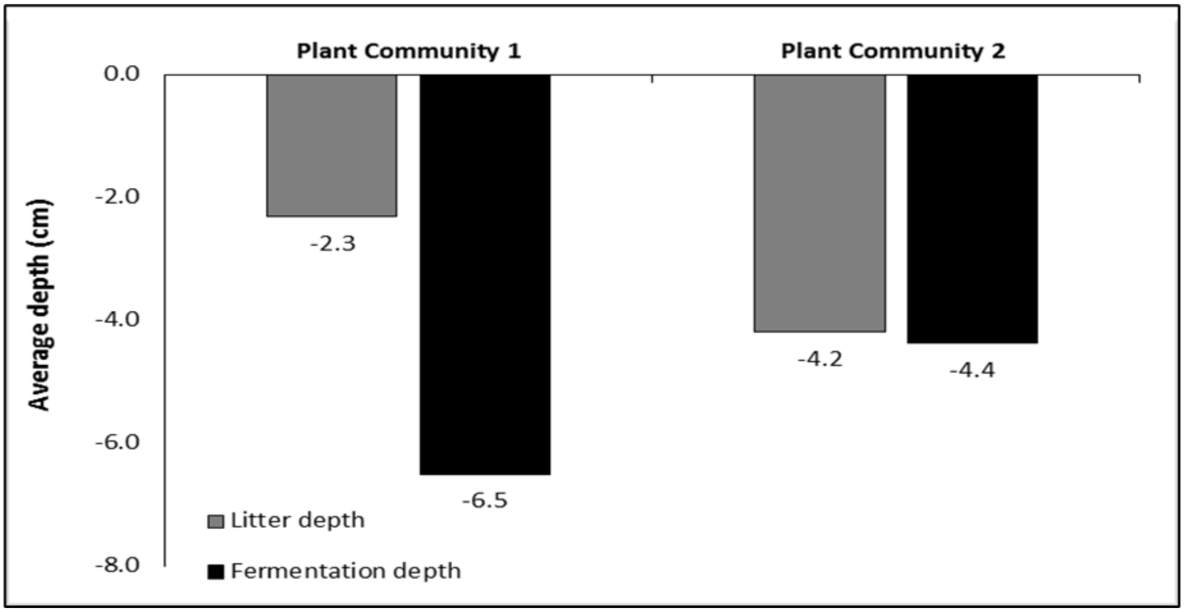


Figure 5-38: The difference between the average (mean) litter depth of Plant community 1 (1t 2.3 cm deep) and Plant community 2 (at 4.2 cm deep) did not test significant. (U = 45; n1 = 8; n2 = 16; P = 0.230)

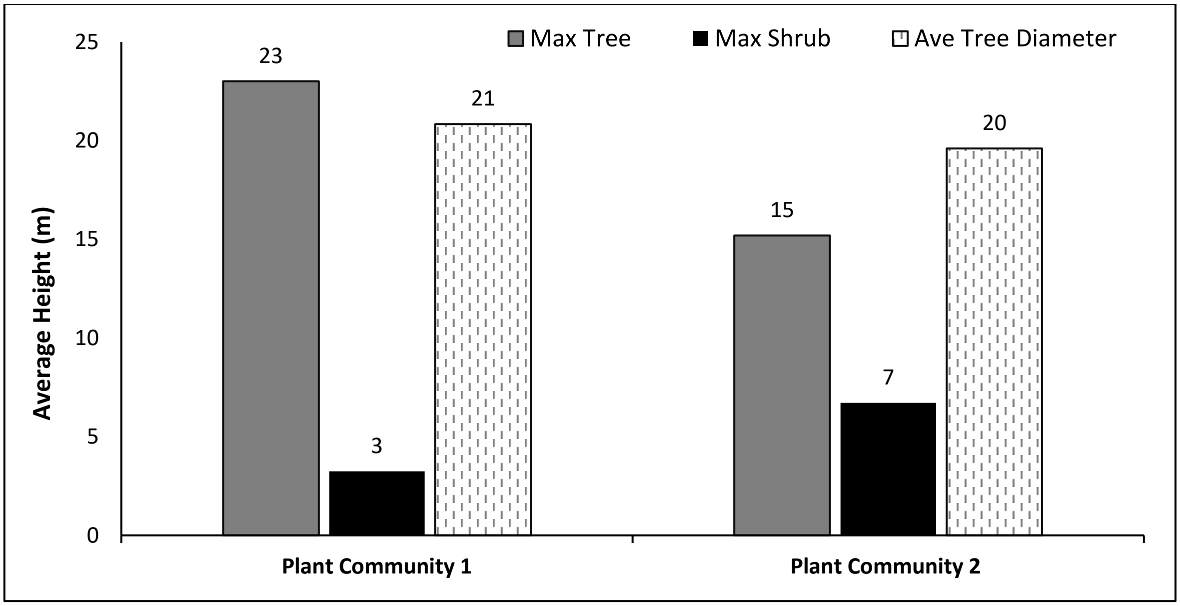


Figure 5-39: Differences in the average maximum height of trees and shrubs as well as average diameter of trees above 6cm BHD, for plant communities 1 and 2. Differences for tree and shrub height tested significant.

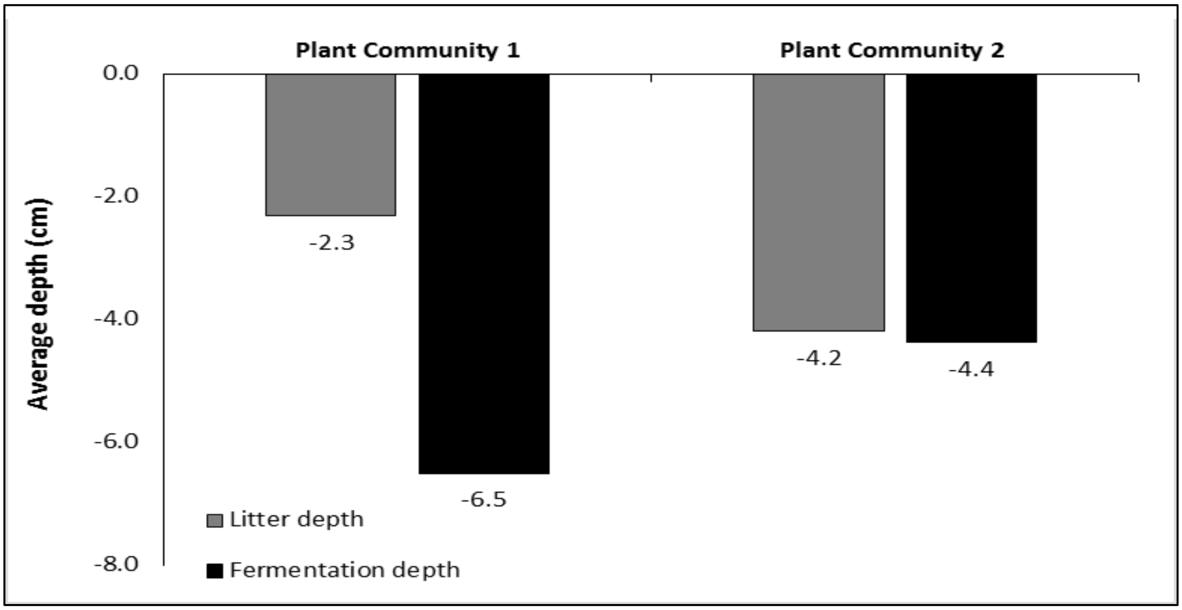


Figure 5-40: Differences between average litter and fermentation depth for plant communities 1 and 2, with difference in fermentation depth testing significant.

Figure 5-41 illustrates the difference in the average number of species per relevé for the four sub-communities – results tested significant (X^2 = 10.92; df = 3; P = 0.012). The difference in the average number of dead trees between the sub-communities also tested significant (X^2 = 11.82; df = 3; P = 0.008).

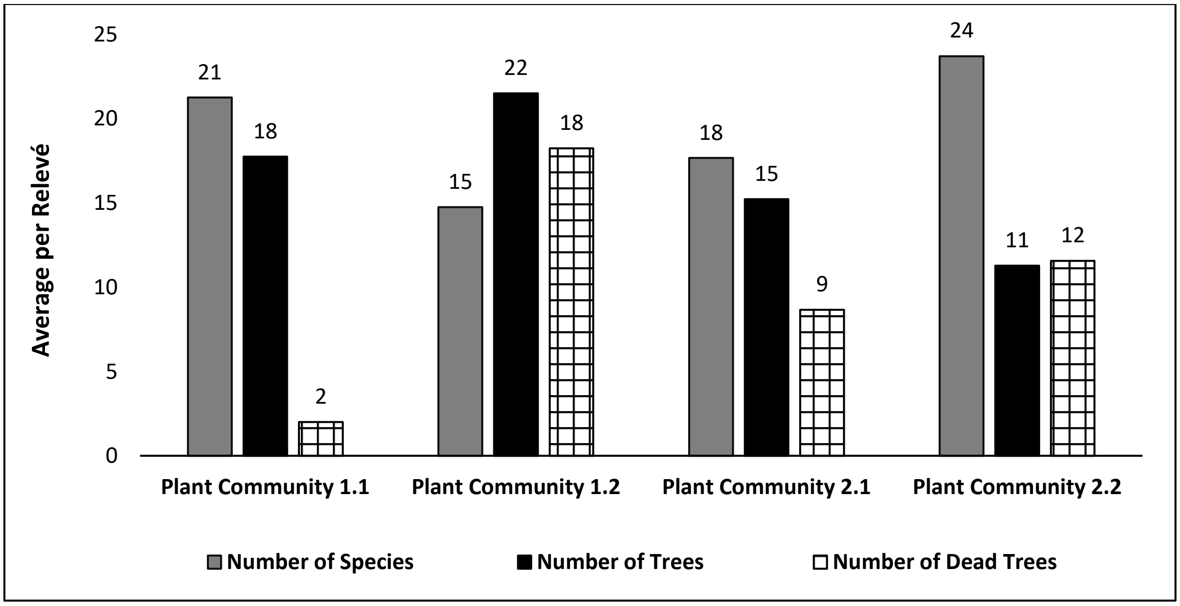


Figure 5-41: Average number of species, trees with a BHD above 6 cm, and average dead trees per relevé.

Differences between the tallest shrubs measured for the four sub-communities are illustrated in Figure 5-42 – with plant community 1.1 having significantly taller trees (X^2 = 11.26; df = 3; P = 0.010) compared to the rest of the island. The difference in height for the tallest shrubs per sub-community was less pronounced, but significant (X^2 = 10.53; df = 3; P = 0.015).

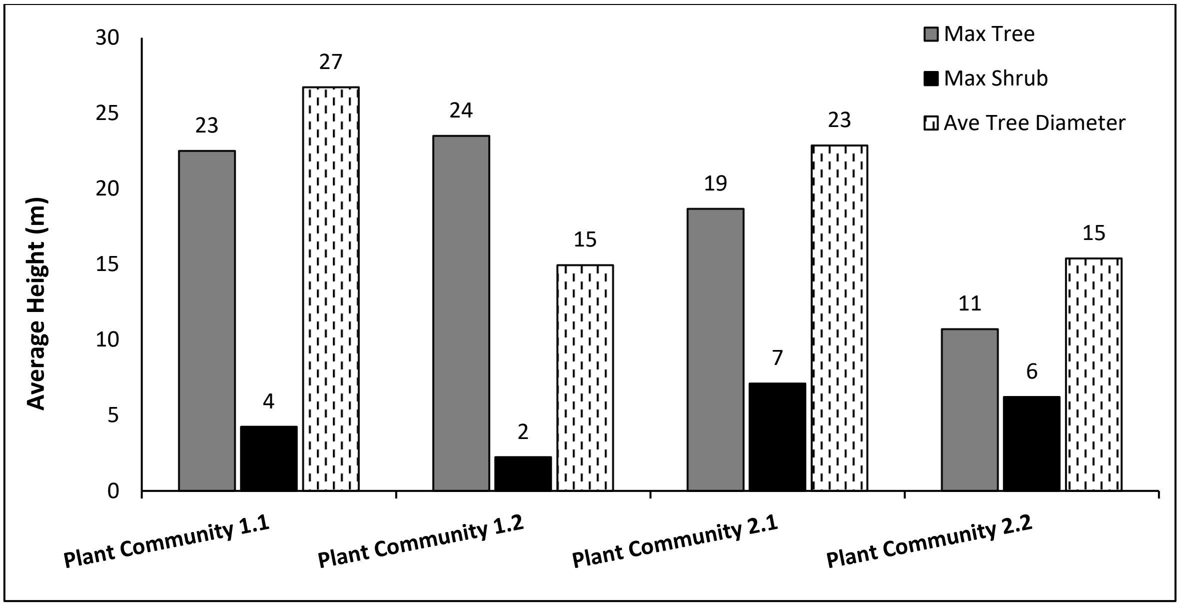


Figure 5-42: Differences between tallest trees and shrubs, and average tree diameter for sub-communities.

Figure 5-43 illustrates the overall difference in vegetation layer cover between the different sub-communities. Grass cover differences tested significant (X^2 = 13.43; df = 3; P = 0.004), which could be explained by the higher grass cover in sub-community 1.1 as illustrated in the graph. The significant difference in tree canopy cover (X^2 = 12.96; df = 3; P = 0.005) is also illustrated in the graph, where sub-community 1.2 had a much lower cover percentage compared to the other sub communities. There was a tendency towards higher shrub and herb cover in sub-community 1.2 and 1.1 but this was not significant.

The average litter depth for sub-community 2.1 was significantly deeper than that of the other sub-communities (X^2 = 10.15; df = 3; P = 0.017). The differences in average fermentation depth for the sub-communities also tested significant (Figure 5-44).

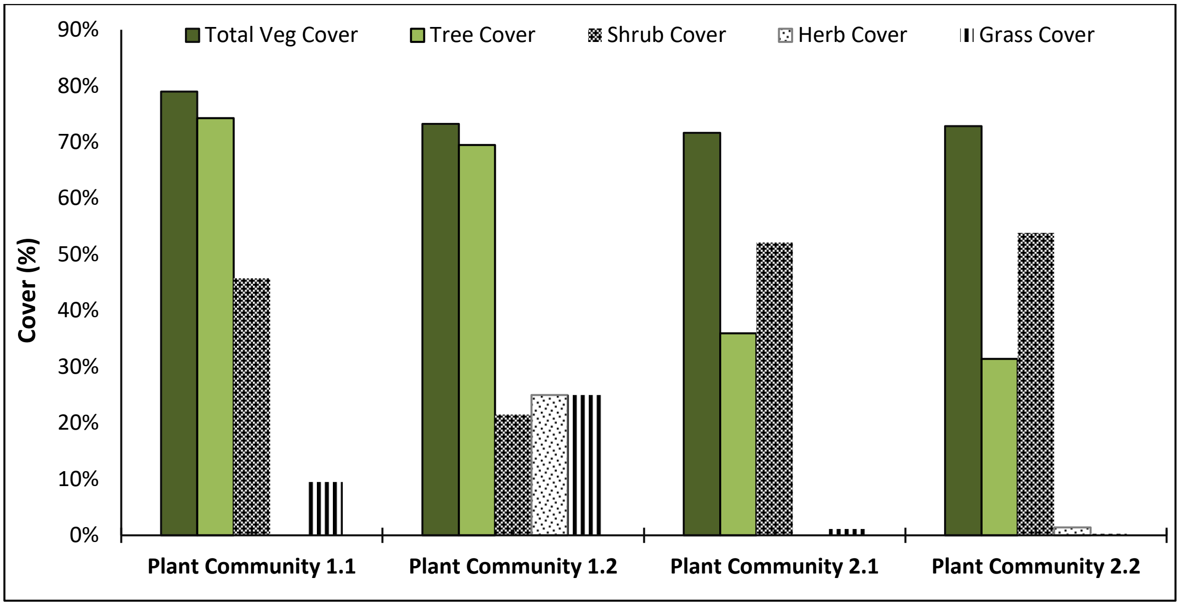


Figure 5-43: Total vegetation cover (% of the surface area of the island for the main communities); and the tree, shrub, grass and herb cover (% contribution to the main communities for the various sub-communities).

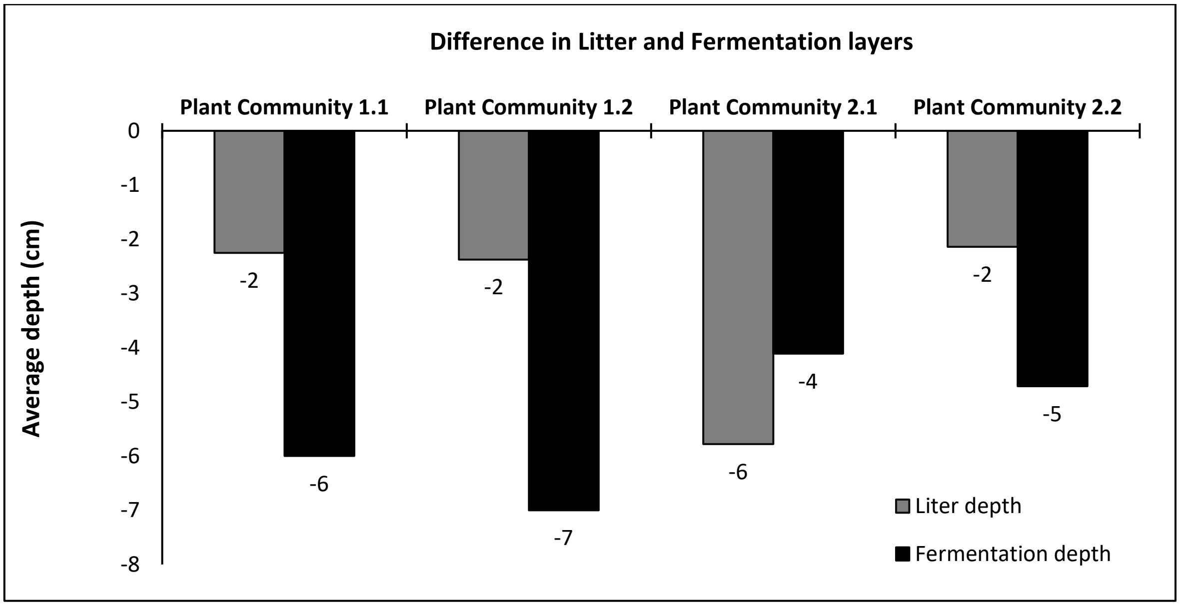


Figure 5-44: Litter and Fermentation layer depths for sub communities on Mnemba. Negative values indicate that these layers were measured downward from the surface level.

5.5 Discussion

Mnemba Atoll's vegetation composition and succession trends displayed affinities with islands in the Indian Ocean, for example Christmas Island, and particularly sandy cays and reef islands such as Heron or Cousin Island from the Great Barrier Reef (Airy Shaw, 1952; Fosberg et al., 1961; Gwynne and Wood, 1969; Mitchell, 1974; Stoddart and Fosberg, 1991; Walker, 1991; Hill et al., 2002). The dominance of sandy loam soil and high drainage conditions confirmed that the island's soil substrate formed from coralline and reef limestone parent material (Haij, 2010). The indigenous vegetation on the island was a mature natural forest, which is an indicator of good soil conditions and typical atoll vegetation succession (Sharples and Cairney, 1998; Woodroffe and Morrison, 2001; Batianoff et al., 2010). Typical species from the Zanzibar-Inhambane edaphic coral-rag scrub forest and undifferentiated forest types were found on Mnemba Island. Species included *Grewia glandulosa, Ludia mauritiana, Euclea racemosa, Flueggea virosa, Mimusops obtusifolia, Pandanus kirkii*, and *Sideroxylon inerme*. Other species typical of scrub forest in the absence of coral karst included *Adenia* spp*., Suregada zanzibariensis*, and *Terminalia catappa*. Zanzibar-Inhambane transitional rain forest species such as various *Ficus* spp*., Morinda citrifolia, Cordia subcordata, Gymnosporia heterophylla* and *Trema orientalis* were also identified at the study site. This type of vegetation composition is representative of the coastal mosaic of East Africa, as was expected for this site (Mustelin et al., 2009; Kindt et al., 2015; van Breugel et al., 2015a; van Breugel et al., 2015b). *Eugenia capensis* (Figure 5-19, Figure 5-20 and Figure 5-21) was the most abundant species in the indigenous forest (Plant community 2). Regional similarities can be found in the coral rag forest from the Tondooni peninsula of Ngezi Forest in Pemba (Beentje, 1990), which listed *Eugenia* spp*., Parvifolia* spp*.* and various *Ficus* spp*.* as abundant.

Prior publications suggested that Mnemba Island was divided into two main vegetation types (Ngoile, 1990) with specific mention to the natural and pine forests. This was confirmed and quantified by the current vegetation analyses and resulted in the delineation of plant community 1 as *Casuarina cunninghamiana–Suriana maritima* open to closed sandy dry coastal forest, and plant community 2 as *Eugenia capensis–Mimusops obtusifolia* coastal forest. This floral composition of plant community 2 was also consistent with literature which refers to coastal forests in this region as coastal thickets and dry evergreen forests (Beentje, 1990). The island's vegetation list was updated and expanded from 32 species recorded previously to 91 species (from 54 families).

The island's vegetation succession has been influenced by the cycle of depositing and abstraction of sand from the cay by the seasonal changes in the East African Coastal Current (EACC) (refer to Figure 2-5) (Dubi, 2000; Odada, 1993; Mustelin et al., 2009). The vector map in Figure 5-45 illustrates the smaller size of the cay in 1973 and the subsequent increase of the south eastern and north eastern corners by 1995. After 1995, the north eastern corner continued to expand, but the south eastern corner started to reduce again while simultaneously moving slightly northward. By 2014 the island had dramatically increased in size.

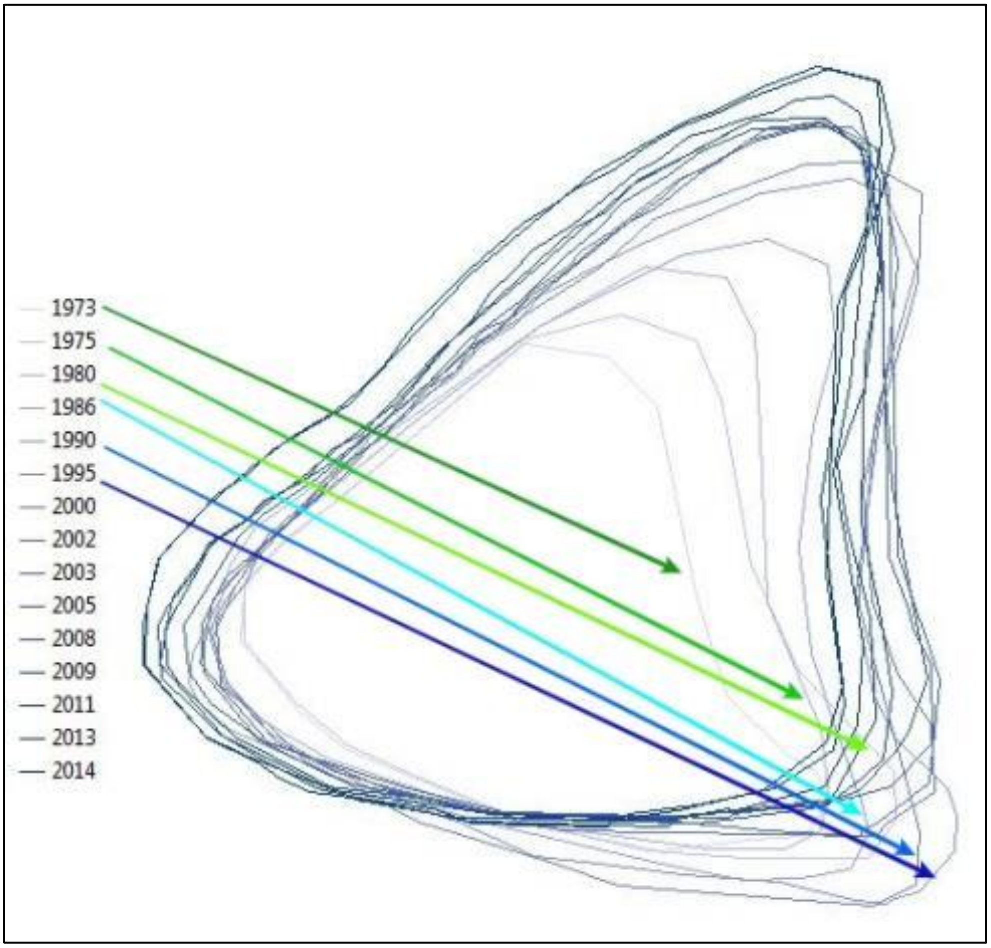


Figure 5-45: Mnemba Island's growth and decline between 1973 and 2014 (AndBeyond, 2014).

The distinct north-south sandy ridges in the center of the island noted by Ngoile (1990) in 1998 (refer to Chapter 3, Figure 3-5) was said to be increasing the island's size at the time. Figure 5-45 confirms this – as Ngoile (1990) suggested, the island has been increasing in size – and as demonstrated in the vector image, the island grew substantially (potentially doubled) over a relatively short period of time (24 years from Ngoile's report to the last vector in the image in 2014). At the time of the report spatial shape files were not available for area calculations of the different dates in the image.

At the time of the current study, the status of Mnemba Island's 'mobility' was one of receding on the north-eastern, eastern, and the south-eastern shores. The incoming waves were interacting with the vegetation edge and uprooting the *Casuarina cunninghamiana* trees, churning the fallen trees during high tide and worsening erosion of the sandy substrate (Swanepoel, 2017). This phenomenon has also been reported for beaches housing *Casuarina cunninghamiana* trees in Unguja (Haji, 2016). During Ngoile's (1990) assessment of Mnemba Island, he reported severe erosion and uprooting of vegetation on the south-western shore of the island, as opposed to the north-eastern shore at the time of the current study. Ngoile (1990) also recorded the direction of surface currents around Mnemba (Figure 3-4) to be opposite to the currents recorded at the time of the current study (Swanepoel, 2017). As described in Chapter 2 (section 2.5.1), the EACC changes direction during the kusi and kaskazi monsoons (Garcia-Reyes et al., 2009; Zavala-Garay et al., 2015) which has a direct impact on the surface currents that pass by the Mnemba Atoll (Swanepoel, 2017). Vegetation succession on Mnemba Island is thus affected by continuous changes in ocean currents and a constant process of erosion and succession. Poor plant species diversity is indicative of atolls, yet these islands are known for housing a distinct group of plants that are adapted to atoll succession through adapted seed dispersal methods (Woodroffe and Biribo, 2011). The vegetation study on Mnemba Island resulted in several species typical to Indian ocean atolls being identified: including *Casuarina cunninghamiana, Trema orientalis*, *Fluggea virosa*, *Searsia natalensis, Caesalpinia bonduc, Melanthera biflora, Boerhavia diffusa, Bidens pilosa, Aneilema indehiscence, Dalechampia scandens, Rhynchosia sublobata, Enteropogon macrostachyus, Panicum repens, Dactyloctenium aegyptium, Kyllinga erecta, Ipomoea pes-caprae, Scaevola sericea* and *S. taccada* (Gwynne and Wood,1969; Barnes et al., 2008; Vesey-Fitzgerald, 1942).

When the vector image in Figure 5-45 was manually overlaid onto satellite imagery (Appendix I), it was evident that the indigenous forest did not expand much in 41 years, apart from a small 50 m section in the North-east corner. In contrast, the *Casuarina cunninghamiana* forest expanded up to 150 m in some areas where sand was deposited. By 1986 (13 years from the first vector line dating 1973 - Figure 5-45), the bulk of the *C. cunninghamiana* on the eastern side of the indigenous forest had formed. By 2000 (14 years from 1986) this entire area as well as the bulk of the outer ring of *C. cunninghamiana* in the current delineation, had been established. The mapped image indicates that the rest of the outer 'rim' of the island's current delineated area had completely formed by 2013. The dynamic nature of the process was especially noticeable in that the vector lines between 1986 and 2009 showed rapid expansion in both sandy substrate and vegetation on the south-eastern and eastern shores, after which it declined again in size through erosion, to the current vegetation edge at the time of the survey.

Besides the natural processes of erosion and expansion of sandy cays (Fonseca et al., 2012), the early influence of human settlement on Mnemba Island led to the establishment of an extensive *Casuarina cunninghamiana* forest, which covered half of the forested area on the island at the time of inquiry. Had the *Casuarina cunninghamiana* trees not been introduced to the island, the increase in the island's size through vegetation succession might not have been as extensive. Although the fast-growing *C. cunninghamiana* trees performed a key role as pioneer species, the mature tree layer in this plant community did not have the same species diversity (Table 5-9) as the indigenous forest. Plant community 1 also demonstrated significantly less development in terms of shrub cover, compared to plant community 2 (indigenous forest). Regrettably, reports indicate that the formation of *Casuarina species* forests have a negative impact on overall vegetation diversity and understory development in the long-term (Potgieter et al., 2014).

The current vegetation survey indicated that the *Casuarina cunninghamiana – Suriana maritimia Open to Closed Sandy Dry Coastal Forest* had reached a mature phase of succession, given the significant tree canopy cover, number of trees with a BHD larger than 6 cm and the significant height of the tree canopy (Potgieter et al., 2014). As described in section 5.4.2, sub-community 1.1 was characterised by a dense cover of *Casuarina cunninghamiana,* interspersed with the broadleaf evergreen coastal shrub *Sideroxylon inerme,* and the screw pine *Pandanus kirkii* in its shrub form. Pioneer grasses and sedges such as *Enteropogon macrostachyus, Panicum repens, Dactyloctenium aegyptium,* and *Kyllinga erecta* indicated that conditions within this sub-community remained favourable to more resilient species, as opposed to secondary indigenous shrubs. This was confirmed statistically with a significant difference in grass cover between sub-communities, with sub-community 1.1 exhibiting the highest percentage of grass cover on the island. Stabilizing species *Ipomoea pes-caprae* and *Scaevola sericea* were present but not abundant as in Ngoile's (1990) study in 1989, when at the time, this part of the forest directly bordered the beach on the eastern side of the island. Ngoile (1990) reported that the presence of a stabilizing *Pemphis acidula* zone on the eastern side of Mnemba Island, in combination with sand deposits, grasses, sedges and creepers, contributed to the formation of a stable beach zone (Figure 3-5). The vegetation survey from the current study indicated that although much grass and sedge cover still existed under the established *Casuarina cunninghamiana* canopy, *Pemphis acidula* or similar beach succession species were not prolific in this region of the island as it was in 1989 (Ngoile, 1990).

Plant community 1.2 was characterised by a thin stretch of typical coastal vegetation dominated by a significantly taller *Casuarina cunninghamiana* forest canopy and a *Suriana maritima* shrub layer on the outer rim of the island. This plant community formed a buffer between the older pine forest (sub-community 1.1) in the east and the beach zone, and between the indigenous forest (plant community 2) and the beach almost entirely encircling the island. In plant sub-community 1.2, *Pandanus kirkii, Suriana maritimia and Sideroxylon inerme* had formed isolated pockets of understory shrub cover along the vegetation edge, especially on the east of the island, but no sandy ridges (frontal dunes) had formed between the scattered shrubs in the “newly established” beach zone, as at the time of Ngoile’s (1990) report. On the northern and western shores of Mnemba Island, a well-established frontal dune system has formed over time, with high tide reaching well below the vegetation edge. This sandy dune did not exist on the western side of the island during Ngoile’s (1990) observations, as he reported uprooting and erosion on the western vegetation edge at the time of his study. Overall, sub-community 1.2 had a significantly lower % of species (Section 5.4.4) on the island, as well as a lower Shannon-Wiener Index and the highest homogeneity of the communitieson the island (Table 5-9) – a trend consistent with other islands and coastal regions where succession by *Casuarina* spp*.* tend to form monotypic stands (Potgieter et al., 2014).

Apart from sea current erosion, other challenges experienced by sub-community 1.2 included continual salt spray and strong winds. *Sideroxylon inerme* shrubs in this community adapted to the salt spray by developing a thicker and waxier leaf structure, and *Casuarina cunninghamiana* trees grew taller as their roots went deeper into the sandy substrate to withstand strong ocean winds. The tallest trees on the island (*Casuarina cunninghamiana)* were recorded in sub-community 1.2. The average breast height diameter was the smallest for this plant community, but the total number of trees (above 6 cm in diameter) surpassed that of the other sub-communities. Sub-community 1.2 was subjected to more environmental changes than the other sub-communities, which explained why this community had the least number of species, thinner and taller trees, the highest number of dead trees (standing and fallen), the shortest maximum shrub height, and the lowest tree canopy cover percentage for all sub-communities on the island. As a succession forest, sub-community 1.2 was expected to house typical pioneer species for the coastal region (Woodroffe and Biribo, 2011). These species were identified as the regenerational *Trema orientalis*, resilient *Fluggea virosa*, and the soil conservator, *Searsia natalensis*. The senna plant, *Caesalpinia bonduc* also added to the pioneers of this community.

As expected, the indigenous forest on Mnemba Island housed mature vegetation with a significantly taller and more abundant shrub layer, compared to plant community 1. The indigenous forest (plant community 2) was protected from the salt spray and strong winds by the surrounding *Casuarina cunninghamiana* stands (plant community 1). Since salt spray can stunt growth for many plant species, it was believed that the shorter average shrub height on the outer rim of the island was partly due to exposure (Niering, 1956). Concurrently, it has been proven that *Casuarina* spp. suppress understory development through a chemical mechanism when pine litter decomposes (Hammerton, 2001; Potgieter et al., 2014). These limitations were anticipated for the pine forest communities on Mnemba Island. The older pine forest (sub-community 1.1) displayed the least developed shrub cover, which was ascribed to this part of the island having less favourable conditions from long-term exposure to allelochemicals in a monospecific environment (Hammerton, 2001; Stamp, 2003; Potgieter et al., 2014).

Overall, the higher % of species for the indigenous forest (Community 2) (Section 5.4.4 and Table 5-9) did not test significant, but the understory structure and abundance were significantly more pronounced in plant community 2. However, the differences in species % between the four sub-communities on the island demonstrated a trend, also evident in the difference in Shannon-Wiener Index for each community (Table 5-9). The outer edge (Community 1.2) had the lowest diversity, followed by the interior pine forest (Community 1.1), then a drastic jump in diversity to the outer parts fo the natural forest (Community 2.1). The smallest sub-community from the innermost sections from the indigenous forest (sub-community 2.2) displayed the highest % of species from all releve’ and lowest homogeneity (Table 5-8 and Table 5-9). The herb layer had significantly higher cover-abundance in the two pine sub communities compared to the indigenous forest, especially sub-community 1.1 (the older pine forest). Herbs occurring in sub-community 1.1 included pioneer species such as

Melanthera biflora, Boerhavia diffusa, Bidens pilosa, Aneilema indehiscence and the climbing herbs *Dalechampia scandens* and *Rhynchosia sublobata.* In all sub-communities where herbs were identified, many species were only present as seedlings. As is typical for small islands in the Indian Ocean, very few of these seedlings survived the dry months from June to September and January to February (Vesey-Fitzgerald, 1942). Shrub seedlings also did not have a long lifespan as observed during the study period. *Mimusops obtusifolia, Pandanus kirkii, Sideroxylon inerme* and other shrub and tree seedlings either dried up or were browsed by Suni and Duiker antelope as soon as seedlings reached a height of between 3 and 10 cm. A poorly developed herb layer was anticipated for the natural forest in this region, where dry coastal conditions, especially on the eastern side of Unguja, has the potential to affect species composition and phenology considerably (Mustelin et al., 2009). The herb layer only reached a cover-abundance of 0.4% in the indigenous sub-communities. During the study period, the effects of the recent drought in the region (Mustelin et al., 2009) also reached Mnemba – the development of the understory of the indigenous vegetation was clearly thwarted by shorter monsoons, less rain, higher temperatures, and the added pressure from antelope browsing seedlings shortly after sprouting.

Sub-community 2.1 made up much of the indigenous forest, and was dominated by *Eugenia capensis, Mimusops obtusifolia*, *Pandanus kirkii* and *Pisonia grandis*. The dominance of *Pandanus kirkii* agreed with Ngoile's (1990) description of the indigenous vegetation of the north-western side of Mnemba Island, 27 years prior to the current findings. Apart from *Pisonia grandis*, all species identified in this plant community were likely to be found on the sandy cay. The forest was further characterised by mature shrubs and vines such as *Grewia glandulosa*, *Pavetta stenosepala*, *Ecbolium ligustrinum*, *Maerua triphylla*, *Secamone punctulata* and *Scutia myrtina*, whereas only immature saplings of *Synaptolepis kirkii* were recorded. The canopy was covered with the parasitic vine *Cassytha filiformis*, but the species was removed from time to time as part of a management program. Another characteristic of this sub-community was the presence of a variety of *Ficus* spp. An ecologically important species that was identified on the island and particularly in plant community 2.1 was the naturalised *T. catappa*, but only a few mature specimens were recorded. Due to the seeds of this species being able to survive for a long time, this tree could potentially increase its cover-abundance on the island in the future (Brown and Cooprider, 2013.) A variety of fungi species made their appearance on the island during the March and April rains in 2016. One particular area in sub-community 2.1 displayed a higher diversity and number of fungal species during these months, and included the duiker food species, *Auricularia auricular-judae*.

Tree canopy coverage was significantly higher in sub-community 2.1 compared to sub-community 2.2, which potentially explained the significantly deeper litter layer from fallen leaves in this community. It was noted that large F*icus* sp. canopies with large leaves contributed to the deeper litter layer in this sub-community, but not to the fermentation layer. Large F*icus* sp. leaves do not decompose as readily as the smaller leaves from the other tree and shrub species, which clarified why the average fermentation layer in sub-community 2.2 with its higher shrub cover was deeper than for sub-community 2.1. A higher percentage of vegetation cover is critically important for ongoing fermentation, moisture retention and continual understory development (Brady and Weil, 2007). Should the sandy substrate become less fertile, the *Casuarina cunninghamiana* forest could potentially invade the indigenous forest (Potgieter et al., 2014).

Another species that lends itself to monospecific stand formation is the Indo-pacific Cabbage tree, *Pisonia grandis.* This species most likely reached Mnemba Island through avian dispersal as its highly effective seed structure allows it to cling to bird's bodies for transmission over long distances. It is not known when the species was initially established on Mnemba Island, but the presence of numerous large specimens indicates that *Pisonia grandis* has been on the island for some time. This tree species thrives in guano rich environments and contributes to soil quality by stimulating the formation of phosphate and a peat like fermentation layer (Walker, 1991). The occurrence of *Pisonia grandis* is believed to have contributed to better soil conditions on Mnemba Island, and potentially assisted in establishing a larger island area during previous sandy deposits and vegetation succession (Sharples and Cairney, 1998; Woodroffe and Morrison, 2001; Batianoff et al., 2010). Accounts of *Pisonia grandis* transforming entire islands into monostands, raise the question about the potential effect that this species could have on the island' diversity in the future (Hill et al., 2002). Walker (1991) describes the extreme adaptability of *P. grandis* to droughts and oscillating weather patterns, and reports that the species thrives in environments with high exposure to sunlight and mycorrhizal fungi. However, *P. grandis* is not as successful in its invasion when competition from other tree species and shaded forests keep it at bay. According to Walker (1991), the distribution of the species has been particularly linked with seabird congregation, distinct from what has been described for any other plant species. The ecological value of this tree species is recognised and should be investigated further as a potential pioneer species for similar islands with poor soil conditions. Furthermore, it was found that all parts of the plant at different phenological phases formed an important part of the Aders' duiker's diet on Mnemba (Chapter 7, section 7.3.3), adding to the ecological significance of the species.

Sub-community 2.2 had the highest density of *Eugenia capensis* and *Grewia glandulosa* compared to other plant communities. From the high species diversity of mostly non-pioneer plants found in this sub-community, it is suggested that this part of the natural forest is the oldest and formed first during atoll formation. Species composition comparisons for the various sub-communities indicate that sub-community 2.2 was recently heavily degraded - the herb layer was almost absent.

From the evaluation of the species composition of Mnemba Island's indigenous plant communities and the frontal beach zone, it was established that the terrestrial environment is associated with the nature of Indo-pacific sandy cays that have been studied by numerous botanists (Airy Shaw, 1952; Walker, 1991; Stoddart and Fosberg, 1991; Hill et al., 2002).

5.6 **Conclusion**

Mnemba Island's flora covered 11 ha of the sandy cay. In general, the vegetation was identified as *Sideroxylon inerme-Grewia glandulosa* coastal scrub forest, with a floristic similitude to the Zanzibar-Inhambane edaphic coral-rag scrub forest. This type of vegetation forms part of the larger coastal mosaic of East Africa (Kindt et al., 2015; van Breugel et al., 2015a; van Breugel et al., 2015b). Noteworthy species included the spiny screw pine *Pandanus kirkii*, the tall multi-stemmed evergreen shrub *Eugenia capensis,* the evergreen trees *Mimusops obtusifolia* and *Pisonia grandis,* as well as the perennial climber *Secamone punctulate,* the endemic scrambling shrub *Capparis viminea var orthacantha*, the parasitic *Cassytha filiformis a*nd a variety of *Ficus* spp.

Of particular interest is the difference in species diversity and composition for the two main physiognomic-physiographic areas that are easily distinguished from aerial and on-site investigations: the "planted" *Casuarina cunninghamiana* section and the natural or original atoll vegetation. Although a lower evenness was expected for the atoll's vegetation, the evidence presented here indicated that the richness and homogenous distribution of species were evidence of connectedness to the main island of Zanzibar, Unguja, and the introduction of regional species through seed dispersion species such as migratory birds and bats (Mligo, 2015). Results from the vegetation survey indicated that the natural forest on Mnemba is ecologically important for maintaining the islands vegetation, the breeding colonies of different bird species, and the highly suitable habitat it provides for the endangered Aders' duiker. However, there is a distinct lack of understory development across the natural forest, signifying that previous overpopulation of Suni antelope affected the regeneration of small shrubs and trees. It is critical to keep the antelope population as low as possible for the forest floor and understory vegetation to recover, especially considering recent droughts. Replacing some or all the *Casuarina cunninghamiana* with indigenous beach stabilising plant species over time will aid in stabilizing the island's soil and vegetation, preventing further erosion. The outcome of the investigation aided in evaluating the ecological value of the *Casuarina cunninghamiana* plantation in the sustainability of the Aders' duiker breeding project. The change in vegetation from the time of Ngoile's (1990) assessment of the island's vegetation to the current study demonstrates the capacity of *C. cunninghamiana* to establish a monostand in a short period of time. Evidence of the island's growth in landmass and subsequent terrestrial ecology through sedimentation encourages the possibility that through dune formation, further sedimentation and active management of indigenous vegetation, the process of erosion could be thwarted.

CHAPTER 6

POPULATION SURVEY AND BIOLOGICAL MEASUREMENTS

6.1 Introduction

Mnemba Island was selected by the Revolutionary Government of Zanzibar in 2005 as a natural habitat breeding site for the rare Aders' duiker, to investigate the sustainability of smaller breeding habitats for conservation purposes.

Ten years into uninterrupted breeding of the core population, the need to review the condition of the population and the vegetative habitat, sparked the current research project as part of a conservation management planning process.

With no records of age, gender, and population growth rate for the Mnemba Aders' duiker population, and only short-term inquiries into limited behaviour and resource use, this study was initiated to collect baseline data from a variety of viewpoints. One of the most important aspects of the study included population estimates, which was used in carrying capacity calculations, estimating an instantaneous growth rate at the current population density, and interpreting the social, territorial, and home range results from the rest of the study.

Given that duiker species are reported to reach an age of fifteen years (East, 1999; Weigl, 2005; Kingdon, 2015), at least some of the group of duikers that were introduced to the small island in 2005, would have survived to 10 years or older in 2015 when this study commenced.

6.1.1 Population Size

It is important to monitor the size of any given wildlife population for conservation purposes (Saunders et al., 2018), especially when meta population numbers for the species decline rapidly, and environmental pressures accelerate (Amin et al., 2015; Payne and Bro-Jørgensen, 2016). Kanga (2002) reiterates the importance of monitoring population figures and distribution in the case of forest duikers in Africa, to prevent diversity loss and to recognize habitat pressures. Estimating animal abundance or population size can be complicated for reasons linked to terrain and species-specific behaviours (Borchers et.al. 2002).

6.1.2 Aders' duiker population surveys

Aders' duiker population surveys have been conducted for Zanzibar and Kenya using both labour intensive and remote means to derive population density counts. Surveys in Zanzibar took place during 1982 (Swai, 1983), 1995 (Williams et al., 1996) and in 1999 (Kanga, 1999). In the first survey (1982) the population on Unguja was estimated at 5 000. Both Williams et al. (1996) and Kanga (1999) used a detailed drive-count net-capture technique, which enables comparison of population figures over time. The drive count method has been reported as the most effective sampling method to be used for estimating duiker population numbers (Newing, 2001; Kanga, 2002; Viquerat et al., 2012). It entails repeated enclosing of sample areas and driving animals into a netted barrier. The number of Aders' duikers trapped in the nets is recorded, and the total number is multiplied by the size for the enclosed area to give a density rate. The total estimated population was deduced from this density rate, by multiplying it with the total area size of suitable habitat across Unguja. The two surveys measured the population at below 2 000 in 1995 and at 614 in 1999, respectively.

In areas such as Arabuko-Sokoke where numbers have dwindled drastically, population estimates are often extrapolated from the only data available (Kanga, 2002; IUCN, 2017). Based on sighting frequency and the size of the area, Kanga (2002) estimated that in 1999 there was only ~500 remaining Aders' duiker in Arabuko-Sokoke. Payne and Bro-Jørgensen (2016) suggested that this sub-population might be the first to disappear in the near future. In Boni-Dodori in Kenya, more frequent sightings of Aders' duiker prompted the use of camera trap surveys to estimate population abundance (Amin et al., 2015). Consequently, using a series of camera traps strategically placed in their study area, the authors approximated a density rate of 7.3 Aders' duiker per km^2. According to the IUCN (2018a), following the discovery made by Amin et al. (2015), an estimated 14 000 mature Aders' duiker are expected to live across their current range. The northern Kenyan population is now the largest known Aders' duiker population in Africa. Provided the sampling and site selection is informed by species' specific behaviour and activity patterns, camera trap methods are especially useful as a repeatable, low impact survey tool in dense large areas (Andanje and Wacher, 2004; Ahumada et al., 2011; O'Connell et al., 2011; Rovero and Marshall, 2004; Rovero et al., 2014; Bowkett et al., 2008, 2009, 2013; Amin et al., 2015).

Population densities are also often determined through line transect surveys. Unlike drive captures and camera traps, line transect surveys can be technically and methodologically tricky in dense habitats (Newing, 1994, 2001). Distance measuring techniques such as line and point transect methods are predominantly pertinent in estimating density in large areas with difficult terrains (Henderson and Southwood, 2016). In an attempt to monitor Aders' duiker population growth on Chumbe Island (similar to Mnemba Island in size and vegetation composition), various attempts at combining transect lines and drive surveys were made. Survey reports produced for Chumbe Island reveal that Aders' duiker's cunningness and the tricky coral rag terrain challenged survey teams. Population estimates on Chumbe have been derived from sightings during transect surveys, but from the reports it appeared that the population size was too small to perform statistical calculations to estimate the actual population size (Lanshammar, 2009). Given the difficult survey conditions and small number of duikers on the island, sightings and signs (fecal piles) are currently the only methods used to determine abundance on Chumbe Island with the last population estimate of five individuals made in 2012 (Mwinyi et al., 2012).

Population survey objectives

Once conservationists establish that a meta-population is declining rapidly, Captive Breeding and Release Programs (CBRP) are initiated to increase species numbers (McCleery et al., 2013). Newing (2001) points out that species such as duikers (with low reproductive rates) might not be ideal candidates for CBRP's as the only form of species recovery. When a CBRP is implemented, one of the key factors in monitoring the program's success, is record keeping of population figures which includes birth and death rates (Ballou and Foose, 1996; Ballou et al., 2010; Koláčková et al., 2011). Growth rate is calculated to assess population growth and stochasticity (variation in population growth), as well as to gain insight into carrying capacity in an enclosed area (Jensen, 1975; Koláčková et al., 2011) and population viability (Lande et al., 2003; Ballou et al., 2010). A captive breeding area reaches a critical point in terms of carrying capacity when the maximum yield causes degradation to the environment due to overpopulation, which in turn compromises the existing population. In the case of Mnemba Island, the introduction of Aders' duiker did not form part of a captive breeding protocol, but rather as a free range in-situ breeding project. Thus, no detailed management protocols, population monitoring or harvesting schedule was developed for this sub population for this site. It would be beneficial if the Aders' population on Mnemba could be considered and managed as a CBRP to ensure relevant and practical management decisions for this population's growth and health.

Suni population dynamics on Mnemba Island

High numbers of Suni antelope on Mnemba Island raised numerous concerns regarding habitat degradation and possible competition with the endangered Aders' duiker. Harvesting (live capture and relocation) of Suni had been done three times to reduce the population, and records of these harvesting events, obtained from the DFNNR, are depicted in Appendix M as part of a logistics growth curve.

As sympatric species, Suni and Aders' duiker's coexistence has recently been studied by Amin et al. (2015) in Kenya. Under spacious free-range conditions Amin et al. (2015) suggested that resource competition still existed. In another study on duiker and Suni sympatry, Prins et al. (2006) did not report aggressive behaviour between the species, although competition among species with similar body sizes and feeding styles exist, as was noted from high levels of dietary overlap. Prins et al. (2006) ruled out competitive displacement as niche development, and evidence of competition between Aders' duiker and Suni could not be defined by Amin et al. 2015. These researchers suggested that differences in population size potentially play a role in the competition strategy between these two species. For example, 'scramble competition' takes place when the species with the largest population finds fallen leaves and fruits first during foraging (de Boer and Prins, 1990).

Suni's are reported to give birth to one young per annum, but Suni males often select two females, increasing the potential rate at which the population increases in a calendar year (Estes, 1991). Breeding occurs between November and March, after which they carry their young for six months and give birth. After two months, the young are weaned and live for up to 10 years. At one to one-and-a-half years of age they reach sexual maturity and give birth to the next generation. Suni antelope are thus potentially a more competitive species in an enclosed area, compared to the Aders' duiker with its monogamous habits. Sharing a small, enclosed environment with no means to migrate poses a challenge for the two antelope species that also have similar dietary requirements.

6.1.3 **Carrying capacity**

Population surveys and carrying capacity estimations are guided by the objectives of a project. As outlined by Dasmann (1964), Caughley (1979) and Bailey (1983), ecological and economic carrying capacities can be distinguished based on the anticipated conditions of the population and habitat in question. The maximum carrying capacity (K) of a small island would be reached when the growth rate approaches or reaches zero; however, maintaining this type of population density might be at the cost to habitat conditions and future populations. The small size of Mnemba Island, and the damage to the vegetation caused by large numbers of Suni antelope and a zero-take-off policy for the Aders' duiker, has urged conservation managers to create a scientific schedule using regular harvesting as a tool to protect the forest. As stated, a no-harvest approach of duiker offspring from Mnemba has been followed since their introduction onto the island, thus it was anticipated that by the time of this study, that the population would have reached a maintenance density, especially under degraded forest conditions and pressure from overpopulation. Guided by the twofold objective, recovery of the forest habitat and population recovery of the rare Aders' duiker, the current study aimed to determine the maximum sustainable density using logistic growth modelling (Wildlife Campus, n.d).

6.1.4 Anatomy and physiology

It is reported that the global population of Aders' duiker is rapidly declining (Ochieng et al., 2017) and that too little information exists about this species. With captive breeding programs proposed as an urgent solution to the population decline (Kanga, 2002; Finnie, 2002), biological data are needed to formulate relevant husbandry protocols to provide information for improving the success of such programs (Newing, 2001). Little to no opportunity currently exists for compiling detailed biological data for the species. The Aders' duiker is not currently being hunted commercially in Zanzibar or housed in captivity, and therefore no measurements or biological information are being collected. Opportunistic data collection would be the only means of obtaining biological information, but from communication with the State Veterinary department in Zanzibar, none of the related departments collect biological data from opportunistic events/specimens on Unguja. Since body size is critically linked to foraging strategies and social habits, collecting data on the size of individuals is important (Jarman, 1974; Newing, 2001; Huffman, 2016a). Very little information is available from existing publications, and additional biological data is required to better understand this species' ecology.

6.1.5 Chapter objectives

The objectives for this chapter are to estimate the current population density and growth rate of Aders' duiker on Mnemba Island, and to provide suggestions for estimating carrying capacity. A further chapter objective is to collect supplementary information on the biological aspects of Aders' duikers so that this can be added to existing baseline data for the species, which would hopefully lead to new research questions and further investigation into the ecology of the species.

6.2 Methods

6.2.1 Study area

Mnemba Island is covered with 11 ha of vegetation (natural and planted) and is located off the north-eastern shore of Zanzibar (S 05 49.219, E 039 22.959'), at 2.7 km from the nearest beach on Unguja. The island is subject to tropical weather patterns that are typical for the East Coast of Tanzania, ranging from monsoon rains to dry hot winds. Chapters 3 and 5 provided detailed information about the terrestrial environment and the vegetation on the island.

The island provides a suitable habitat for the indigenous Aders' duiker antelope and has been successful in sustaining a breeding population since 2006. The duikers frequent the natural forest in the interior of the island, foraging from a variety of trees and shrubs, and sheltering from the elements and commercial human activity. The island offers a haven for the small population, with zero predators and no natural or anthropogenic threats.

The resident Aders' duiker population cannot replenish its own gene pool or move to other forest habitats on Zanzibar through migration. These duikers have been sharing the island with Suni antelope for the past ten years since their introduction. As outlined in the introduction, the Suni were introduced in 1995 and have been breeding very successfully, while being harvested from time to time to alleviate pressures on the island's vegetation. To date no attempts have been made to harvest Aders' duiker.

6.2.2 Population survey

A drive method with multiple mark-recapture samples was selected as the survey method for estimating population size (Newing, 2001; Kanga, 2002; Viquerat et al., 2012). Capture results were analysed using the Schnabel index and the Schumacher-Eschmeyer equation. Three population values were obtained for each of the equations – 'no replacement', 'partial replacement' and 'replacement' of captured animals.

The Schnabel index equation is delineated as follows:

$$3.\quad \widehat{N} = \frac{\sum_t (C_t M_t)}{\sum_t R_t}$$

Where $\widehat{N}$ is the population estimate;
C_t = the number of duikers caught during sample day t;
R_t = the number of duikers captured on sample day t already bearing marks;
M_t = the cumulative number of all marked duikers up to the day before sample day t.

For comparison of results, a ‘replacement’ calculation was done using the mark-recapture data in the Schumacher-Eschmeyer equation. This method is said to be more accurate in closed samples, which include Islands and captive breeding environments for multiple sample mark-recapture surveys (Krebs, 2014, 2016). The Schumacher-Eschmeyer equation was used with the same input data as in the Schnabel index:

$$4.\quad \widehat{N} = \frac{\sum_{t=1}^{s} (C_t M_t^2)}{\sum_{t=1}^{s} (R_t M_t)}$$

Where $\widehat{N}$ is the population estimate;
s = total number of samples;
C_t = the number of duikers caught during sample day t;
R_t = the number of duikers captured on sample day t already bearing marks;
M_t = the cumulative number of all marked duikers up to the day before sample day t.

The total number of recaptures for the survey was less than fifty individuals, which led to confidence limits being obtained from the Poisson Distribution Table for both methods (Krebs, 2014, 2016). All calculations were done in MS Excel and results rounded up to three decimal points.

During 12 months of data collection on Mnemba Island, all known births and deaths were recorded, and the instantaneous population growth rate calculated.

The instantaneous population growth rate was calculated from r = b – d in the equation:

$$5.\ \frac{dN}{dt} = bN - dN$$

Where dN/dt = the rate of change in N;
b = the instantaneous birth rate;
d = the instantaneous mortality rate;
N = the population size derived from the mark-recapture survey.

An intrinsic growth rate, r_m (maximum growth rate per capita) was derived from the population survey results and the instantaneous population growth rate using the equation:

$$6.\ \frac{dN}{dt} * \frac{1}{N} = r_{max}$$

Where dN/dt is the instantaneous growth rate;
N = the population size derived from the mark-recapture survey;
r_{max} = the maximum intrinsic growth rate per capita given the current population data.

Population doubling time was calculated using the equation:

$$7.\ t = In(2)/r$$

Where t is the time it will take for the population to double its size;
r = intrinsic growth rate from equations 4 and 5.

6.2.3 Carrying capacity

Carrying capacity (k), which is defined as the point in a population when the growth rate reaches near zero, is mostly determined by using multiple survey results (Swannack, 2008). Since no previous surveys have been done for the Aders' duiker population on Mnemba, carrying capacity was estimated using population survey results from the current study (D_{est}) (Bobo et al., 2015). This method of estimating carrying capacity ($k = D_{est}$) for duiker species has been performed for undisturbed and disturbed habitats (Robinson and Redford, 1991;

Bodmer et al., 1994; Fa et al., 1995; Feer, 1996; Delvingt et al., 1997; Dethier and Ghuirgui, 1999; Noss,1998; Muchaal and Ngandjui, 1999; Ngandjui and Blanc, 2000).

The model proposed by Robinson and Redford (1991) was used to calculate the maximum sustainable harvest:

$$8.\ \ P_{max} = (0.4 * k * \ e^{rmax}) - (0.4 * k)$$

Where P_{max} = maximum production at the intrinsic growth rate;
r_{max} = maximum intrinsic growth rate per capita;
0.4 = production success rate for red duikers (Robinson and Redford, 1991);
k = carrying capacity expressed by current population (D_{est}).

Population results (D_{est}) from the Schnabel Index and the Schumacher-Eschmeyer Estimate were used to replace k in equation 8 to estimate the P_{max} value for the current population. The same population results (D_{est}) were substituted for K in the logistic growth equation over 20 years, to simulate population growth for each potential value of K, starting with a population of eight in 2006:

$$9.\ \ \frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

Where dN/dt is the change in population density over time;
rN = is the instantaneous growth observed per time unit (b – d);
K = Carrying capacity = D_{est};
N = Population at time t.

A harvesting schedule was simulated for each population scenario, where the number of animals taken off does not exceed P_{max}, and the resulting population (N) would be reduced to half the value of K, at a two-year interval. The total number of animals to be harvested over a period of 20 years (t_{20}) was summed. The difference between N(t_{20}) *with harvest* and N(t_{20}) *without harvest* was recorded as the surplus values for each population scenario. Finally, the total population growth (surplus plus remaining population) for each scenario was compared. The scenarios and results are presented in section 6.3 in this chapter.

6.2.4 Anatomy and physiology

Data on the biology of the Aders' duiker was collected opportunistically during the mark-recapture drive survey. Although the objective of the survey was to count the population and to attached GPS collars, all measurements that we could collect were recorded and summarised for baseline purposes. When an Aders' duiker was entangled for more than a minute, animals were marked and released without measuring all body dimensions. When measurements were possible, standard methods were used (Ansell, 1965). In Chapter 4, section 4.5, Figure 4-2 describes the methods used for measuring body dimensions in detail. Measurements were collected from seven males and seven females during the survey (one of the females died due to natural causes). The length of the head (from the atlas joint to the nose tip) was estimated based on a premeasured skull size, and tail length was not physically measured. This strategy was used to minimize the handling time and capture stress. The total body length was calculated by combining the measured spine length and the estimated head value. No weight measurements were possible. Hair samples were collected for genetic analyses, but laboratory tests revealed contamination of the samples, which caused the genetic component of the study to be disregarded. Further research into gene pool diversity and inbreeding depression is highly recommended.

6.3 Results

6.3.1 Population estimates and growth rate

A range of results were calculated using the Schnabel Index and the Schumacher-Eschmeyer estimate. The Schnabel Index reportedly functions better without replacing the marked animals in the sample pool to be counted on the same day of the survey – not to be confused with the Removal method (Zippin, 1958). For the Schumacher-Eschmeyer estimate, marked animals are put back into the sample pool, and this estimate is recommended as the preferred option for a small, enclosed population (Krebs, 2014) – mark-recapture "with replacement" – marked animals recaptured multiple times on the same day were counted each time. Due to the restricted size of Mnemba Island and the limited duiker population, some animals were marked and captured multiple times. A third mark-recapture condition was fulfilled to compensate for the possible bias created by the small population size, by using unique marks and to only count marked animals once if they were recaptured – this was called the "partial replacement" option, adapted as suggested by Krebs (2016). Results from each of the three mark-recapture scenarios were inserted into the two equations, Equation 1, section 6.2.2 and Equation 2, section 6.2.2. Results from the mark-recapture survey are tabulated in Table 6-1 – producing a range of population estimates for the island. Refer to Appendix N for calculations. The grey shading in the Table 6-1 indicates the values obtained for each calculation under suggested replacement conditions

The results using the Schnabel Index (without replacement, the proposed method for this calculation) produced a population estimate of 25 Aders' duikers on the island. The population estimate, using the Schumacher-Eschmeyer estimate (with replacement, the proposed method for this method) was calculated as 23. The "partial replacement" approach using the Schumacher-Eschmeyer estimate produced a population estimate of 30 animals.

Table 6-1: Results of Mark-Recapture survey for Aders' duiker on Mnemba Island in April 2016.

	With replacement	**Partial replacement**	**Without replacement**
Schnabel Index: N =	**14**	**20**	**25**
Variance	0,000	0,001	0,001
Standard error	0,029	0,0265	0,029
95% Upper limit	92	57	32
95% Lower limit	9	8	7
Schumacher-Eschmeyer: N =	**23**	**30**	**36**
Variance	0,196	0,283	0,501
Standard error	0,001	0,001	0,000
95% Upper limit	**25**	32	38
95% Lower limit	21	28	34

One death that occurred in the first twelve months of the study, due to unusual circumstances brought about by capture stress, was excluded from the calculation because it was 'research induced' and would not have taken place outside the current study. Aders' duiker births (n = 6) and deaths (n = 3) for October 2015 to September 2016 were used to calculate the instantaneous growth rate (n = 3) (Equation 3, section 6.2.2). The instantaneous growth rate was used to calculate the maximum intrinsic growth rate (r_{max}) per capita (Equation 6, section 6.2.2) and population doubling time for each value of N presented in Table 6-2. The doubling time was established from Equation 7 (section 6.2.2). At the lower end of the suggested D_{est}, (D_{14}), the population was due to double in size every three years. If the population size were 20 or 23, the doubling time would be every five years. A population estimate (D_{est}) of 25 corresponded to a doubling time of every six years, at D_{30} every seven years and at D_{36}, every eight years.

Table 6-2: Maximum growth rate per capita and doubling time for different results obtained in population survey calculations.

Population estimate (N = D_{est})	**Growth rate per capita r_{max} = dN/dt * 1/N**	**Doubling time (years)**
14	0,214	3
20	0,150	5
23	0,130	5
25	0,120	6
30	0,100	7
36	0,083	8

Figure 6-1 illustrates the logistic growth curve for each value of D_{est} at the corresponding growth rate (r_{max}).

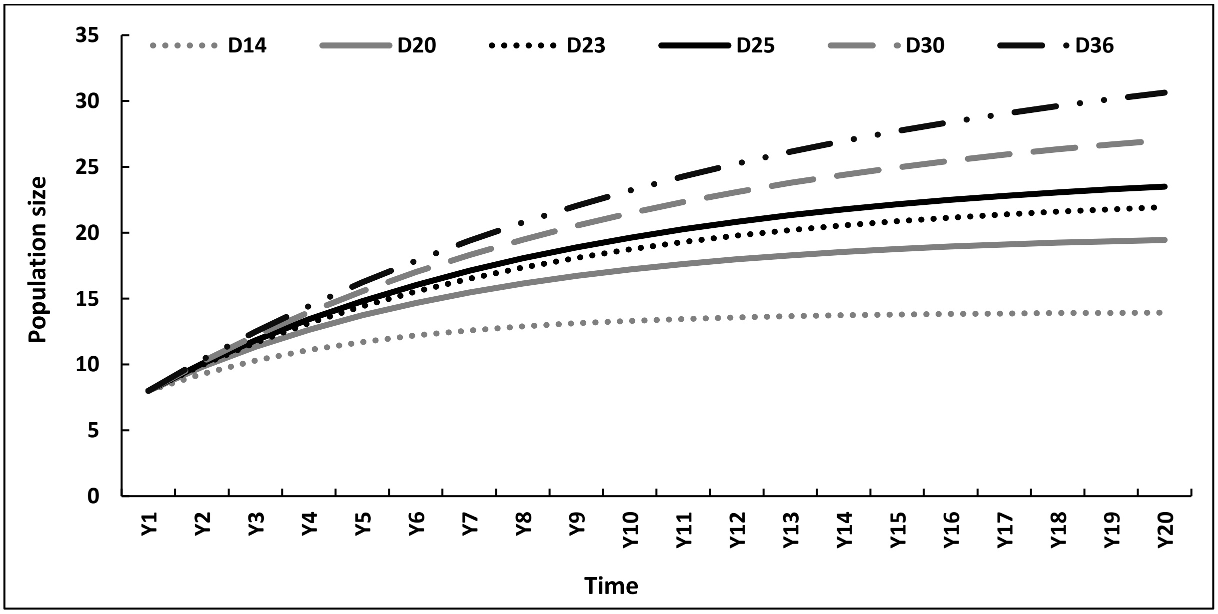


Figure 6-1: Logistic growth curves for estimated duiker population size on Mnemba Island over 20 years, starting from eight individuals.

Figure 6-2 shows how the maximum growth rate was inversely related to the size of MSD.

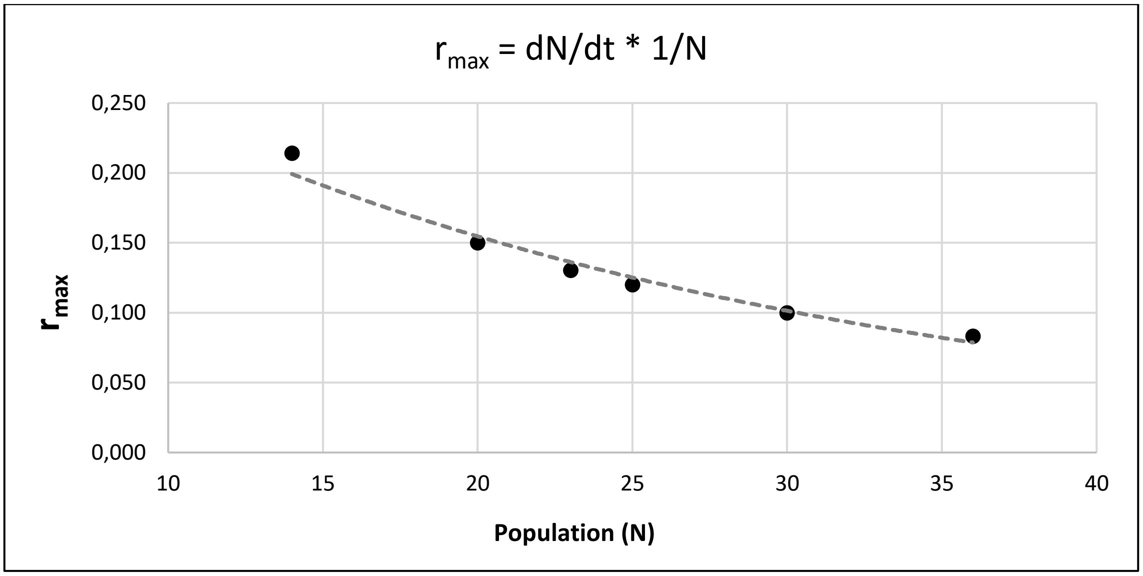


Figure 6-2: Population estimate values from the survey of duikers on Mnemba Island in relation to maximum growth rate.

6.3.2 **Carrying capacity for Aders' duiker**

By substituting r_{max} calculated for each D_{est} into Equation 8, the maximum production (P_{max}) was calculated as three individuals. The number of animals to be harvested should thus not exceed three, and the MSD maintained to ensure a positive population growth for this population. As demonstrated above, the population survey results provided six possible values for D_{est}. Using the logistic Equation 9 (section 6.2.3), six potential harvesting schedules were simulated – see Table 6-3 below. Logistic growth simulation tables with and without harvesting are available in Appendix M.

The number of surplus animals to be harvested every alternate year, starting at year four when the population surpasses K * 0.5, was calculated by subtracting the K * 0.5 from N(t). This was done for each of the scenarios from the survey results. In Table 6-3, the value for 'surplus yielded', represents the number of animals to be removed, while maintaining the population at D_{est} * 0.5. The total surplus amount after 20 years was comparable to a sustainable harvest rate of 40% of annual production over 20 years (rate for red duikers) (Robinson and Redford, 1991).

For example, if the value for D_{est} is 25, the Maintenance density (K) for the island would be 25, and the Maximum harvest density set at K * 0.5, is 13 animals. Following the harvesting schedule of every alternate year, and not removing more than three animals at a time (P_{max}), the number of animals to be harvested every two years would serve to maintain the population on the island at 13 individuals. If no harvesting took place, the population would reach a maintenance number of 24. If the harvesting schedule was followed according to the simulation, an additional 11 animals would have been bred from at an intrinsic growth rate of 0.12. For a population density of 25 maintained at maximum capacity, the 40% of annual production over 20 years also equates to 11 animals. At the lowest possible survey result of 14 animals, the logistic growth model did not provide a feasible harvesting schedule and resulted in a population implosion.

Table 6-3: Harvesting schedule options: Schnabel Index (SI) and Schumacher-Eschmeyer (SE) estimates. Pop D(t_{10}) = k was the estimated population size (D_{est}) at the time of the survey, ten years after the introduction of eight individuals.

	With replacement		**Partial replacement**		**Without replacement**	
	SI	**SE**	**SI**	**SE**	**SI**	**SE**
Pop D(t_{10}) = k	14	23	20	30	25	36
r_{max}	0,21	0,13	0,15	0,10	0,12	0,08
D(t_{20})	14	22	19	27	24	31
Max Harvest density	7	12	10	15	13	18
Harvest schedule (yr.)	-	2	2	2	2	2
Surplus yielded	-	12 (63%)	16 (80%)	10 (38%)	11 (50%)	7 (25%)
D(t20) + surplus	-	34	35	37	35	38
40% of annual yield over 20 years	2	11	11	12	11	13

Figure 6-3 illustrates the effect of density dependence on the total population growth and surplus yield after 20 years, for the different survey results where D_{est} = K (excluding D_{14} as the MSD value was too small for the simulation). Simulating a larger Maximum Sustainable Density for the duiker population resulted in a drastic drop in surplus yield, also illustrated in Figure 6-3. The values can be used as part of a management plan to monitor and simulate changes in the population when extreme events or conditions occur, by adjusting the figures accordingly.

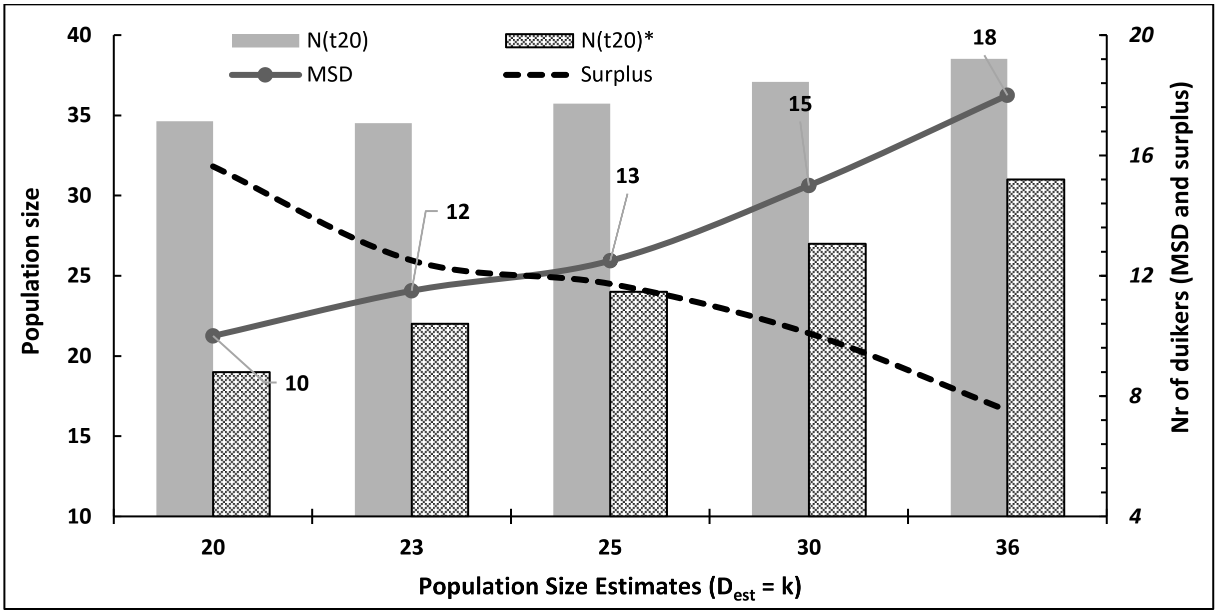


Figure 6-3: Total growth in population size after 20 years and the effect that MSD has on the total population size with (N(t_{20})) and without harvest (N(t_{20})*). Surplus yield also declines with an increase in MSD.

A comparison of the historical population and harvesting data for Suni antelope on Mneba Island (as obtained from the DFFNR) as well as Aders' duiker data collected in this current study, is briefly illustrated in Appendix M for non statistical purposes.

6.3.3 Anatomy and physiology

Not all the planned measurements were possible for all animals during the capture. Biological data were collected from seven male and six female Aders' duikers during the drive net capture survey in April 2016 and from one dead female in January 2016. When an animal appeared to be too stressed, to reduce handling time only the measurements that were possible were taken. Table 6-2 and Table 6-3 summarizes measurements obtained for males and females, respectively. Measurements from young animals were not included in the calculation of averages (means).

The average shoulder height for males was measured at (40.0 cm; n = 6) and for females (41.2 cm; n = 5). The horn length was found to be 3.9 cm for males (n = 5) and 3.1 cm for females (n = 3), while girth circumference for males (n = 4) averaged at 46.8 cm and for females (n = 2) at 46.0 cm. Males also tended to have larger neck circumferences (28.3 cm; n = 5) compared to the females (26.8 cm; n = 5). Females' average total body length measured 74.6 cm (n = 5), 2.9 cm longer than the average male body (71.7 cm; n = 6). Body length had the biggest standard deviation for both genders while males had a larger standard deviation for neck circumferences than females.

Table 6-2: Measurements of seven male Aders' duiker on Mnemba Island in 2016.

Age group	**Body length (cm)[a]**	**Head (cm)+**	**Total Body length (without tail) (cm)**	**Height (cm)[b]**	**Neck circumf. (cm)[c]**	**Horn length (cm)[d]**	**Girth (cm)[e]**
Adult	63	12	75	39	28	no data	47
Adult[24]	64	12	76	40	30	3	47
Adult[23]	58	11	69	40	30	broken off	45
Adult	60	12	72	43	29	4,5	48
Adult	58	11	69	39	23	3,2	no data
Adult	57	12	69	39	30	4,8	no data
Young*	***58***	***11***	***67***	***38***	***20***	***2***	***no data***
Ave	60,0	11,7	71,7	40,0	28,3	3,9	46,8
StdDev	± 2,9	± 0,5	± 3,2	± 1,5	± 2,7	± 0,9	± 1,3

*Standard methods for a, b, c, d, e, d are described in the section 4.5. + was estimated from premeasured skull. * young animal data not included in the average and StdDev calculations. Adult[24] = unsuccessful deployment of GPS collar; Adult[23] = successful deployment of GPS collar.*

Table 6-3: Measurements of seven female Aders' duiker on Mnemba Island in 2016.

Age group	**Body length (cm)[a]**	**Head (cm)+**	**Total Body length (cm)**	**Height (cm)[b]**	**Neck circumf. (cm)[c]**	**Horn length (cm)[d]**	**Girth (cm)[e]**
Adult	65	13	78	44	no data	no data	no data
Adult	no data	no data	no data	no data	26	no data	no data
Adult[26]	57	12	69	39	27	no data	no data
Adult[25]	64	12	76	39	27	3.00	47
Adult	65	13	78	44	27	3.20	no data
Adult	58	14	72	40	30	3.00	45
Young*	***52***	***11***	***63***	***37***	***22***	***2***	***20***
Ave	61,8	12,8	74,6	41,2	27,4	3,1	46,0
SD	± 4,0	± 0,8	± 4,0	± 2,6	± 1,5	± 0,1	± 1,4

*Standard methods for a, b, c, d, e, d is described in the section 4.5. + was estimated from premeasured skull. * young animal data not included in the average and StdDev calculations. Adult[26] = unsuccessful deployment of GPS collar; Adul[25] = successful deployment of GPS collar.*

Births were recorded in January, April, August, September, and October. A large female and the fetus died due to dystocia (difficulty with the birth process). An autopsy revealed that an abnormal position of the fetus during delivery was the cause. Nursing of young was observed during dry and wet months. No definite information was obtained with regards to gestation period, but from literature on similar duiker species, it was reasonable to believe that duikers were pregnant for up to seven months (Bruner-Lorand, 1965; Farst et al., 1980; Kranz and Lumpkin, 1982; Hart, 2013a, 2013b; Kingdon, 2015). Additional information collected on anatomy is included in Appendix L.

6.4 Discussion

With no historical records of growth rates for the Aders' duiker population on Mnemba, it was not possible to measure population dynamics such as stochasticity (Barnes, 2002; Boyce et al., 2006; Hempson et al., 2015; Kiffner and Lee, 2019). However, using the Schnabel Index and the Schumacher-Eschmeyer estimate to calculate population density from mark-recapture data, it was possible to estimate a harvesting schedule from five possible Maximum Harvest Density figures. An estimated population count of sixteen in April 2011 (Fiske, 2011) aligns with a logistic growth curve where $D_{est} = 25 \pm 2$ animals. From the growth rate calculated for $D_{est} = 25$, the doubling time estimate for the population also aligned with Fiske's (2011) and Rivers' (2012) population estimates in April 2011 and September 2012, respectively.

At a population density of 25 individuals on the 11-ha island, each animal theoretically occupies 0.44 ha if no overlap of range is considered. This density estimate does not consider that only half of the 11 ha of forest is covered in natural habitat with suitable food species, or that duikers were mostly observed in pairs, sharing ranges and potentially overlapping ranges. Based on the Body-weight-range theory, where each duiker should occupy about 19.2 ha (Amin et.al. 2015), Mnemba Island is over-populated by more than 25 times its capacity. In another comparison, the already degraded Aders' duiker population density in the forested environment on Unguja was estimated at 4.5 duiker per 100 ha (Williams et al., 1996), which is less than one animal for an 11-ha area (i.e. 22 ha/duiker). Density counts from Kenya ranged between 2.8 duikers per 100 ha (Arabuko-Sokoke forest) and 7.3 Aders' duiker per 100 ha (Boni-Dodori forest), which also relates to less than one animal in an area the size of Mnemba Island. These comparisons and the unique environment on Mnemba Island led to the decision that population densities on the Island cannot be compared to free range Aders' duiker populations which face natural predators, hunting by man and environmental threats, but should rather be equated to artificial breeding conditions in a protected environment. The high density of duikers on Mnemba Island provides evidence of the feasibility of setting up natural habitat sanctuaries within protected forest reserves, provided the Maximum Sustainable Density takes into account regeneration of food species, and following a harvesting schedule that considers population growth rates and socio-demographics of the breeding population.

The Aders' duiker, like other duikers such as *Cephalophus zebra* and *Cephalophus natalensis* with similar body sizes, produce one offspring annually (Macdonald, 2006). Newing (2001) indicates that duikers are not ideal species for captive breeding programs, as the only form of population recovery, due to their low birth rates and pair-bond forming behaviour. Robinson and Redford, (1991) explained the importance of understanding reproductive characteristics when planning production programs for a species. The number of births observed (n = 6) for the Mnemba duikers over twelve months suggested that at least six females were sexually mature at the time of the study. However, the instantaneous growth rate was low due to a high number of deaths (three) occurring in the same twelve months, suggesting that the population had reached a density level that was near its equilibrium. Density dependence factors such as food stress and territorial bouts can lead to die-off as a form of ecological population regulation (Prins et al., 2006). Competition on various levels has a critical influence on reproductive rates. Robinson and Redford (1991) also cited the availability of food resources as an important factor that could influence stochasticity in population dynamics.

The Aders' duiker population was introduced to Mnemba Island as a secondary antelope population. The smaller Suni antelope had already been breeding on the island for twelve years by the time of the Aders' duiker introduction. The year before the duikers were introduced to Mnemba, the Suni population was reduced, and the mark-remove survey indicated that Suni had increased to a minimum of 155 animals by that time. In 2014 70 Suni were removed. The exponential growth curve indicates that four Suni were left on Mnemba after the removal in 2004, for the population to breed back to 74 by 2014. Suni antelope have two young per year in contrast to the Aders' duiker's one young annually. Suni also tend to mate with more than one female at a time. Fiske (2011) suggested that the Suni antelope were posing a threat to the successful breeding of the endangered Aders' duiker and advocated total removal of the smaller and more prolific antelope from the sanctuary. The

Suni population explosion can be directly attributed to regular harvesting of the population, favourable breeding conditions on the island and a high intrinsic growth rate for the species.

It is suggested that management of the island habitat focus on the capacity of the island to house only the Aders' duiker, which would simplify the harvesting schedule and lead to an increase in the duiker population on Unguja. To stimulate population increase for the Aders' duiker, harvesting simulations suggest maintaining an intermediate population density of between 10 and 13 animals (MSD equivalent to half the maintenance density or carrying capacity). Doing this should result in increased yields of between 50% and 80%. Robinson and Redford (1991) suggest a 40% production success rate for red duikers, corresponding to an estimate P_{max} of 3 individuals. The objective of the Aders' duiker program guides the decision to keep the MSD as low as possible, because a larger MSD value would slow down the growth rate and put pressure on recovering vegetation. At the lower end of the population estimates (D = 14) suggested by the Schnabel Index (with replacement), see section 6.3.1, the corresponding MSD of 7 was ruled out due to low projected growth rates with no surplus for relocation, and an inevitable population implosion. The population growth simulation from higher population estimates obtained from the Schumacher-Eschmeyer equation with partial replacement (D = 30) and full replacement during the survey (D = 36), would not provide the necessary safeguard for changes in the environment. Correspondingly, with yield percentages dropping to below 37%, maintaining an MSD between 15 and 18, could potentially lead to a highly stochastic population dynamic with alternating growth and implosion cycles (Milner-Gulland and Mace, 1998; Jennings et al., 2001). Pressure on the island's vegetation from a higher MSD could also lead to an overall reduction in carrying capacity through long-term degradation. An MSD between 10 and 13 yielded favourable results in the population growth model – medium growth rates and lower impacts on vegetation.

Monitoring of harvesting schedules and resulting population figures is critical to the successful implementation of such programs. Population demography and dynamics provide key inputs into more detailed growth projections as a breeding project develops. For example, collecting information on breeding peaks, gestation periods and gender ratios can help account for population growth stochasticity. During the investigation it was noted that breeding was spread out throughout the year (breeding observations were made on January, March, April, June, August and November). These findings agree with previous research done for different duiker species (Farst et al., 1980; Kranz and Lumpkin 1982; Dubost and

Feer, 1992). Births coincided with favourable conditions in August, September, October, January and April. Studies from other forest duiker species (such as *C. monticola*, *C. dorsalis*, *C. callipygus*, and *H. aguaticus*) suggested that births coincide with fruit abundance (Aeschlimann, 1963; Dubost and Feer, 1992; Gaillard et al., 1993; Newing, 1994). Phenology of food species on Mnemba Island suggested that fruit abundance was highest between October and December, and between March and May (Chapter 7, section 7.4). It could be motivated that parturition on Mnemba Island also followed fruiting abundance, but further studies are required to confirm this. The influence on seasonality and rainfall has been shown to be relevant in the timing of parturition in Ungulates. Not only can seasonality cause variation in parturition in the same species from different regions, but also from year to year in the same population (English et al., 2012; Ogutu et al., 2014). The rutting behavior in the current study indicated seasonal differences (Chapter 7) while parturition did not show the same patterns. This is potentially due to differences in rainfall between the year before the current study (2014 / 2015) and the time data was collected (2015 / 2016) and the effect it had on both rutting and birthing peaks (Ogutu et.al., 2014).

During the current study it was observed that female Aders' duiker gave birth to one young at a time, this was expected based on existing literature (Estes, 1974); however, definite gestation periods could not be established. Variability found in gestation periods for different duiker species in the literature ranged from four to eight months (Bruner-Lorand, 1965; Farst et al., 1980; Kranz and Lumpkin, 1982; Hart, 2013a, 2013b; Kingdon, 2015). From three observations of gravid females and the discovery of newly born lambs, the gestation period was calculated as over five months and potentially closer to the seven-month end of the range. Apart from recording the months during which births took place, clear observed signs of pregnancy and anticipated parturition, no futher reproductive data was collected on specific individuals. No mating observations took place. Maternal care was not often observed, and young were hidden from sight for at least one month post birth. Young duikers would forage alone once they started leaving the nesting site. These observations agreed with information on other duiker species (Estes, 1974; Kranz and Lumpkin, 1982; Kingdon, 2015). The small size of the study population and observation time (one year) did not allow for collection of sufficient data on sexual maturity. However, based on limited observation, it was suspected that young males were not sexually mature at age one, as has been suggested for species such as *Cephalophus niger* (Farst et al., 1980). Observations also suggested that the Aders' duiker were monogamous and clear pair bonding of recognizable males and females was seen; however, focussed research is required to rule out polygyny and the effects that overpopulation and the absence of migration has on mating behaviour (Aeschlimann, 1963; Rails, 1973; Kranz and Lumpkin, 1982; Dubost and Feer, 1992; Newing, 1994).

The longevity of the Aders' duiker potentially agrees with that of other red forest duikers. For example, Bowland (1990) cites a range between nine and fifteen years, of which the latter was recorded for a captive animal. At the time of the current study, a few of the females and males observed on Mnemba Island were noticeable larger than the rest of the population. These individuals were potentially from the original eight animals relocated to the island ten years earlier, but no data existed on individuals to confirm this. One of the large duiker females on Mnemba died due to dystocia caused by mal disposition. Bowman and Plowman (2002) also reported dystocia in Maxwell's duiker at the Dambari field stations in Zimbabwe. The age of the female, if one of the original females relocated to the island in 2006, would be more than 10 years old. A brief investigation of the teeth did indicate wear, but age was not estimated based on the teeth. More research is needed with regards to longevity of the Aders' duiker and the genetic diversity of this population.

Measurement results (Table 6-2 and Table 6-3) fell within size ranges from available literature sources for duikers of comparable size. Clear body dimorphism in the Aders' duiker was not observed, as was expected from previous accounts (Kingdon and Hoffman, 2013). On average, the males were not significantly larger than the females at girth circumference, but certain features such as horn length, and neck circumference tended to be notably larger for males. The increased size of these features on the male duikers can potentially be linked to territoriality and hormones. Alternatively, females had notably longer bodies and stood 1.2 cm taller on average. Females also tended to have slightly longer heads. Kingdon and Hoffman, 2013 (2013) noted that duiker females were slightly larger than males, although the differences did not resemble dimorphism. The total body length, excluding the tail, revealed longer females on average – total body length presented the biggest standard deviation for both genders while males had a much larger standard deviation for neck circumferences. Averages were calculated from duikers over one year of age, while data from one young male and one young female under a year old was not included in the averages. Wilson et al. (1984) suggested that duiker sizes beyond a year old would not be a gauge of age. He also reported that the variation between individuals complicate any attempt at estimating age from body size.

Measurements for Aders' duiker taken from various sources (Kingdon, 1982, 1997; Wilson, 1987, 2001; Kanga and Mwinyi, 1999) was summarised by Huffman (2016c) and reproduced in Chapter 2, Table 2-4. On average these sources reported a total body length of 68.8 cm, compared to an overall average of 71.7 cm from the sample taken on Mnemba Island, and a shoulder height of 38.6 cm compared to Mnemba's average of 40.0 cm. It is not confirmed from the different sources whether the measurements were taken using a similar method to the current study, but in conclusion these findings agreed closely with the results from Mnemba's population. Monitoring individual differences in anatomy and physiology in animals in a breeding program is important for population management, especially in the case of the Aders' duiker, as little is known about this species. Furthermore, intensive breeding projects with regular harvesting schedules require accurate morphological data (including weight which was not collected for this study but is used for determining drug dosages should animals require medical intervention or immobilization). The chemical capture methods used by Dr. Cooper during the current study were successful and provided useful data for future relocation activities. It is important to note that recovery time after immobilization is critical to the success of chemical capture methods.

6.5 Conclusion

Population surveys in small, enclosed areas offer statistical challenges when estimating density and carrying capacity using conventional equations. However, the best fit methods utilized for this study yielded satisfactory results for a range of possible densities. These methods and accurate record keeping form an empirical starting point for a more in-depth approach to the Mnemba Aders' duiker breeding project, providing information for suggested harvesting schedules. Unfortunately, simplified logistic growth models do not account for population age, sexual maturity, or gender ratios. For an intense breeding program and future population analyses to be meaningful, individuals need to be marked, measured, and monitored to acquire essential details.

At the time of the survey, it was estimated that the indigenous forest, covering 5.12 ha of the island, provided each duiker around 0.2 ha of suitable habitat. By reducing the population to between 10 and 13 animals, pairs and individuals would be able to increase their range to 0.4 ha. This estimate is based purely on the population density and growth rate results, not adjusting for resource distribution or habitat heterogeneity.

The outcome of the study provides a practical guide to regulating the breeding population for optimum production at no cost to habitat quality. Careful selection of younger animals, unpaired mature animals, and old animals during take-off, and taking care not to disturb breeding pairs, would stabilise population size and growth rates. It is strongly encouraged to plan more guided research to collect information on inter-birth intervals and age of reproduction, along with social dynamics of pair-bonding in reproductive competition. Annual research projects focusing on consistent data collection are recommended for long-term analyses and population adjustments to the in-situ breeding project. Mnemba Island provides a unique opportunity for in-depth biological research into the species.

CHAPTER 7

ACTIVITY BUDGET AND FOOD HABITS OF ADERS' DUIKER ON MNEMBA ISLAND

7.1 Introduction

Williams et al. *(*1996) and Kingdon (1997) refer to the challenges of describing *Cephalophus adersi* behaviour in detail, attributing this to the species' secretive nature and preference for dense forest cover, which keeps their activities hidden from plain sight. Combined with a small population size and limited distribution range, this challenge has been the main barrier to collecting adequate data to describe the species' finer scale activity patterns and their resource utilization. The current study site, Mnemba Island, is the only sanctuary where a population of Aders' duiker can be freely observed. No other captive population existed at the time the study was initiated. For an opportunity to collect a sizeable amount of data over a minimum of one annual cycle, Mnemba Island was the best location to study the species in detail. However, due to the shy nature of the species, it was envisaged that challenges with regards to observability would still be faced (Kranz and Lumpkin, 1982; Bowland and Perrin, 1995; Schrodt, 2005; Edwards and Tollington, 2008; Andanje et al., 2011; Fiske, 2011).

Guided by the crucial need for data to facilitate management of the Mnemba Island Aders' duiker population, predetermined aspects of the ecology of the species were selected for non-experimental investigation. This chapter describes the findings of the Mnemba Island Aders' Duiker activity budget observations, including overall movement versus sedentary states, as well as foraging activity patterns and food habits. Seasonal and gender comparisons provided new information for the species with regards to resource use and social dynamics.

7.1.1 Activity patterns and duiker behaviour

Monitoring behaviour is an essential component of any conservation program, and activity budget studies help with management decisions, for example, designing and refining species-specific survey methodologies (Viquerat et al., 2012). Time-activity budgets have been adopted as management tools in both wild and captive population conservation programs (Bercovitch and Ziegler 1989; Maple and Finlay, 1989; Melfi and Feistner, 2002;

Wich et al., 2008; Powell and Mitchell, 2012; Christiansen et al., 2013). Activity budget investigations are designed to answer specific questions set out by the researcher, including questions about social interaction, foraging strategies, movement patterns, resource use and competition (Jarman, 1974; Rugg and Buech, 1990; Neuhaus and Ruckstuhl, 2004; Brown and Gordon, 2008).

Activity patterns of duikers in the wild have been found to correspond with those of captive populations kept in semi-natural environments (Dubost, 1980; Smithers, 1983). This agreement allows extrapolation of findings between wild and captive studies. Activity patterns for diurnal forest duikers such as Maxwell and Zebra duikers indicated that between 64 and 71% of all activity takes place during the day (Newing, 1994). Based on the information from other forest duikers and from previous observations of Aders' duiker in the wild, it is anticipated that they would follow a diurnal activity pattern with crepuscular peaks (Williams et al., 1996; Finnie, 2002; Amin et al., 2015).

Seasonal variations in activity patterns have been studied for a variety of African antelope species using an assortment of observation methods. As Wiafe and Amfo-Out (2012) found, the activity patterns of four duiker species (Bay, Maxwell, Black- and Yellow-backed duiker) occurring in the Kakum conservation area in Ghana, did not differ seasonally, and thus concluded that broad activity patterns remained constant throughout the year. Employing direct focal observations to establish a time-activity budget for Impala (a social ungulate living in groups), seasonal comparisons indicated little difference in an enclosed conservation area in Zimbabwe (Muposhi et al., 2013), with foraging and vigilance being the dominant activities for both seasons. Establishing a baseline of seasonal activity patterns for a species serves as an important blueprint for future comparisons of behaviour. For example, Majolo et al. (2013) points out that certain species display behavioural differences due to changes in the climate. Detecting changes in behaviour can serve as an early warning of climatic changes in a given habitat. Also, if seasonal differences in activity patterns are anticipated, Dunbar et al. (2009) campaigns that it should be considered when designing behavioural research studies.

Similarly, gender differences in activity patterns are important as they contribute to ongoing research design and conservation management plans. It is evident that time budget differences and related foraging strategies in certain male and female ungulates reflect a dynamic interaction between changing habitat conditions and gender specific needs, to either minimize time or maximize energy intake (Bergman et al., 2001). Not only does variances of food intake depend on fixed morphological characteristics i.e., species and gender size differences, but also on physiological cycles such as rutting, lactation and pregnancy (Newman et al., 1995). Studies have indicated that female ungulates often increase their food intake during lactation (Bunnell and Gillingham, 1985) by spending more time foraging on poor quality and quantity food patches (Clutton-Brock et al., 1982). Neuhaus and Ruckstuhl (2004) concluded that body size (whether it be due to sexual dimorphism, age or inter- and intra-population size differences), provides the main explanation for sexual and social segregation, based on underlying energy requirement similarities of same size ungulates. An extrapolation of the results from other antelope species leads one to expect that female Aders' duikers would change foraging patterns due to annual gestation and lactation (Ruckstuhl and Festa-Bianchet, 2001). However, the lack of sexual dimorphism for the species, and existing evidence of social foraging and inter-gender group formation, advocates that overall activity budgets between males and females would in fact not show significant differences.

7.1.2 Foraging patterns and food selection

Jarman (1974) created a classification system for feeding strategies, based on social structure, size and food type selection. Antelope species can be allocated to Classes (A through E) depending on the nature of their behaviour, social orientation or ecological characteristics, with class A generally consisting of small selective feeders living alone or in pairs, and class E comprising larger bovine species living in large herds. Corresponding foraging styles (a through e) are directly linked to food availability and dispersal. The class 'a' feeding strategy pertains to small antelope with discerning feeding habits and includes many duiker species and Suni antelope. Jarman (1974) found that in class 'A' antelope species the social arrangement is not dependent on season. He proposed that antelope species in class 'A' reduce the number of associated members during foraging as a predator avoidance strategy, and further suggests that grouping tendencies are directly influenced by the presence or absence of predators.

Kingdon (1997) and Wilson (2001) found that Aders' duiker forage at dawn and dusk when individuals, pairs or family groups actively feed. Aders' duiker has been observed moving around individually or in pairs (males and females move together within territorial boundaries) (Swai, 1983; Kingdon, 1997). More recent short-term studies on Mnemba Island reveal that different group combinations, including pairs, adults and sub-adults, and small groups of three individuals forage together (Huffman 2016a; Fiske 2011). To formulate an understanding of the Aders' duiker feeding strategy, a foundation of knowledge is first needed about the species' foraging activities and food selection.

Although the Jarman-Bell Principle is a practical guideline for anticipating what to expect with the Aders' duiker feeding strategies, Bowland and Perrin (1998) pointed out that duikers do not conform to the principle in the aspects of time activities and food type selection. It is however commonly accepted that Aders' duiker follows a typical frugivorous diet, consuming fruits and buds, sprouts and seeds, and dicotyledonous leaves (Swai, 1983). From studies in different areas in the region, we know that plant species such as *Euclea schimperi*, *Polyspheria* spp., *Clerodendrum* spp., *Suregada zanzibariensis* and *Ficus* spp. make up part of the duiker's diet. A comprehensive vegetation composition for Mnemba Island (listed in Chapter 5) was established in this study. Food species selection data can thus be compared to the total availability of relevant species to assess diet composition in their selected habitat. Once diet composition is known, monitoring of food plant species availability is a key component to managing duiker population viability in an enclosed area, especially if competition is high and habitat quality is low.

7.1.3 Chapter objectives

This chapter aims to describe the Aders' duiker's activity budget with regards to its behaviour repertoire. The results are presented to show diurnal activities, and which activities receive the most attention. The data are further analysed across seasons and gender and is used to form an initial idea about the species' adaptation to a variety of internal and external factors in its Island habitat. In the absence of predators, the population has potentially adapted its foraging strategy and activities to non-bimodal patterns that differ from the bimodal patterns seen for populations living in forest reserves in Kenya (Amin et al., 2015). Any digression from species specific diel patterns would provide evidence to the level of adaptation to the conditions in this specific habitat. Conditions such as overpopulation, particularly related to the Suni population, has potentially also influenced the activity patterns of this sub-population of Aders' duiker. Finally, the chapter provides a description of the Aders duikers' diet and food type selection.

7.2 Methods

7.2.1 Study area

Mnemba Island is an 11-ha vegetated sanctuary situated 2.7 km off the north-eastern shore of Zanzibar (S 05 49.219’, E 039 22.959’). The ‘island’ part of the oval shaped atoll is a typical sandy cay. The atoll reef area is approximately 150 ha in size, measuring 7 km from the northern to the southern reef along a very shallow reef flat (which is completely exposed during low tide) (Revolutionary Government of Zanzibar, 2005; Swanepoel, 2017). Mnemba Island experiences the broad the seasons of Zanzibar and the Tropical East Coast of Tanzania, with a dry season, short rain season and long rain season. However, Mnemba’s locality contributes towards its own unique climatic expression. Rainfall patterns, for example, was not the same as Unguja’s weather data that is generally collected at the airport in Stone Town on the West coast. With Mnemba being a low-lying atoll on the east of Unguja, a much dryer climate compared to other areas in Unguja was expected (Yu and Lei, 2001) and confirmed (Section 3.4.1.)

The island supports approximately 113 300 m^2 of vegetated habitat (106 740m^2 if building footprints are discounted), of which 47% consists of indigenous forest and 53% is dominated by whistling pine (*Casuarina cunninghamiana*) plantations. Manmade structures displace 6% of the total vegetated area on the island. Two main plant communities were identified in the vegetation survey (Chapter 5, Section 5.4), including two sub-communities for each main community. Figure 7-1 illustrates the location of plant sub-communities and infrastructure in relation to the pre-determined track (section 4.6) used during focal samples.

Focal observations in the natural vegetation corresponded with plant sub-communities 2.1 (*Eugenia capensis–Mimusops obtusifolia–Scutia myrtina* Coastal Forest) and 2.2 (*Eugenia capensis–Mimusops obtusifolia–Clerodendrum glabrum* Coastal Scrub) (Figure 7-1). The focal track also covered a small section of plant sub-community 1.1 (*Casuarina cunninghamiana–Suriana maritime–Grass4* Sandy Dry Coastal Forest Community). Plant sub-community 1.2 (*Casuarina cunninghamiana–Suriana maritime–Chrysothrix* Open Sandy Dry Coastal Forest) was excluded from the focal observation schedule because most of this plant community was located in front of guest rooms (this area could not be accessed for eleven months of the year while guests visit the island). During times when no guests were present it was also noted that large parts of this sub-community (on the eastern side of the island) was not used by the Aders’ duiker. For all data containing wet and dry season comparisons, wet season months consisted of March, April, May, October, November, and December. Dry season months consisted of January, February, June, July, August, and September.

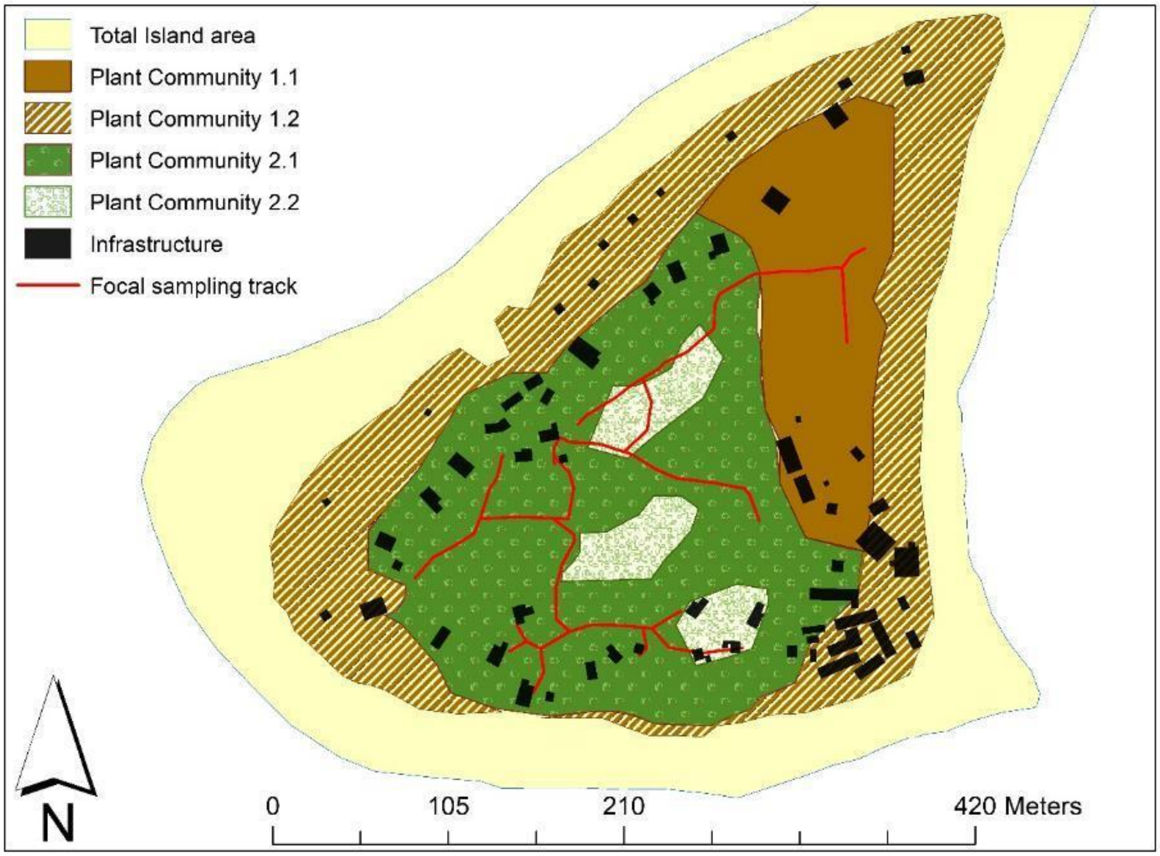


Figure 7-1: Plant communities and infrastructure on Mnemba Island in relation to the sample track followed during focal observations.

7.2.2 Activity budget

Focal session scheduling followed a mixed purpose sampling design. The Time activity budget was assumed to be heterogenous for different times of the day. At the onset of the study, all research site visit days were tabled, and specific days allocated for focal sessions. A stratified approach was taken to ensure that each research site visit included focal observations from all daylight hourly strata (time category). As the study progressed, duration of observation was pooled for the hourly strata, and if observation time was low for a certain time category, focal session was prioritised for that hour of the day (on focal session days). The cumulative observation time was also pooled for hourly time categories and between the two seasons, to ensure comparable observation times for behaviour for different times of the day and between dry and wet seasons (Braude et al., 2002). The duration of behaviour activities was rounded to the nearest 10 seconds, which was later rounded up to 10 secons for expression of rates.

The focal sampling protocol was implemented by observing one animal at a time, for as long as the animal was in view or until 20 minutes passed. The upper limit of 20 minutes was chosen based on researcher fatigue, trial observations of the sample animals, and existing design methodologies (Altman, 1974). Duration of observations depended largely on visibility and movement. A focal observation started as soon as an Aders' duiker was located along the track. Upon location, a new observation was initiated on the Trimble GeoExplorer (6 000 series) handheld computer. The GPS location of the starting point of each focal observation was automatically stored (with a maximum of 20 m accuracy). If animals moved out of view, the sample period was terminated, and the end time recorded. No "out-of-view" data were collected. The next available animal was located, and a new focal observation initiated. This was repeated until the hour had passed. If no more hourly focal sessions were scheduled for that day, other research activities would take place. If another focal hourly session was scheduled, the same track would be followed from the beginning of the next session. All behaviour activities during a focal observation were recorded in sequence and coded according to a pre-set ethogram. Development of the ethogram was discussed in section 4.6 and a detailed description can be found in Appendix J.

Each duiker (entire population) had an equal chance of being observed multiple times for the duration of the study, which rulled out the issue of sample bias, and allowing generalisation of the whole population on the island. At the time of data collection, no population size or home range information was known. Data were pooled for all animals observed, and individual identification was only recorded when identification was certain (Braude et al., 2002; Apio and Wronksi, 2005). The methods overview in Chapter four, section 4.6, explained the challenges around identifying individual focal animals. Observations obtained from nine individuals that were positively identified at times, were not compared statistically but interpreted qualitatively. The sample was thus not stratified by individual duiker (this is impossible in a natural environment with no identification of all individual animals) but by time category. The differences between behaviour categories of the collective activity pattern were being tested and all individuals in the population contributed to this collective activity pattern. This was done by pooling "in view" focal observation time per hourly time category, to ensure a workable sample size for each time of the day (hourly) was obtained.

For evaluation of time spent in each exclusive behavioural category, raw data were converted to rates of the relevant base totals for sub samples being compared (gender, season, and time category) (Altman, 1974; Rugg and Buech, 1990; Martin and Bateson, 1993; Crockette and Ha, 2015). The fact that all individuals in the population most likely contributed equally to the pool of behaviour data, negated the need for complex comparative statistics, as the data represents the entire population to a certain degree (Calkins, 2005). However, significant tests were performed to anticipate the likelihood of differences between seasons and genders, where behaviour trends could be anticipated from the sample of behaviour data for this population. As reiterated in the introduction to this thesis, it is important to note that all potential trends discussed in this study are aimed at raising hypotheses for further indepth research for this species as part of a broader species recovery initiative.

The investigation into diel patterns is particularly important when considering research design. For the current study, it was assumed that the Aders' duiker's diel pattern would result in minimal nocturnal activity and thus it was not deemed necessary to perform nocturnal focal observations. Results from the daytime focal sessions served to confirm crepuscular activity for the species in the small island habitat. Aders' duiker is reportedly crepuscular (Amin et al., 2015; Kingdon and Hoffman, 2013), active in the day with peaks at dawn and again at dusk (Ensing et al., 2014; Ikeda et al., 2016). Civil twilight (Van Flandern and Pulkkinen, 1979) is observable light from the sun without the sun being visible. In Zanzibar this occurs swiftly around 06:00 (dawn) and 19:00 (dusk), but visibility also depended on the moon's cycle and cloud cover.

Non-parametric tests in SPSS (version 15) were used when datasets were not normally distributed. The analyses of the behaviour categories were focussed on the description of a comprehensive time activity budget for the population on the island. No hypotheses were set for specific behaviour categories between season and gender, and the results obtained from this study would be used to develop new areas of research that will include experimental designs with sampling methods to conduct compositional analyses.

All tests were two tailed with the critical significance levels (α) set at 0.05. Data preparation was done in MS Excel.

7.2.3 Food selection

Food species selection data were collected during 50 focal foraging sessions (when focal animals were close enough to observe foraging detail) and 10 ad hoc observations over a period of 18 months. From the 50 foraging sessions, 32 sessions included positive identification of the food species being consumed. The relative abundance (r_i) of each food plant species identified, was calculated as a proportion of the total number of food species identified during focal observations. Each food species' total relative abundance (P_i) on the island was also calculated as a proportion or percentage of all species on the island (which was obtained from Braun-Blanquet abundance ratings during the vegetation survey - Section 5.4.1). Food species electivity was evaluated using the Ivlev electivity index (Krebs, 1999) using the equation:

$$10. Ei = \frac{(r_i - P_i)}{(r_i + P_i)}$$

Where E_i is the Electivity Index;

r_i = relative abundance, as a proportion or percentage of the total of food items/species (i) consumed;

P_i = the relative abundance, as a proportion or percentage of the food item/species on the island.

When Ei was closer to -1 the food species/type was deemed as almost inaccessible or not preferred/selected. An Ei around 0 represented food species/types that are regularly available but non-selectively foraged or consumed in relation to availability, while Ei values approaching 1 indicated a preference or selection for the given food species.

Food type (part of the plant or non-plant items) was recorded for all items consumed during the 50 focal foraging observation sessions. Focal sessions were split into 27 dry season sessions and 23 wet season sessions. Relative abundance (r_i) of each food type was calculated and total relative abundance (P_i) for each food type was calculated by using the average P_i for all food species that were identified as contributing towards the provision of the specific food type. A seasonal electivity index for food types was compiled using relative abundance values to evaluate the role that each food type played in the composition of the duiker's diet for the two seasons.

A ‘bite rate’ approach (Ferretti et al., 2014) was adapted to determine the ‘number of items’ consumed by Aders’ duiker, as well as the duration of consumption of the observed number of items in minutes. Consumption rate data were used to establish seasonal dietary composition patterns. Estimated daily consumption was calculated for each food type by converting the raw consumption rate values to an hourly rate. The hourly rate was then multiplied by the seasonal relative abundance (r_i) for each food type in the diet, as well as by the daily foraging proportion in the activity budget for each season.

Chi-square test statistics (Beasley and Schumacker, 1995; Agresti, 2007; Sharpe, 2015) were used to test for significant differences in seasonal dietary composition and for the estimated daily consumption rate of specific food types. In cases where the Chi-square test dealt with degrees of freedom above one, post-hoc standard residuals were used to test for the source responsible for the significance, suggested by Sharpe (2015) (alpha set at 0.05).

During vegetation surveys and voucher specimen collection, phenophases (aspects of a seasonal cycle) of food species were noted as present or absent for the following: New leaves, Sprouts and Seedlings; Fallen leaves - green; Fallen leaves - yellow; Green fruits; Green fruits - fallen; Ripe fruits; Ripe fruits - fallen; Fresh fungus; Flower and Buds; and Fallen flowers. Data were pooled (Braude et al., 2002) for dry and wet seasons to create a list of species for each phenological aspect per season. At the time when the current study commenced, a substantial population of Suni antelope and a visibly smaller population of Aders’ duiker were resident on the island. Fallen fruits and leaves were difficult to find due to the high rate of consumption by these antelope. Although fallen fruit and leaf traps were considered, it was decided that such an investigation would be more valuable once the population of antelope had been reduced, and the forest recovered from overutilization. The outcome of the phenology inquiry served as ancillary food habit data, used to support the interpretation of dietary composition, food availability and electivity results.

7.3 Results

Over 55 sample days, 175 tracking sessions (each an hour long) produced a total 300 focal observations with a mean of 10 minutes per focal observation. Dry season data were collected over 26 days and Wet season data over 29 days. Appendix J also includes a map of all points from where the observation was made along the sampling track.

By the end of the sampling schedule on the island, a total of 300 focal observations of varied length were collected. With a population of 25 duikers (Chapter 6) on the island, if equally surveyed over 300 focal observations, at equal times, each duiker would have been surveyed 12 times for 10 minutes. Probability that each duiker was potentially surveyed was 1200%.

By stratifying observations by time category and adjusting observation schedules to collect similar amounts (time) of observation for each category, time bias could be evaluated. Time and seasonal bias in the time-activity budget was ruled out by testing the hypothesis of no significant difference between the means of each time category (grouped by season), using a two-sample test assuming unequal variances for pooled observation duration from each hourly category (t-test: t19 = 3.22; P = 0.004). Table 7-1 summarises the results of the stratified sample and frequency expressed as minutes for each time stratum, grouped by season. The activity budget data did not satisfy any of the distributional assumptions for a MANOVA and did not have multivariate normality. Based on the distribution of the data, comparisons of season and gender with the rates of behaviour for the different categories were tested for significant differences separately.

Table 7-1: Sample size expressed as minutes per time category and grouped by season.

	Dry Season		**Wet Season**		**Annual**	
Time Category (Hour of the day)	**Pooled Freq (min) (mean)**	**% sample time**	**Pooled Freq (min) (mean)**	**% sample time**	**Pooled Freq (min) (mean)**	**% sample time**
06:00 -07:00	112 (9)	7%	111 (7)	8%	223 (8)	7%
07:00 -08:00	117 (11)	7%	107 (11)	8%	224 (11)	7%
08:00 - 09:00	140 (8)	8%	100 (10)	7%	240 (9)	8%
09:00 - 10:00	112 (12)	7%	90 (9)	7%	202 (11)	7%
10:00 - 11:00	145 (12)	9%	113 (14)	8%	258 (13)	8%
11:00 - 12:00	128 (12)	8%	148 (10)	11%	276 (11)	9%
12:00 - 13:00	131 (9)	8%	98 (14)	7%	229 (11)	7%
13:00 - 14:00	149 (19)	9%	65 (13)	5%	214 (16)	7%
14:00 - 15:00	142 (13)	8%	154 (13)	11%	296 (13)	10%
15:00 - 16:00	141 (13)	8%	103 (8)	8%	244 (10)	8%
16:00 - 17:00	140 (16)	8%	79 9 (10)	6%	219 (13)	7%
17:00 - 18:00	107 (6)	6%	103 (8)	8%	210 (7)	7%
18:00 - 19:00	128 (8)	8%	95 (8)	7%	223 (8)	7%
Total pooled time sample (minutes)	**1 692 (11, ±3)**	**1**	**1 366 (10, ±2)**	**1**	**3 058 (10, ±3)**	**1**

7.3.1 Activity patterns and duiker behaviour

The amount of time spent observing the Aders' duiker in focal sessions were pooled (Braude et al., 2002) and grouped per daylight hour to ensure a representative sample of observation time throughout. The amount of time for each pooled observation hour as set out in the methods section of this chapter (Table 7-1) was tested for differences between seasons using a Chi-square test. No significant differences were found between sampling times for each category across wet and dry seasons (chi-square test: $X^2 = 4.73$; df = 3; $P = 0.19$). Differences in the sampling times between the different time categories were also tested and not significant (t-test: $t_6 = 2.28$; $P = 0.06$). The amount of data collected was thus confirmed as representative of a daily activity budget.

Allocations of time to the behaviour states or categories in the activity budget revealed that foraging activities made up 39% of the duikers' time during daylight hours (between 06:00 and 19:00), while ruminating made up 24%. Another 17% was spent resting (standing or lying down with no ruminating or grooming). These behavioural states constituted the greater portion (80%) of daytime activities observed. Figure 7-2 illustrates the thirteen exclusive behavioural states and the proportion (%) of time spent on each activity. Social activities, vigilance, territory, traveling and other behaviours made up the rest (20%) of the duikers' daytime activities combined.

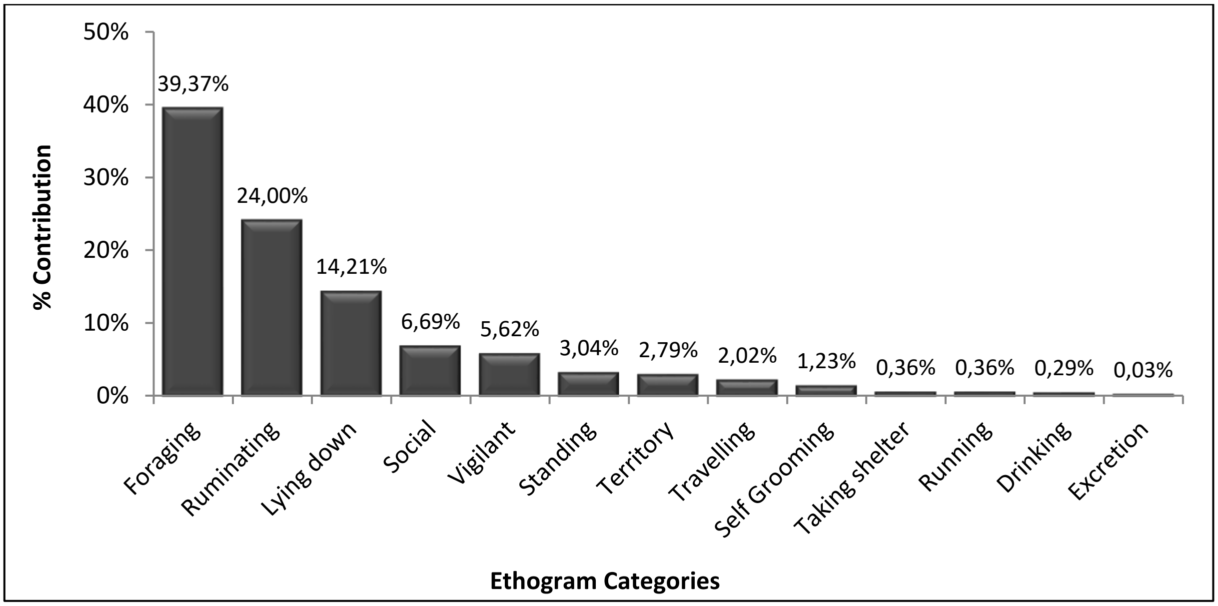


Figure 7-2: Exclusive behaviour categories in the Aders' duiker Ethogram and percentage time spent in each category between 06:00 and 19:00.

All behavioural categories recorded during focal observations were coded as exclusively sedentary or moving behaviours. Grouping of activities into these two broad categories allows for an overview of the time spent on expending energy through movement, or conserving energy through resting. Results indicated that 51% of all time was spent in a sedentary state and 49% in a moving state. Seasonal, gender and diel analyses were undertaken to understand the dynamics of the population's activity patterns, behaviour and resource use.

Overall seasonal and gender differences in activity patterns

The wet season showed 2% more sedentary behaviour than the dry season. Mann-Whitney U tests indicated no significant difference between overall sedentary and movement conditions (U = 81861.0, n_1 = 332, n_2 = 535, P = 0.05), but there was a significant difference between males and females (U = 60814.0, n_1 = 440, n_2 = 336, P < 0.00), as well as between seasons (U = 79044.0, n_1 = 475, n_2 = 392, P < 0.00). Males were much more active in the dry season (39%) compared to activity in the wet season (25%), followed by sedentary behaviour in the wet season (19%) and sedentary behaviour in the dry season (17%) (Figure 7-3). Females displayed the opposite pattern, with 39% of all behaviour spent sedentary in the dry season, followed by 22% moving in the dry season, 21% sedentary in the wet season and lastly, 18% of all tie spent on movement in the wet season (Figure 7-3Figure 7-4). Over the course of the study, females spent 60% of their time resting while males only rested 36%.

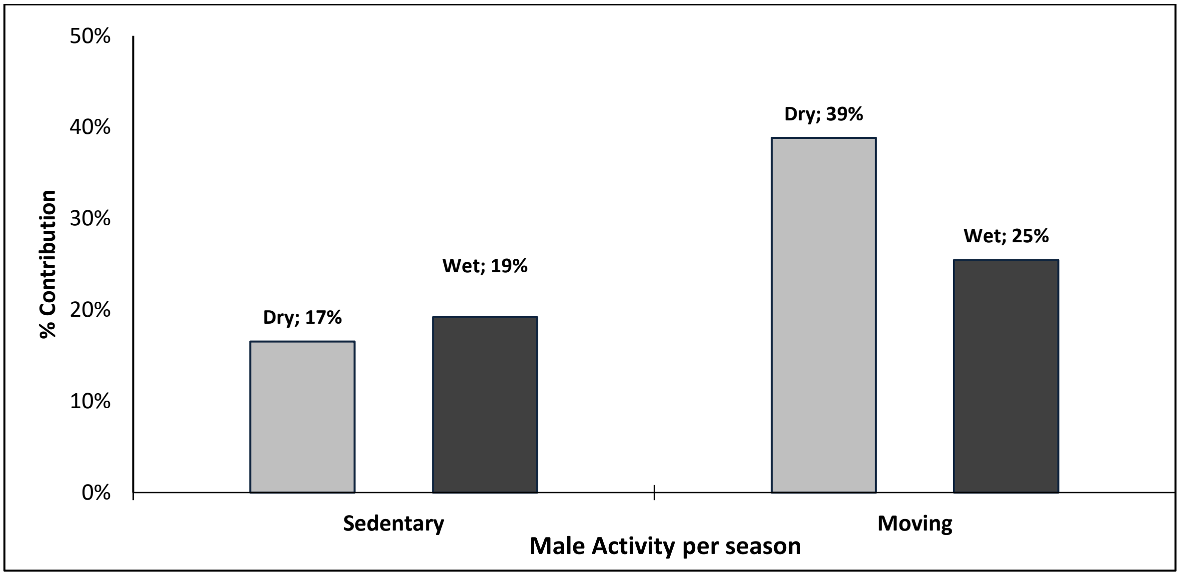


Figure 7-3: Sedentary and moving behaviour for female Aders' duiker on Menba Island, further grouped by season – all values adding up to 1.

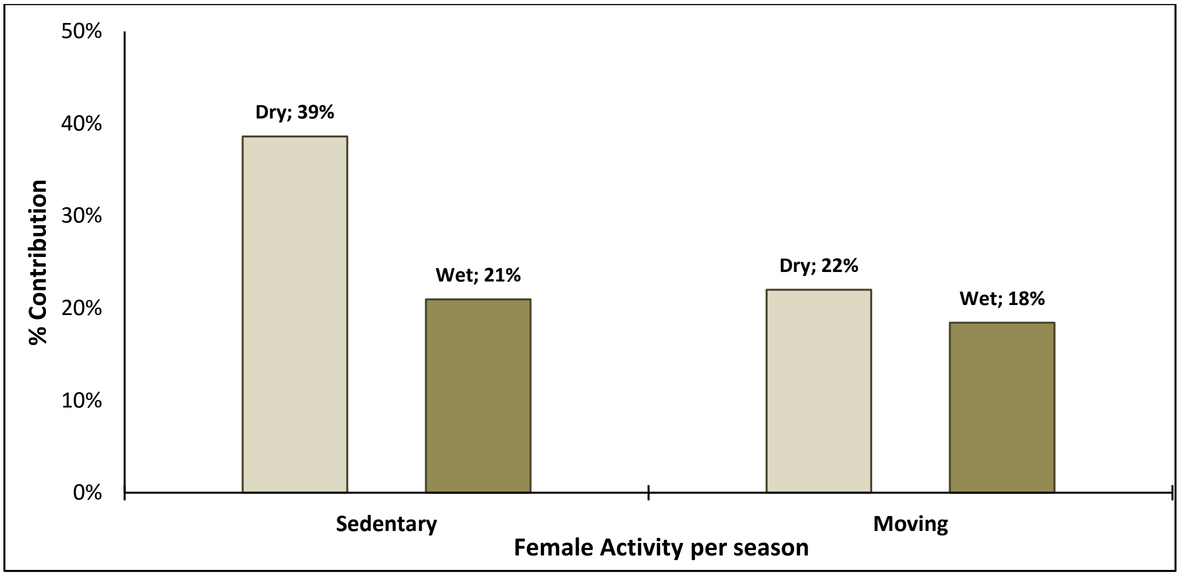


Figure 7-4: Sedentary and moving behaviour for male Aders' duiker on Menba Island, further grouped by season – all values adding up to 1.

Ten of the thirteen main activity states in the Ethogram had enough data for seasonal difference testing, as shown in Table 7-2, while three activities did not.

Table 7-2: a) & b) Main behavioural states tested for significant differences between wet and dry seasons, using the Mann-Whitney U test (all *P* values are for 2 tailed tests; (α) set at 0.05) (Behaviours that tested significant are indicated with an *).

a)

Behavioural state	Dry Season (%)	Wet Season (%)	U	n_1 and n_2	P
Forage	41.23%	37.07%	4 765	121; 92	0.072
Ruminate	27.70%	19.41%	493	43; 27	0.291
*Lying down**	11.29%	17.83%	219	25; 27	***0.029***
Social	3.98%	10.05%	349	26;36	0.089
*Vigilant**	4.21%	7.36%	416	36; 34	***0.021***
Stand	3.91%	1.95%	221	28; 16	0.941
Territory	3.70%	1.66%	62	16; 8	0.902
*Travel**	2.15%	1.87%	299	36;25	***0.025***
*Self-groom**	0.80%	1.76%	24	11; 12	***0.009***
Run	0.30%	0.43%	82	13; 18	0.152

b)

Behavioural state	**Dry Season (%)**	**Wet Season (%)**	**U**	**n_1 and n_2**	**P**
Take shelter	0.27%	0.48%		*Not enough data*	
Drink	0.41%	0.15%		*Not enough data*	
Excrete	0.05%	0.00%		*Not enough data*	

In table Table 7-2, the Mann-Whitney U test results are listed for each state. Time spent ‘foraging’ and ‘ruminating’ were higher in the dry season, although differences were not concluded as significant. Aders’ duiker spent more time ‘lying down’ and ‘socialising’ in the wet season, but only ‘lying down’ was confirmed as significantly different across the seasons. Small but significant differences were detected for ‘vigilance’ and ‘self-grooming’ (more time spent during wet season) and ‘travelling’ (more time during dry season).

The thirteen main ethogram categories were condensed into eight categories for a cleaner graphic representation of seasonal differences (the label field indicates condensed categories) – illustrated in Figure 7-5. Values indicate the percentage contribution of time spent in each exclusive category by male and female Aders’ duiker.

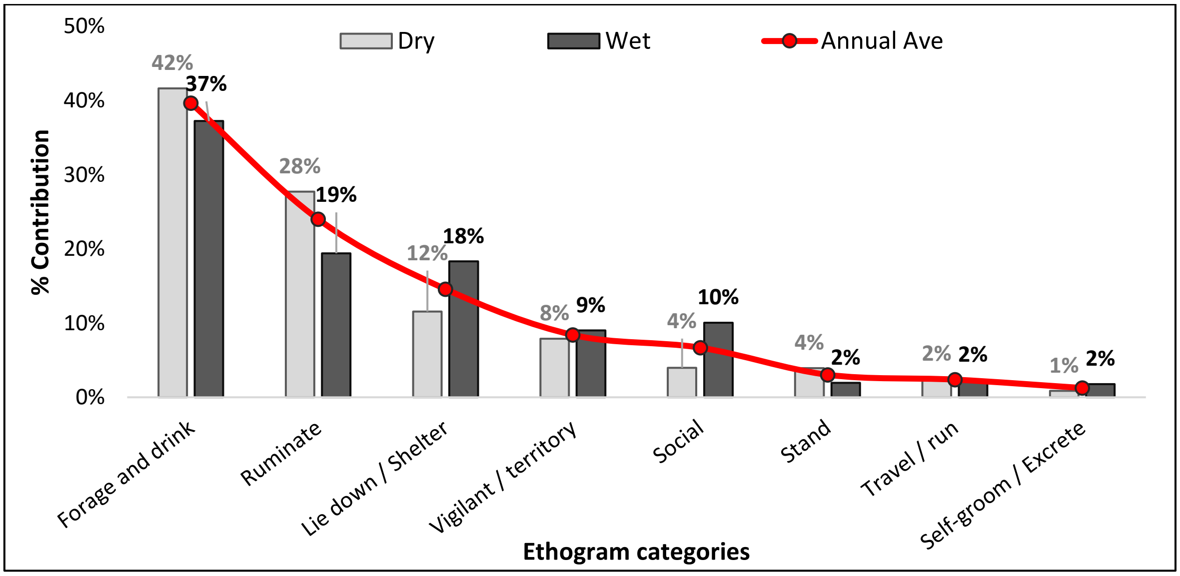


Figure 7-5: Eight main behaviour categories from the Aders’ duiker Ethogram on Mnemba Island, grouped by season.

Ten out of the thirteen main states in the Ethogram had enough data for difference testing of activity data between males and females. In table Table 7-3, the Mann-Whitney U test results are listed for each state. Males spent over 50% of their time 'foraging', while females only 'foraged' for 38% of their entire activity budget (06:00 to 19:00), but this gender difference did not test significant for annual data. Females 'ruminated' significantly more than males. More time was spent 'socialising' and 'resting' by females but did not prove to be significant. Differences between 'territorial behaviour' for males and females were also not significant, although males were more territorial than females. A small but significant difference was tested for females 'grooming' themselves more than males. Negligible differences between 'travelling' and 'standing' were recorded between genders.

For a cleaner graphic representation of gender differences in the overall ethogram composition, Figure 7-6 illustrates a condensed graph consisting of eight behaviour categories (condensed categories are indicated in the label fields). Values are indicated as the percentage contribution of time spent on each exclusive category.

Table 7-3: Main behavioural states tested for significant differences between males and females, using the Mann-Whitney U test (*P* values for 2 tailed tests; (α) set at 0.05).

Behavioural state	**Male (%)**	**Female (%)**	***U***	**n_1 and n_2**	***P* (2 tailed)**
Forage	50.70%	34.59%	4640	111; 84	0.955
*Ruminate**	15.59%	27.87%	261	27; 31	**0.014***
Lying down	9.82%	16.52%	188	18; 24	0.476
Social	4.21%	8.86%	293	29; 25	0.226
Vigilant	6.16%	4.61%	430	32; 27	0.976
Stand	3.38%	2.80%	148	25; 16	0.162
Territory	4.85%	1.15%	42	16; 7	0.347
Travel	2.80%	1.55%	295	33; 19	0.722
*Self-groom**	0.83%	1.76%	22	10; 11	**0.017***
Run	0.57%	0.15%	67	18; 9	0.461
Drink	0.65%	0.00%		*Not enough data*	
Take shelter	0.43%	0.08%		*Not enough data*	
Excrete	0.00%	0.06%		*Not enough data*	

Foraging data were further tested for seasonal differences between males and females (Figure 7-7a), using the Kruskal Wallis test, which concluded that the difference was significant when evaluating gender differences based on seasonal foraging, as opposed to annual foraging patterns only (X^2 = 27.09; df = 3; P = 0.000). All ethogram categories with significant seasonal and gender results for annual activity budgets, as discussed above, are illustrated in Figure 7-7, providing a finer scale result.

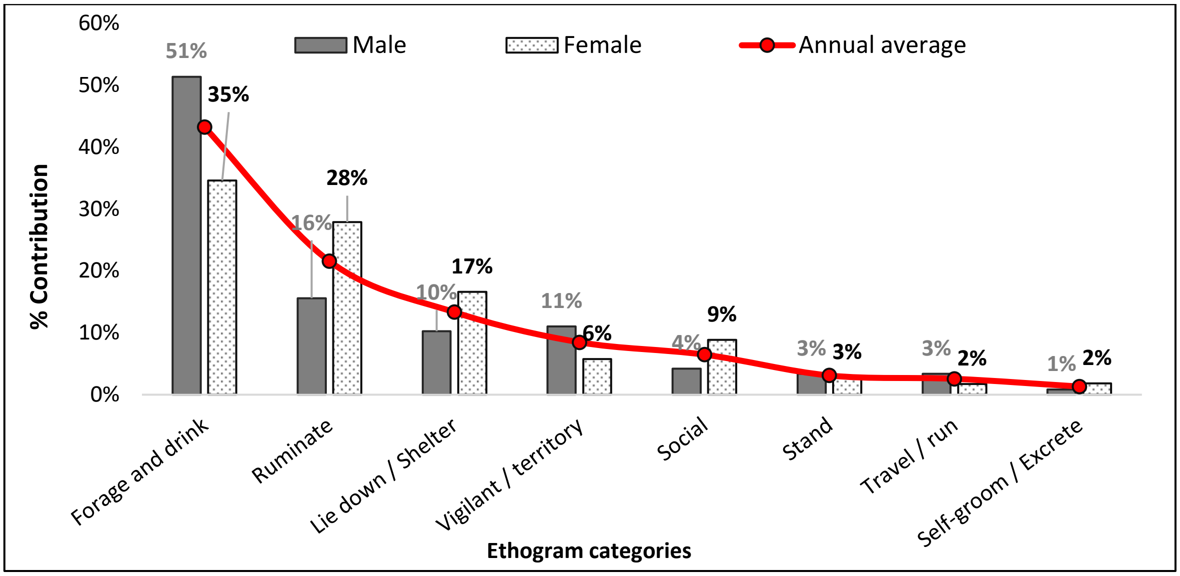


Figure 7-6: Eight main behaviour categories from the Aders' duiker Ethogram.

Foraging differences for males and females indicated a contrasting pattern with males foraging 12% much more in the dry season, and females foraging 10% less in the dry season. Ruminating differences in annual data only tested significant for gender, and not for seasonal data. Female ruminating in the dry season contributed to this difference with double the amount of time spent ruminating compared to the wet season and compared to ruminating by males for both seasons (Figure 7-7b. Males ruminated slightly more in the wet season. Lying down, vigilance, and travelling were significantly different between seasons. Results showed that males spent very little time lying down in the dry season (5%), compared to the wet season (16%), while females spent almost equal amounts of time down lying down across the seasons (17% in the dry season and 16% in the wet season). Vigilance for male Aders' duikers increased by more than double the amount of time in the wet season (9%) compared to the dry season (4%), females spent almost the same amount of time being vigilant across the seasons (4% wet season and 5% dry season). Although small, the source of seasonally significant differences in travelling are ascribed to male duikers spending more time travelling than females in general. Males showed a small increase in the wet season, while females reduced their time spent travelling during the same season. Self-grooming differences for both gender and seasonal data tested significant. Figure 7-7f clarifies this result by illustrating that female self-grooming in the wet season exceeded that of the dry season and the male's self-grooming for both seasons.

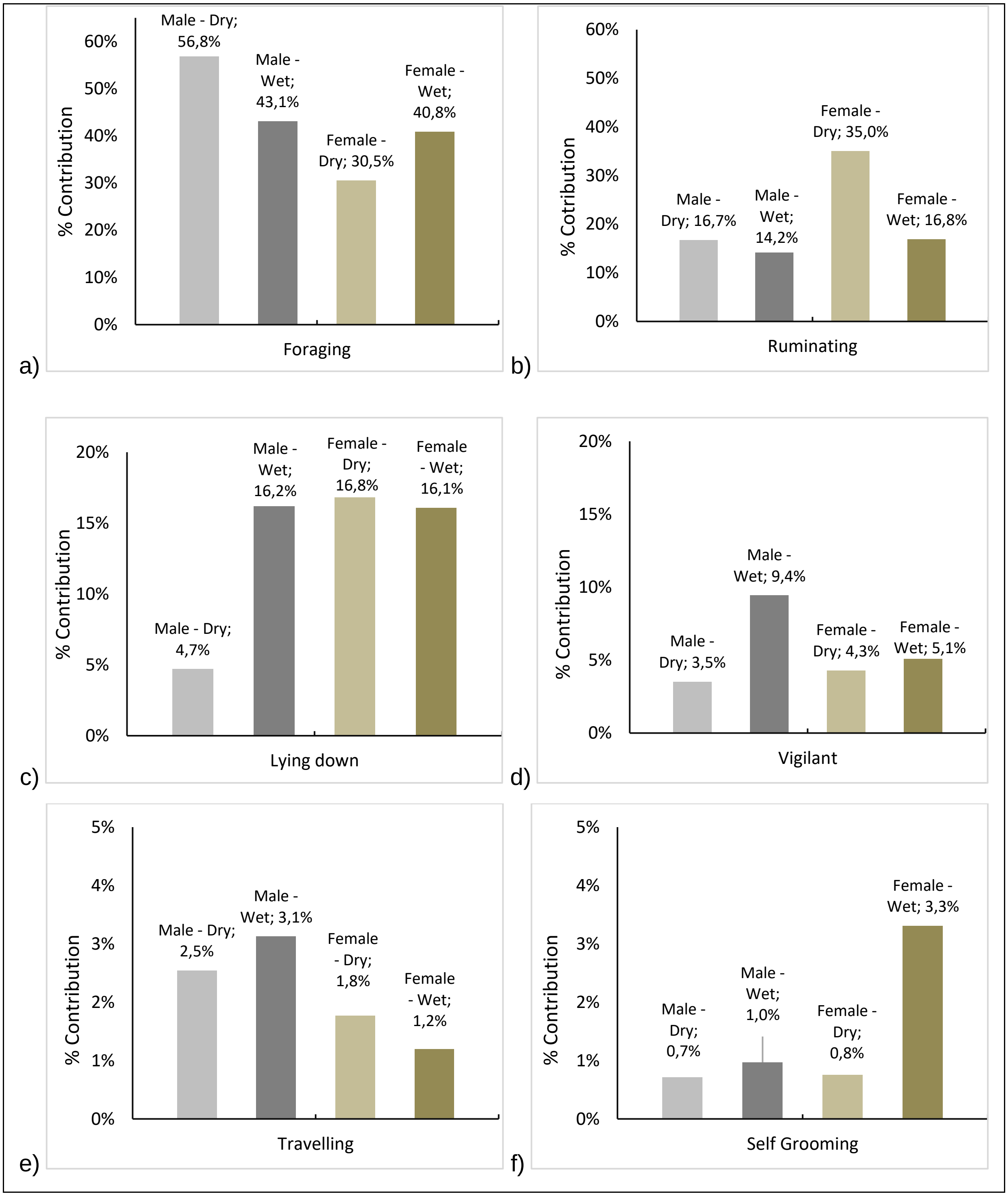


Figure 7-7: Ethogram categories with significant differences between season and gender.

Diel patterns

The evaluation of the Aders' duiker's diel activity patterns was obtained by extracting data from behaviour states that required movement and pooling the percentage of time spent moving during each daylight hour (Braude et al., 2002). Figure 7-8 illustrates that movement behaviours peaked before 7:00 in the morning and after 16:00. Two smaller activity peaks were observed between 11:00 and 12:00 and between 15:00 and 16:00. The lowest contribution towards activity was recorded between 14:00 and 15:00. A Kruskal-Wallis test confirmed the significant difference in peaks of activity at various hours of the day (X^2 = 576.85; df = 12; *P* = 0.000).

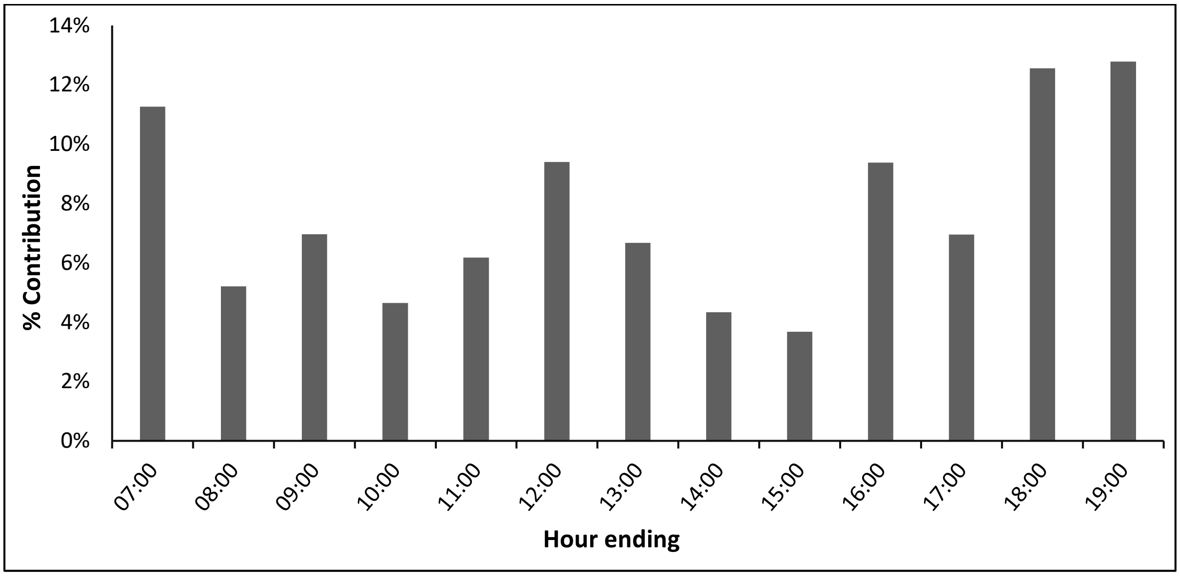


Figure 7-8: Activity of Aders' duiker on Mnemba Island based on focal observation of behaviour states that require movement. Percentage contribution of time spent during each daylight hour illustrates trimodal activity peaks at dusk and dawn, and around 11:00.

Grouping of duiker movement by season revealed significant differences between seasons, with a more pronounced trimodal pattern in the dry season (Kruskal-Wallis test: X^2 = 41.602; df = 7; *P* = 0.000), as illustrated in Figure 7-9.

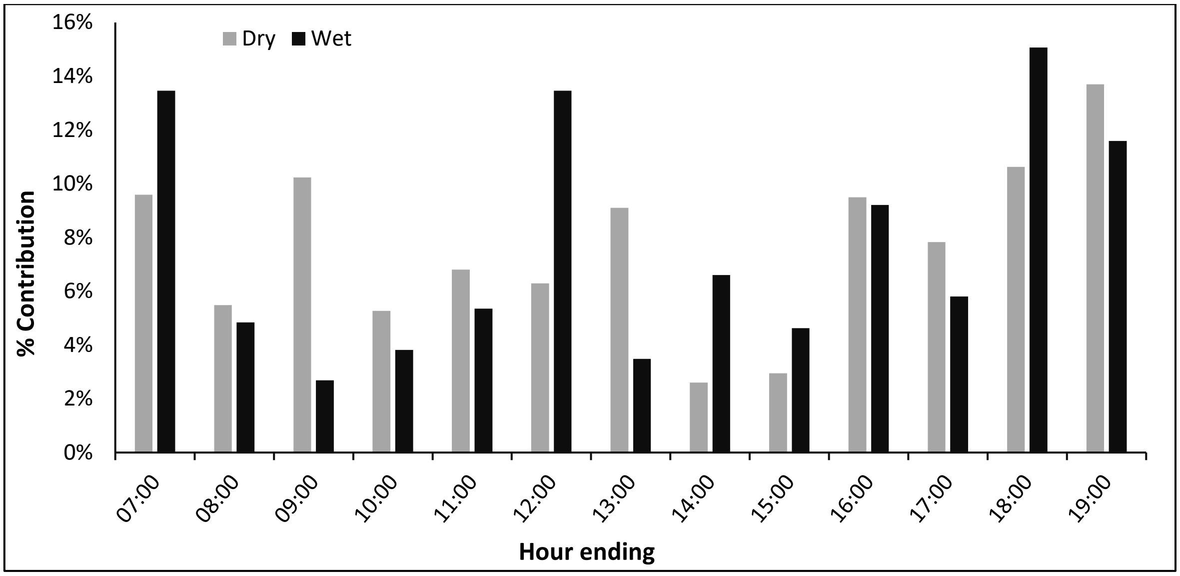
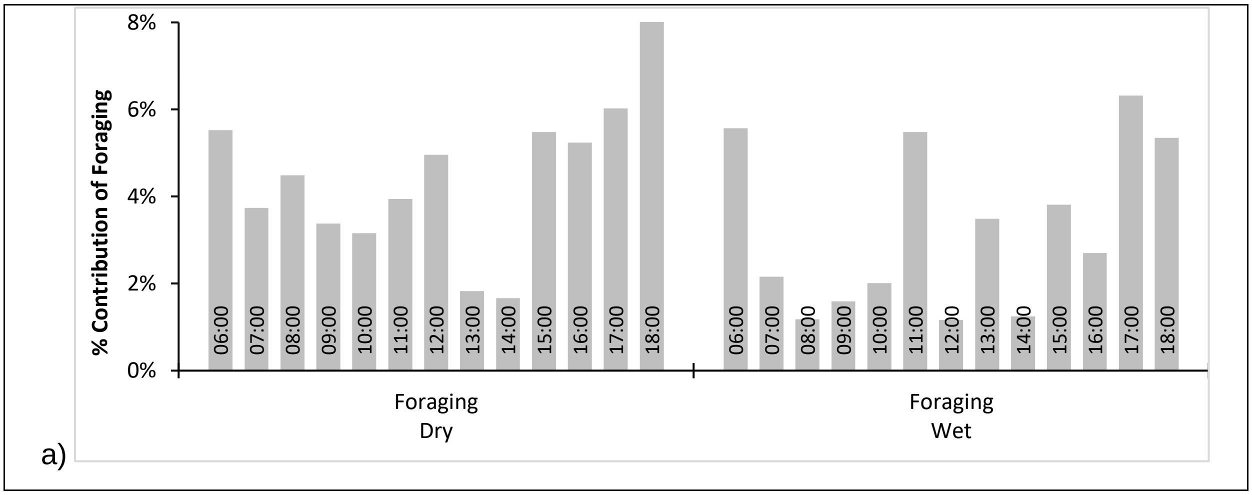


Figure 7-9: Diel movement behaviour showing diurnal activity with trimodal peaks in the wet season and bimodal peaks in the dry season.

The four main behaviour categories that contributed toward movement behaviour were foraging (80%), social interaction (7%), territorial activities (6%) and travelling (4%). Seasonal differences in diel patterns for each of these categories are illustrated in Figure 7-10, as a percentage contribution of the total time spent on individual behaviours (not as a contribution to the total activity budget): a) foraging, b) social, c) territorial and d) travelling. Behaviours show different peaks during the day and across the two seasons.



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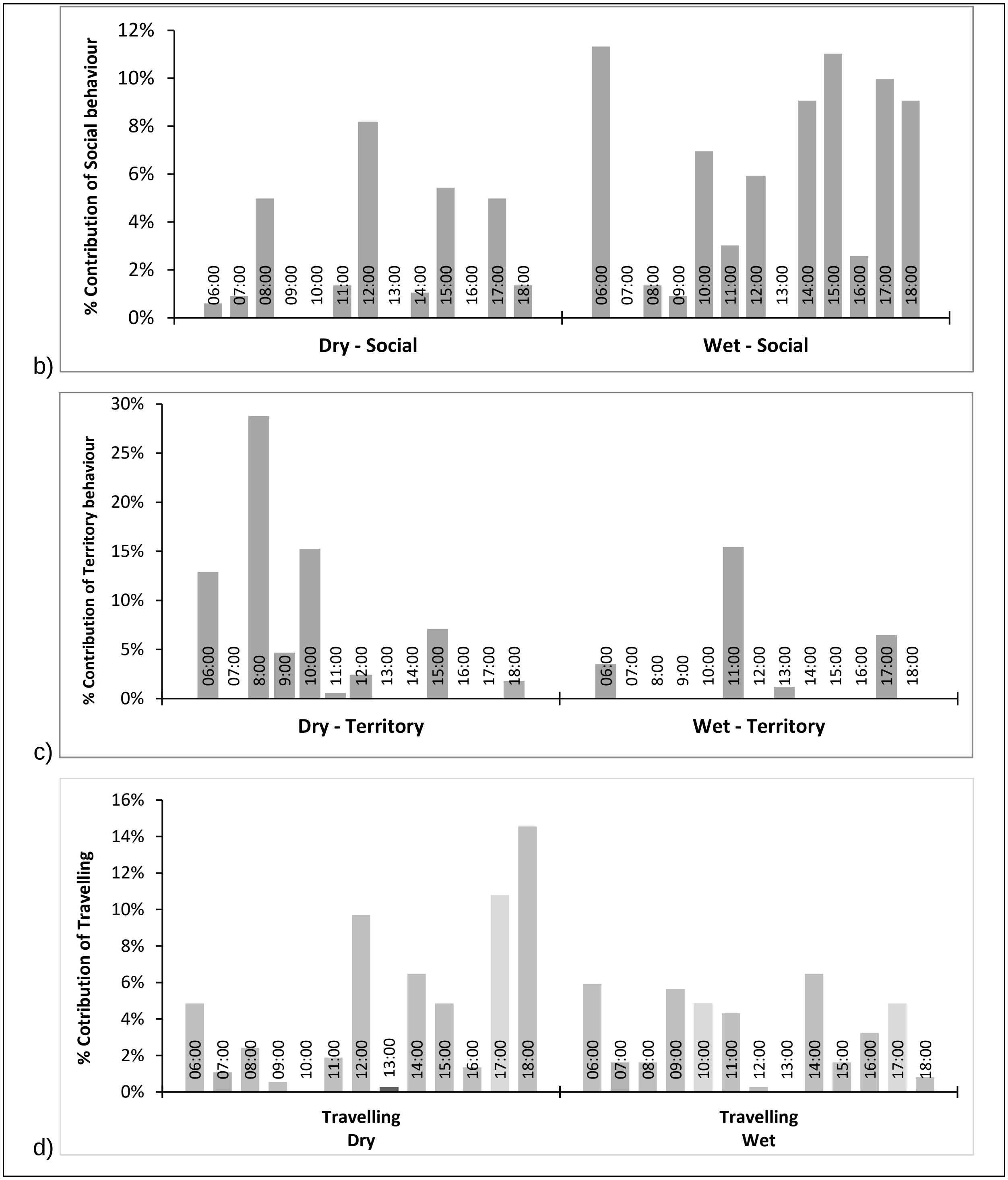


Figure 7-10: Diel patterns of four movement related behaviour categories in the Aders' duiker's activity budget.

Additional detail about foraging patterns is discussed in the next section. In the dry season social behaviour was more prevalent at noon, while almost no social interaction occurred at dawn and dusk. In contrast, the wet season revealed three social peaks during the day, at dawn, dusk and between 14:00 and 16:00. Territoriality contributed to an activity peak between 08:00 and 09:00 in the dry season, and a peak 11:00 and 12:00 in the wet season. Travelling in the dry season resembled a crepuscular pattern, but not in the wet season.

Male and female diel patterns for overall movement illustrated in Figure 7-11 indicates a clear gender difference in daily activity patterns. Females were more active between 16:00 and 19:00 (almost 50% of all time spent moving about), while males were more active from first light to 09:00 (30%). Males also tended to have a trimodal diel pattern with a matutinal trend, while females demonstrated a clear vespertine curve. Differences in gender diel patterns were confirmed as significant (Kruskal-Wallis test: $X^2 = 71.932$; df = 7; $P = 0.000$).

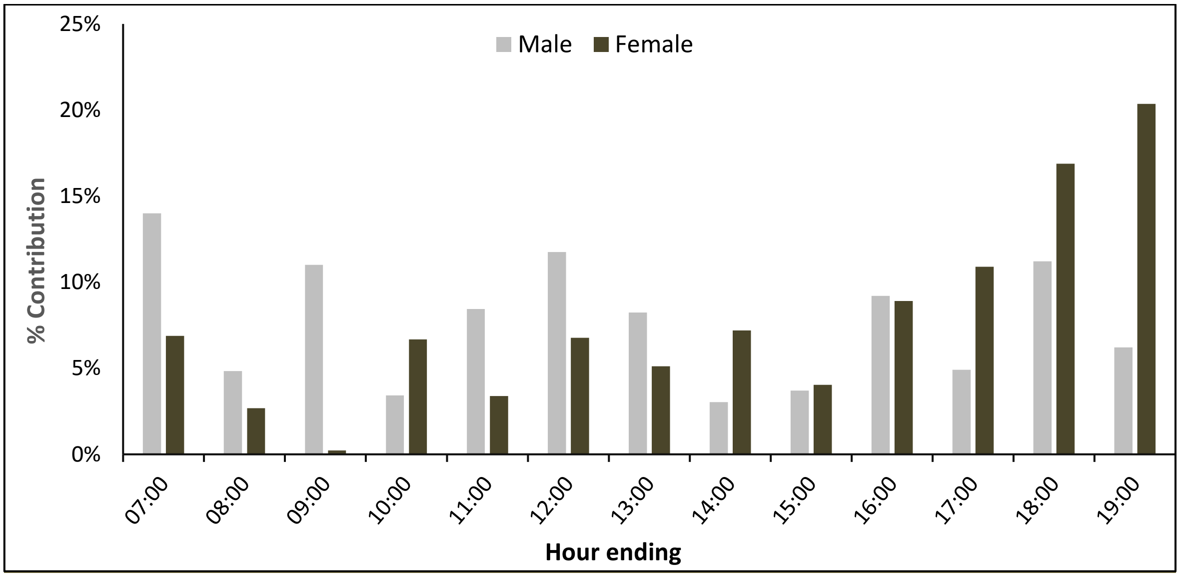


Figure 7-11: Gender differences in diel movement patterns. Males are noticeably more active in the mornings and females in the late afternoons.

7.3.2 **Foraging and social patterns**

All movement behaviour for Aders' duiker was found to consist of 80% foraging activities. Comparisons of foraging activity across seasons revealed strong trimodal peaks in the wet season, while the dry season had a slight vespertine trend. Differences in seasonal foraging peaks tested significant (Kruskal-Wallis test: $X^2 = 27.498$; df = 7; $P = 0.000$). Figure 7-12 illustrates the differences in peaks as well as the influence that foraging had on the overall movement pattern for the duikers (dotted line in the graph).

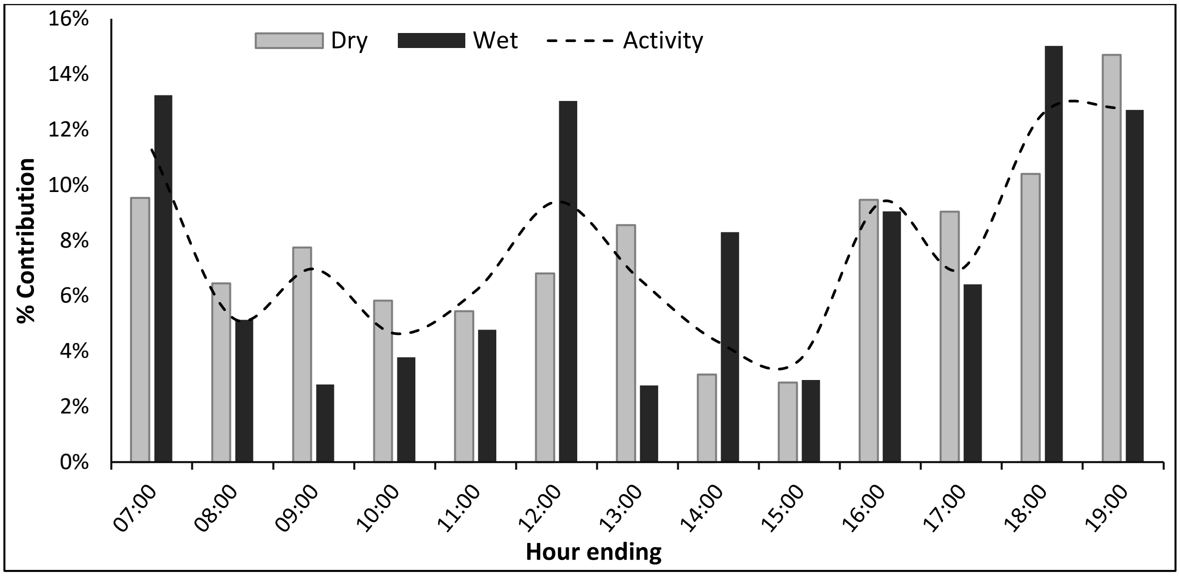


Figure 7-12: Diel foraging patterns during dry and wet seasons. Clear trimodal peaks exist in the wet season. The broken line represents all movement activity across seasons.

Diel patterns for foraging activities were further grouped by male and female. Overall differences between male and female foraging patterns tested significant (Kruskal-Wallis test: $X^2 = 52.568$; df = 7; $P = 0.000$). Seasonal differences between male and female foraging patterns were also significant (Kruskal-Wallis test: $X^2 = 27.089$; df = 3; $P = 0.000$).

Figure 7-13 illustrates diel foraging patterns for males and females in the dry season. Male duikers showed a trimodal pattern with foraging activity peaks in the morning between 07:00 and 09:00, between 12:00 and 13:00 and again between 15:00 and 16:00. Females had a more bimodal pattern, with a morning peak between 09:00 and 10:00 and an extended activity peak from 16:00 to dusk.

Figure 7-13 illustrates a somewhat pronounced diel pattern for both males and females in the wet season. Both genders had peaks in activity between 06:00 and 07:00 and between 11:00 and 12:00. Males had a third peak between 17:00 and dusk, while females had two additional peaks, one between 13:00 and 14:00 and the other from 16:00 to 18:00.

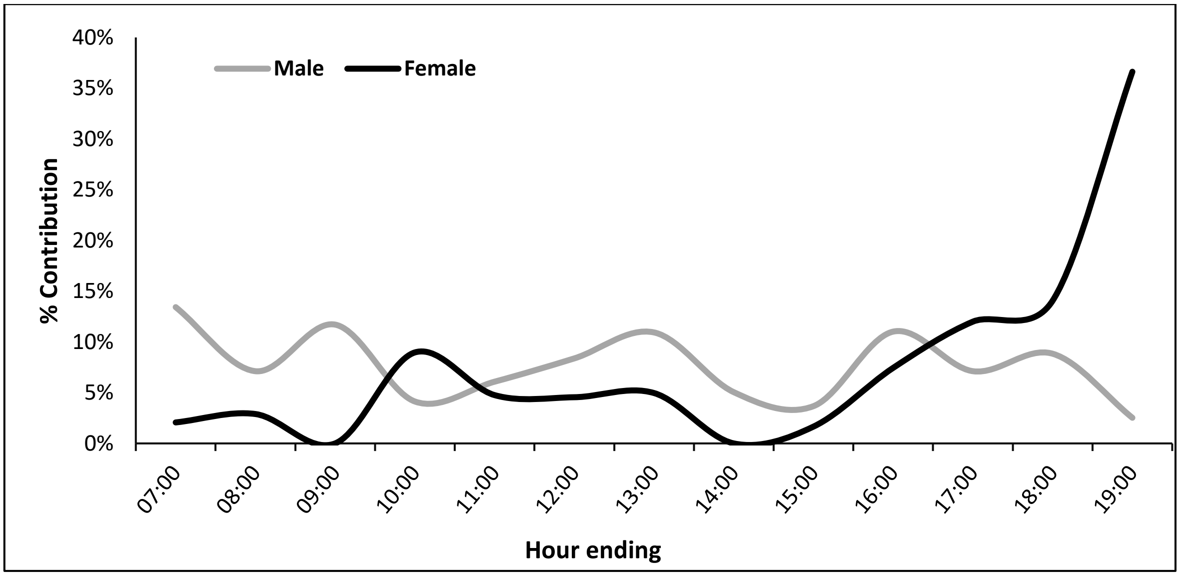


Figure 7-13: Diel foraging activities measured for male and female duikers in the dry season.

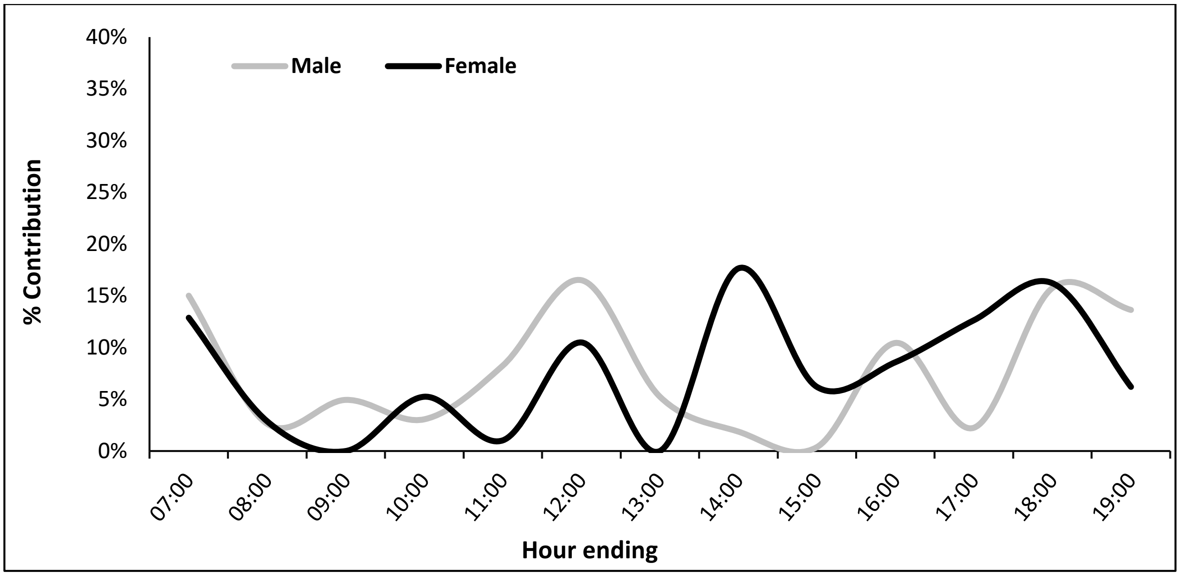


Figure 7-14: Diel foraging activities measured for male and female duikers in the wet season.

Foraging sub-states provided more detail about the nature of foraging in the two main seasons. Almost half (45%) of all foraging was done at a slow pace, with 27% at a medium pace (forage walking). More of the slow-paced foraging was recorded for the dry season, but differences were not significant. More medium paced foraging (forage walking) was recorded in the wet season, but differences were also not significant according to the results in Table 7-4. A small difference between seasons for ‘Social foraging’ tested as significant, concluding that foraging was more of a ‘social event’ in the wet season. All other seasonal differences between sub-states were not significant. Foraging sub-states grouped by season are illustrated in Figure 7-15.

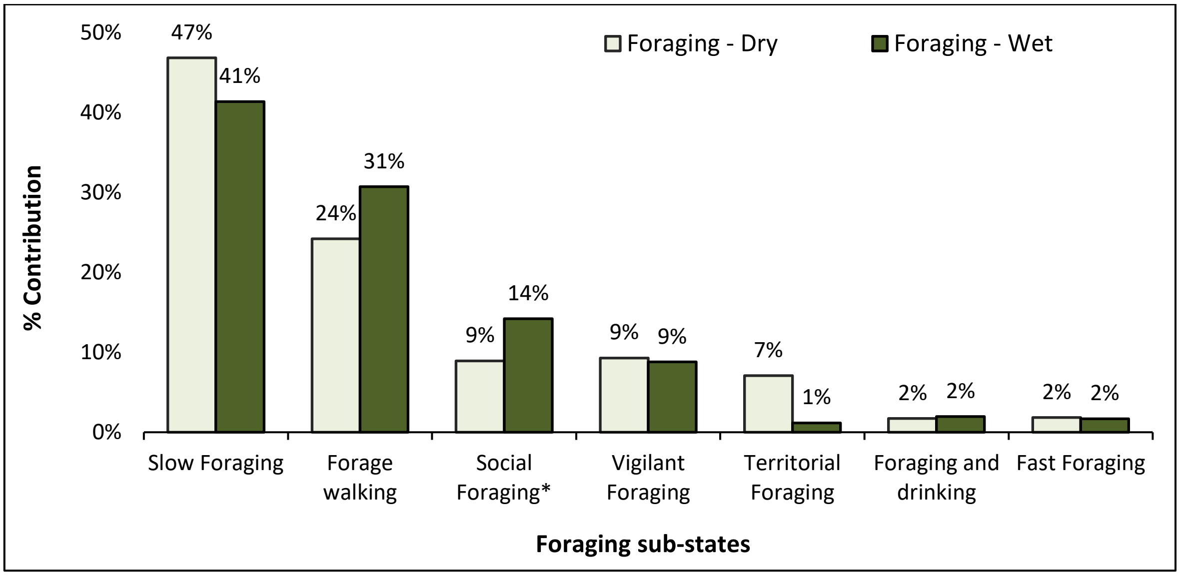


Figure 7-15: Foraging sub-states grouped by season (* = significant result).

Table 7-4: Foraging sub-states tested for significant differences between wet and dry seasons using the Mann-Whitney U test.

Behavioural state	**Dry season (%)**	**Wet season (%)**	***U***	**n_1 and n_2**	***P* (2 tailed)**
Slow Foraging	47%	41%	2171,000	72; 63	0,668
Forage walking	24%	31%	1329,000	56; 52	0,431
Social Foraging	9%	14%	36,000	21; 14	**0,000**
Vigilant Foraging	9%	9%	70,000	22; 10	0,102
Territorial Foraging	7%	1%	5,000	3; 5	0,453
Fast Foraging	2%	2%	2,000	10; 1	0,337
Foraging and drinking	2%	2%	0,000	3; 1	0,180

Gender comparisons of foraging sub-states showed that females spend significantly more time ‘Slow foraging’ than males. They also ‘Forage walk’ and ‘Social forage’ more than males. Male duikers showed a tendcy to be more engaged in ‘Vigilant foraging’ and ‘Territorial foraging’. Foraging sub-states, grouped by gender are illustrated in Figure 7-16, and related Mann-Whitney U test results summarised in Table 7-5.

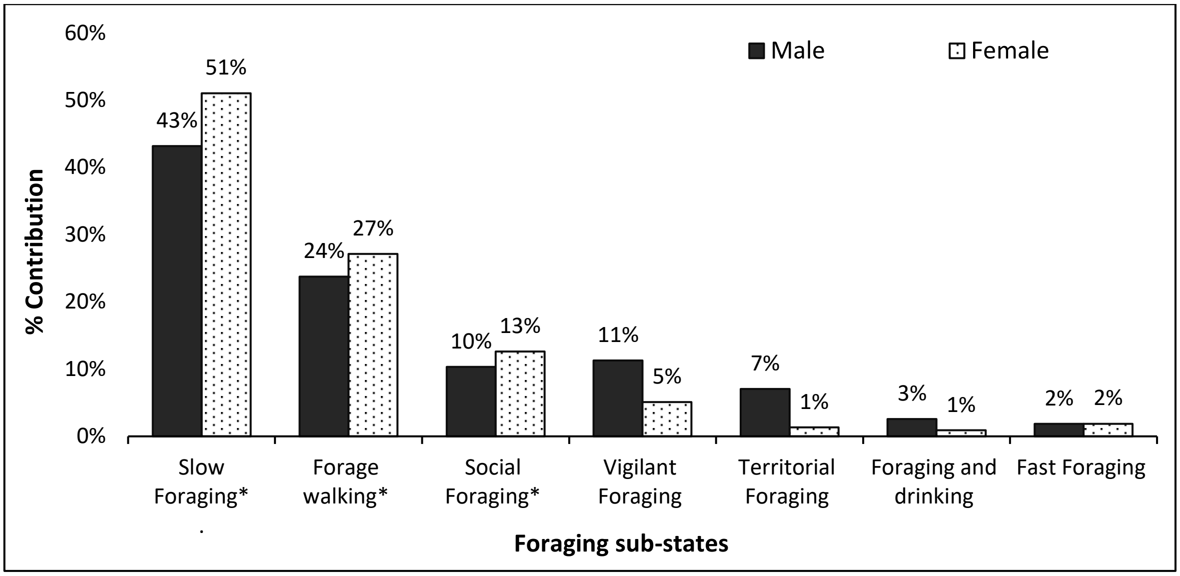


Figure 7-16: Foraging sub-states grouped by gender.

Table 7-5: Foraging sub-states tested for significant differences between male and female duikers, using the Mann-Whitney U test.

Behavioural state	***U***	**n_1 and n_2**	***P* (2 tailed)**
*Slow Foraging**	1556	78; 55	***0,007***
Forage walking*	730	54; 42	**0,003**
*Social Foraging**	53	21; 13	**0,003**
Vigilant Foraging	70	19; 9	0,445
Territorial Foraging	8	9; 2	0,813
Fast Foraging	5	3; 5	0,453
Foraging and drinking	1	3; 1	0,655

Group size was recorded for each focal session. The current study indicated that Aders' duiker was both solitary and social. For more than 42% of focal sessions, only one duiker was observed. Another 30% of observation sessions included two duikers, mostly male-female pairs, but also adult and offspring pairs. Groups of three (14%), four (9%) and five duikers (5%) were observed where individuals in the group were foraging, socialising, resting and travelling together. For three focal observation sessions, group sizes of six, seven and nine were observed. In at least 38% of all focal sessions, at least one male and one female were observed.

The number of duikers foraging together are illustrated in Figure 7-17, showing that overall, 37% of all foraging observations included solitary duikers. Groups of two foraging together were recorded 29% of the time, while trios made up 18% of observations. Group size of four or more animals was found foraging together 16% of the time. In the dry season, the percentage of solitary foraging was 17% higher than in the wet season. Pairs and groups sizes of four and bigger were more prevalent in the wet season. Seasonal differences in foraging group size were tested with a two-way classification Chi-square test (X^2 =12.830; df = 3; P = 0.00). Results concluded that foraging group size and season are associated.

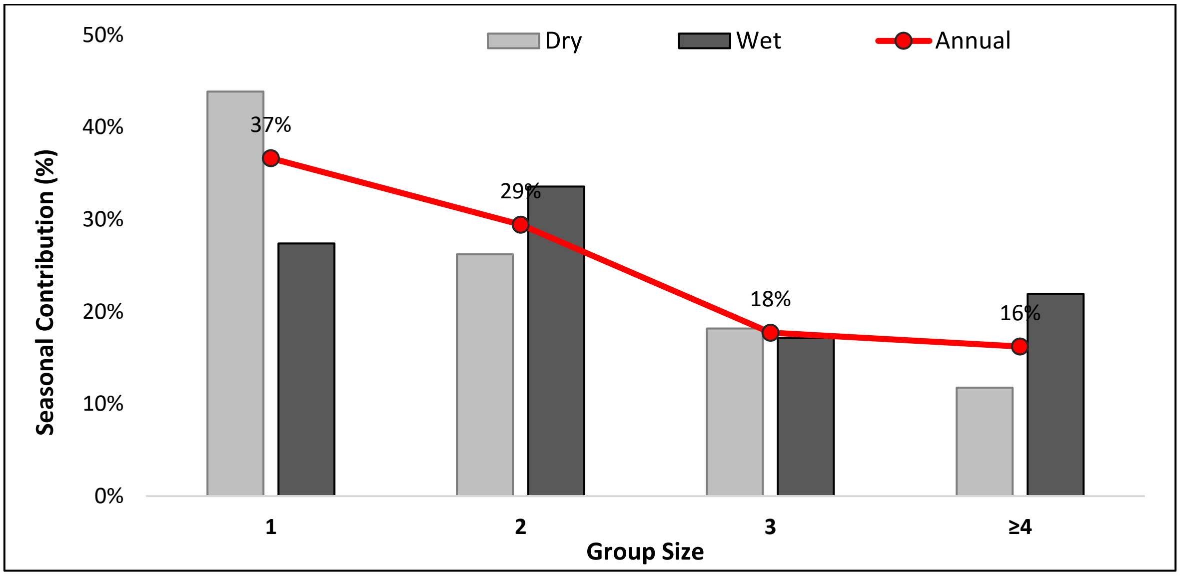


Figure 7-17: Number of duikers foraging together, grouped by season.

Group size did not follow a Poisson distribution (KS test: z = 2.18, p = 0.00), and was found to be underdispersed (mean = 2.07, var = 1.57).

Social interaction, excluding social foraging and territorial clashes, was observed for almost 7% of the entire activity budget. Interaction with Suni antelope during focal observation was limited. Only ten focal observations included Suni in visual proximity to Aders' duiker focal individuals and/or groups. Of the ten cases, nine took place in the dry season and one in the wet season. All cases were recorded between 16:00 and 19:00. In nine of the cases, Suni antelope showed no visible reaction to the presence and activities of Aders' duikers, and vice versa. In one case Suni antelope changed from being relaxed to being vigilant, immediately after Aders' duiker displayed vigilant behaviour.

Social behaviour was grouped into seven sub-categories in the Ethogram - Figure 7-18.

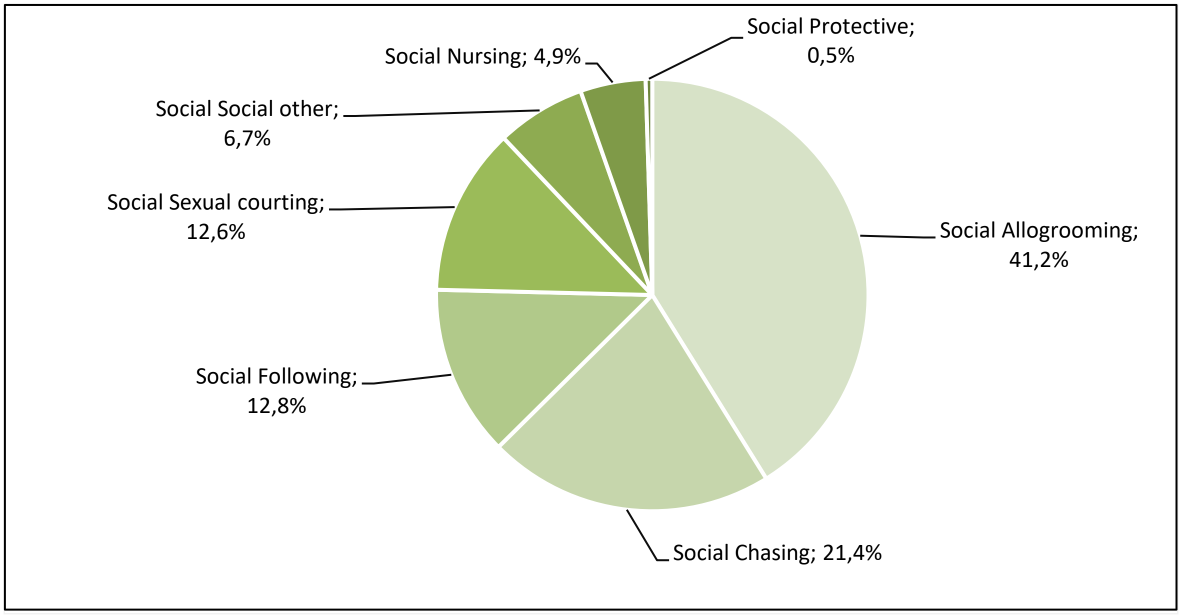


Figure 7-18: Social activities: percentage of time spent on sub-states of all social activities observed.

Mann-Whitney U test results indicated that social interaction was more prevalent in the dry (Mnd = 11) season than in the wet (Mnd = 5) season ($U = 3$; $P < 0.00$). Duikers followed one another 24% of the time in the dry season, compared to 7% in the wet season. Figure 7-19 illustrates a weak seasonal tendency for chasing and sexual courting. Table 7-6 illustrates grouped results for social interaction sub-states by gender and season. Sub-states in the table indicated by a (g) represents significant results for gender differences, and an (s) for significant seasonal differences.

Table 7-6: Allocation of time to social interaction sub-states for male and female Aders' duiker, expressed as a percentage of all social time observed per gender per season.

	Male		Female	
Social Sub-state	Dry Season	Wet Season	Dry Season	Wet Season
Allogrooming **(g)**	10%	8%	49%	79%
Following **(s)**	21%	19%	28%	3%
Sexual courting **(g)**	21%	50%	3%	1%
Chasing	9%	16%	6%	8%
Social other	18%	8%	0%	9%
Nursing / being nursed	16%	0%	15%	0%
Protective	5%	0%	0%	0%

The Mann-Whitney U test indicated that allogrooming behaviour was more prevalent among females (Mnd = 13) than males (Mnd = 4) (*U* = 5; *P* < 0.00), owing to the 67% of social interaction by females being allogrooming, as opposed to males only spending 9% of their social budget on allogrooming. Figure 7-20 illustrates the gender differences in social subcategories.

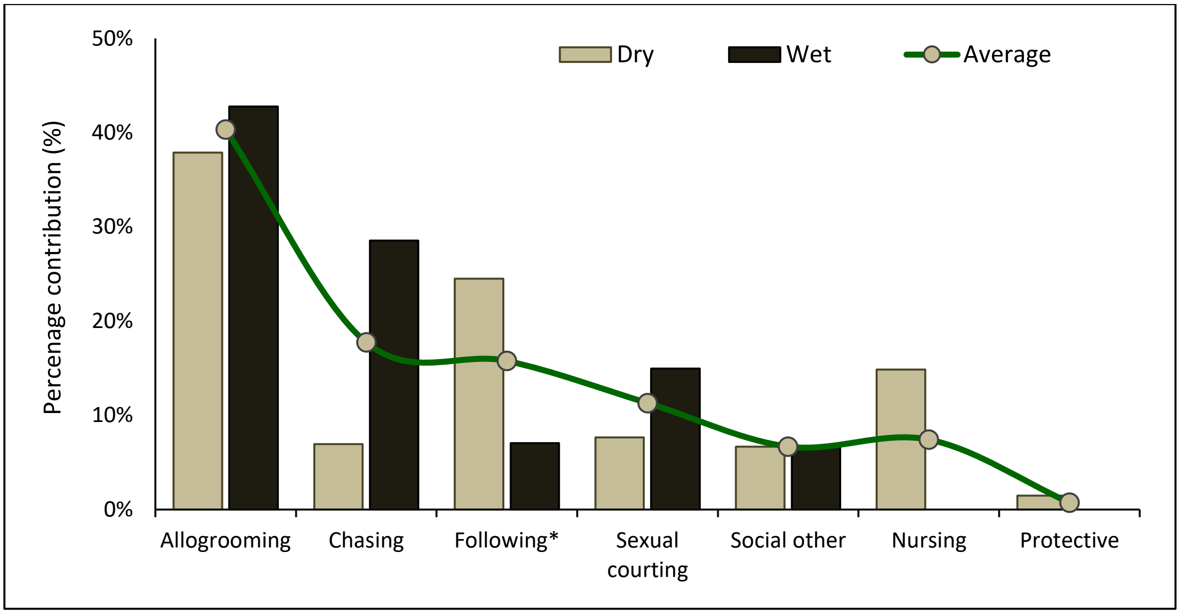


Figure 7-19: Seasonal differences for social behavior.

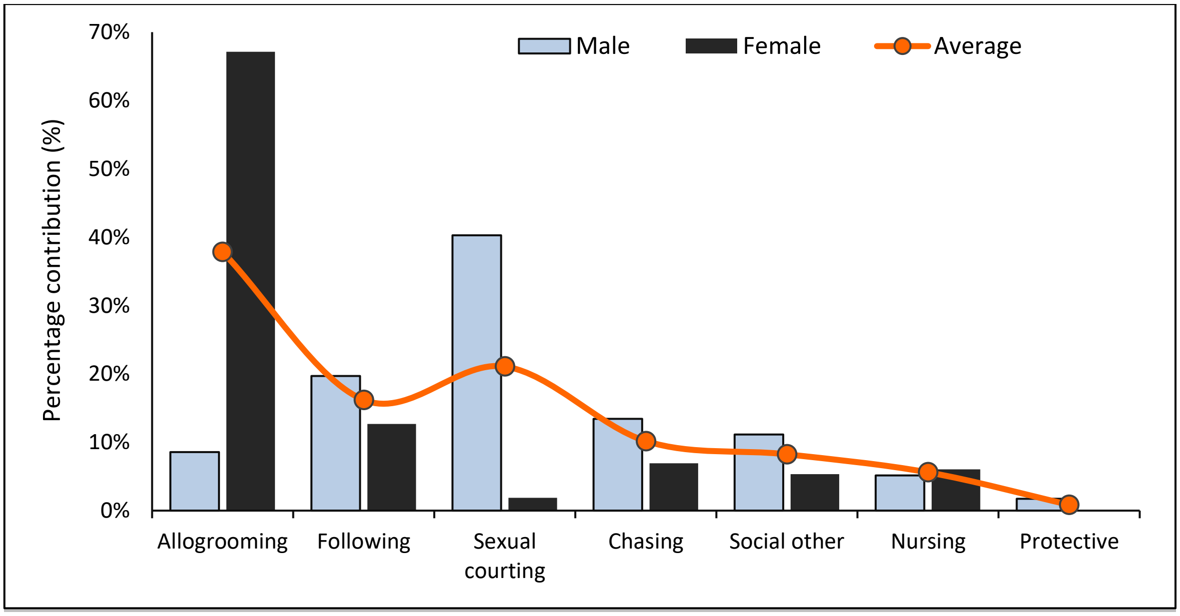


Figure 7-20: Gender differences in social behavior.

7.3.3 Food selection

Food species and type

A total of 20 food plant species were recorded for Aders' duiker on Mnemba Island. Nine of the species observed included 'bite rate' (number and type of items consumed) during focal observations, while eleven additional species were noted for selection during ad hoc observations, without the opportunity to record the number of items consumed. All 'bite rate' observations included the type or part of the plant.

Of the nine species consumed, two species made up 64% of the Aders' duiker selection - *Grewia glandulosa* and *Pisonia grandis.* The leaves, fruits and leaf stems of *Grewia glandulosa* were consumed at a ratio of 68:31:1 respectively. The electivity index for *G. glandulosa* leaves was calculated as 0.73. The leaves, leaf stems and flowers of *Pisonia grandis* were consumed at a ratio of 78:16:7 respectively. Electivity index score for *P. grandis* leaves was 0.69. Species and food types with electivity indexes above 0.8 were *Terminalia catappa* leaf stems, *Ficus polita* fruit, *Ehretia amoena* fruit and *Ficus scassellati* leaves. These items constituted 18% of the observed diet, with *T. catappa* leaves only contributing towards 1% and the remaining three species contributing similar portions to the remaining 17% of the diet.

Table 7-7 lists the nine species identified during focal foraging observations, broken down into type (part of the plant) and ranked from largest to smallest in terms of relative abundance (r_i). Availability (the relative abundance of the species among all species on the island) and Ivlev Electivity Index (E_i) for each diet component (species and food type) of the diet is provided in the table. The plant community to which each species belongs is also listed in the table. A regression analyses concluded that Electivity (E_i) and Availability (P_i) is linearly related ($F_{1,13}$ = 16.12; P = 0.00) with a fairly strong relationship (Multiple R = 0.75) between availability being a predictor of electvity where 55% of variance in electivity can be explained by the availability of the food species. Table 7-8 lists the ten additional food species identified during ad hoc observations on the island. Availability is expressed as the relative cover-abundance of the species, derived from the results of the vegetation survey (Chapter five). Abundance values for species indicated with * were extrapolated from abundance values for species with a similar distribution in the vegetation survey. These two species were not situated in any of the vegetation plots during the survey but were recorded during the voucher sample collection.

Table 7-7: Food species by type - identified during bite rate observations for Aders' duiker on Mnemba Island, including diet proportion and availability on the island.

Diet component Species	Type	Diet proportion (r_i)	Availability (P_i)	Electivity (E_i) *Specialty	Plant community
Grewia glandulosa	Leaves	23.65%	3.68%	0.73	2
Pisonia grandis	Leaves	22.17%	4.00%	0.69	2
Grewia glandulosa	Fruit	10.84%	3.68%	0.49	2
Ficus polita	Fruit	6.90%	0.18%	0.95	2.1
Mimusops obtusifolia	Fruit	6.40%	13.61%	-0.36	2
Ehretia amoena	Fruit	5.42%	0.18%	0.94	General
Ficus scassellati	Leaves	5.42%	0.36%	0.88	2
Sideroxylon inerme	Leaves	5.42%	6.98%	-0.13	General
Pisonia grandis	Leaf stems	4.43%	4.00%	0.05	2
Mimusops obtusifolia	Leaves	2.96%	13.61%	-0.64	2
Pisonia grandis	Flowers	1.97%	4.00%	-0.34	2
Sideroxylon inerme	Fruit	1.97%	6.98%	-0.56	General
Terminalia catappa	Leaf stems	0.99%	0.02%	0.96*	General
Auricularia auricula-judae	Fungus	0.99%	0.18%	0.70*	2.1
Grewia glandulosa	Leaf stems	0.49%	3.68%	-0.76	2

Total availability (P_i) of dominant species identified as food in the different plant communities, were calculated. Food species that were dominant in plant community 2 had the largest total availability (P_i = 61.73%) with an electivity index (E_i) of 0.12. Food species found across all plant communities had a combined availability of 14.66% and an E_i of -0.03. Food species from sub-community 2.1 had a combined availability of 0.55% and an electivity index of 0.87. The last group of food species from sub-community 1.2 was represented by two species only and had a P_i of 0.30% and electivity index of -1.00.

Table 7-8: Food species by type, identified during ad hoc observations for Aders' duiker on Mnemba Island, including availability on the island.

Diet component			
Species	**Type**	**Availability (P_i)**	**Plant community**
Bouganivillea glabra	Leaves	0.02%	1.2
Ficus lutea	Fruit	0.19%	2.1
Guettarda speciosa *	Flowers	0.02%	General
Eugenia capensis	Fruit	26.51%	2
Pandanus kirkii	Sprouts	9.97%	2
Capparis viminea	Sprouts and leaves	4.22%	General
Cassytha filiformis	Vine	3.60%	2
Cordia subcordata	Flowers	0.28%	1.2
Suregada zanzibariensis	Sprouts and leaves	2.16%	General
Polysphaeria parvifolia	Fruit	1.06%	General
*Todalia asiatica**	Leaves	0.02%	General

Total availability (P_i) results are depicted in Table 7-9 and Figure 7-21 below.

Table 7-9: Plant communities represented by food species availability, with combined diet proportion, availability and electivity listed for each plant community.

Plant Community (n = species)	**Diet proportion (ri)**	**Availability (Pi)**	**Electivity (Ei)**
2 (n = 7)	78.33%	61.73%	0.12
2.1 (n = 3)	7.89%	0.55%	0.87
General (n = 8)	13.80%	14.66%	-0.03
1.2 (n = 2)	0.00%	0.30%	-1.00

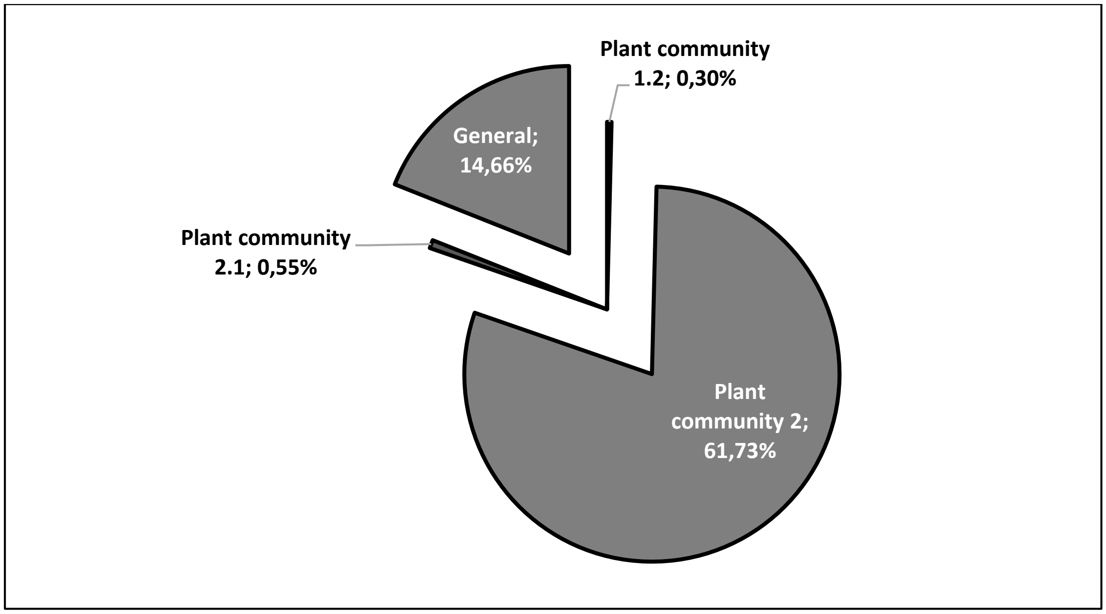


Figure 7-21: Availability (P_i) of food species that are characteristic for each plant community.

In addition to species composition, food type composition was investigated by recording 'bite rate' (adapted as number of items consumed) and rate of consumption (recorded as number of items per minute). Data were grouped by food type (leaves, fruits and seed, flowers and flower stalks, leaf stems and sprouts, fungus, grass and roots) and relative abundances were calculated. It was found that the Aders' duiker diet on Mnemba consisted of 49% leaves and 43% fruits and seeds. The remaining portion of the diet consisted of just over 4% flowers (and flower stalks), 2% roots, 1% leaf stems and sprouts, 1 % fungi and grass combined, and less than 1% invertebrates (worms and insects).

Ivlev Electivity Index scores for food type are illustrated in Figure 7-22. Fruits and seeds rated above 0.7 for both the dry and the wet season observations. Fungi had an index of almost 0.8 in the wet season, and -1 in the dry season, indicating specific availability during the monsoon rains. Grass, flowers and flower stalks, and leaf stems and sprouts, had an index of -1 in the wet season independently. An electivity index of -0.7 for roots in the dry season and around 0 in the wet season was calculated. Leaves (both seasons) as well as dry season consumption of leaf stems and sprouts, and grass, had an index value close to 0 independently.

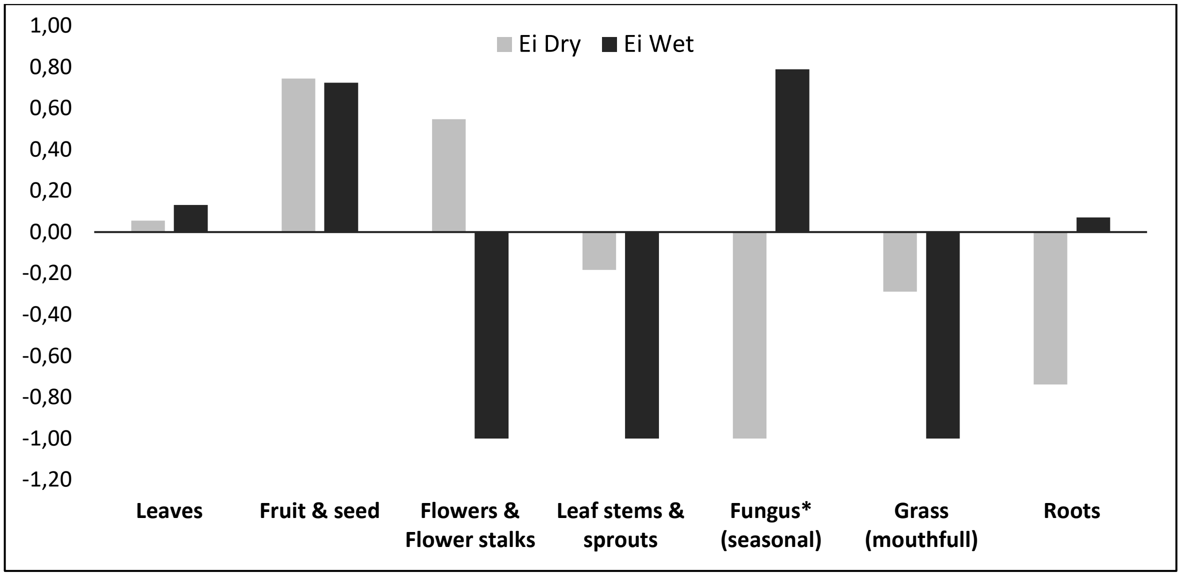


Figure 7-22: Electivity Index for food type items per season.

Consumption rate and browsing units

An hourly consumption rate for each food type was calculated from the ‘bite rate’ data. The biggest component of the duiker’s diet, leaves, were eaten at a rate of 53 items per hour, which resulted in an estimated number of 134 leaves per day in the wet season and 129 in the dry season. An estimated 166 fruits were consumed per day in the dry season, and 134 fruits daily in the wet season (at 71 items per hour).

Flowers and flower stems were predominantly observed as part of the diet in the dry season, at a daily consumption rate of 18 items, while less than one flower was observed per day in the wet season. Flower selection was based on availability on the ground or close to the ground, and not in the canopy. Fungi were only observed in the wet season and consumed at five items per day. Roots were consumed in the wet season at an estimated daily rate of three items. A root ‘item’ was defined as the consumption of a tip of an exposed root, after an individual duiker had spent time digging up the root with its front hooves. It was estimated that less than one of each of root items, leaf stem or sprout, and mouthful of grass were consumed daily in the dry season. One worm or insect was estimated per day in the dry season and less than one in the wet season.

Table 7-10 summarises the findings for food items consumed. Seasonal comparison of daily diet composition was estimated by totaling the number of items for each food type. Dry season diet composition had 36 more items per day than in the wet season.

Table 7-10: Estimated number of food items consumed per day, per season.

		Dry		**Wet**	
Hours spent foraging per day, per season:		**5,4**		**4,8**	
Food type	**Rate of consumption (nr/h)**	**Seasonal ratio in the diet**	**nr/day**	**Seasonal ratio in the diet**	**nr/day**
Leaves	52.5	0.45	128.5	0.53	133.9
Fruits and seeds	70.5	0.44	166.3	0.40	137.0
Flowers and Flower stalks	45.9	0.07	17.6	0.00	0.4
Roots and vines	16.4	0.01	0.5	0.04	3.3
Leaf stems and sprouts	7.8	0.02	0.7	0.00	0.0
Fungi	60.0	0.00	0.0	0.02	4.9
Worms and insects	17.1	0.01	1.0	0.00	0.1
Grass	30.0	0.01	0.9	0.00	0.1
			316		280

Diet composition and daily consumption were tested for significant differences between the two seasons. Food type categories with small contributions to the diet were grouped as ‘other’ resulting in three categories for the two seasons: leaves, fruits and other. An omnibus Chi-square test indicated that overall diet composition differences were not significant across seasons (X^2 =30.11; df = 2; P = 0.21). A post-hoc test using standard residuals confirmed this result. In other words, the ratio of leaves to fruits to other items in the Aders’ diet did not differ significantly between the wet and dry seasons. A Chi-square test performed with daily numbers of items consumed also indicated a non-significant result across seasons for the three categories (X^2 =5.65; df = 2; P = 0.06). A post-hoc test of cell-by-cell comparisons confirmed the Chi-square test result.

Figure 7-23 Aders’ duiker foraging on leaves from *Grewia glandulosa* at 1.1m above the ground. A combined list of Aders’ duiker food species from this study and a literature review can be found in Appendix K.

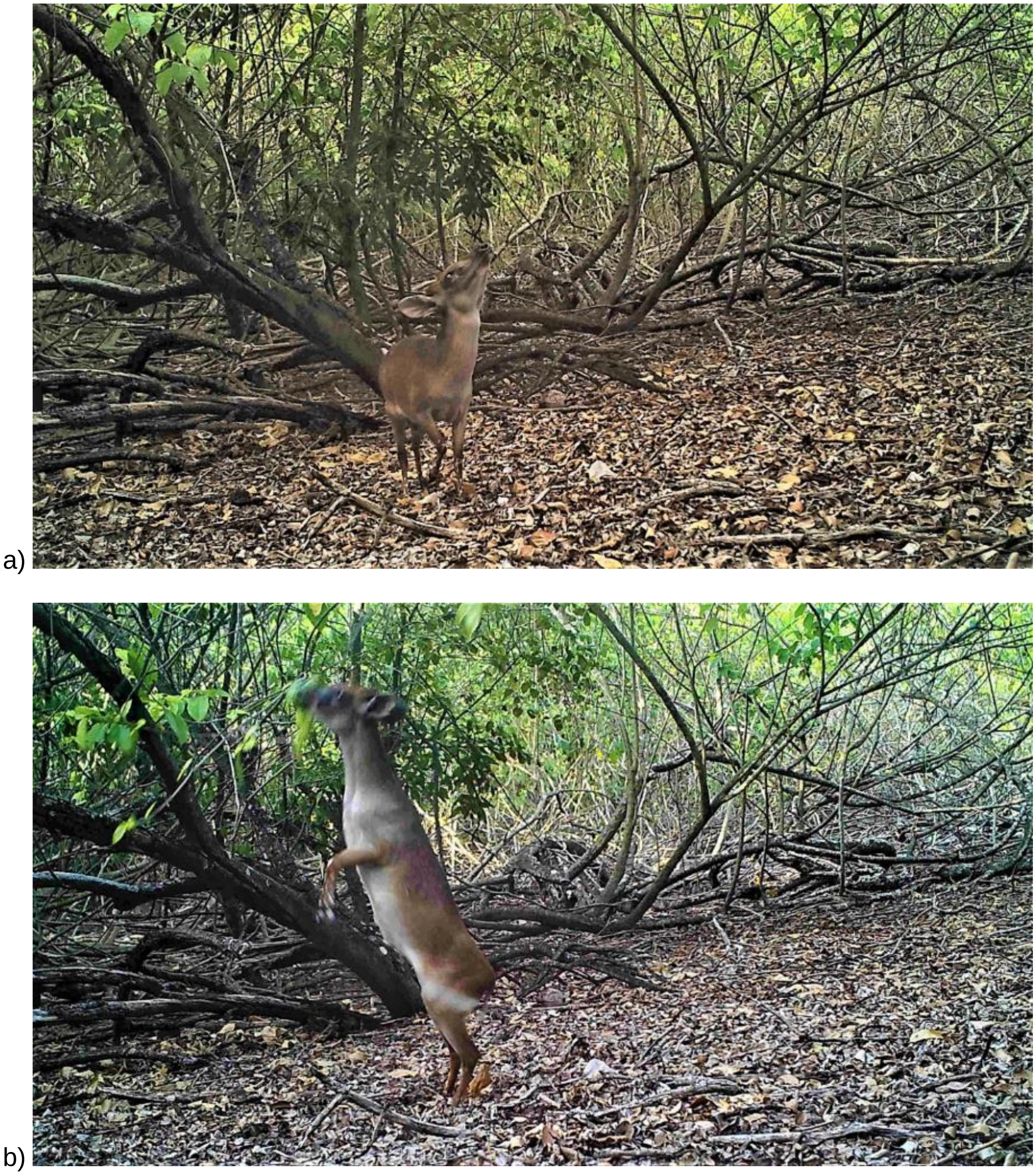


Figure 7-23: Aders' duiker searching a) and reaching b) for leaves at 1.1 m above the ground. Leaves belong to the *Grewia glandulosa* shrub.

Phenology of food plant species

Phenological aspects of the 20 food species identified for Aders' duiker on the island are listed in Table 7-11, where W = wet season and D = dry season. In the wet season, twelve of the species were fruiting while eight species were fruiting in the dry season. Fallen fruits were noted from six species in the wet season and from four species in the dry season. Eleven of the 20 species were budding and flowering in the wet season. In the dry season only eight of the 20 species were budding and flowering, with two of the species not recorded in the wet season, *E. amoena* and *P. multiflora*. Fallen flowers from three species were noted in the wet season and only from one (*P. grandis*) in the dry season. Fallen leaves were recorded for more species in the wet season than in the dry season. Fallen green leaves were noted for seven species in the wet season and for five of the same seven species in the dry season. Fallen yellow leaves were noted for nine species in the wet season and for four of the nine species in the dry season. *C. subcordata, S. inerme, F. polita* and *G. speciosa* only had visible fallen leaves in the wet season.

A summary of the number of species contributing to each phenophase, grouped by season, is illustrated in Figure 7-24: Number of species for each phenophase grouped by season.

The wet season saw a higher number of species contributing to all new growth, fruiting, flowering, and fallen items than during the dry season.

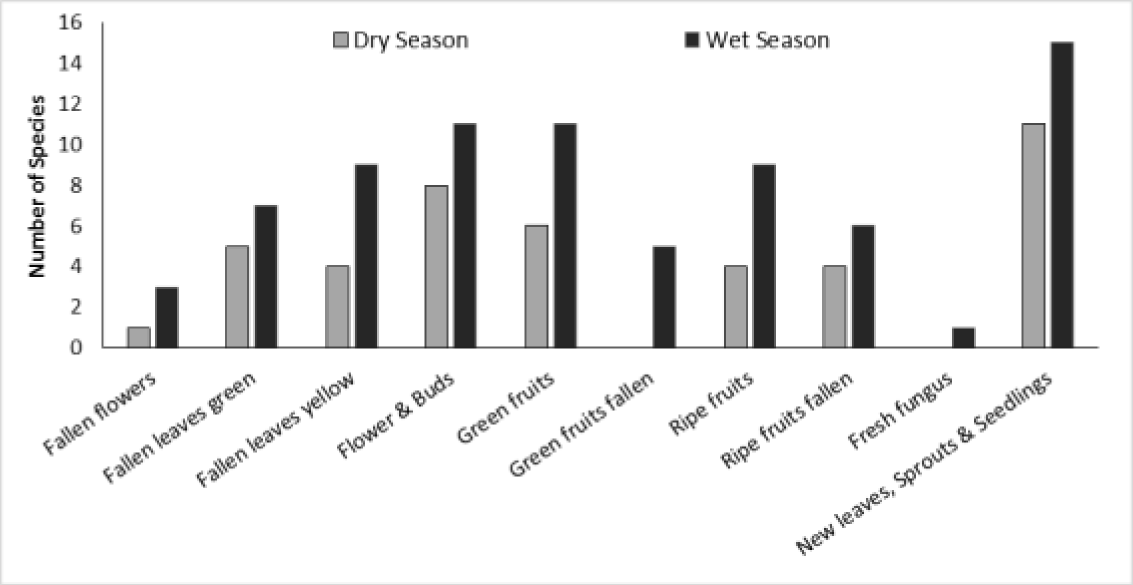


Figure 7-24: Number of species for each phenophase grouped by season.

Table 7-11: Phenological aspects of the 19 food species identified for Aders' duiker on Mnemba island. ("**-**" *No phenophase; "**/**" item not consumed; "**x**" not observed)*

	LEAVES			FRUITS				FLOWERS		
Species/Plant part	New leaves, Sprouts & Seedlings	Fallen leaves green	Fallen leaves yellow	Green fruits	Green fruits fallen	Ripe fruits	Ripe fruits fallen	Flower & Buds	Fallen flowers	Fresh Fungus
Auricularia auricula-judae	-	-	-	-	-	-	-	-	-	W
Bouganivillea glabra	W	x	x	-	-	-	-	/	/	-
Capparis viminea	W/D	x	x	x	x	D	x	W	x	-
Cassytha filifomis	-	-	-	x	x	W	x	W/D		-
Cordia subcordata	W	W	W	W	x	W	x	W	W	-
Ehretia amoena	D	x	x	W	x	W/D	x	D	x	-
Eugenia capensis	W/D	x	x	W	W	W	W	W	x	-
Ficus lutea	x	W/D	W/D	x	x	x	x	x	x	-
Ficus polita	W	x	W	W	W	x	W/D	x	x	-
Ficus scassellatii	W	W/D	W	D	W	x	W	x	x	-
Grewia glandulosa	W/D	W/D	W/D	W/D	x	W	D	W/D	x	-
Guettarda speciosa	W/D	x	W	W	x	x	x	W	x	-
Mimusops obtusifolia	W/D	W/D	W	W/D	W	W/D	W/D	W/D	x	-
Pandanus kirkii	W/D	x	x	/	/	/	/	x	x	-
Pisonia grandis	W/D	W/D	W/D	-	-	-	-	W/D	W/D	-
Polysphaeria multiflora	W/D	x	x	W/D	x	W	W	D	x	-
Sideroxylon inerme	W/D	W	x	W/D	W	W/D	W/D	W/D	x	-
Suregada zanzibariensis	W/D	x	x	W/D	x	x	x	W/D	x	-
Terminalia catappa	W/D	x	W	W	x	x	W	W	W	-
Toddalia asiatica	x	x	x	x	x	x	x	x	x	-

Table 7-11 should ideally become part of an ongoing program to monitor important climate impacts on the island’s vegetation.

7.4 Discussion

All results are discussed here for completeness of the species' behaviour on Mnemba island as a case study, especially considering that the entire population contributed to the sample observations. Where differences in results resembled a trend, but did not measure significant, these trends *were not* omitted as unmeaningful. If a difference in frequencies of certain behavouirs tested insignificant between genders or seasons but raised questions about potential links with other categories, these links are discussed in terms of potential hypotheses for further research. For example, the rate of daily foraging activites was tested, but quality and quantity of food patches were not, so a question is raised below about the potential link between characteristics of food patches and other behaviours. With no literature focussing on this species' activity budget, it was important to discuss all the potential trends and point out the gaps for future studies.

7.4.1 Aders' duiker behaviour, interaction, and activity budget on Mnemba Island.

Overall, sedentary and movement activity were almost equally divided during the day, which was expected from reports in the literature (Newing, 1994). Foraging time took up 39.4% of the Aders' duiker activity budget. This proportion indirectly reflects the overall quality and availability of food, and the amount of time it takes the duikers to acquire the necessary nutrients they need to meet their metabolic requirements (Barrett, 2005; Jaman and Huffman, 2008). As selective feeders, duikers seek out food items that are nutrient rich and less fibrous, affording them more time for other activities like resting between foraging bouts (Hart, 2001; Shipley, 2005). The foraging/resting synergy thus implicates food availability directly. Foraging contributed 80% to all movement behaviour while another 11% of movement was made up of various modes of travelling, such as running, walking, chasing, and following other duikers. Findings from the Mnemba investigation suggest that the Aders' duiker population on the island can support their daily nutritional needs from the current food species available to them within five hours. Larger animals need more time to forage and can often spend more than twelve hours a day looking for food (Ramesh et al., 2015). The findings from the current study does not consider the current condition of the individuals and whether the diet is nutritionally adequate, nor can it conclude that all foraging activity takes place only in the day.

Subsequently, 51% of the daily time budget was allocated to sedentary behaviour, which included ruminating, resting, self-grooming and social behaviour. Antelope species with smaller bodies have been noted to rest more than larger species due to the amount of nutrients that can be accumulated in a shorter time to feed the smaller body (Hofmann, 1973; Jarman, 1974). Various findings of activity studies on Blue, Red, Maxwell’s, Zebra, Ogilby’s and Common duikers in wild and captive environments indicate that resting takes place between 20 and 70% of the day (Hofmann, 1973; Dubost, 1980; Newing, 1994, 2001; Skinner and Smithers, 1990). This wide range confirms that biological and environmental factors like body size and habitat conditions influence the outcome of activity patterns (Jarman, 1974; Newing, 2001; Ramesh, 2015). Based on body size, Aders’ duiker’s 51% of time spent resting corresponds mostly with findings from the Natal red duiker (average resting of 47%), and loosely with Maxwell’s duiker (36%), while Newing’s (2001) results for Zebra duikers (29%) differed by 22% (Hofmann, 1973; Dubost, 1980; Bowland and Perrin, 1995; Newing, 2001).

Methods and conditions under which activity budgets are compiled are not always comparable between studies and care needs to be taken when interpreting or comparing results. The current study considered only activities that took place during daylight hours. Results are thus not directly compared with 24-hour studies of similar sized duikers. Another consideration to note when interpreting the Mnemba population’s foraging patterns is the absence of predators. Conditions on Mnemba do not require major predator evasion that would otherwise influence foraging strategies and energy use (Jarman, 1974). Personal observation confirmed that although vigilance was practiced by the duikers when human activities took place along foot paths, duikers showed a fair level of habituation. Considering the evidence presented by other duiker and small forest antelope studies, it is believed that the 39.4% of time spent foraging by Aders’ duiker (with an average weight between 7 and 12 kg) on Mnemba Island is plausible based on the island’s protected forest environment (Ansell, 1950; Dubost, 1980; Newing, 1994; Jarman, 1974; Skinner and Smithers, 1990).

When Mnemba’s duikers were not foraging, ruminating or resting, they were engaging each other (6.7%), being vigilant (5.6%), marking and patrolling territories (2.8%) or travelling (2.4%) between areas. Aders’ duiker, like many other duiker species, are solitary or live in pairs (Hart, 2001), and monogamy has been proposed as the most likely form of pair-bonding for the species (Finnie, 2001). On Mnemba Island, foraging activities were mostly observed for solitary animals or pairs (66%), supporting previous observations in literature for Aders’ and other duiker species. Group foraging and activities were also anticipated and confirmed by the 34% of focal observations for groups of three or more animals. During the current study, a few observations included large groups of up to nine individuals coming together from different directions to engage each other. In the events where these groups congregated, the assembly of the group took place rapidly, shortly before dusk. Individuals travelled towards the area where the group started forming, and at the sight of the group, individuals sped up and trotted towards the herd. On arrival, mutual grooming and sniffing took place between various members of the group. Grunting sounds could be heard as these interactions took place. After social interaction, some of the individuals foraged in the area while others settled under trees at various distances from each other. To date, no other reports have been made where such large groups of Aders' duikers were seen herding together. Hart (2013b) reports that the Natal Red duiker, although normally solitary, can also be found in pairs and groups of up to five animals, but Bowland and Perrin (1995) suggests that Natal red duiker only bond with mates and young offspring. It is considered that the small and enclosed conditions under which the Mnemba population lives, potentially contributes to unique social expressions. Group formation, sexual segregation and foraging patterns for antelopes the size of Aders duiker are interdependent of body size, energy requirements, food availability, territoriality and breeding seasons (Jarman, 1974; Neuhaus and Ruckstull, 2004). It was found that solitary foraging on Mnemba was significantly higher in the dry season, while pairs and bigger groups were more likely to forage together in the wet season. With breeding taking place throughout the year, it is more likely that food availability explains the propensity for increased social foraging in the wet season. Non-foraging congregation of large groups was noted in both dry and wet seasons.

Newing (1994) summarised the social structure for 16 duiker species, indicating that there are gaps in information for many duiker species. Wyen's duiker for example has been reported to have group sizes of between three and five animals (Karesh et al., 2005). At least three male-female pair bonds were observed on Mnemba; however, polygamy could not be ruled out, as males and females from some of the pairs (not all of the pairs) were not observed together all the time. One female duiker (female 'B') was often observed foraging with a small group (group 'A') consisting of a male (male 'A') and bigger female (female 'A') in a pair bond (pair A), and two to three other males. The other males would from time to time "test" female 'A' for oestrus and approach her for grooming when male 'A' was not around. The smaller female 'B' and other males in the group were assumed to be the offspring of the bigger female 'A', since she groomed all of them on numerous occasions. Four months after observation commenced, female 'B' was pregnant, but was not seen to be in a specific pair bond with a male.

During group observations of Aders' duikers on Mnemba, grooming was exchanged between all genders and ages. For example, allogrooming was observed between many different individuals in group 'A' and group 'B' (possibly a sub-group of group 'A'), and it was evident that a social bond existed between individuals of certain sub-groups of the population. Of all social or engaging behaviour, 41% was dedicated to allogrooming. The importance of allogrooming in social cohesion has been described for many different animals (Hart, 2001). As with self-grooming, the role that mutual grooming plays in parasite control for antelope species, especially those spending extended periods of time on the forest floor, is well-known and serves as an important maintenance of individual condition (Hart, 2001). It is possible that grooming another would also benefit the 'giver' when parasite infestation is kept under control within the group. A very good description of the way duikers engage in allogrooming was published by Geist and Walther (1974). These grooming styles were confirmed for the Aders' duiker on Mnemba Island.

In group 'A', territoriality did not appear to be playing an important role until female 'B' was pregnant. Female 'A' was observed, chasing and ramming her horns into female 'B''s stomach on two occasions, while female 'B' was visibly pregnant. Territorial marking and fighting were observed for a total of 2.8% of all focal observations' duration. Duikers spent an additional 1.4% of their time chasing one another. Chasing was recorded when one duiker (pursuer) initiated a running bout towards another (recipient), and the recipient responded by running away from the pursuer. Possible reasons for chasing are territorial or sexual pursuit, and a few times it was clear that the pursuer wanted to have sole access to a foraging patch, because the chase was recognised by shorter bouts and immediate consumption of food items after displacing the recipient. At least two other male-female pairs (pairs 'B' and 'C') displayed territorial behaviour during foraging and were not seen foraging in groups or interacting with any other duikers on the island.

A combination of pair patrolled territories and group territories were observed on Mnemba Island, with both males and females protecting the boundaries of their territories to varying degrees. Male Aders' duiker activity budgets on Mnemba included 4.9% territorial activity, while female activity budgets included 1.2% of territorial related behaviour. Forage patch rivalry was observed between duikers on the island, matching a type of competition described by de Boer and Prins (1990) as 'scramble competition'. No such competition was observed between the Suni and Aders' duiker.

It was expected that aggressive territorial behaviour between Aders' duiker and Suni antelope would be prevalent under overpopulated conditions on the island, as the two species potentially competed for the same food in a small area (Fiske, 2011; Rivers, 2012; Amin et al., 2015). Contrary to this prediction, the only aggressive behaviours observed were conspecific aggression. Suni males were observed fighting among themselves from the onset of the study until a large portion of the population was removed five months into the current study. Aggressive behaviour by Suni antelope was also directed towards guests and staff members, which led to the decision to remove most of the individuals from the island. Fiske (2011) and Rivers (2012) also reported very little interaction between Suni's and Aders' but found that Suni responded to duiker vigilance behaviours - startled and staring at staff passing by or snorting and running off. Hart (2001) explains that smaller antelope, such as Suni's, remain still during threats. It is possible that Suni antelope depend on the vigilance of the taller Aders' duiker to detect danger, viewing this as a trade-off for sharing resources, although Jarman (1974) states that little evidence exists for this theory.

Territorial aggression, over and above rutting between males (head butting), was observed on multiple occasions between different individuals on Mnemba, such as the 'attack' of female A on female B when she was pregnant. It was later noted that female A was also pregnant at the time. In another suspected conspecific act of aggression, a young Aders' duiker (female C, about two months old) died from injuries sustained to her stomach. A few weeks before the incident, it was observed that an adult male (male B) duiker lowered his head and swiftly approached a young duiker (female D, also about 2 months old) causing her to quickly press her stomach firmly to the ground with her hind quarters still slightly raised. Male B did not immediately retreat while female D remained flat on the ground. After approximately five minutes of male B standing in front of female D, male B walked off and the female resumed foraging. Geist and Walther (1974) reported this belly flopping response as submissive behaviour in Dik-dik fawns that are old enough to find their own territory but choose to stay in their area of birth. When female C (similar age as female D) was found dying, with subcutaneous bleeding under the belly, it was almost certain that the fatal injury was caused by the horns of an aggressive adult duiker. Female C's mother was lying two meters away when the dying duiker was found. The time of death (January) coincided with a period when Aders' duiker were seen chasing each other around. It is not yet certain why adult duikers would see young ones as a threat, but overpopulation of the small island is suspected to exacerbate conspecific aggressive behaviour. Kranz and Lumpkin (1982) reported male Yellow-backed duikers in captivity becoming intolerant of duiker calves at times that could lead to injuries if the young ones remain in the same enclosure. Territoriality and aggression have been shown to manifest increasingly with an increase in population density for blue duikers (Kranz and Lumpkin, 1982; Bowland and Perrin, 1995). Some of the female duikers on Mnemba had head-butting marks on their foreheads, suggesting that females also engaged in aggressive territorial behaviour.

No copulation was observed during any focal or unstructured observations, but could easily have been missed, since Hart (2001) describes duiker copulation as a very quick process. Sexual behaviour observed during focal sessions consisted entirely of one-sided actions from male Aders' duikers towards females, and included sniffing, licking and nudging females from behind. Males were also observed showing flehmen with their necks stretched out, their noses slightly raised in the air, and the corners of their mouths curling up after tasting and smelling females or female urine. This behaviour is well-known among duikers and other species (Hart, 2001). Of all social behaviours observed, sexual courting occurred 12.6% of the time. It can be assumed that some of the chasing that was observed, which made up 21.4% of social behaviours, was linked to sexual behaviour during mating. Of all chasing events recorded during focal observations, 89% was observed in the wet season, specifically in April and November. Chasing in the dry season took place in January and August. For the Maxwell's duiker, chasing was reported to decrease between April and July (Newing, 1994), and males were sometimes seen chasing females shortly before attempting copulation. Newing (1994) described some of the Maxwell's duiker chasing as high-speed events – this was also observed for the Aders' duiker. It was not uncommon for Aders' duiker to chase each other for extended periods of time across the island's interior forest. No focal observations were made at night, but during times of high-speed chases, thrashing could be heard at night, sometimes continuing for over an hour. The amount of noise suggested that it was the larger Aders' duiker chasing one another, as opposed to the Suni antelope which were also often engaged in aggressive pursuits. Bowman and Plowman (2002) described similar nocturnal chasing activity for Blue duikers, especially when females were in oestrus. The Aders' duiker males demonstrated extreme aggressive chases and collisions, as do Maxwell's duiker males (Newing, 1994). Consistent with current observations, local hunters have reported such aggressive interactions for Aders' duiker on Unguja (Lanshammar, 2007). Territorial chasing was observed for both genders and in different scenarios on Mnemba, during foraging, resting, and while marking territories.

As described, protection of foraging patches was observed, but males were also seen protecting their females. During one focal observation, pair A was foraging together and as they approached the researcher with the male walking ahead, he noticed the researcher and immediately turned towards the female and pushed his face against hers. When she tried to continue on the path, the male pushed her gently in the side and steered her into a different direction away from where the observation was taking place. The female from pair A was well habituated, provided that the researcher remained on the footpaths. She did not show much caution during observations. The male was visibly more alert and attempted to protect her from potential harm by actively changing their course.

‘Following’ behaviour was recorded in 12.8% of all social behaviours for the Aders’ duiker on Mnemba. ‘Following’ was described as one Aders’ duiker walking behind another in the same path or direction as the leading duiker, and at the same pace as the leader. This behaviour was observed between foraging sessions and when pairs and groups were travelling, often resulting in a pair or small group arriving at a resting place and/or ended in allogrooming. Newing (1994) found that Maxwell’s duiker females led groups and pairs in more cases than did males. This phenomenon was also reported for the Blue duiker (Dubost, 1980), and similarly for Aders’ duikers on Mnemba, where females led more than 80% of observed pairs walking together, and more than 65% when travelling as trios. Newing (1994) pointed out that this practice is common for antelope species with monogamous pair bonding. Social behaviour not classified into any of the other social categories made up 6.7% of observations, and nursing behaviour made up another 4.9%. Nursing was not observed often, but mother duikers refused their young suckling opportunities on the few nursing occasions that were observed, only allowing the young to suckle when the pair had walked much further away from the footpath and the researcher. Suckling was then observed from up to 40m away using binoculars. Newing (1994) reported that suckling was never observed during focal observations of Maxwell’s duiker, due to the secretive nature of the young ones hiding for a few weeks and staying close to the lair for approximately two to three months. This hiding routine was also observed on Mnemba, but due to the small size of the forest, secretive behaviours were easier to observe from a distance using binoculars. Young duikers were seen foraging alone around the lair, and after approximately two months foraged further away, but were often still alone while vigilantly scanning the environment and staying away from the foot paths.

Frequency and patterns of vigilance and scanning have been linked to predator detection, discovering food items, social cohesion, and overall influencing foraging styles (Underwood, 1982). Time spent on vigilant standing and vigilant walking actions recorded during focal observations of Aders' duiker, consisted of 5.6% of the total activity budget, in addition to 3.6% for vigilant foraging, 1.9% vigilant ruminating, 0.8% vigilant resting and 0.2% vigilant running. These different expressions of vigilance made up 12% of the daily activity budget for the Aders' duiker on Mnemba Island. One observation was also made of a male duiker urinating, while frequently scanning the environment. The main behavioural state 'Vigilant' included sub-states such as standing or walking. During vigilant-standing, duikers would stand and stare in the direction of a potential source of danger, sniffing the air, incessantly licking their noses and moving their ears in different directions - often with a stretched-out neck and nose slightly tilted up. The duikers sometimes assumed an overextended posture with hind legs stretched backwards while staring intently. Vocal expressions during vigilant standing included snorting and barking. On a few occasions during fieldwork, duikers would approach the researcher to investigate while snorting and bobbing their heads up and down and from side to side, in a jerky figure eight type movement. It is possible that the duikers used the head movements to get a better look at the researcher or to estimate the distance to the researcher, but no literature was found about this curious behaviour in duikers to confirm the theory. Once the duikers heard the researcher's voice or identified that no threat existed, they would resume foraging or walking activities.

Vigilant walking was classified as walking with an arched back and taking short irregular steps, often with pauses between steps and keeping one leg in the air during a pause while the duiker scanned the environment. Kranz and Lumpkin (1982) also reported that the Yellow-back duiker would pause with its one leg in the air when startled. Vigilant-walking was regularly done in a zig-zag path, and sometimes followed by quick running bursts in an opposite direction. Bursts would end abruptly with a quick change of direction and the duiker disappearing into the forest. These dummy-runs were observed a few times after vigilant standing or vigilant walking behaviour. All running that took place as a result of being startled, or as a clear evasive tactic were classified 'running-vigilant'. Thumping or 'alarm stamping' of the feet, as Hart (2013) described it for the Natal Red duiker, was also observed for the Aders' duiker. Thumps often coincided with loud alarm calls which resembled a bark or as Hart (2013) wrote, a "hoarse alarm whistle". Duikers are known for their skittish nature, and although the Aders' duiker on Mnemba Island is accustomed to human activity, the species displayed all the expected freezing, diving and evading behaviour described for duikers in the literature (Estes, 1991; Newing, 1994; Hart, 2013a, 2013b). Jarman’s (1974) portrayal of class A antelope (discussed in section 7.1) suggests that avoidance behaviour is the first form of defense when facing predators. This too is evident in the evasion behaviours observed for the Aders’ duiker on Mnemba. Initial defensive behavior was observed as a freeze pose, followed by a vigilant dummy run and frequent changing of direction. At times females appeared to be luring the researcher away from their young.

Vigilant-foraging comprised 9% of the time for all foraging observations. This type of foraging was distinct from non-vigilant foraging in that constant scanning (Underwood, 1982) was accompanied by foraging. Sniffing for food on the ground was alternated with a swift lifting of the head and looking around before taking another step or two and foraging again. Vigilant scanning patterns during foraging and underlying conditions of such behaviour have been studied in gregarious antelope species such as the impala (Dunham, 1982) and Blesbok (Dalerum et al., 2008). Researchers suggested that predator evasion is not the only basis for foraging group dynamics and vigilant foraging. Social foraging and group dynamics are often complex - further research is needed to describe the Aders’ duiker gregarious foraging strategies.

Territorial patrolling and scent marking constituted 2.8% of all focal observations, but behaviour categories such as territorial and vigilant foraging (5.4%), chasing (1.4%), and fast walking (0.5%) are also potentially linked to territorial behaviour. Territorial patrolling and scent marking were recognised when duikers are observed smelling branches, twigs and middens, as well as marking items with olfactory glands. Marking of twigs and branches were frequently done at a height above the individual’s natural eye level, but tree trunks and lower branches were also rubbed with horns and olfactory glands. The male from pair B was seen marking the base of a tree for over two minutes, rubbing his glands and horns vigorously against the bark. At times, fast pace patrolling by territorial males was observed, during this activity no foraging was observed, and the males would mostly be alone. These patrolling events would lead to males encountering and chasing one another, often to the point of physical impact. At other times, foraging would take place before or after scent marking and a female from the pair would be in close proximity to the male. Territorial foraging behaviour appeared to be taking place at a slower pace than non-foraging patrolling. Newing (1994) and Hart (2013) found that scent marking locations were only situated on range boundaries. Aders’ duiker males on Mnemba were seen following the same path during patrolling activities and re-marking the same trees. Scent locations were marked by more than one male during observations, confirming similar reports from Unguja (Lanshammar, 2007). Territorial marking for males and females alike is common for many of the duiker species (Newing, 1994), but like with Maxell's duiker, the Aders' duiker female was not seen rubbing horns on the vegetation during scent marking. Communal middens were scattered across the natural forest for both duiker and Suni antelope. A combination of the small size of the island, the lack of information at the onset of the study about territoriality for the Aders' duiker, as well as the high number of Suni and duiker resident on the island, made a dung pile survey impractical at the time.

Focal observations provided the necessary information to assess the overall behavioural activities of the species. Between activities, the Aders' duiker spent 2.4% of their time travelling across the forest. Walking was categorised as medium paced walking (1.4%), fast paced walking (0.5%), and trotting (0.1%), with no foraging, following or other activities taking place. Running that was not overtly linked to any specific behaviour (thus excluding running-vigilant of 0.3%), made up 0.1% of the daytime activity budget. The inability of the Mnemba duikers to migrate potentially affects the amount of travelling that takes place. The current study did not quantify behaviour categories after dark and before 06:00, however data retrieved from the GPS tags of two duikers on the island provided additional insight into 24-hour activity patterns (see Chapter 8).

Duikers were seen taking shelter (0.36%) during light and hard rain and were particularly vigilant during hard rain showers. At the onset of a rain shower, duikers would trot to the nearest tree or shrub for cover. Once standing or lying down under cover, duikers continually scanned the environment and moved their ears around in all directions. Kranz and Lumpkin (1982) suggest that sound plays a lesser role in communication for duiker species, compared to scent marking and visual signs and motions. They also report that the smaller Blue duiker depends more on visual communication than does the Common duiker and the nocturnal Bay duiker. Contrary to what Kranz and Lumpkin (1982) found as limited interaction between family groups, there were noticeable amounts of interaction for certain members of the Aders' duiker population on Mnemba.

Overall, the Aders' duiker focused on foraging, ruminating and resting for more than three quarters of the day. Seasonal variations in these behaviours were investigated by pooling all the wet and dry season data from this study.

7.4.2 Seasonal differences in the activity budget for Aders' duiker on Mnemba Island.

Since many abundance studies for different duiker species and behaviour surveys for related ruminants have shown no difference between seasons, it was expected that the overall seasonal activity pattern for the Aders' duiker would not differ significantly either (Norberg, 1977; Komers et al., 1992; du Toit and Yetman, 2005; Wiafe and Amfo-Out, 2012; Muposhi et al., 2013). By assigning the category 'movement' or 'sedentary' to each behaviour sub-state in the ethogram, it was established that sedentary behaviour (inactivity) and movement behaviour (activity) differed by 2% in the wet season, due to more resting and grooming, and less foraging and territorial activity in the rainy months.

The decrease in movement activity in the wet season, even though small, tested significant. A plausible explanation is found in Bowland and Perrin (1995), where they illustrate how the availability of high nutrient value food items during rainy months, in combination with the species' energy requirements, afford duikers more time for resting and other activities compared to in dryer months. Congruently, Aders' duiker spent significantly more time lying down in the wet season, while foraging increased by 4% in the dry season (although not concluded as significant; see Table 7-2 for seasonal results on main behaviour categories). Muposhi et al. (2013) also found an increase in foraging during dry months for the gregarious Impala, but as with the current study, seasonal foraging differences did not test significant. In addition to an increase in foraging in the dry months, the Aders' duiker showed intensified territorial activity, presumably linked to a decrease in food availability and quantity, leading to augmented competition for food patches (Jarman, 1974; Hart, 2001). During the dry months, vegetation became sparse and there was a visible reduction in foliage within reach of the duikers, other than fallen items on the forest floor. Due to the effects of overpopulation on the natural vegetation on Mnemba Island, conditions were not ideal to conduct seasonal studies on food species. Yet, results from the current study can be used to formulate questions and methodologies for further studies on seasonal food availability.

Although increased foraging and ruminating in the dry season did not test significant, studies on wild impala found that an increase in 'ruminating' can result from the effect that poorer food quality has on the ruminant's digestive system, especially when a bigger variety of poor-quality items contribute to the dry season diet (Jarman and Jarman, 1973; Blanchard and Fritz, 2008). It has also been suggested that with poorer food quality during the dry season, increased 'travelling' and 'foraging' is necessary for adequate nutrition intake (Dunham, 1982; Di Blanco and Hirsch, 2006). Overall activity budget proportions for travelling in the dry season appeared small but tested significant. When isolating travelling behaviour for the Aders' duiker, results indicated an 18% increase for travelling in the dry season. In combination with higher foraging rates and reduced vegetation quality, an increase in travelling is most likely related to food patches being further apart in the dry months (Di Blanco and Hirsch, 2006).

The proportion of time spent on vigilant behaviour was noticeably pronounced for Mnemba's duikers during the wet season (almost double the proportion of time spent on vigilance in the dry season). Correlations were not directly tested between vigilance and social behaviours, but it is interesting to note that during the wet season, chasing and sexual courting was much higher than in the dry season (although not tested as significant). It is likely that vigilance was correlated with the rutting and poor quality and quantity of food patches. Underwood's (1982) detailed investigation into vigilance provided evidence that during sexually active times of the year, female Impala and Tsessebe are particularly disturbed by male behaviour, which manifests as an increase in time spent on vigilance and decreased foraging time. It is believed that if focal sampling was designed to test the correlation between vigilance and sexual activity for the Aders' duiker on Mnemba, larger data samples would yield significant correlations. Additional correlations between vigilance and forest density (in other words decreased visibility) in the wet season are also worth exploring in future studies (Underwood, 1982; Newing, 1994).

Seasonal influences on self-grooming revealed that small but significant increases in grooming during the wet season exist. An explication could be linked to moisture saving practices - grooming related evaporation of moisture from the tongue could be less pronounced when coats are already wet from the rain (Hart, 2001). One of the smaller behavioural categories in the ethogram was "taking shelter" from the elements. This action was recognised when a duiker would trot or walk at a fast pace towards a shrub or tree during the heat of the day or during a rain shower, and abruptly stop under the tree or shrub for cover. This behaviour was calculated as less than 0.4% of the entire activity budget and was recorded twice as much in the wet season than in the dry season, visibly owing to duikers looking for cover when monsoon rain showers started falling. Environmental influences on the subtleties of the duikers' behaviour could provide new insights into the species' ecology on the island. Another example drawn from the activity budget is the higher proportion of 'standing' behaviour in the dry season, suggesting that this could be related to the increase in foraging in the dry season, indicating a possible time minimizing strategy

(Ruckstuhl,1998). Accordingly, during the wet season when food quality and quantity is higher, more energy is available to lie down between foraging bouts (Ruckstuhl, 1998).

Drinking was observed six times during all focal observations, and thus not enough data were collected for seasonal testing, but it is noted that five of the drinking observations took place directly after rain showers. Of the five cases, four were in the dry season when unexpected showers left water on dry leaves. Aders' duiker were also seen consecutively eating completely dried out leaves in the dry season, soaked in moisture from rain that had fallen. Two of the drinking observations took place in the rainy season when the duikers were seen stretching their necks to reach water inside tree hollows and lapping up moisture from large leaves on the ground. Opportunistic observations were also made of duikers sniffing around water pipes outside guest rooms. Staff members reported that in the dry seasons, duikers and Sunis would drink from the foot baths left outside staff rooms. It was anticipated that no drinking would be observed (Bowland and Perrin, 1995; Hart, 2001), but it is evident from the observations that the Aders' duikers do take advantage of water sources when such are available.

Seasonal differences in social behaviour as a main state were not significant, yet results indicated increased social interaction in the wet season. Of the seven distinct social interaction sub-behaviour categories (results in section 7.3.2), it was found that in the wet season there was increased allogrooming, chasing and sexual interaction compared to the dry season. As already explained for the increase in self-grooming, this result (although not significant) might be linked to moisture saving behaviour due to the presence of extra moisture on pelts during the rainy season (Hart, 2001). A higher proportion of chasing behavior was recorded for the wet season activity budget (29% of all social behaviours) as opposed to 7% in the dry season. Chasing and sexual courting (double in the wet season compared to the dry season, yet not significant) are suspected to be interlinked, and associated with season. Reports for Aders' duiker suggest a year-round breeding pattern, with either one or two peaks during the year (East, 1988; Huffman, 2016a; Lanshammer, 2007). Results from Mnemba Island support findings that breeding takes place throughout the year but indicate that there might be a preference for the wet season, likely due to increased resource availability and quality. Seasonal birth patterns have been found for the Black duiker, where a peak in the number of births was noticed in wet months (Wilson, 2001). Depending on gestation periods (which is not yet available for the Aders' duiker), birthing peaks could be anticipated at around four to seven months after breeding peaks. Bimodal birth peaks have been established for the Blue and Common duiker (Bowman and Plowman 2002). During focal observations, nursing was only observed in the dry season, but opportunistic notes revealed that nursing also took place in some of the wet months. Mnemba Island experienced a very dry year during the focal study, as also reported by local staff. The effect that the drought had on resources would potentially have played a role in the number of births and the timing of parturitions (Gaillard et al., 1993). As was described in Chapter 6, annual variation in seasonality and rainfall (especially from climate change in the region) lead to variation in birth peaks across seasons (Ogutu et.al., 2014). This phenomenon could explain why birthing patterns during the time of the study (which was affected by the previous season's rainfall) and the rutting behavior during the current study (with dryer season all together) did not share the same seasonal patterns.

The only seasonal difference that tested significant for a social sub-behaviour category was 'following' behaviour, as described in section 0. In the dry season, duikers followed one another around over three times more than in the wet season. This was not inline with the overall findings that more social interaction coincided with the wet season. A possible explanation for an increase in 'following', could be related to resource scarcity. More research is needed to understand the dynamics between social behaviour, season, and resource distribution. From observations of 'scrambling competition' discussed in the preceding section (0), it is speculated that during dry months when food patches are few and far between, duikers would spend more time competing for these food sources. Jarman (1974) describes the degree of precision involved in finding food items for selective feeders, especially when items are not available for a long time. By following one another, individuals ensure a higher rate of detecting when others find resources, which prevents them from 'losing out' on a potential meal. The poor condition of the vegetation on Mnemba undoubtedly contributed to the urgency with which the duikers foraged in the dry season. Duikers are adept at memorising food locations (Hart, 2001). The "race" to food patches produces an increase in intraspecific competition during times of poor resource quality and low abundance. Selective feeders are also more subjected to seasonal availability than generalists (Jarman, 1974). Jarman's (1974) theory suggests that selective feeders are separated by each individual's pursuit for finding specialised items. This was confirmed for the Aders' duiker, by the large proportion of solitary foraging observations, but it is suggested that the level of competition in the dry season altered this dynamic, possibly leading to individuals increasing the intensity of competition for food patches. Seasonal foraging patterns are further discussed in section 7.4.5.

7.4.3 Male and female Aders' duiker differences in activity budget proportions.

The current study was designed to explore fundamental behavioural components for the first time for this species. The results obtained from focal observations proved that when compiling activity budget data, male and female differences are important for inferring activity patterns to the species. For example, no differences were found between the amounts of time spent on a sedentary or movement states across pooled focal data, but when testing the results for males and females, significant differences were distinguished along with seasonal variation. The results suggested that monomorphism did not lead to the same proportion of overall activity / inactivity for males and females. Female Aders' duikers were noticeably more sedentary than males, especially in the dry season. Free range female Maxwell's duiker also yielded similar seasonal patterns, but the contrary was reported for Water chevrotain, Peters', and Bay duikers (Newing, 1994). Dubost (1984) ascribed increased activity for females to a larger body size and associated increased energy needs during gestation and lactation. Too little information was available to correlate reproductive events with resultant activity patterns from the female Aders' duiker, but the current findings indicate that females foraged more during the wet season, most likely due to lactation and preparation for the next gestation. Increased 'resting' in the wet season was specifically noticeable for male Aders' duiker, while females spent comparable proportions of time resting throughout the year. Muposhi et al. (2013) reported similar resting patterns for the dimorphic Impala male.

It was expected that foraging activity would not differ between male and female Aders' duiker based on the documented absence of dimorphism for this species (Gross et al., 1996, Ginnett and Demment, 1997; Bergman et al., 2001; Neuhaus and Ruckstuhl, 2004). However, gender specific energy needs for the species have never been established and could not be ruled out as a potential factor in foraging differences. If females require additional nutrients during lactation or pregnancy, it would be revealed in the extent of foraging in their overall activity budget, and in sexual segregation during foraging (Ruckstuhl and Festa-Bianchet, 2001). Furthermore, during rutting seasons increased vigilance, territorial activity and mating behaviour could lead to reduced foraging activities by males (Wronski, 2002; Apio and Wronski, 2005).

Contrary to expectations, Aders' duiker males spent 51% of their annual activity budget on foraging, as opposed to females' who spent only 35% - this was not a significant difference. As with overall activity, when foraging efforts for males and females were tested across seasons, differences were significant. Taylor et al. (2006), on Chanler's mountain reedbuck, reported no difference between male and female daytime foraging, and suggested that sexual dimorphism was not pronounced enough to influence activity patterns. Similarly, Apio and Wronski, (2005) investigated a selective feeder, the Bushbuck, in a bimodal rainfall area similar to Mnemba Island, and found that although males forage slightly more than females, there is no significant difference between genders. Apio and Wronski, (2005) ascribed their findings to the fact that Bushbuck breed year-round and have similar energy requirements across seasons. Both studies presented gender and seasonal differences separately across the entire study period. In the current study, once data for males and females were grouped by season, significant finer scale energy requirement differences became apparent. Interestingly, male and female Aders' duikers presented opposite seasonal foraging patterns, suggesting that they have different seasonal energy requirements and foraging strategies. Opposing foraging patterns for males and females agree with the indirect scramble-competition hypothesis, which explains the alternating gender specific foraging peaks for Aders' on Mnemba (Clutton-Brock et al., 1987; Ruckstuhl, 2007). This form of competition excludes foraging competition by one sex on another through segregated foraging times, as opposed to spatial segregation.

Sub-states in the duikers' activity budget revealed that female's higher activity levels in the wet season resulted from social and slow foraging behaviour, while a considerable increase in ruminating contributed to decreased activity during the dry months (Figure 7-7b). Male duikers displayed the opposite pattern, in that they were more active in the dry season compared to the rainy months. The increased activity for males in the dry season was mostly due to slow foraging, territorial foraging, territorial patrolling, scent marking and small amounts of fast foraging. Reduced activity in the wet season was caused by males lying down significantly more than during the dry season. Males and females displayed smaller differences between movement and inactivity ratios in the wet season. These behavioural differences suggest that the duikers on Mnemba employed habitat segregation strategies for 1) the forage-selection hypothesis, and 2) the indirect scramble-competition hypothesis. The first hypothesis is supported by results showing that females foraged more during high food-quality months as opposed to males. The latter hypothesis is supported by the distinct reversed seasonal foraging patterns observed. The data in this study supports these hypotheses as it indicates potential exclusionary mechanisms for foraging patches (Prins et al., 2006; Ruckstuhl, 2007).

As mentioned previously, Dubost (1984) theorised that females would forage more than males to satisfy their metabolic requirements during breeding. The Aders' duiker females on Mnemba Island did not conform to this theory but were more sedentary and spent less time foraging than males overall. Within the female's annual activity budget, foraging increased when food was more abundant during the wet season, suggesting that females are energy maximizers according to the foraging optimisation theory. During the wet season, males acted as time minimizers and energy savers when they reduced their foraging effort, a common strategy for ruminant males during the rut (Forchhammer and Boomsma, 1995; Willisch and Ingold, 2007; Shi and Dunbar, 2009). Unlike findings from studies conducted on Goitered Gazelle, the Aders' duiker male spent more time lying down during times of sexual courting (Xia Canjun et al., 2013).

Another means of interpreting foraging differences between males and females is by comparing foraging patterns according to the activity budget hypothesis (Neuhaus and Ruckstuhl, 2004). This hypothesis states that no sexual segregation will occur for a species such as Aders' duiker due to the limited body size differences between sexes and subsequent similarities in energy requirements - this is opposite to what Dubost (1984) proposes. Our results indicate that sexual segregation was partially observed for the duikers on Mnemba Island. Findings that suggest this include 1) foraging was observed to be a solitary activity in 37% of all focal observations for Aders' duiker on the island; 2) seasonal differences in time spent on foraging activities were significant between genders, indicating that males and females have different seasonal energy requirements; and 3) gregarious activities and group foraging was only confirmed for a minimum of 32% of all focal sessions. Group size differences for dry and wet seasons, specifically during foraging activities were significant (Section 7.3.2). Based on partial segregation at different times, it is inferred that monomorphic male and female Aders' duikers have separate energy requirements at different breeding times and phenological cycles. Further research is needed to describe the nature and exact sources of partial sexual segregation.

Remaining behavioural categories from the activity budget also revealed gender differences, of which ruminating and self-grooming variations were significant over the annual cycle. In general, Aders' duiker females spent significantly more time ruminating. The males ruminated more in the wet season, corresponding with an increase in foraging. Females however, doubled the time spent ruminating in the dry season, while simultaneously decreasing foraging effort. This suggested that females either consumed a lower quality diet in the dry season (and were possibly more selective in the wet season), or that when food quality was reduced female digestive efficiency was much lower than that of the males (Ruckstuhl, 2007; Blanchard and Fritz, 2008; Han et al., 2019). Studies on Impalas revealed that ruminating effort increased in the dry season as a direct influence of poorer quality food in their diet. Yet, unlike the seasonal variation in ruminating among the Aders' duiker males and females, the Impalas in Blanchard and Fritz's (2008) study showed no overall gender differences. Pérez-Barbería and Gordon (1998) explains that the condition of food consumed before rumination impacts the nature of rumination patterns. In other words, for ungulates this means that items consumed with a higher fiber content would naturally take longer to chew and re-chew (ruminate) (Blanchard and Fritz, 2008). Further research is needed to establish if Aders' duiker females are less selective in the dry season, or if digestive effectiveness is considerably less than their male conspecifics.

Self-grooming differences for both gender and seasonal grouping tested significant. Figure 7-7 demonstrates how self-grooming proportions of the female's activity budget quadrupled in the wet season. This marked increase in grooming for females in the wet season corresponds with findings from an Impala study by Muposhi et al. (2013). Wetter weather has been described as an optimum condition for duikers' tongue-based grooming to reduce evaporation from the tongue (Section, 7.4.2; Hart, 2001), which the female Aders' duiker took advantage of. The amount of time spent on self-grooming by males was similar for both seasons, showing no seasonal pattern, and similar in proportion to the female's dry season grooming activities. Due to increased vigilance and courting during the wet season for males, it is suspected that they took less advantage of favourable grooming conditions in the rainy season (Dunham and Murray; 1982).

Activity budget results for resting in a lying down position revealed that male duikers spent much less time lying down in the dry season. Seasonal differences discussed in the previous section described that reduced resting in the dry season was possibly linked to the protection of limited food patches. Only male Aders' duiker displayed a decrease in dry season resting. In context of the males' total activity budget, the marked reduction in lying down can be explained as a seasonal trade-off. By male duikers not increasing foraging in the wet season when food is more abundant and of higher quality, and rather foraging more and increasing territorial activities in the dry months, it is suggested that males exercise a trade-off between reproduction and maintenance, as part of an overall energy maximizing strategy (Willisch and Ingold, 2007; Ruckstuhl and Neuhaus (2002)). With lower quality food items and limited food resources in the dry season, males increased their foraging time and potentially increased competition with other males for resources. Territorial patrolling, marking and fighting were thus much more pronounced by males in the dry season. Females spent similar amounts of time lying down during both seasons, similar in proportion to the male's resting in the wet season. Gender differences in seasonal resting behaviour (lying down) is potentially explained by the indirect scramble-competition hypothesis (Ruckstuhl, 2007), owing to the male duiker trading resting time for foraging activities.

Significant differences in seasonal travelling were attributed to contrasting locomotive behaviour patterns for male and female Aders' duiker. Travelling behaviour was classified exclusively as locomotion and serves as a link between other activities (0). Males spent more time travelling than females in general, as was also reported for the Bay duiker, proposedly due to increased territorial and sexual activities by males (Newing, 1994). Aders' duiker males showed a small increase in travelling in the wet season (by less than 1% of their total activity budget), while females reduced their travelling time (by less than 1%) during the same season. An increase in sexual courting by male Aders' duikers in the wet season corresponds with the notion that males travel more during surges in sexual activity.

Along with sexual courting and chasing behaviour that increased in the wet season, it was evident that the male Aders' duikers focused more on breeding during this season. Concurrently, male Aders' duikers doubled their vigilance in the wet season, compared to the dry season. During breeding peaks, male ungulates are known to adjust their activity budgets by decreasing foraging and increasing species specific behaviours associated with the rut. Han et al. (2018) studied the Siberian ibex in this regard and suggested that the energy-saving and foraging-constraint hypotheses were considered plausible explanations for the Ibex's response to an increase in breeding activities. Duiker males, as explained in section 0, engage in violent head butting, chasing and collisions when protecting territories and during the rut. The anticipation of meeting an opponent causes an increase in vigilance, especially for defenders, and results in increased travelling for both the chaser and the defender. A significant seasonal difference was established for wet season vigilance and it was suggested that a variety of factors could be associated with an increase in this behaviour (Underwood, 1982). While male duikers on Mnemba demonstrated a significantly higher rate of vigilance during the rutting season, females only increased vigilance by 1% in their seasonal activity budget. The absence of predators on the island simplifies the interpretation of vigilant behaviour, in that foraging strategies are minimally influenced by predator evasion strategies (Jarman, 1974). Male reproductive activities are the most likely explanation for vigilance in the current study.

In Figure 7-25, the collared male is facing an intruder. Figure 7-26 shows a vigilant intruder leaving the collared male's territory. Figure 7-27 precedes a 10-minute-long chase where the collared male actively protects his home range.

Figure 7-25: The collared male Aders duiker (Nr 1623), on the edge of his territory, and a male from the neighbouring territory become aware of each other.

Figure 7-26: A possible intruder stands vigilant on the edge of collared male 1623’s territory.

Figure 7-27: The collared male nr 1623 stands vigilantly on the edge of his territory, shortly before a 10-minute territorial clash.

Overall visible territorial behaviour only made up 3% of all focal observations. Males showed a tendency to have a higher territorial component in their activity budget, with four times more time spent on territorial activities compared to females. Males doubled their territorial efforts in the dry months by increasing the patrolling of territories and by fighting more with other males, potentially due to an increase in foraging competition. Small increases in male scent marking were found during the wet season, possibly due to the corresponding surge in sexual activities. Certain males occupied territories on the outskirts of the forest, while other males utilised the interior of the island. It was noticed that males on the outer edge of the forest would come into violent contact with other males when wandering into the interior to forage. Three of the males from territories on the outskirts were visibly losing condition during the dry season, and displayed stress when reaching or crossing the boundaries of their territories. Two of the outer males had completely or partially broken horns, while many of the males in the interior had long and sharp horns. Resource distribution was not mapped and quantified, so a lack of access to certain resources by the males on the outskirts of the natural forest, cannot be ruled out as a reason for these males' loss of condition during the dry season. Results suggested that aggressive behaviour for the Aders' duiker males on Mnemba was more prevalent during food scarcities than during the breeding peak. Newing (1994) suggested that aggression between Maxwell's duiker males increased during the rutting season, but the increase in stress during dry and poor vegetation conditions at the time of the current study on Mnemba could have led to exaggerated aggression between males during the dry season.

Territorial foraging was classified when duikers patrolled, scent marked and foraged at the same time, and was especially observed when males foraged on territory boundaries. Territorial foraging made up 7% of all male foraging activities (compared to 1% for females) and was observed more during the dry season. In line with the preceding discussion, results provide fine scale evidence (although sample sizes for smaller behaviour categories were not suitable for significance testing) that males traded-off increased time spent on reproduction in the wet season for more maintenance during the dry season. Poor vegetation quality and overpopulation potentially caused increased conflict between males during the dry season when they competed for limited food patches.

Females maintained the same overall territorial effort throughout the year, but with marking and investigative urinating more prevalent in the wet season, and general territorial patrolling recorded more during the dry season. Females displayed territorial behaviour towards other pregnant females, where in one event a female scooped another pregnant female under the buttocks and in the stomach, jabbing her horns into the other female. The pregnant female squealed and tried to retaliate but when the aggressor kept coming for her, she ran off. These two females were grooming each other a few months before this event, and it was presumed that the older (larger) female was the mother of the slightly smaller female. Overpopulation and poor vegetation quality could cause increased aggression by males due to competition for natural resources (Bowland and Perrin, 1995). Overpopulation could also exaggerate social behaviours by forcing individuals to share ranges they might not have shared if migration was possible.

Overall social behaviour patterns did not test significant for gender or seasonal differences, but further investigation into social sub-states revealed fine scale nuances for the species. Female Aders' duikers spent a larger proportion of their social activities involved in allogrooming compared to males, with almost double the amount of allogrooming taking place in the wet season. These findings were directly comparable with the seasonal tendency for females' self-grooming results. As already discussed, due to duikers grooming with their tongues instead of their teeth, wetter conditions provide duikers with an opportunity to save moisture while grooming (Hart, 2001). It was also referred to previously in this section that males potentially did not take advantage of wet season conditions due to their focus on sexual activities.

Sexual pursuit was also classified under social behaviours. Of all social interactions, male Aders' duikers spent 21% of their time in the dry season and 50% in the wet season on sexual interaction. Sexual pursuit took place throughout the year with a peak in March and April and again between August and November. No information about gestation period is available for the Aders' duiker, but based on body size comparisons with other duikers, it is estimated that a period of six to seven months is likely. If this estimate is correct, a breeding peak in March and April would result in a birthing peak in September and October. Correspondingly, five births (out of 11 recorded) took place during September and October. The second breeding peak was estimated to take place over four months (August through to November) and should have resulted in a birth peak between February and June. Three births were logged in April, while the remaining three births recorded took place in January and August. Evidence of year-round breeding and birthing was thus concluded, with at least one peak around September and October. These results were expected based on data from other duiker species. Birthing peaks for the Bay duiker was found to be linked to fruit abundance, as was suggested for Maxwell's duiker, which reportedly bred year-round with birth peaks during months when fruit was more readily available (Aeschlimann, 1963; Newing, 1994).

A social sub-state was distinguished for duikers "following" one another, as discussed in the previous section (0). Overall, a non-significant trend indicated that males spent more time following others, while an overall increase in following behaviour for all duikers during the dry season tested significant. Seasonal differences between genders further indicated that females displayed the most variance in this behaviour, in that they tended to reduce following behaviour in the wet season. Corresponding to an increase in sexual pursuit by males in the wet season, this tendency fits the overall seasonal activity pattern.

The activity budget composed in the current study provided a detailed overview of all behaviours that were observed on a daily and seasonal basis for males and females. Due to some activities only being observed for short durations, sample sizes for these categories are too small to test for seasonal and gender differences. However, it is still necessary to consider the tendencies that emerged from these categories to inform and interpret all behaviour as part of a complete Ethogram for the case of Mnemba island. Drinking water and taking shelter were observed more among male Aders' duikers. Further investigation is needed to determine if males need more moisture than females. Females showed significant increases in grooming and self-grooming during wet conditions when moisture saving was optimum. Males on the other hand did not take advantage of the rainy conditions in this way. However, if males truly did drink more than females, it is suggested that they compensated by ingesting moisture, as opposed to utilising moisture saving practices.

During focal observations, excretory behaviour was seldom observed, while females were slightly more likely to be seen urinating and excreting. Dung piles and middens were mostly located in the interior of the forest, away from foot paths. Duikers utilise these dung piles to mark territories (Dubost, 1980; Newing, 1994; Hart, 2001). Due to the locations of these middens and the researcher not leaving the foot paths explains why not many observations of defecating behavior were recorded. Based on opportunistic observations, it is also suspected that marking of territories using middens takes place at dusk and dawn, when focal observations are constrained by low light conditions. These crepuscular activities have been described by many studies on forest antelope species (Dubost, 1980; Feer, 1988; Newing, 1994; Bowland and Perrin, 1995; Williams et al., 1996; Finnie, 2002; Bowman and Plowman, 2002; Hart 2013a, b; Amin et al., 2015).

Limitations from only observing the duiker in daytime is recognised for this study. As already stated, the assumption was made from literature that this species is not very active at night. Further studies are needed to investigate the nature of the Aders' duiker's movements after dark.

7.4.4 Diel patterns for the Aders duiker on Mnemba Island.

Various observation of the Aders' duiker in its natural habitat have so far revealed that a bimodal activity peak is common - early in the morning and late afternoon (Willimas et al., 1996; Kingdon, 1997). Similar patterns are observed in other forest duikers such as the Red and Blue duikers, Water Chevrotain, Peters' and Maxwell's duiker, Suni antelope, etcetera conform to a crepuscular pattern of overall activity (Dubost, 1980; Feer, 1988; Newing, 1994; Bowland 1990; Estes, 1991; Bowland and Perrin, 1995; Williams et al., 1996; Kingdon 1997; Wilson, 2001; Finnie, 2002; Bowman and Plowman, 2002; Hoffman and Bowland, 2013; Hart 2013; Amin et al., 2015).

Pure diurnal, nocturnal and mixed activity patterns have been described as a form of niche development in foraging activity patterns for forest antelope species, to reduce competition between sympatric species (Newing, 1994; Amin et al., 2015). Seasonal and individual activity pattern differences have also been observed for blue and red duikers, where activity spikes at midday were related to dry season food scarcities and territorial patrolling (Dubost, 1980, Feer, 1988; Bowland and Perrin 1995). Leuthold and Leuthold (1977) associated a stern crepuscular pattern with predator evasion behaviour, which was confirmed by Ding et al. (2012), who further suggested that nonconformity to crepuscular patterns by species that would otherwise be strictly crepuscular, could be attributed to the non-existence of natural threats and predators in each environment.

Amin et al. (2015) described the diel patterns of Aders' duiker in its natural habitat in Kenya, from analysing camera trap images. The study identified Aders' duiker as diurnal with peaks of activity between 7:00 and 10:00 and again between 17:00 and 19:00. Evidence from these studies suggested that the Aders' duiker on Mnemba could display a similar bimodal activity pattern, irrespective of the differences in predatory and population density conditions. Based on observations of Aders' duikers in forests where predators and other threats are abundant, this species is thus believed to be strictly diurnal with crepuscular peaks (Finnie, 2001; Amin et al., 2015). Although crepuscularity was anticipated in the current study, in the ansence of predators, noncomformity to a very strict crepuscular pattern was potentially expected for the Aders' duikers on Mnemba Island.

Behaviour categories in the activity budget that were coded as 'movement', were pooled for each hour of daylight, including dawn and dusk (between 06:00 and 19:00). Instead of a pure bimodal pattern in the graph, two extra activity peaks were found between 11:00 and 12:00 and between 15:00 and 16:00. This increase in activity in the daytime is likely linked to a lack of predators and other threats to the duikers' foraging routine, allowing a less stringent crepuscular pattern (Ding et al., 2012). Spikes in midday activity, as mentioned, can also be affected by food scarcity in the dry season or territorial patrolling of forage patches (Dubost, 1980, Feer, 1988; Bowland and Perrin 1995). When the overall hourly activity on Mnemba duikers is compared to the hourly camera trap results from Amin et al.'s (2015) study in Boni-Dodori, Kenya, the Mnemba population presented a cyclical diurnal activity pattern as opposed to the pure bimodal pattern from Kenya's Aders' population. Due to political unrest and soldiers hunting with dogs around the Boni-Dodori forest area, the duikers from these forests would benefit from a stricter crepuscular pattern. In the absence of predators on Mnemba Island, antelope are flexible to spend time that would normally be used for vigilance and predator evasion on other activities. In a recent study on Nakanoshima Island, Ikeda et al. (2016) found that owing to the lack of predators on the island, Sika deer adjusted their activity patterns to forage and move about more in the day and in twilight.

In Figure 7-10 the fine scale seasonal differences indicated that social behaviour was observed most around noon in the dry season but spread out over the day in the wet season, with interaction peaks at dawn and dusk in the rainy months. A much higher foraging peak at dusk as well as an extended morning foraging session in the dry season, contributed to a more pronounced bimodal pattern during months with lower food quantities. Territoriality also influenced the diel pattern with a specific matutinal peak in the dry season, from dawn to 09:00. Travelling contributed to the diel pattern with a vespertine peak in the dry season. These seasonal differences in diel patterns are believed to be linked to activity trade-offs in the dry season when food resources are less abundant (Hamel and Côté, 2008), and time is spent on securing food patches through travelling or actively protecting resources within territories.

As discussed in the preceding sections, it was expected that seasonal activity patterns for the Aders' duiker would not differ significantly (Norberg, 1977; Komers et al., 1992; du Toit and Yetman, 2005; Wiafe and Amfo-Out, 2012; Muposhi et al., 2013). However, a seasonal comparison of diel activity patterns resulted in a noticeably pronounced bimodal pattern during the dry season.

In addition to seasonal fluctuations, gender differences influenced the overall activity patterns for this population. A significant difference in the diel activity patterns for male and female Aders' duikers supported the theory that different energy requirements and foraging strategies are employed by the different sexes. Female Aders' duikers on Mnemba displayed a significant increase in activity between 16:00 and 19:00, while males were much more active between 06:00 and 10:00. These behaviour differences between genders further suggest that habitat segregation strategies, such as 1) the forage-selection and 2) indirect scramble-competition hypotheses are relevant to the interpretation of Aders' duiker's activity patterns. Both hypotheses are supported by the fact that male and female activities peak at opposite ends of the day and that these distinctions are likely to exclude each other from foraging patches thereby avoiding competition (Prins et al., 2006; Ruckstuhl, 2007). Activity patterns are thus influenced by seasonal variation in food availability, gender specific behaviours and competition strategies. A baseline in foraging behaviour and food selection was compiled to assist with interpretation of overall activity patterns.

7.4.5 Foraging patterns and food selection by Aders' duiker on Mnemba Island.

Foraging activities on Mnemba Island was observed and recorded in the context of a small and enclosed natural forest, surrounded by a plantation, beach and the ocean. Preliminary observations suggested overgrazing of the understory in the natural forest from the ground up to 1.3 m high. Suni antelope were frequently seen along the forest tracks and it was evident that the island was housing a large population of Suni antelope. Aders' duiker was also encountered along these paths, but not as frequently as Suni antelope. The Island's vegetation was visibly distinct between *Casuarina cunninghamiana* plantations around the edge of the island, and indigenous vegetation concentrated in the centre. Other than food items falling onto the ground during the dry months, very little foliage were in general reach of the duikers. A decision to remove most of the Suni antelope from the island during the current study was made to assist urgent vegetation recovery. In addition to the Suni removal, four Aders' duikers were removed from Mnemba once fieldwork was completed, as a starting point for reducing pressure on the island's vegetation. Foraging patterns from the current study were influenced by the condition of the vegetation during the time of investigation, and results should be interpreted considering the status quo. Future comparative studies are important to compare foraging patterns once the forest has recovered, and to evaluate the extent to which vegetation conditions contribute to foraging activity patterns. Without accounting for the forest's condition, it was expected that the Aders' duiker would forage mostly at dawn and dusk, and that solitary, as well as paired and limited group foraging, would be observed (Swai, 1983; Kingdon, 1997; Wilson, 2001; Huffman 2016a; Fiske 2011).

In sections 7.4.2, 7.4.3 and 7.4.4 foraging differences were discussed in the context of seasonal variations, gender variations, daily movements and overall diel patterns. The previous sections provided evidence and explanations for the differences in male and female activity patterns, specifically related to foraging. The reiteration of gender patterns in this section serves to focus purely on foraging as a separate category in the ethogram, and also looks at further interpreting the findings from foraging activities, food species selection, basic phenology and diet composition.

Previous studies reported that seasonal differences in foraging activity are not significant for similar species, which led to the anticipation that seasonal differences in the Aders' duiker foraging patterns would not be significantly different (Norberg, 1977; Komers et al., 1992; du Toit and Yetman, 2005; Wiafe and Amfo-Out, 2012; Muposhi et al., 2013). As concluded in the preceding sections, when ignoring gender differences for seasonal foraging patterns, the Aders' duiker population on Mnemba Island showed a non-significant tendency to forage more in the dry season. Separate to seasonal predictions, as discussed previously, overall (annual) activity patterns were also not anticipated to yield drastically varying results between male and female Aders' duiker (Gross et al., 1996, Ginnett and Demment, 1997; Bergman et al., 2001; Neuhaus and Ruckstuhl, 2004). As we saw from the results for the Aders' duiker population on Mnemba, annual trends in foraging were not significant between genders, but males tended to spend more time foraging.

The overall seasonal and gender trends for foraging prompted further testing of between-gender differences for seasonal foraging. Statistical tests confirmed that foraging activity for males and females were linked to season (Figure 7-7a). As suggested in the preceding sections, female Aders' duiker took advantage of the wet season when food resources were abundant, while males traded off this time to pursue females for mating. Males then increased their foraging efforts significantly in the dry season to replenish their nutrients, which led to an increase in territorial patrolling to protect food resources (Dunham, 1982; Jarman, 1974; Hart, 2001; Blanco and Hirsch, 2006). Female Aders' duiker are potentially less adapted to poor quality food resources, as is the case for other ruminant antelope such as Impala (Jarman and Jarman, 1973; Blanchard and Fritz, 2008), which would explain the significant increase in ruminating that female duikers on Mnemba Island displayed in the dry season. Food species availability and preferences between genders have been shown to affect seasonal differences in foraging activities for dimorphic antelope such as Kudu and Impala (Owen-Smith, 1979; Wronski, 2002), but should be further investigated for monomorphic duiker species to understand the underlying factors in seasonal variation. When foraging activities were grouped by season and gender, significant patterns emerged for both conditions.

Foraging activity patterns mirrored the pattern for all movement, which signifies the role foraging plays in the overall activity of the species (Figure 7-13). Specifically, the dry season had less pronounced peaks in foraging and for overall activity, compared to the wet season. These findings are aligned with Dubost's (1980) study on the Blue duikers' diel patterns, where less pronounced crepuscular peaks were observed in the dry season. Diel foraging patterns indicated that males and females often forage at different times in both seasons (Figure 7-13). Four small foraging peaks were recorded for males throughout the day in the dry season, while the wet seasons had a more pronounce trimodal pattern (Figure 7-13 and Figure 7-13). Females foraged less throughout the day in the dry season but maximized in the afternoon until dusk. In the wet season more foraging peaks were shared between males and females, but again, females had a peak at a time when males were not foraging. In the case of the Blue duiker (Dubost, 1980), the presence of predators would have influenced the duration and time of foraging activities. It is suggested that the lack of predators on Mnemba Island removed the time restriction that duikers would have to adhere to during food scarcities. This potentially allows the Aders' duiker to increase the number of foraging peaks according to resource availability and to alternate peaks between genders to ensure that competition is kept to the minimum. This adaptation would not have been possible if the island had natural predators.

Under the enclosed conditions of the island, the consequential between-gender foraging differences raised the question of gender-based competition strategies. Prins et al. (2006) suggested that competition would be strongest among monomorphic herbivores. Aders' duiker on Mnemba Island showed resource division across seasons and diel patterns to prevent intraspecific conflict (Clutton-Brock et al., 1987; Ruckstuhl, 2007). As suggested in the previous sections, seasonal foraging results can be interpreted in line with the foraging optimising theory, which classifies Aders' duiker females as energy maximizers, and males as time minimizers and energy savers (Forchhammer and Boomsma, 1995). Bergman et al. (2001) suggested that maintenance or foraging related movement can range between time minimizing and energy maximizing over time, prompted by the need for improved nutrition. Male and female Aders' duiker displayed varying nutritional needs in the different seasons, which were prompted by different activities. Focused investigations into these claims are necessary to confirm the gender specific strategies for this species. It was further established that the Aders' duiker conformed to partial gender separation. When interpreted as part of the activity budget hypothesis, the results provided insight into the energy requirement differences for males and females (Neuhaus and Ruckstuhl, 2004). It was also established that group-foraging and gender separation was influenced by season.

Feeding strategies for the Aders duiker, as discussed previously, could be anticipated from the Class A foragers in Jarman's (1974) theory, displaying foraging styles that correspond to selective feeders in small groups or pairs. Aders' duiker on Mnemba foraged alone or in pairs for two thirds of all foraging observations, as was expected. However, Jarman's (1974) Class A foragers would theoretically not change their group structures during the different seasons. The current study found the contrary for Aders' duiker with a significant increase in solitary foraging in the dry season, which is supported by Bowland and Perrin (1998) in their notion that duikers do not strictly conform to the Jarman-Bell feeding strategies. The absence of predators, the poor condition of the natural vegetation, and the high density of duikers on Mnemba are potential factors affecting social foraging on the island.

Fine scale foraging behaviour was analysed from the activity budget's sub-states, recorded under the foraging main behavioural state. Findings suggest that Aders' duiker tend to be slow foragers, especially during the dry season when food resources are scarce, with a higher portion of wet season foraging done at a medium pace (forage-walking). Another factor that was influenced by food scarcity was a small but significant decrease in social interaction during foraging in the dry season, unlike the typical Class A forager in Jarman's (1974) feeding strategy theory. Gender played a bigger role in foraging patterns than season. Three foraging sub-states tested significant for between-gender differences. Females had higher proportions of slow, medium and social foraging making up their foraging activities. Males on the other hand showed higher proportions of vigilant and territorial foraging, although these two sub-states did not yield enough data to test for significance. Data from sub-states made up small portions of the total sample size in the current study, not permitting rigorous testing of these differences, indicating that further research is required to gain a better understanding of seasonal and gender differences in Aders' duiker foraging strategies. Fine scale differences in foraging strategies are critical for understanding this dynamic in the ecology of the species, and the subsequent management of habitat and population composition on the island. For example, population gender ratios and timing of removal of individuals from the island should consider the condition of the animals and their gender specific behaviours at various times.

From available literature, drinking was initially not anticipated as part of ingestion observations (Fitzsimons, 1920; Blarney and Jackson, 1956; Kingdon, 1982; Smithers, 1983; Hart, 2001), but as explained in the previous sections, drinking was observed on at least five occasions. Conditions on the island during the current study were described by long-term staff as being dryer than normal, and the availability of foliage was visibly limited in the dry season. These conditions potentially contributed to the need for the duikers to ingest additional water, over and above what was available in their diet. Considering that frugivores are in general not dependent on additional water intake, the condition of the vegetation on the island raises a concern for continual provision and suitable sustenance, especially in light of the effects from over-browsing. Additionally, climate stresses on the small forest contributes to a highly volatile situation that needs regular monitoring to ensure proper management of the forest and its food species diversity.

The Aders' duiker are believed to follow a typical frugivorous diet (consisting of fruits, buds, sprouts, seeds, and dicotyledonous leaves), which would mean that their diet on Mnemba Island would consist of similar ratios of fruits and leaves as other forest duiker species. Previous short-term studies on Mnemba Island indicate that the Aders' duiker and Suni consume at least 11 food plant species (Fiske, 2011; Rivers, 2012). During the current study, 20 food plant species were recorded, but it is likely that more species are consumed. Studies on Black duikers (Wilson, 2001; Hofmann and Roth, 2003) found that 33 fruit species alone contributed to the diet of these forest duikers. The number of species in the diet would naturally depend on the diversity of the habitat. Leaves, fruits, and leaf stems from the *Grewia glandulosa* shrub made up the largest proportion of identified species consumed during the bite rate assessment (35.0%), but the availability index for this species was relatively low for the island (3.68%). With an Electivity Index of 0.73, this species was identified as a key food species for Aders' duiker on Mnemba. Additional species that contributed a significant proportion to the Aders's diet were leaves, flowers, and leaf stems from *Pisonia grandis* (28.6% consumed). An availability index of 4.00% and an Electivity Index of 0.69 was calculated for *P. grandis*. These two species combined were observed to play an important role in the Aders' duiker food selection on the island. At times when the *P. grandis* was dropping flowers, duikers were seen foraging from one *P. grandis* tree to the next. Food species with a very high availability were *Mimusops obtusifolia* (13.61%) and *Eugenia capensis* (26.51%). Both species provided fruits for the Aders' duiker, with *M. obtusifolia* fruits contributing 6.40% to the diet and having an Electivity Index of -0.36. The diet proportion and Electivity Index of *E. capensis* is unknown. A regression analyses concluded that Electivity (E_i) and Availability (P_i) (from bite rate results in Table 7-7) were linearly related. This result corresponds with various findings (Dubost, 1984; Gautier-Hion et al., 1985; Newing, 1994; Hofmann and Roth, 2003; Shipley, 2005) that duiker diet composition is linked to availability of food species and type, especially the ratio of fruits in the diet.

No seasonal comparison of species electivity was possible, but across all bite-rate observations with species identification, the species with the highest E_i were *Ficus polita* (Fruit), *Ehretia amoena* (Fruit), *Ficus scassellati* (Leaves), *Terminalia catappa* (Leaf stems). These items were actively selected in addition to *Grewia glandulosa* and *Pisonia grandis* leaves and contributed to a further 18% of the diet proportion from the bite-rate study. *Ficus* spp. are well known for their important role in forest ecosystems. Not only do frugivores depend on the asynchronous fruiting phenology of *Ficus* spp., but *Ficus* spp. depend on frugivores for dispersal of seeds (Beck, 2008). The presence of multiple fig species on the island contributes to the success of the resident Aders' duiker population, especially in the dry season when fewer species yield fruits (Figure 7-24). Figs are also sought after by many bird and bat species, which aids in the distribution of the fruits to the duikers below. It was observed how *Eidolon helvum* and *Epomophorus wahlbergi* bats fed on *Ficus* spp. fruits at dusk, while Aders' duikers took advantage of the "fruit rain" below the tall trees, accessing fruits they would otherwise not be privy to. During monsoon, the duikers actively sought out the fleshy bracket fungus *Auricularia auricula-judae*. This fungus has been found to be high in protein, very high in carbohydrates, provides 1.7% fat, and has many nutrients and essential amino acids (Kadnikova et al., 2015).

The ratio of foliage to fruits and other items in the diet of the Aders' duiker on Mnemba Island was calculated as 0.5:0.4:0.1 (proportions of leaves: fruits and seeds: other food items such as flowers, insects, roots etcetera). These findings correlate with reports from various other duiker species, that the most important components of the duiker's diet are fruits and leaves (Eves et al., 2002; Hofmann and Roth, 2003; Hart, 2013). The contribution of fruits to diet composition depends on availability (as mentioned previously), but also on the size of the fruit and the duiker. Various studies found that fruit size selectivity was subject to duiker body size, with smaller duikers selecting smaller fruits and larger duikers, larger fruits (Gautier-Hion et al., 1985; Hart and Hart,1989; Newing, 1994; Shipley, 2005). Shipley (2005) stated a range of 25 – 89% of fruit in duiker diets, while Dubost (1980) and Estes (1991) indicated that duikers generally consume a considerable foliage component as part of their diets. A further notion exists that body size is positively linked to an increase in the ratio of foliage in the diet (Shipley, 2005). Although the Aders' duikers on Mnemba Island consumed a smaller fruit portion compared to Shipley's (2005) average, results fell well within the proposed range. Findings from the Natal Red duiker (Faurie and Perrin, 1993; Bowland and Perrin, 1998; Hart, 2013b) indicated a higher ratio of foliage (66%) and less fruits (25%) than in the current study. Newing (1994) indicated that Maxwell's duikers selected and avoided certain fruits as abundance and shortages fluctuated. This suggests that duikers adjust their diet proportion according to seasonal changes and nutritional needs. Due to overpopulation of Suni and Aders' duiker on Mnemba, a shortage of foliage during the dryer months potentially influences fruit selectivity and diet composition (Owen-Smith, 1979).

Additionally, small but important items in the Aders' duiker diet included flowers (4%), roots (2%), leaf stems and young sprouts (1%), and fungi and grass (1%). Worms and insects made up less than 1% of their diet. These results are consistent with studies on other duiker species such as the Natal Red duiker, which also included 1% of flowers and below 1% insects in its diet (Faurie and Perrin, 1993, Bowland and Perrin, 1998). Black, Maxwell's and Red flanked duikers were also found to consume fungi, flowers, and excavated roots (tubers), especially the Black duiker (Wilson, 2001; Hofmann and Roth, 2003). During the current study, on several occasions, Aders' duikers were observed digging for roots with their front hoofs.

The Ivlev Electivity Index revealed that fruits and seeds were actively selected during both seasons, while leaves were more likely to be randomly selected year-round (Figure 7-22). Seasonal fruit availability was found to play an important role for other duiker species, explaining the tendency of fruits to be selectively foraged as availability changes (Owen-Smith, 1979; Davies and Birkenhager, 1990; Hart, 2013a, 2013b). Hoffmann and Roth (2003) found that only certain fruits species were actively selected by black, red-flanked and Maxwell duiker. Not all the species of fruit items in the current bite-rate study were identified, but as discussed, *Ficus polita* and *Ehretia amoena* had a very high electivity index compared to other fruit species, which agrees with Hofmann and Roth's (2003) results. In addition to electivity, the number of items consumed per hour was calculated from the bite rate results and multiplied with the daily foraging proportion in the activity budget and the seasonal relative abundance (r_i) of the food type (Table 7-10). These calculations revealed that the Aders' duiker on Mnemba consumed 3% more fruits in the wet season and 8% more leaves in the dry season. Since fruit consumption has been shown to depend on availability, it was established that Mnemba Island's fruit abundance is slightly higher in the wet season. Although seasonal differences in diet composition and food type electivity did not test significant, the increased trend in leaf consumption in the dry season points towards a diet adjustment based on lower fruit abundance (Owen-Smith, 1979). The relatively small seasonal differences in the Aders' duiker's diet compares with Hoffmann and Roth's (2003) findings, but the Aders' increased leaf consumption in the dry season contrasted with duiker species in the Hoffmann and Roth study.

A high electivity index (0.8) for fungi in the wet season and low index (-1) in the dry season was expected (Figure 7-22). The *Auricularia auricula-judae* only grows during the long rain season when wet conditions prevail for several weeks. Duikers were observed as they actively sought out this fungus on trunks and low branches in the forest during the monsoon. Comparable with Hoffmann and Roth's (2003) diet composition study, the Aders' actively selected flowers and flower stalks in the dry season (0.6), as opposed to the wet season (-1). Apart from a nutritional analyses of duiker diet composition by Dierenveld et al. (2002), which found that flowers tested higher for Calcium content than the fruit component, no explanation for an increase in floral consumption in the winter was found in the literature. Availability is the most likely explanation, as various duiker species have been shown to adapt to the predominant food types available to them in the different seasons and regions (Wilson, 2001). The amounts of grass, leaf stems and sprouts consumed by the Aders' duikers were small. These items were not actively selected in the wet season and randomly consumed in the dry season. Grass has been listed as part of duiker diets but was only a very small part of the overall diet composition on Mnemba (Wilson, 2001, Hoffmann and Roth, 2003). Small portions of roots and tubers are commonly reported in duiker diets, especially during the dry season (Wilson, 2001, Hoffmann and Roth, 2003). On Mnemba Island, Aders' duikers consumed roots randomly in the wet season and unselectively in the dry season.

The overall number of items consumed daily in the dry season was calculated to be slightly higher (~36 more per day) than for the wet season, but this result was not significant, and was also not consistent with findings in the literature (Wilson, 2001, Hoffmann and Roth, 2003). The current study did not investigate the dry mass consumed in the typical daily diet, but based on the outcome of the current study, further nutritional research should be done to evaluate this and the general nutritional composition of the Aders' duiker' diet on Mnemba Island. Overall daily consumption of biomass should range between 3 to 5% of a duiker's body weight and consist of low quantities of starch, relatively high tannin contents, and reasonable amounts of crude protein and selective fibers (Dierenveld et al.2002).

When comparing the daily consumption rates extrapolated from the work of Rivers (2012) for the Suni antelope on Mnemba Island (±100 items daily), the results indicated that the Aders' duiker consumed on average three times more items per day (±298) than the Suni do.

It was anticipated that the Aders' duiker would only utilise natural vegetation for food and shelter. Focal observations took place along sample tracks (Figure 7-1), visually covering all plant communities, but very few sessions were recorded in Plant communities 1.2 and 1.1 (Appendix J). At times, focal observations saw duikers venturing into the planted forest along the edges of the natural vegetation, to forage on fallen flowers and leaves from the indigenous vegetation growing on the outer edge of the natural forest. No consumption of *Casuarina cunninghamiana* needles was observed and duikers were visibly nervous when stepping out of the natural forest into the more exposed plantation. The availability index (P_i) for each food species was obtained from the vegetation survey results (section 5.4), which was then summed to derive a combined availability for each plant community (Table 7-9 and Figure 7-21). Seven dominant food species occurring across major plant community 2 had the highest joint P_i of over 60%, providing the Aders' duiker with most of their food. Plan community 2 was foraged frequently and at random. The availability index P_i for eight food plant species from group G totaled 15% (Table 5-2) that occurred across all plant communities on the island, with an electivity index of around 0.00.

The risk of perceived predation and human activity would have affected the frequency at which duikers accessed the open areas in the plantation, and the edges between the indigenous forest and the *C. cunninghamiana* stands. Opportunistic observations during the closed tourist season when guest rooms were vacant revealed that duikers preferred the forest edge along the guest rooms as opposed to the forest edge without infrastructure. The guest rooms provided additional cover for quick retreat from the open plantation forest into natural thickets. Sub-community 2.1 (section 5.4) was represented by three dominant food species and provided 0.55% of the diet. The E_i for this group of food species was close to 1.00, indicating high selectivity in this plant community. Two of the three food species belonged to the Ficus genus, which has previously been discussed as an important component of a frugivorous diet. *Ficus polita* and *Ficus lutea* were almost absent from sub-community 2.2. The third food species in sub-community 2.1 was the bracket fungus, *Auricularia auricula-judae*, also discussed earlier in this section. No food species were dominant in sub-community 1.1 and 2.2, but sub-community 1.2 was represented by one exotic *Bougainvillea glabra* specimen*,* and three indigenous food species specimens. *Cordia subcordata* provided flowers during the wet season. The twenty species identified as food represented thirteen plant families (Appendix K), of which Moraceae and Rubiaceae contained the most species per group, with three species each.

From the phenology table for the identified food species (Table 7-11) it is suggested that overall, there were more available food species during the wet season, and that more species (~12) yielded fruit in the wet season, as opposed to approximately eight in the dry season. Edible flowers are also potentially more prevalent in the wet season (~11 species) compared to the dryer months (approximately eight). Six species that fruited in the wet season were not noted in the dry season. These species were *Cordia subcordata, Ehretia amoena, Eugenia capensis, Ficus polita, Guettarda speciose*, and *Terminalia catappa*. The duikers depended largely on fallen items, and although very little browsing was observed, the overpopulated state of the island likely contributed to the patterns that were observed. More fallen leaves were noted in the wet season, including green and yellow leaves.

As mentioned previously, increased foraging and ruminating in the dry season did not test significant. Phenology analyses indicated that fewer food species and items were available in the dry season. Coupled to this is the possibility that food quality is poorer in the dry season, which results in increased rumination to maximize nutrient extraction (Jarman and Jarman, 1973; Blanchard and Fritz, 2008). No gender differences were tested for food items consumed due to small sample sizes and further research is required to assess gender differences in food selection and seasonal adaptation. We also recommend that the nutritional value of food items consumed by Aders’ duiker on Mnemba be evaluated to quantify seasonal differences and the impacts that phenology has on diet selection.

7.5 Conclusion

This chapter describes the behaviour of Aders’ duiker in its natural forest environment on Mnemba Island from a time-activity perspective and presents findings in a manner conducive to understanding the ecology of the species. Direct focal observations were selected as the main method of collecting behavioural data, which provided adequate opportunities to study the antelope species in detail (Newing, 2001). The research site, Mnemba Island, was found to be a suitable location for observing this elusive species while it performed its daily routine. Sufficient data were collected to perform gender and seasonal comparisons between the key behaviour categories from a comprehensive ethogram.

The limitation of this study was found in the lack of literature for this species, lack of individual identification during focal observations, as well as logistical restrictions. The sampling design (pooling the data for all observations over one year), was the most practical design for collecting a reasonable amount of data over time.

It is recognised that many potential methodologies could have been employed, but with limited time and resources for fieldwork, the methodology of choice was to compile a complete set of behaviours for the Aders' duiker on the island to evaluate how they spend all their time, and whether seasonal differences could be found. Although gender differences are expressed in terms of season in certain sections, these expressions were not aimed at proving the interaction between season and gender, but to raise new questions for future research. Chapter 9 explores these questions in more detail and in context of the rest of the study.

CHAPTER 8

SEASONAL HOME RANGE PATTERNS OF ADERS' DUIKER ON MNEMBA ISLAND

8.1 Introduction

Management of the small Aders' duiker population in a limited resource environment such as Mnemba Island requires fine scale information about the use of space on an individual duiker level. Although literature reveals that duiker and other small antelope's home range sizes are adjusted according to resource conditions and population density (Trewhella et al., 1988, Bowland and Perrin, 1995), Mnemba Island is an enclosed site and does not allow duikers to enlarge home ranges when pressures on space and resources occur. Section 4.8 discussed the application of spatial ecology and the practical use of the technology in the context of this study. This chapter briefly summarises the review in section 4.8 before presenting the results from two successful deployments of GPS collars, collecting detailed location data over a period of one year. Although two individuals are not considered a statistical sample, the results provide invaluable insights into the spatial use of the duikers on the island. This chapter is not a stand-alone chapter but compliments the results from the previous three data chapters and should be read as such.

8.1.1 Home and Core ranges

Home ranges are most accurately calculated from long-term data collected at high-resolution and frequency (a substantial number of location points with short intervals between readings) (McCullough et al. 2000; Dewhirst et al., 2016). Advancements in data analyses methodologies and location technology have contributed to increased accuracy and detailed collection of information in field of spatial ecology (Aung et al., 2001). The inclusion of Global Positioning Systems (GPS) in wildlife telemetry has made it easier for ecologists to collect information on elusive and highly mobile species (Cooke et al., 2004; Göpper, 2012; Butler, 2017). Radio Frequency (RF) tracking technology has been upgraded to integrate GPS tags that deliver more data points at higher frequencies compared to manual logging during tracking exercises. These GPS tags are combined with traditional RF tracking collars that can be fitted to an array of animal species (Baílloa and Chacón, 2018). Based on the review of spatial ecology for duikers in section 4.8, it was expected that seasonal home and core range sizes for the Aders duiker would differ significantly between the dry and wet seasons, due to seasonal resource fluctuations (Gregory, 2017; McCullough et al., 2000).

8.1.2 Diel patterns

Studying the diel patterns of a species forms a fundamental component to understand the ecological processes when planning conservation programs for species in the wild (Hertel et. al. 2017). The activity patterns serve as a foundation in understanding life cycles and relationships of the individual (and species) with its surroundings (ecology) (Ahrestani et. al. 2012; Jhala and Isvaran, 2016; Renu et. al. 2017).

Activity patterns in mammals take on four types (broadly), where most activity is either enacted in one of two patterns in the day (diurnal or cathermal) or at night (nocturnal), or during the two twilight phases of a day (crepuscular). Bimodal (such as crepuscular) activity peaks are common for many mammal species, which generally constitutes two peaks of foraging with rest periods in between (Harcourt, 1978; Jarman, 1974), where foraging plays the most important role in determining the nuances of the bimodal peaks. As seasonal and individual changes influence foraging patterns, so also, is the diel pattern adjusted. Other environmental factors that play a part in changing a population’s or individual’s diel patterns include anthropogenic events, competition for resources, interactions with predators, weather and climate, and the duration of daylight hours (Beier and McCullough, 1990; Linkie and Ridout, 2011; Foster et. al. 2013; Bennie et al. 2014; DõÂaz-Ruiz et al. 2016).

Where breeding groups are introduced into new habitats for proliferation, movement patterns provide conservationists with information about the population’s adaptation strategies (Matthews, 1990; de Mrignac, 2000) and niche partitioning (Frey et. al. 2017) in the new environment. Where home range describes the spatial component of resource use for an individual or group, diel patterns pertain to the temporal aspect of movement within the home range (de Marignac, 2000). Further ecological interests underlying diel patterns of a species can be raised once a clear understanding exists of how a certain population utilizes time and space within the available habitat.

The context of existing literature and the anticipation of what was to be expected for the Aders’ duiker in terms of activity patterns was discussed in sections 2.8.3, 4.9, and 7.3.1. It was anticipated, from literature (Bowland and Perrin, 1995; Ruckstuhl and Neuhaus, 2002), that the absence of clear dimorphism in the species would lead to no significant differences in average (overall) daily distances travelled by the collared male and female in this study. However, along with seasonal home range size, it was postulated that significant differences would be measured between the male and female's average distances travelled for the different seasons, due to gender specific responses to biological and climate related changes in resource use (Bowland and Perrin, 1995; Ruckstuhl and Festa-Bianchet, 2001).

8.1.3 Carrying capacity

In chapter 6, population survey results were used to estimate maximum harvest density for Aders' duiker on Mnemba Island. As also explained in chapter 6, carrying capacities are not fixed, and should be adjusted according to resource availability and conditions. Iijima and Mayumi (2016), in a study on Japanese sika deer (*Cervus nippon*), demonstrated the effect of spatial heterogeneity on the variability in carrying capacity between cells/locations within the same habitat. Information obtained through spatial location data enriches the interpretation process of maximum harvest density values, by considering the spatial distribution of resources that underlie home range use patterns. Maximum harvest density values obtained from maximum carrying capacity could not account for size and geographic restrictions on the island and would also not reflect the effect that overpopulation has on the capacity of the natural habitat to sustain the population.

This chapter offers a detailed description of home range results for two Aders' duikers (one male and one female – not a breeding pair), including diel and seasonal movement patterns for the period April 2016 to April 2017. The results were used to evaluate the maximum harvest density results obtained from population survey results (refer to Chapter 6, section 6.3) and to make further recommendations with regards to the proposed harvesting schedule for Aders' duiker on Mnemba Island (Ryan and Jammieson, 1998). Diel patterns were also used to enrich the results and interpretation of the annual Activity budget described in Chapter 7.

8.2 Methods

8.2.1 Study area

Mnemba Island is a sandy cay with a vegetated area of 11 ha, housing two main plant communities: a natural vegetation community, and a coniferous plantation (Chapter Five). Both the natural and planted vegetation plant communities were further divided into two distinct sub-communities. Focal observations and food species investigation in the current study and previous investigations on Mnemba Island (Fiske, 2011; Rivers, 2012), indicated that Aders' duikers do not forage in the coniferous plantation (plant community 1), but only in the natural vegetation (plant community 2) and in the ecotonal area on the fringe of the forest where plant community 1 and 2 meets. The natural forest is 51 189 m^2 in size (excluding building footprints) and is situated in the interior of the island, providing suitable habitat for the current Aders' duiker and Suni antelope populations. Figure 5-4 illustrates the delineation of vegetation on the island. Mnemba Island is located within the tropical monsoon region. The 'short rain' months of October to December are followed by two dry months January and February, after which the 'long rain' months from March to May comprise the main monsoon. The driest time of the year is between June and September. During the current study, the highest daily average temperature was recorded in December (39°C) and the lowest in June and July (26°C). Extreme individual temperatures of over 40°C were recorded during July, November, and December.

The island is remote, providing no means for natural movement (migration) of antelope to and from the main island of Unguja. Suni antelope offspring have been removed from the island multiple times to relieve pressure on the island's vegetation and carrying capacity, but the government department of wildlife has not yet decided to take off any Aders duiker. Suni removal was necessary due to the exponential growth of their population, but the Aders' duiker population grew slowly and steadily up to the time of the current investigation. The following summary of methodological approaches pertain to the analyses of the data obtained from the GPS collars. For a detailed discussion about the deployment of the collars, refer to section 4.8.3 in Chapter 4.

8.2.2 Home and Core Ranges

It was accepted that the Aders' duiker is a territorial species and that findings during spatial investigations could be linked to territoriality (Kingdon, 1982; Swai, 1983). Home range (HR) represents a certain probability value for where an individual animal lives and traverses throughout the year, and core ranges (CR) a probability value for where the main feeding and resting activities take place. In this stydy, the HR was set at probability value of 0.95 and the CR at a probability value of 0.50 (Downs et al. 2001). As discussed in Chapter 4, location points collected over time are used as input data for the calculation of these ranges. A popular density estimate used by spatial ecologists is the Kernel Density Estimate (KDE), which is known to provide accurate results for small, enclosed areas and for data sets containing short distance linear paths (Walter et al., 2011; Gregory, 2017; Nekolny et al., 2017). The KDE assigns a weighted value to each input point and produces a three-dimensional density raster output. Location data points are assumed to be independent (Baílloa and Chacón, 2018) and the applicable bandwidth or search radius is calculated from the data set (Walter et al., 2011; Gregory, 2017). Input data were not weighted beyond the environmental settings in ArcGIS to further correct for under- and over-sampled days (Fleming et al., 2018; Winner et al., 2018).

Spatial location points were collected using GPS enabled UHF (ultra-high frequency) tracking collars, fitted to two Aders' duikers for 12 months. Data were extracted in CSV file format, prepared for analyses in MS Excel and imported into ArcGIS 10.4.1 for spatial home range analyses (HRA) and diel pattern evaluation (DPE). Distance data (cumulative distance travelled per day) for different time categories were pooled.

As a first step in producing the home and core range output files, a Kernel Density Estimate (KDE) was calculated in ArcGIS (ARCTOOLBOX > SPATIAL ANALYSIS TOOLS > DENSITY > KERNEL DENSITY). Environment settings for the KDE are listed in Table 8-1. Where environment settings were optional, no custom settings were selected, since the automated algorithm was deemed adequate.

Table 8-1: Kernel Density Estimator – environment settings in ArcGIS 10.4.1.

Environment	Input/Selection
Input	GPS points file.
population_field	NONE.
cell_size (optional) or bandwidth	AUTO computed from the shorter of the width or height of the output extent in the output spatial reference, divided by 250.
search_radius (optional)	AUTO computed radius from the dataset using a spatial variant of Silverman's Rule of Thumb.
area_unit_scale_factor	SQUARE METER.
out_cell_values (Optional)	DENSITIES — The output values represent the predicted density value. This is the default.
Method (Optional)	GEODESIC — This method takes into account the curvature of the spheroid and correctly deals with data near the poles and the International dateline. Although the input data set spans across short distance, this option was selected as a better suited method for geographic projections.

KDE raster outputs were created for both the male and female Aders' duiker across the twelve-month study period. For comparison of seasonal home and core ranges, data from all dry season months and all wet season months (see section 8.2.1) were pooled and the same KDE process repeated for the two seasons for male and female data. Raster values from the kernel density surface table were linked to raw location data points from the collars (ARCTOOLBOX > SPATIAL ANALYSIS TOOLS > EXTRACTION > EXTRACT VALUES TO POINTS) and new point shapefiles were created for the next step in determining home and core ranges.

New point shapefiles contained all the original data in addition to a new field called 'RasterValue'. Interpolation of values at point locations were selected – this function uses valid values from the adjacent cells only (bi-linear interpolation) to calculate the raster cell value that corresponds with the point's location. By not selecting interpolation, all points in a cell would receive the value of the center point of the cell, which loses detail in the output values. The small study area required fine scale outputs; hence detail was preserved by selecting interpolation during this step of the process.

In the attribute tables from the new points-shapefiles, the 'RasterValue' fields were sorted in descending order. The total number of points (records in the table) were divided by two, to find the median record – representing the break value for establishing the 50% Core Range (Fleming and Calabrese, 2017). The 'RasterValue' was extracted from this line record and documented for the concluding step that produced a spatial representation of the core range. The process of obtaining break values was repeated for the Home Range point file by determining the 95% 'RasterValue' (multiplying the total number of records in the file by 0.95 and extracting the 'RasterValue' for that record in the table). Core and home range 'RasterValue's' were obtained for annual data, as well as for data pooled from all dry months (Dry season CR and HR) and all wet months (Wet season CR and HR) (section 8.2.1), for both the male and the female Aders' duikers. A summary of the different home and core range data sets and the extracted raster values are presented in Table 8-3.

The 'RasterValue' point files for the core ranges were reclassified in ArcGIS into two classes: "NoData" and "50" (SPATIAL ANALYSIS TOOLS > RECLASS > RECLASSIFY). The "NoData" class represented raster values below the break value, and the "50" class contained all values from and above the break value to the maximum. This process was repeated for home range by setting a "95" break value. The reclassified raster files were converted to polygon shapefiles in ArcGIS and renamed as 50% core ranges and 95% home ranges (CONVERSION TOOLS > FROM RASTER > RASTER TO POLYGON). The conversion of raster files to polygons allowed for calculations of home and core range areas in ArcGIS. Annual and seasonal range overlaps between the two collared duikers (who occupied adjacent territories) were extracted and final area sizes were calculated in ArcGIS (ANALYSES TOOLS > EXTRACT > CLIP).

8.2.3 Daily distance travelled and diel patterns

To assess seasonal diel activity patterns, ‘daily distances travelled’ were extracted by combining straight-line distances between successive GPS points (Pepin et al., 2004). The method of inferring activity patterns from daily distances was successfully used for antelope species such as the Muntjac in China (McCullough et al., 2000) as well as for Red Deer and North American Elk (Ensing et al., 2014). For the current study, all distance analyses were done in MS Excel. Longitude (x) and Latitude (y) values were converted to positive decimal degrees. The ‘Great Circle’ distance between points was calculated by multiplying the spherical central angle between each successive pair of longitude and latitude values in decimal degrees, by the radius of the earth. The angle was converted to radians before multiplying by 6370.973 (the radius of the earth in nautical kilometers).

The formula used was as follows:

11.

$$\Delta\hat{\sigma} = 2 \arcsin\left(\sqrt{\sin^2\left(\frac{\Delta\emptyset}{2}\right) + \cos\emptyset_s \cos\emptyset_f \sin^2\left(\frac{\Delta\lambda}{2}\right)}\right)$$

Where arcsin = Radius of the earth in nautical km (6370.973);
$\Delta\hat{\sigma}$ = Distance between two points, in nautical kilometers;
$\Delta\emptyset$ = Difference between latitude1 and latitude 2;
$\emptyset s$ = Latitude 1;
$\emptyset f$ = Latitude 2;
and $\Delta\lambda$ = Difference between longitude1 and longitude 2.

The formula in Excel was expressed as follows:

```
= 6370.97327862273*((2*ASIN(SQRT((SIN((RADIANS(Lat1) RADIANS(Lat2))/2)^2)+
COS(RADIANS(Lat1))*COS(RADIANS(Lat2))* (SIN((RADIANS(Long1)-RADIANS(Long2))/2)^2)))))
```

Once the distance was obtained in nautical kilometers, the value was multiplied by 1.151 to convert to statute kilometers. The final distance value for each straight-line calculation was expressed in meters (statute kilometers multiplied by 1 000).

Total ‘daily distance travelled’ (DDT) was calculated by summing all straight-line distances for a given day. Pivot tables were created in excel to express the difference between average daily distances travelled for a variety of time periods. First, all daily distance values from days in the dry and wet seasons were pooled for seasonal comparison. Next, all daily distances for the twelve consecutive month study period were pooled for comparisons between the different months. Finally, all distances travelled for eight three-hour time-periods constituting a full day were pooled (1:01 – 4:00, 4:01 – 7:00, 7:01 – 10:00, 10:01 – 13:00, 13:01 – 16:00, 16:01 – 19:00, 19:01 – 22:00, 22:01 – 1:00) to determine diel activity patterns. The differences in distances travelled between seasons, months, time of day, and sexes were tested for significant differences using Independent and Paired T-tests in MS Excel.

8.2.4 Carrying capacity

In Chapter Six, the results from the first official population survey of the Aders’ duiker on Mnemba was analysed and discussed. A maximum sustainable harvest density (MSD) was derived from population growth modelling at a time when the island was reaching its capacity.

Ryan and Jamieson (1998) used the average (annual) home range size to estimate carrying capacity for pairs of Takahe birds on Mana Island in New Zealand. The researchers divided the size of the available habitat on the island by the average home range size recorded for the birds on the island. Results for the study indicated the number of pairs that would ‘fit’ into the natural habitat of the island. Ryan and Jamieson (1998) extrapolated the increased potential carrying capacity for the island by dividing the total island size (including currently unsuitable areas) by the average home range size, should the habitat be restored to its natural state. This method was adapted to estimate the current and potential carrying capacity for Mnemba’s Aders’ duiker population. The maximum current capacity referred to the area of natural vegetation, whereas the potential capacity extended to the entire vegetated area if the *C. cunninghamiana* plantation was to be replaced with natural vegetation. To interpret the spatial implications of the estimated MSD, the average (annual) home range sizes obtained from two Aders' duikers on Mnemba island at the time of investigation, were divided into the total size of suitable habitat on the island to describe the spatial carrying capacity under the current conditions (Ryan and Jammieson, 1998; Adcock, 2009; Downs et al., 2008, 2012).

Limitations with regards to spatial inference from only two individuals could be expected. However, a high number of input points (6 219 location points) were collected for the two collared duikers (8% of the population) over a period of 12 months. The tags were set to collect an average of 7 data points per day, ensuring fine scale delineation. The size of both home ranges covered 25% of the small island's total vegetation for the same period in time and under the same resource distribution conditions. Since duikers are from the same population and use resources in a similar way on the island, it is suggested that results can be extrapolated to estimate the island's carrying capacity (Fleming and Calabrese, 2017; Winner et al., 2018).

8.3 Results

The two successfully collared animals were regularly observed as part of separate pair-bonds. Size measurements for these two animals are listed below in Table 8-2. Standard methods for measurements are described in section 4.4.3. Measurements for the duikers with unsucsessful collar attempts can be found in Table 6-2 (male) and Table 6-3 (female). In Figure 8-1, fixes for both male and female indicate the spread of individuals' location points.

Table 8-2: Biological data collected for the two successfully deployed collared Aders' duiker at the time that tracking devices were fitted.

Capture date	**Gender**	**Body length (cm)[a]**	**Head (cm)***	**Tot. Body length (cm)**	**Height (cm)[b]**	**Neck circ. (cm)[c]**	**Horn length (cm)[d]**	**Girth (cm)[e]**
22 April 2016	Female	64	12	76	39	27	3	47
20 April 2016	Male	58	11	69	40	30	broken off	45

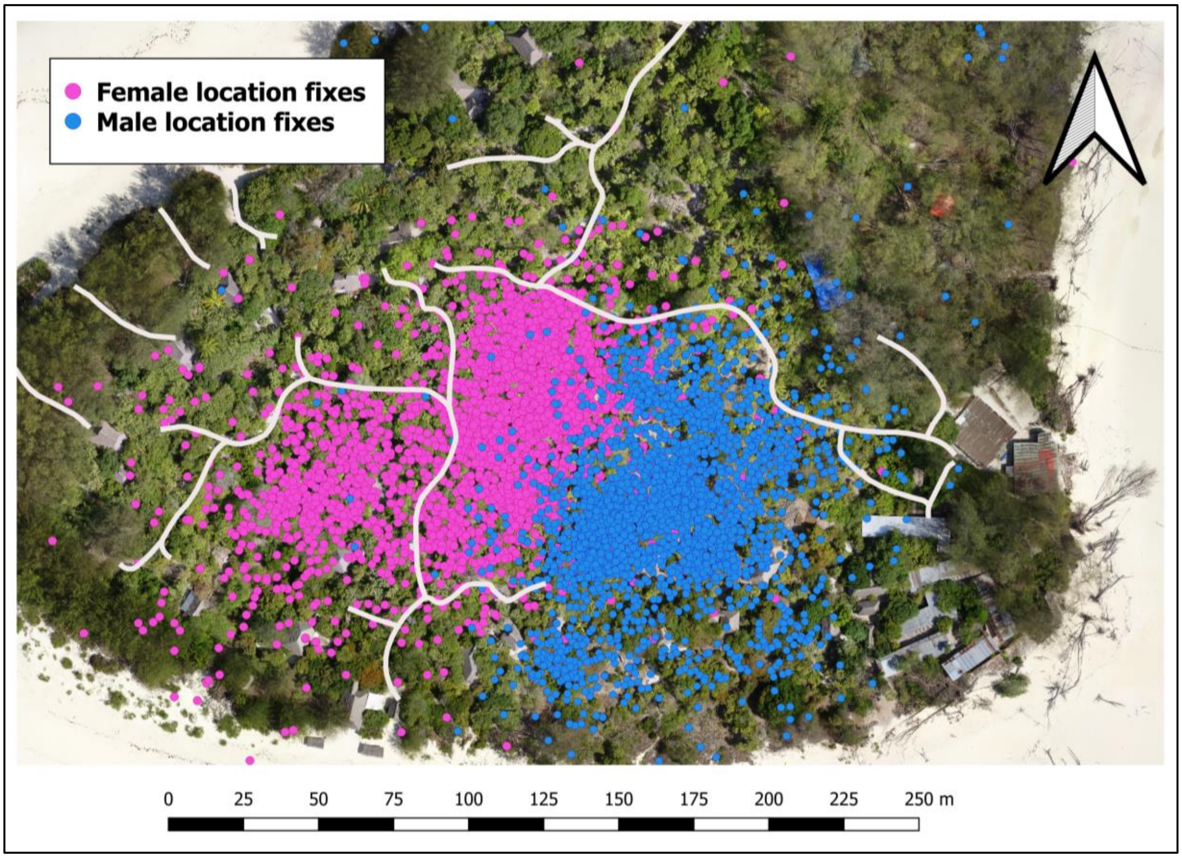


Figure 8-1: Location fixes for male and female Aders' duiker – fixes in pine forest in the north east were from the first few days after the capture, incl. the first few days after deployment.

GPS location points (10 m accuracy) were collected every two hours and 55 minutes when conditions were favourable. By not rounding off the interval to three hours, the incremental differece in the time of subsequent fixes resulted in location data being collected across all time categories (hourly) over 12 months. A maximum of 9 fixes per day was possible, but due to cloudy conditions, not all 9 fixes were collected on all days. Summary statistics of the pooled number of sample points revealed that each hour had comparable numbers of readings, with a SD of ± 6.2 (for the male) and ± 6.9 (for the female) (Table 8-4).

Location fixes collected between 27 April 2016 and 23 April 2017 for the female, and between 29 April 2016 and 24 April 2017 for the male, were used to calculate annual and seasonal home ranges. Fixes from the first few days after the capture were omitted to ensure that only data from the animals' natural activity patterns were used in the analyses. Out lying points in the *C. cunninghamiana* plantation seen in the image were part of the records removed from the fist few days, before the home range analyses was done in ArcGIS. A total of 3522 GPS readings were usable for the female (86% fix success rate) and 2 695 fixes for the male (84% fix success rate) (Table 8-3; Table 8-4). Weather conditions, as well as tracking activities using pinging functions, contributed towards the difference in fixes collected between the two collared animals. This difference did not affect the accuracy of the home range comparison between the two animals (Dewhirst et al., 2016).

Table 8-3: Summary of the number of inputs points, and the ‘RasterValue’s (Kernel Density values) for annual, dry and wet season core and home ranges, for the male and female Aders’ duiker.

a)

Individual	**Data Stratification**	**Number of Points**	**Core Range (50%) Raster values**	**Home Range (95%) Raster values**
Male – Tag 1623	Annual data	2695	0.422	0.041
	Dry season	1336	0.250	0.030
	Wet season	1359	0.192	0.020

b)

Individual	**Data Stratification**	**Number of Points**	**Core Range (50%) Raster values**	**Home Range (95%) Raster values**
Female – Tag 1625	Annual data	3522	0.394	0.037
	Dry season	1758	0.270	0.032
	Wet season	1764	0.199	0.021

Table 8-4: Sample statics for the number of fixes, pooled per time category (hourly), for both male and female collared duikers.

	Number of Fixes, pooled per time category (hourly)	
Time Category	**Female Aders' Duiker**	**Male Aders' Duiker**
00:00-00:59	162	111
01:00-01:59	148	110
02:00-02:59	151	112
03:00-03:59	146	100
04:00-04:59	142	114
05:00-05:59	139	114
06:00-06:59	143	100
07:00-07:59	145	111
08:00-08:59	142	113
09:00-09:59	154	109
10:00-10:59	148	116
11:00-11:59	148	110
12:00-12:59	144	117
13:00-13:59	137	102
14:00-14:59	133	109
15:00-15:59	137	120
16:00-16:59	143	110
17:00-17:59	151	114
18:00-18:59	159	125
19:00-19:59	149	109
20:00-20:59	150	121
21:00-21:59	154	119
22:00-22:59	151	110
23:00-23:59	146	119
Grand Total	**3522**	**2695**
Std Dev	±7	±6
Mean nr of fixes / per time category (hour)	147	112

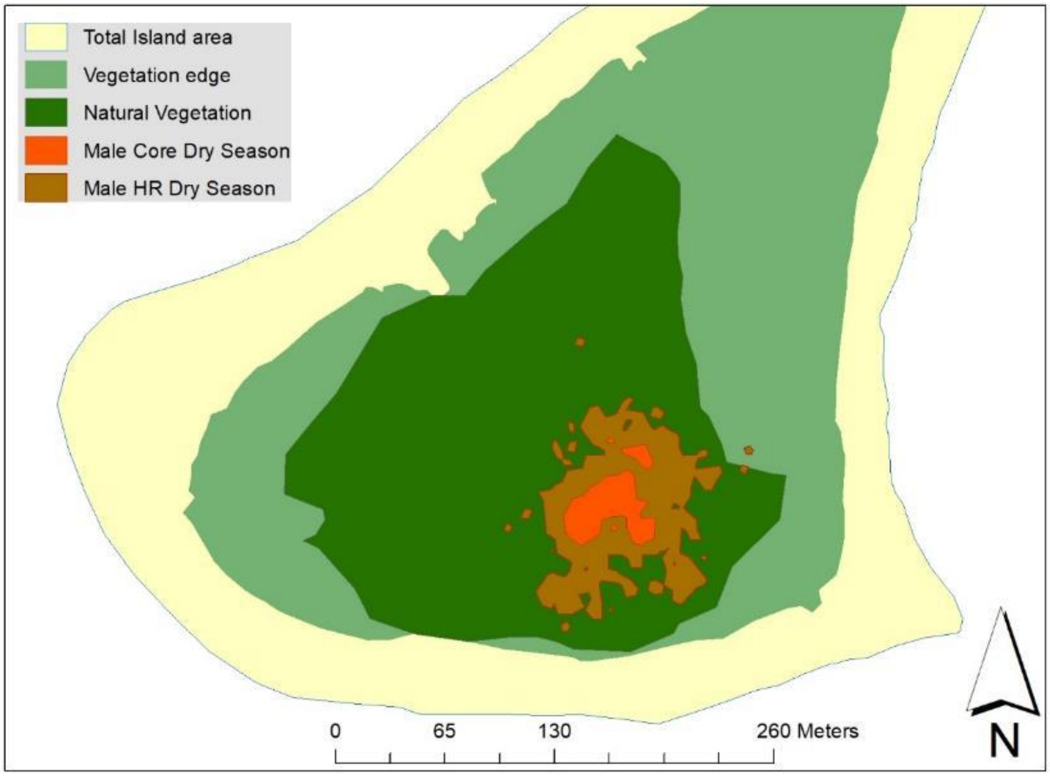
8.3.1 Home and Core ranges

Male Aders' duiker

The male Aders' duiker's annual HR was calculated as 11 310 m^2, consisting of 22% of the natural vegetation on the island (excluding building footprints). In the dry season the male's HR was 8 184 m^2 compared to 11 027 m^2 in the wet season (25% smaller in the dry season). This corresponds to a use of 16% of the natural vegetation in the dry season and 22% in the wet season. The CR was also smaller in the dry season (1 539 m^2) compared to the wet season (1 929 m^2). The annual CR constituted 4% of the natural vegetation. Table 8-5 summarises the results of the male's HR's and CR's. A map of the male's seasonal HR and CR is illustrated in Figure 8-2.

Table 8-5: Male core and home range size and percentage of natural vegetation, expressed for annual and seasonal ranges.

Range	**Area (m2)**	**% of Natural Vegetation** **51 189 m^2 Natural vegetation**
Annual Home range (95%) area	11 310	22%
Home range (95%) area in Dry Season	8 184	16%
Home range (95%) in Wet Season	11 027	22%
Annual Core range (50%) area	1 927	4%
Core area (50%) in Dry Season	1 539	3%
Core area (50%) in Wet Season	1 929	4%



a)

b)

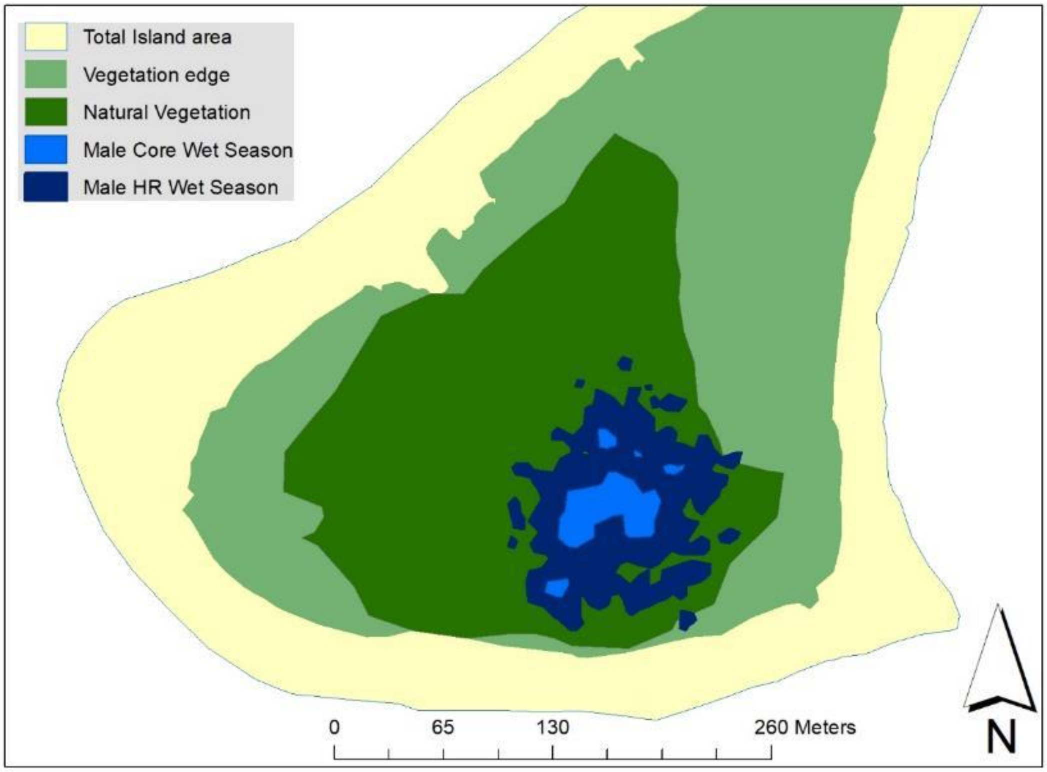


Figure 8-2: Mnemba Island April 2016 to April 2017 male Aders' duiker home ranges depicting a) dry season home range (95%) and core range (50%); b) wet season home range (95%) and core range (50%).

Female Aders' duiker

The female Aders' duiker had an annual HR size of 14 008 m^2, spanning 27% of the natural vegetation, excluding building footprints. The biggest seasonal HR (12 935 m^2) was measured in the wet season and spanned over 25% of the natural vegetation. The dry season HR was 23% smaller than in the wet season (9 963 m^2) and spanned 19% of the natural vegetation. The female's annual CR consisted of 2 440 m^2, which spanned across 5% of the natural vegetation. In the dry season the CR was 27% smaller than in the wet season, at 1 864 m^2 and 2 564 m^2 respectively, constituting 4% and 5% of the available habitat. Table 8-6 summarises the results for the female's HR and CR analyses.

A spatial depiction of seasonal differences in the female's HR and CR is illustrated in Figure 8-3.

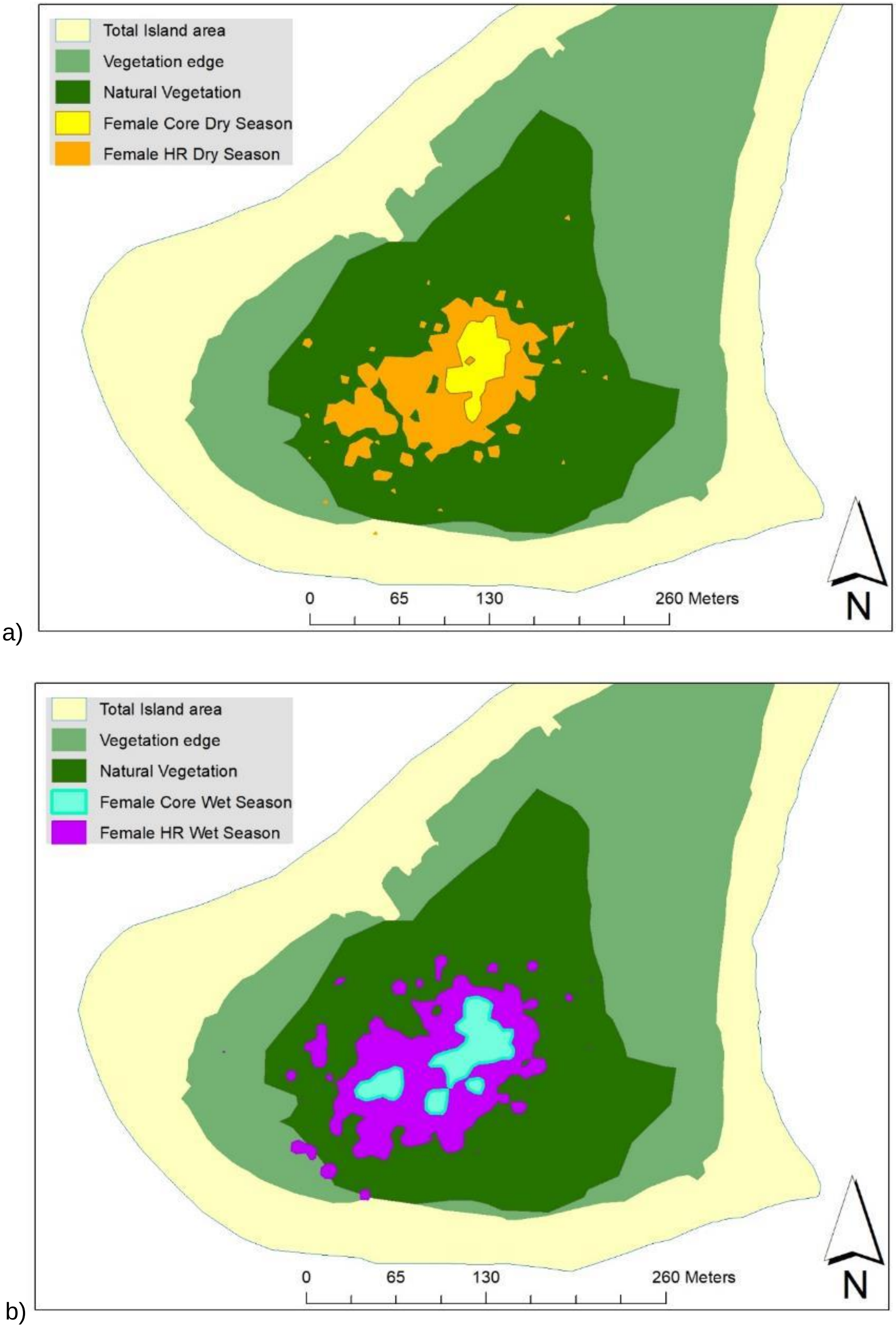


Figure 8-3: Mnemba Island April 2016 to April 2017 female Aders’ duiker home ranges depicting a) dry season home range (95%) and core range (50%); b) wet season home range (95%) and core range (50%).

Table 8-6: Female core and home range size and percentage of Natural vegetation, expressed for annual and seasonal ranges.

Range	Area (m^2)	% of Natural Vegetation 51 189m^2 Natural vegetation
Annual Home range (95%) area	14 008	27%
Home range (95%) area in Dry Season	9 963	19%
Home range (95%) in Wet Season	12 935	25%
Annual Core range (50%) area	2 440	5%
Core area (50%) in Dry Season	1 864	4%
Core area (50%) in Wet Season	2 564	5%

Home range overlap and resource use

A map (Figure 8-4) depicting the spatial layout of the two collared individual's home ranges in relation to the vegetation, infrastructure, focal field tracks and four trail cameras aided in the interpretation of the data. For example, the collared male HR was 'locked in' between the staff village and the rest of the indigenous forest. This geographic restriction could not be discounted as a contributing factor to his smaller home range compared to that of the female duiker.

On average, the female used 5% more of the island's vegetation than the male did. An average HR overlap between the male and female was calculated at 2 424 m^2 (Figure 8-5: Overlap for male and female duiker on Mnemba Island showing a) annual home a). A smaller overlap of 1 300 m^2 was calculated for the dry season compared to 2 225 m^2 for the wet season. No overlap of the core range (50%) was recorded (Figure 8-5: Overlap for male and female duiker on Mnemba Island showing a) annual home b). The collared female was repeatedly seen sharing her space with multiple other duikers, not just with her mate. The collared male and his female were only seen socialising with each other. The collared male was often observed to be rutting with other males in the overlapping area.

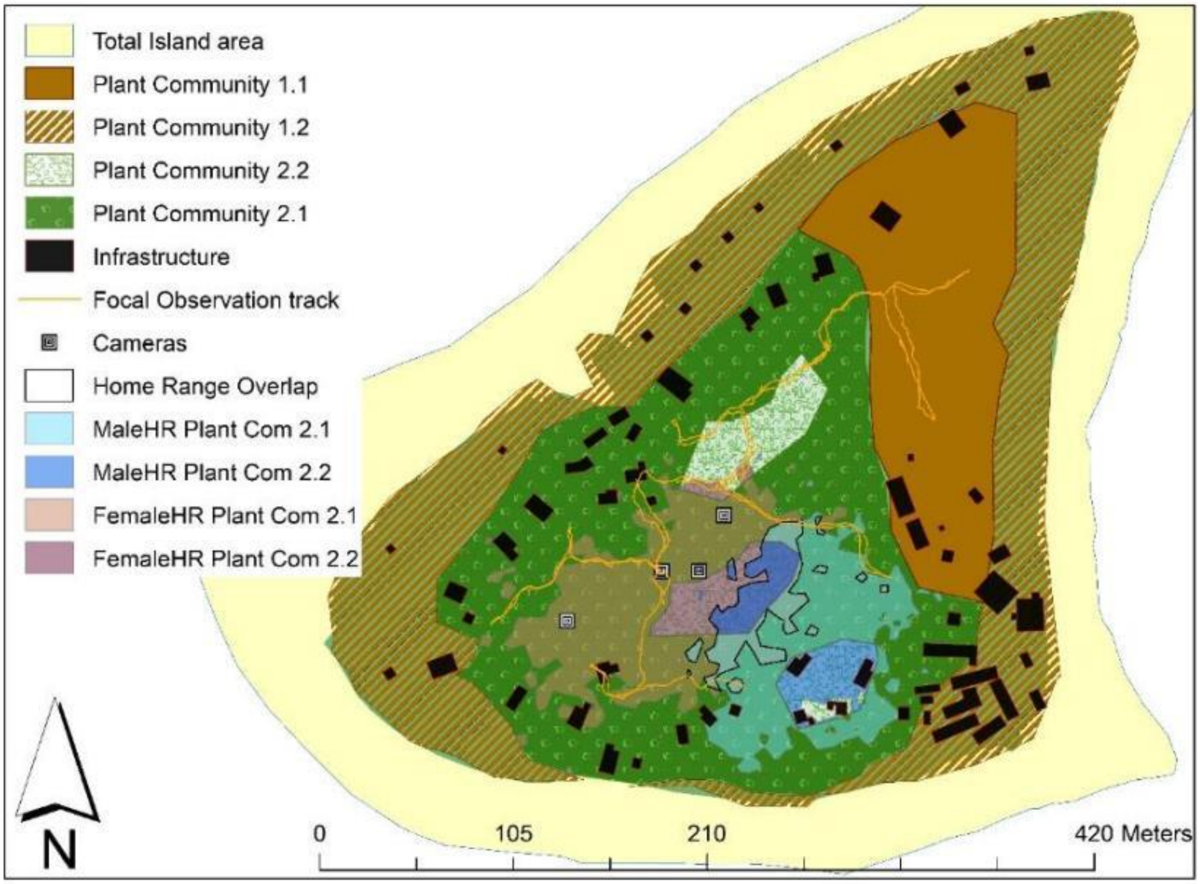
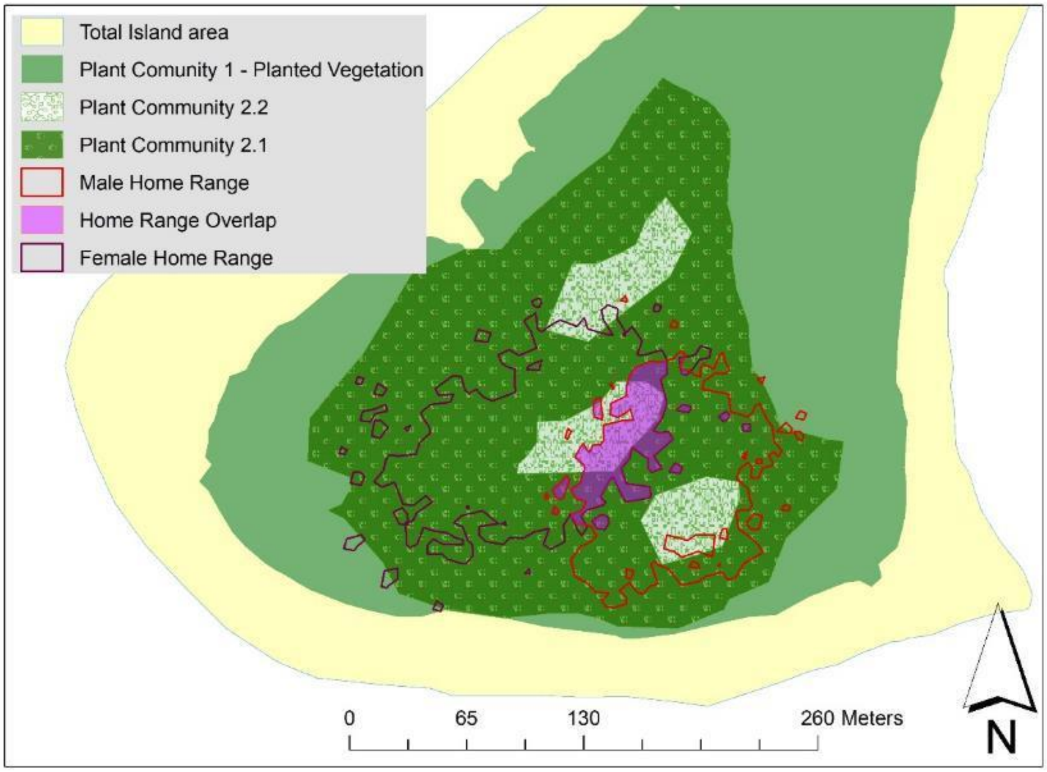


Figure 8-4: Summary home range map for the two collared Aders'duikers on Mnemba.

From the data obtained, it was calculated that two pairs of duikers that occupied the mapped home ranges (thus four duikers), utilised at least 50% of the natural vegetation on the island. Annual home ranges for the collared duiker were overlaid onto the two indigenous plant communities identified in chapter five. Results indicated that the collared female spent 77% of her time in plant community 2.1 and 19% in plant community 2.2. The collared male spent 67% of his time in plant community 2.1 and 24% in plant community 2.2. The remaining 4% of the female's HR was outside the indigenous forest, but still within the ecotone (natural vegetation canopy overlaps with the undergrowth of the coniferous vegetation). The male spent 9% of his time in ecotonal areas. The area size for plant communities 2.1 and 2.2 within the male and female duikers' home ranges are listed in Table 8-7. For ease of comparison, these values were converted into percentages that each community contributed to the total surface area of HR sizes.

a) 

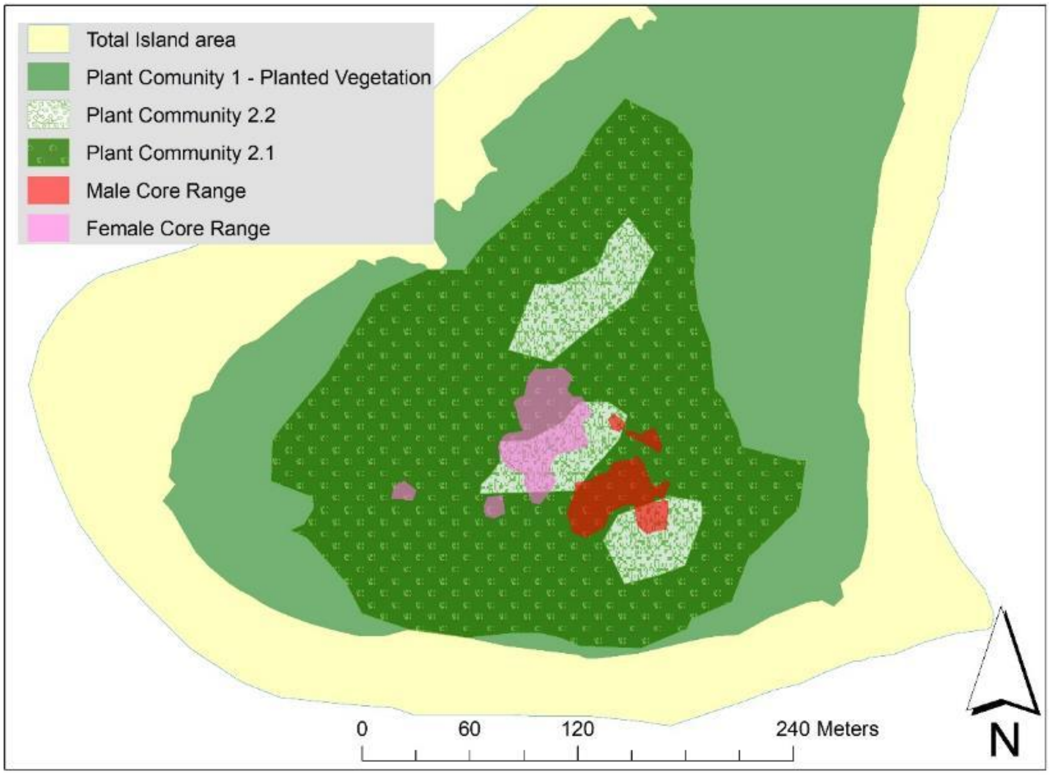
b) 

Figure 8-5: Overlap for male and female duiker on Mnemba Island showing a) annual home range overlap (of 2 424 m^2) and b) no core area overlap.

Table 8-7: Extent (%) of natural vegetation (plant communities 2.1 and 2.2) that made up home range surface area for the male and female collared duikers.

	Female HR size (m^2)	% of HR (14 008m^2)	Male HR size (m^2)	% of HR (11 310 m^2)
Plant Community 2.1	10 770	77	7 565	67
Plant Community 2.2	2 640	19	2 721	24

8.3.2 Daily distances travelled

The annual and seasonal daily distances travelled by the two collared Aders' duikers were calculated from the GPS data points obtained from the tags.

Male average daily distances travelled

On average, the male duiker travelled 354 m per day (±32 m), with seasonal distances averaging 337 m in the dry season and 373 m in the wet season. Monthly differences in average daily distances revealed that the male travelled the furthest in April (mean of 415 m), while the lowest daily average travelled was recorded in August (306 m). A two tailed t-test on daily distances travelled, indicated that overall seasonal differences in the male's distances were significant (t_{340} = 3.048; P<.00). Table 8-8 illustrates average daily distances travelled by the male for each month of the study period.

Table 8-8: Average daily distances (mean) travelled (s = 32 m) by the collared male Aders' duiker, grouped by month, over a twelve-month period on Mnemba Island (April 2016 to April 2017).

	JAN (D)	FEB (D)	MAR (W)	APR (W)	MAY (W)	JUN (D)	JUL (D)	AUG (D)	SEP (D)	OCT (W)	NOV (W)	DEC (W)
Ave Daily distance (m)	325	322	360	415	398	358	353	306	342	326	382	358

Female average daily distances travelled

On average, the female duiker travelled 483m per day (±163 m), with daily distances averaging 528 m in the dry season and 438 m in the wet season. In February, the average daily distance reached the highest mark at 850 m, while May yielded the lowest daily average of 248 m. Figure 8-6 illustrates all average distances per month. Significance in the differences of daily distances travelled in the two seasons was confirmed statistically (t-Test two tailed: $t348$ = 3,326, P < .00).

Table 8-9: Average daily distances (mean) travelled (s = 163 m) for Female Aders' duiker grouped by Months, over twelve months on Mnemba Island. Data collected from April 2016 to April 2017.

	JAN (D)	**FEB (D)**	**MAR (W)**	**APR (W)**	**MAY (W)**	**JUN (D)**	**JUL (D)**	**AUG (D)**	**SEP (D)**	**OCT (W)**	**NOV (W)**	**DEC (W)**
Ave Daily distance (m)	704	850	610	388	248	410	395	376	431	477	456	447

Male and female comparison

The differences in the male and female average daily distance travelled per month over the 12-month study period were tested and found to be significant (t-test: t_{511} = -9,221, P < .00). Based on the test results the assumption was rejected, indicating that the female did in fact have a significantly different annual activity pattern. Figure 8-6 illustrates the differences in average daily distances travelled for each month, for the male and female Aders' duiker. The male and female followed a similar travelling pattern between June and December, but then the female increased travelling distances significantly between January and March, while the male slightly reduced his travelling distances in these months. The female also noticeably reduced her travelling distances during May.

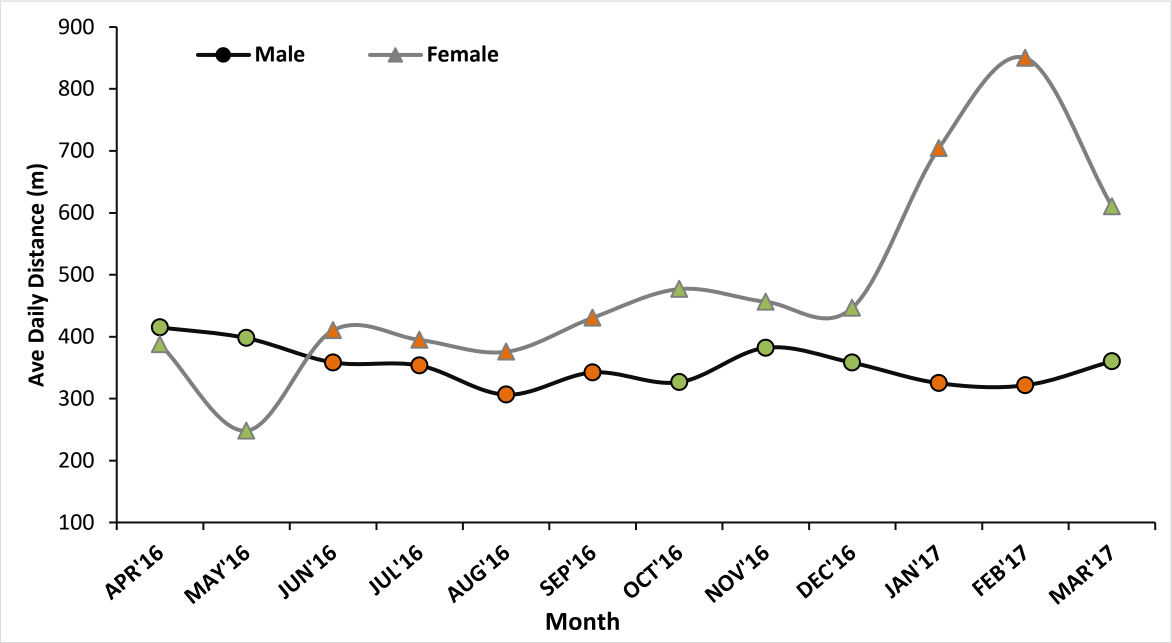


Figure 8-6: Average daily distances travelled, grouped by month, for a male and female Aders' duiker on Mnemba Island.

Diel patterns

The results from the activity budget in 7.4.4 provided evidence of nonconformity to strict crepuscular patterns for the Aders’ duiker population on Mnemba. Given that detailed temporal-spatial data was only obtained from two collared animals, this section of the study could not be generalised to the rest of the island’s duiker population. However, activity peaks from the two duikers were anticipated to follow the findings from the activity budget inquiry in Chapter 7, or at least similar peaks to that from the camera trap study in the Arabuko Sokoko forest in Kenya, where Aders’ duiker showed a crepuscular diel pattern (Amin et al., 2015).

Average seasonal distances travelled by the male duiker, were pooled into eight three-hour time categories to demonstrate the peaks in activity across day and night. Typical crespuscular antelope species would show more activity at first light until mid morning, and again from mid afternoon until just after dark.

Figure 8-7 illustrates the results from the male’s distance data, grouped in time category. On average, a bimodal pattern was observed for the male, with most travelling taking place between 04:00 and 07:00 and between 13:00 and 16:00. Although the wet season showed a more pronounced bimodal (crepuscular) diel pattern, the differences between seasons did not test significant (Wilcoxon rank sum test: n = 8, W = 53; P = 1.80; two-tailed).

The average seasonal distances travelled by the female duiker, pooled into eight three-hour time categories, are illustrated in Figure 8-8. A bimodal diel pattern was observed on average for the female, with most travelling taking place between 13:00 and 16:00 and between 04:00 and 07:00. Both seasons reflected this bimodal pattern. Differences were not significant between seasons (Wilcoxon rank sum test: *n* = 8, *W* = 86; *P* = 0.12; two-tailed).

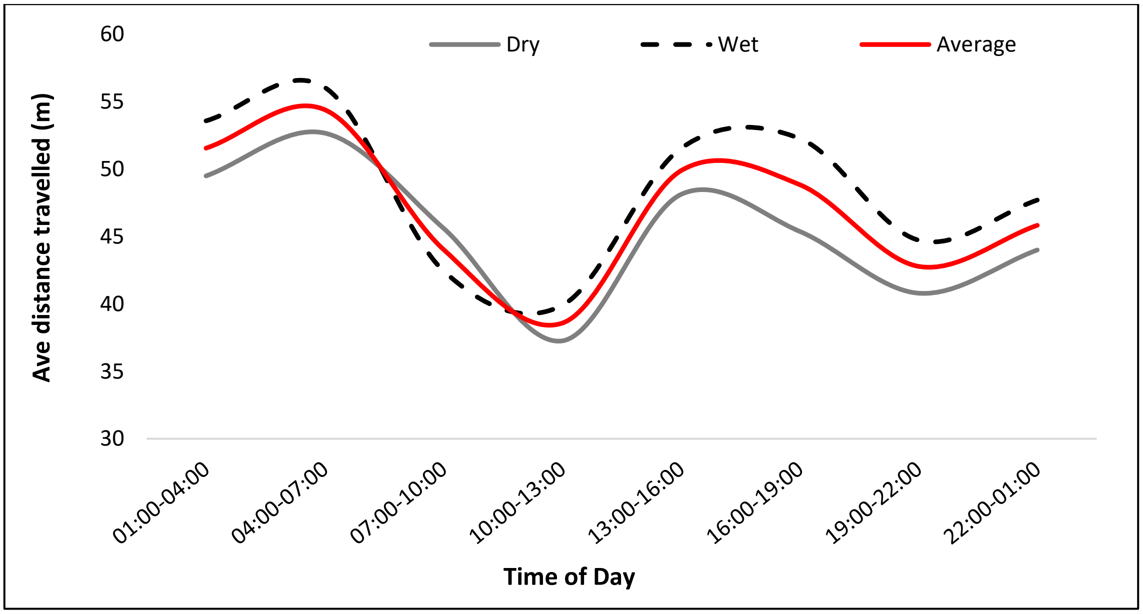


Figure 8-7: Average seasonal distances travelled by a collared male Aders' duiker for eight three-hour time-categories (Braude et al., 2002).

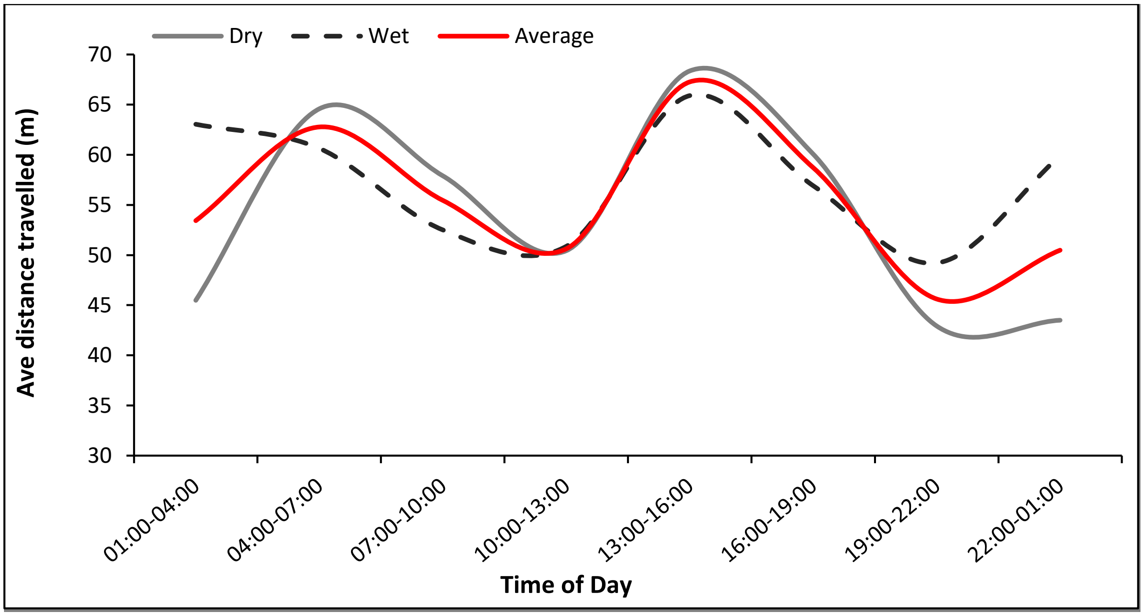


Figure 8-8: Average seasonal distances travelled by a collared female Aders' duiker for eight three-hour time-categories (Braude et al., 2002).

In Figure 8-9 the distances travelled by the male and female for each time category is compared. The graph indicates that in terms of distances travelled, the female was more active in general. However, testing the difference between the male and female's daily pattern did not yield a significant result (Wilcoxon rank sum test *n* = 8, *W* = 86; *P* = 1.99). Both male and female distances travelled followed a similar bimodal curve (Figure 8-9).

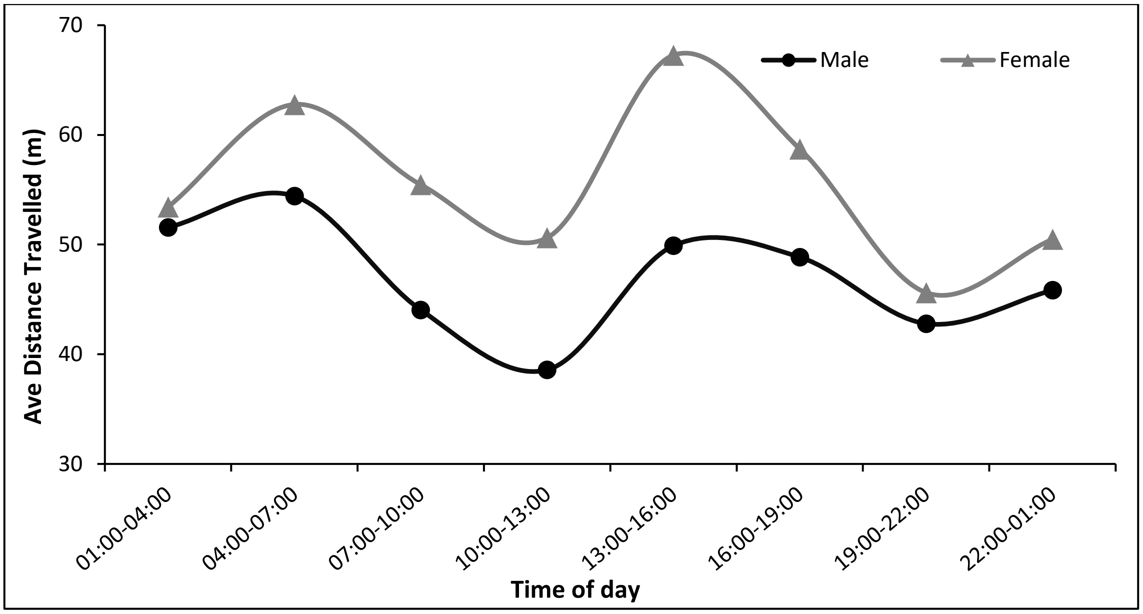


Figure 8-9: Male and female diel patterns based on average distances travelled.

Figure 8-10 combines the seasonal variation within male and female data comparisons, with the between male and female comparison in Figure 8-9.

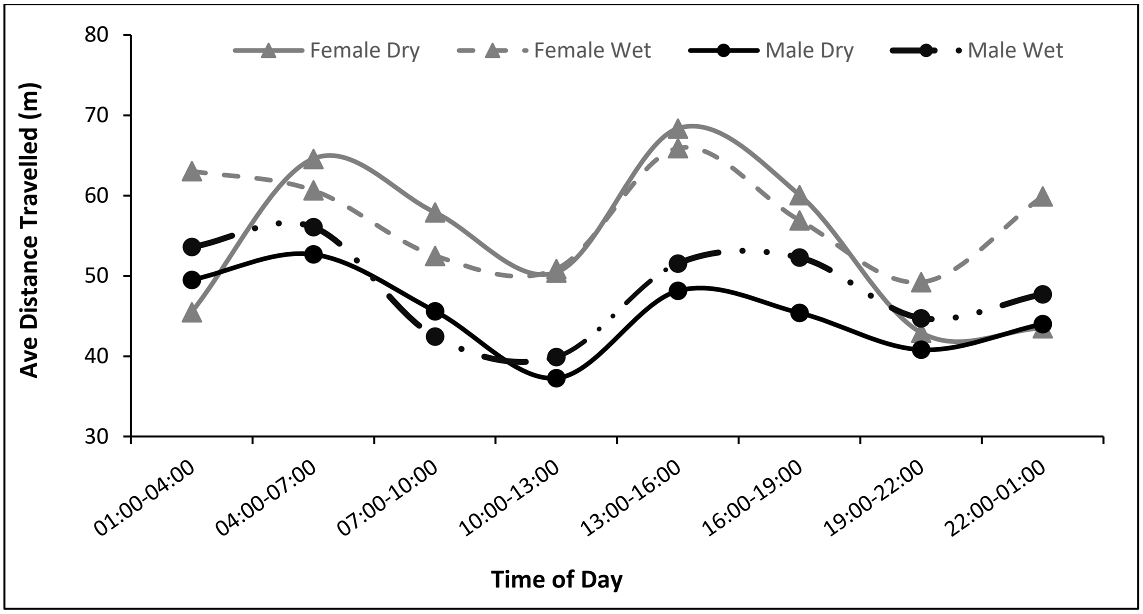


Figure 8-10: Average daily distances travelled grouped by time of day, season and gender.

8.3.3 Carrying capacity

Results for different home range combinations from section 8.3.1, with and without overlap between ranges, were divided into the size of the current suitable habitat on the island. Table 8-10 shows the number of territories extrapolated from the female's annual HR size, the male's annual HR size and from the mean HR size from both animals. The female's larger HR size translated to four potential territories, while the male's smaller HR size suggested five territories. The mean HR also confirmed that the natural habitat could house five territories.

Table 8-10: Spatial carrying capacity, estimated by using average home range sizes (not considering overlap) and the size of the area containing indigenous vegetation (51 189 m^2)

Scenario	Nr of territories	Std Dev
Spatial Capacity from female HR	4	±1
Spatial Capacity from male HR	5	±1
Spatial capacity from combined HR	5	±1

One territory would theoretically provide enough resources for a pair of duikers and their recent offspring. During focal observations, it was found that the collared female shared her HR with her mate and at times with up to six or seven other duikers. Moreover, the HR results indicated an overlap in HR between the collared female and the adjacent collared male (and his mate). Focal observations also suggested that the mate of the collared male ventured further into the collared female's HR. Observations indicate that the collared female occupied a central range on the island, which other duikers would move through or fringe on. Given this level of overlap, the territory estimates were repeated by deducting the average and seasonal overlaps between the collared male and female from their HR sizes, before dividing this into the habitat size. The results provided a seasonal comparison to explain how overlap is influenced by resource availability in the different seasons (Table 8-9). The calculated overlap size was assumed to be an accurate representation of the degree of territory sharing, and thus used to extrapolate to the rest of the natural habitat (Fleming and Calabrese, 2017; Winner et al., 2018).

Potential overlap between territories increases the island's spatial capacity when calculated from the male's average and seasonal HR sizes, as well as from the female's dry season HR size (with overlap). Based on the conditions of the vegetation at the time of investigation, the spatial capacity of the island thus ranges between 4 and 7 territories, depending on season and social interaction.

Table 8-11: Spatial carrying capacity scenarios considering changes in seasonal range overlap.

Scenario	**Nr of territories**	**Std Dev**
Average Spatial Capacity from female HR	4	±1
Wet season Capacity from female HR	5	±1
Dry season Capacity from female HR	6	±1
Average Spatial Capacity from male HR	6	±1
Wet season Capacity from male HR	6	±1
Dry season Capacity from male HR	7	±1

Investigating the possibility of increasing the island's capacity for breeding of Aders' duiker (Ryan and Jamieson, 1998), the spatial capacity for the entire vegetated area was estimated. Should the coniferous vegetation (plant community 1) be rehabilitated to contain indigenous vegetation resembling that of plant community 2, the potential carrying capacity of the island could be increased (Table 8-12).

Table 8-12: Potential spatial carrying capacity scenarios from home range data, estimated using average home range sizes and the size of the area containing all vegetation on the island (106 740 m^2)

Scenario	**Pairs**	**Std Dev**
Potential capacity female data	9	±2
Potential capacity male data	11	±2
Potential capacity average	10	±2

Results suggest that the island could increase capacity to between 9 and 11 territories, almost double the current capacity, should the planted forest be transformed to contain the same structure and diversity of the natural habitat.

8.4 Discussion

The home range investigation for two collared Aders' duikers over a twelve-month period was undertaken to better understand their use of the space available to them on Mnemba Island. Home range sizes were extrapolated to determine the island's spatial carrying capacity for the species (Ryan and Jamieson, 1998), and to evaluate the suggested maximum sustainable harvest density (MSD) derived from population growth modelling in Chapter 6. Due to the small size of the island habitat, by obtaining only two home ranges, it was still feasible to deduct a practical spatial capacity for the duikers on the island. Observations of social and territorial behaviour was used as supporting evidence to interpret the data obtained from the home range inquiry.

The female collared duiker's HR and CR was 1.2 times the size of the male's HR and CR on average. It is suggested that the larger home range size was linked to the female's social group size and frequent interaction with other duikers, but further research is needed to test the link between sociability and home range size (Damuth, 1981; Bowland and Perrin 1995). During focal observations, the collared female's larger home range was seen to overlap with the home ranges of neighbouring duikers. Several other duikers traversed her home range while travelling between resources. The collared female seemed to be related to groups of younger duikers frequenting her range and often interacted with them through grooming and resting together. Based on the Scramble Competition Theory and Resource Dispersion

Hypothesis, a larger home range would be required to accommodate the group dynamic in the female's HR, compared to the male collared duiker who only shared with one female.

The collared male was observed to be less tolerable of overlap and resource sharing in his slightly smaller home range – he was only seen interacting with his paired female. The male's slightly smaller HR could also be ascribed to lower resource abundance, due to the location of his territory – being locked between the staff village and the rest of the forest. The male's HR included 9% ecotonal areas where the coniferous and natural vegetation overlapped, as opposed to the female's 4% overlap with ecotonal zones.

Body size and energy requirements are known to be accurate predictors of home range size, but due to the absence of dimorphism, home range differences between the male and female Aders' duiker on Mnemba were expected to be negligible (Newing 1994; Bowland and Perrin, 1995; Amin et al., 2015). Anatomical results from Chapter 6 indicated that male and female Aders' were similar in size. Behaviour differences between genders would thus more likely be based on factors such as territoriality or reproduction. Territoriality was noticeably more evident among the males on the island. The collared male was observed in frequent territorial bouts with other males on the edges of his home range. During focal and informal observations, the collared male was often nervous and regularly patrolled his territory. The dynamics between social, geographic and resource factors determine home range sizes and consequent overlap. Individual home range sizes reflect the extent to which they are willing to share space and resources with other members of the population, which in turn is based on social relationships and resource dispersion. More research is required to investigate the differences in energy needs between male and female Aders' duiker. Current evidence suggests that gender differences in home range size are inadequate to predict significant differences in energy requirements, at least not in a small, enclosed area.

Both collared duikers adjusted their home range sizes across seasons: dry season HRs were at least 25% smaller than wet season HRs. As was expected, seasonal changes in resource availability influenced range size (Dubost, 1980; Newing, 2001). A larger overlap during the wet season was evidence for increased resource sharing during abundance, as predicted by the Resource Dispersion Hypothesis (Gregory, 2017; McCullough et al., 2000; Johnson et al., 2002). Considering the overall poor condition of the vegetation and some of the duiker males, as well as the incessant fighting between neighbouring males, the spatial capacity of the island was reaching a point where the growth rate would start to slow down from an increase in deaths related to these pressures.

On average, the two home ranges measured on the island were found to span half the natural habitat. By dividing the natural habitat size by the average HR, it was found that in its simplest extrapolation, the island offered four home ranges to four minimum units (pairs of duikers) with one offspring per pair. From the population survey results (Chapter 6) it was proposed that the island had reached a maintenance population density (MD) of 25 Aders' duiker at the time of investigation. Based on population growth modelling, this MD estimate agrees with preliminary approximations for the island (Fiske, 2011; Rivers, 2012). If four main home ranges fit into the natural habitat, a population density of 25 would translate to more than six duikers per range, unless other duiker pairs on the island had smaller ranges. Focal observation data indicated that for more than 34% of observation time, three or more duikers were observed in close proximity to one another (see section 7.3.2). It was also observed that multiple groups and individuals accessed the same resources on the island at different times of the day (Johnson et al., 2002). Although it is accepted that the same resources can be rotated among groups, an increase in population density would undoubtedly place pressure on territorial males, resource availability, and resource quality.

By reducing the density for each of the four proposed home ranges to one pair and one offspring (as opposed to 6 animals per HR at the current density), the proposed Maximum Sustainable Density (MSD) of between 10 and 13 animals from Chapter 6, corresponds with the spatial capacity of the island. This proposed density of the population would produce surplus offspring more regularly without putting pressure on the island's vegetation. The harvesting schedule suggested in Chapter 6 would serve to maintain these home range conditions, prevent overpopulation and reduce fatalities due to infighting.

Based only on the size of orbital glands, Wilson (2001) suggested no territoriality for Aders' duiker. However, from the current study's focal observations of incessant scent marking, violent rutting bouts, and clear nervous displays by individual males when foraging on the edge of another male's territory and preliminary home range investigation, it is hypothesised that Aders' duiker is positively territorial (Harris et al., 1990; McCullough et al., 2000). Kingdon (1982) and Lanshammer (2007) also indicate that the species is territorial. Assuming then that the Aders' is territorial, the spatial analyses of the two duikers on Mnemba would indicate no overlap of core ranges of adjacent home ranges, which was indeed the case.

More interestingly, when the average measured core range size was multiplied by the estimated population density of 25 at the time of the study – the total size equaled 51 100m^2, which is essentially the size of the indigenous forest (51 189 m^2) on the island. This deduction supported the notion that the maximum carrying capacity had been reached at 25 individuals, and that the density of the island had reached a point where no spatial buffer existed between the cores of each neighbouring territory. This explained the constant bouts between neighbouring males and the observed skirmishes between females.

The second part to the home range inquiry was the comparison of daily distances travelled (DDT) by the two collared duikers. The larger home range measured for the female would naturally have caused further distances to be travelled, which was the case. Similar findings were used to infer activity patterns for the Muntjac in China by McCullough et al. (2000) and the Red Deer and North American Elk by Ensing et al. (2014). For the Aders' duiker, DDT was used to evaluate if the two individuals followed a diurnal diel pattern with bimodal peaks, as found for Aders' in Kenya by Amin et al. (2015), and suggested by many other researchers (Estes, 1991; Williams et al., 1996; Kingdon, 1997; Bowman and Plowman, 2002; Amin et al., 2015). It was not surprising when the results revealed that both male and female duiker showed bimodal peaks in the morning and afternoon. The DDT the results further indicated that the female peak resembled a vespertine pattern (more active at dusk), and the male a matutinal pattern (more active in the morning).

As discussed already, sexual dimorphism is principally absent in the Aders' duiker, which suggests that overall activity differences between males and females should not be pronounced. It was thus anticipated that there would be no significant difference in the average DDT between the collared male and female in the study (Ruckstuhl and Neuhaus, 2002). Data were limited to only one male and one female, which made generalisation between genders difficult. However, a large sample size of 3 523 GPS points from the female and 2 696 GPS points from the male collected over twelve months was adequate to conduct a Two-Sample t-Test, assuming unequal variances to test for significant differences in the distance pattern between the two duikers. When the average daily distance travelled (DDT) per month was compared between the male and female, results indicated that the female did in fact have a significantly different annual activity pattern, rejecting the hypothesis that there would be no differences in annual patterns. It is suggested that significant differences between the male and female's annual DDT patterns can be interpreted as differences in foraging strategies and social interaction. More in-depth research is needed to understand gender specific resource requirements, since the effects of pregnancy and lactation could not be evaluated with one male and one female in the sample (Newing 1994; Bowland and Perrin, 1995; Amin et al., 2015).

Along with seasonal differences in home range sizes, it was hypothesized that significant differences would be measured for average daily distance travelled between dry and wet seasons, specifically due to the duikers' response to changes in resource quality, abundance, and distribution (Bowland and Perrin, 1995). It was anticipated that lower resource availability and poorer habitat quality in the dry season would result in duikers displaying overall seasonal patterns i.e., an increase in effort through travelling distance in the dry season. Seasonal differences did test significant for both male and female, but the male travelled less in the dry season, not more. As discussed above, the geographic attributes of the male's home range caused a 'boxing in' effect and potentially prevented him from expanding his range, or alternatively he stayed closer to his CR, protecting his resources and range more in the dry season when resources were low.

In contrast, the average daily distance recorded for the female was significantly higher in the dry season, as was to be expected at a time when duikers had to spend more time travelling between less abundant resource patches. Although the female's HR was physically smaller in the dry season, she spent more time moving about within the smaller range. From focal observations, it was clear that social dynamics affected the female's daily patterns. In section 7.3.2, it was shown that solitary activities were significantly higher during the dry season. As anticipated, these results support the Scrambling Competition Theory and the Resource Dispersion Hypothesis, suggesting that lower resource abundance in the dry season, in combination with a higher population density in the females' HR, increased her travelling efforts (Gregory, 2017; McCullough et al., 2000; Johnson et al., 2002).

Although the absence of dimorphism suggests that males and females should have equal energy requirements, the Aders' duiker female adjusted her seasonal travelling patterns in line with their reproductive activities, which affects energy requirements. The female's average daily distance travelled was 483 m per day (±163 m) while the male's average was 354 m per day with much less variation per month (± 32m). The collared female was visibly pregnant from June to August (Figure 8-6), with conception having occurred sometime before June. During May, the female had a visible drop in her travelling efforts by almost half the average per month. Since gestation length is not known, it can only be speculated that the sudden extreme increase in the female’s travelling efforts between January and March were linked to an increase in energy intake (Ruckstuhl and Neuhaus, 2002). More focused studies are needed to investigate the difference in energy requirements for the species.

By grouping the daily distances travelled for the male and female into eight time-categories in line with typical studies on crepuscularity, it was possible to evaluate the diel patterns and compare the findings for the two collared animals. Results from focal observations were used to complement the results for interpretation. As stated in the introduction to this chapter, it was anticipated that diel patterns for this species would reveal bimodal activity peaks (Amin et al., 2015). GPS data collected for the two duikers confirmed that their activity peaks occurred in the morning and late afternoon / early evening. Like the pattern observed from focal observations, GPS data from the collared male also presented a more matutinal pattern (see Figure 7-11). Likewise, the female’s data resembled the results from focal observations, in that she displayed a more vespertine pattern. Although the sample only consisted of one male and female, making it difficult to test gender differences, the specific diel patterns found between the collard male and female resembled the diel patterns obtained from male and female focal observations from a large sample size, with diel pattern differences statistically testing significant (Chapter 7, section 7.3.1). It is probable that the collared male and female behaved characteristic of the rest of the males and females on the island.

In Chapter 7, section 7.4.4, observed gender differences were potentially explained as habitat segregation strategies, such as 1) forage-selection and 2) indirect scramble-competition hypotheses. The activity peaks at opposite ends of the day for male and female Aders’ duiker are likely due to a strategy to exclude each other from foraging patches and to avoid competition (Prins et al., 2006; Ruckstuhl, 2007). Activity patterns are thus influenced by seasonal variation in food availability, gender specific behaviours and competition strategies. During focal observations it was found that a bimodal diel activity pattern was significantly more pronounced in the dry season (Chapter 7, section 7.3.1). The collared female increased her DDT in the dry season which also led to more pronounced bimodal peaks in the dry season. The collared male had an opposite pattern with weaker bimodal activity peaks in the dry season. Although these peaks are clearly aligned with the gender differences obtained focal observations, a sample size of two animals was not large enough to generalise (results from difference tests were not statistically significant, although the rest of the study provided evidence that the differences in peaks were most likely due to gender specific behaviours.)

8.5 Conclusion

The establishment of Home range and core range sizes was successful. Interpretation of the CR size and lack of CR overlap, in context with focal observations, suggested that the Aders' duiker was postitively territorial. Stress related behavior which included aggression was observed at the current population density, suggesting that the maximum carrying capacity of 25 Aders duiker on the island had been reached, and that direct competition was steering towards equilibrium in population growth, which could be followed by a potential population implosion if not managed. To maintain a healthy breeding population while allowing the vegetation habitat to recover, the MSD between 10 and 13 Aders' duikers was proposed from population growth modelling and agreed with the spatial capacity for four breeding pairs (each occupying one of four home ranges on the island), whilst catering for one offspring per home range. To ensure population viability through maximum birth rate, older breeding pairs should be removed when either one of the males or females reach 8 to 10 years of age and replaced with younger offspring. Introducing new genes into the breeding population is highly recommended when older pairs are replaced. Genetic diversity testing on the current population is also highly recommended to evaluate diversity of the duiker population on the island.

Rehabilitation of the planted forest (*C. cunninghamiana*) to incorporate more natural habitat, would potentially double the carrying capacity of the island. If this is considered as a conservation priority, continual monitoring of the population and growth rates is important to adjust the carrying capacity of the island and optimize breeding of the Aders' duiker.

Results from Chapter 6, along with DDT results from this chapter, show that the Aders' duiker has bimodal annual activity patterns. Differences between the collared male and female suggested that underlying factors in energy requirement for the sexes, including reproduction, social dynamics, and territoriality play an important role in the diel patterns for the species.

CHAPTER 9

DISCUSSION

The following discussion aims to bring together all the different chapters in the context of the study objectives. This chapter was designed in a way that can serve as a summary of the discussions in the different data chapters, in a way that it can be used as a conservation tool to ensure the survival of the Aders' duiker in Zanzibar. No new information is introduced. For detailed discussions on the various inquiries of this study, please refer to Chapter 5 through Chapter 8.

In the context of the ecology of the Aders' duiker population on Mnemba Island, the vegetation survey produced invaluable data to further interpret the antelope's spatial and resource utilisation of the enclosed natural sanctuary. The plant species identified on Mnemba Island corresponded with the expected vegetation for the region. As part of the Zanzibar-Inhambane edaphic coral-rag scrub forest, and perhaps more similar to the undifferentiated forests described in the literature (Mustelin et al., 2009; Kindt et al., 2015; van Breugel et al., 2015a; van Breugel et al., 2015b), the island housed species such as *Grewia glandulosa, Ludia mauritiana, Euclea racemosa, Flueggea virosa, Mimusops obtusifolia, Pandanus kirkii*, *Sideroxylon inerme, Adenia* spp*., Suregada zanzibariensis*, and *Terminalia catappa*. Also typical of Zanzibar-Inhambane transitional rain forest species, *Ficus* spp*., Morinda citrifolia, Cordia subcordata, Gymnosporia heterophylla* and *Trema orientalis* were prolific on the island. *Eugenia capensis* (Figure 5-19, Figure 5-20 and Figure 5-21) was the most abundant species in the indigenous forest on the island. This vegetation composition has ensured the success of the Aders' duiker population on Mnemba island, even throughout decadal changes (Duvat, 2018; Kench et.al. 2014, 2015, 2018; Fonseca et al., 2012) in the shape and size of the island. The indigenous forest (classified during investigation as plant community 2) has generally maintained its size over time, while the *Casuarina cunninghamiana* forest (classified as plant community 1) expanded and retracted with the sedimentation and erosion cycles characteristic of atolls. Essentially the natural forest has been providing the same stable habitat for the Aders' duiker since the beginning of the relocation project, which has led to the increase in the duiker population (Mwinyi and Hija, 2008; Mwinyi et al., 2012). Not only is proliferation of the duiker population on Mnemba island supported by the diversity of flora, but by the habitat conditions that favour the survival of this endemic species. Some of these conditions contrast with the Aders' duiker project on Chumbe Island. A brief investigation into Chumbe's habitat conditions and Aders' duiker project records revealed that although the vegetation composition is adequate, the terrain is very tricky to navigate. Potentially, Chumbe Island poses certain mobility challenges for the species, especially with regards to the large dongas and sharp coral edges which have to be navigated during evasion dashes and territorial bouts. This could be one of the reasons why the population introduced to Chumbe did not increase significantly (Lanshammar, 2009; Mwinyi et al., 2012). Population growth rate simulations from the current study also suggested that the initial breeding group on Chumbe island did not constitute sufficient numbers and ratios of male and female duikers for a positive growth curve to take off.

Mnemba island was found to be subject to its own microclimate, which further contributes to the overall ecology of the duikers on the island. It was expected that Mnemba, as reported of the Eastern side of Unguja, would experience a slightly drier climate than Stone Town (also known as Zanzibar City) (Siex, 2011). It was found that the island received less rain overall than Stone Town did during the annual cycle of observation and lacked the North-east monsoon winds and accompanying short rains or (North-east kaskazi monsoon) during the study period. Concurrently, Stone Town received its projected rainfall during the kaskazi monsoon. Historical weather data for Mnemba island is not available for longitudinal comparisons but concerns from local staff members who have witnessed the “drying” up of the kaskazi monsoon over time, indicated that weather cycles are potentially more volatile on the east coast of Unguja and on Mnemba Island specifically. These climate effects have management implications for the duiker sanctuary. During dry cycles the vegetation condition on the island would support fewer duikers than during wetter cycles. Dry cycles also necessitate water points for dehydrated antelope since a lack of succulent vegetation reduces the moisture intake through their diet (Kingdon, 1997). These climate cycles can be anticipated by incorporating onsite weather monitoring as well as regional monitoring of the El Niño Southern Oscillation (ENSO). Long term monitoring of leaf and fruiting phenology on the island would also provide critical warnings to upcoming pressures on the vegetation and prompt the need for reduction in the core duiker population (Beck, 2008). These management measures are important to maintaining optimum breeding rates and preventing drastic population stochasticity (Baker and Hobbs, 1982; Cook et al., 2001).

This study identified at least 20 of the food plant species selected by the Aders’ duiker on Mnemba Island. A sample study revealed that two plant species made up 64% of the Aders’ duiker’s food selection - *Grewia glandulosa* and *Pisonia grandis.* A regression analyses concluded that Electivity (E_i) and Availability (P_i) for all food species was linearly related, providing evidence that the duikers are adjusting their intake to the availability of resources on the island. Within this context of availability, *Grewia glandulosa* and *Pisonia grandis* were thus the most prominent food species. Food species that were dominant in plant community 2 had the largest total availability (61.73%), as was anticipated from the onset of the study. The sample investigation of types of plant material (or non-plant food items) consumed by the Aders' duiker, revealed that leaves consisted almost half (49%) of all items consumed, while fruits and seeds made up 43% with the remainder consisting of other items. Although there was a trend in the difference between the seasonal volume of the food types consumed, as well as seasonal differences between the phenology of the different food species, these differences did not test significant. These results indicate that there is enough choice of food items for the duikers to select from as and when it becomes available, but during extreme droughts and or overpopulation, this adaption mechanism could reach a limit. For example, Aders' duikers like most duikers are said to obtain all dietary moisture from their food, but observations on Mnemba suggested otherwise. The lack of natural water sources and drier seasons necessitated actual water intake. Signs of dehydration was evident in a few of the duikers and water consumption was observed on more than one occasion. Staff reported that duikers would seek out water from their foot baths, and one duiker was seen around a dripping water pipe at a guest bungalow during a focal observation. These findings practically inform population management and maintenance of the island's carrying capacity, as dry seasons would demand additional water sources to be implemented and if animal condition appears to be severely affected by droughts, ad hoc take-off could be considered.

In order to quantify the carrying capacity of the island, results from the home range (HR) analyses of one male and one female Aders' duiker were extrapolated to the rest of the island and population. The HR analyses indicated that the two pairs combined occupied half the natural forest. This inference was based on the size of the forest, the current plant community delineation, and occupation of one duiker pair per home range. The outcome suggested that the island can spatially support four home ranges for four duiker pairs (or eight individuals with equal gender ratio). However, home range overlap does occur among duiker species, and was also recorded on Mnemba, specifically due to the relatively large population size for such a small island and the lack of migration possibilities. When the core range (CR) results for the two collared duikers were extrapolated, spatial simulation suggested that at the current population size and extent of the natural forest, no overlap between the core ranges was necessary, but that all CRs would fit tightly, side by sides into the size of the forest. Focal and opportunistic observations lead to the conclusion that not all the core ranges provided the necessary resources for the resident duikers to be content, causing home range overlap, in search of resources to be extensive. Challenges between individuals were observed on the boundaries of core ranges, as well as in the larger home range areas that overlapped with neighbouring residents. Aggressive bouts and violent clashes were common during focal and opportunistic observations. Confrontation between the duikers were exacerbated by overpopulation of the island's antelope species (Suni and Aders' duiker) as well as by the lack of vegetation during the drought. Although no direct aggression was recorded between the two species of antelope, the pressures of overgrazing had far-reaching effects within the duiker population. Various attacks were observed between duikers. In one such observation a mature duiker female butted another pregnant female in her stomach, and in another observation a mature duiker male was investigating a young female of a few months, causing her to protect her stomach instinctively from being butted, by pressing it down to the ground. A short time after this observation, the female was found dying of stomach injuries. Other less aggressive conflict indicated that competition for food patches occurred between duikers when resources were under stress. During opportunistic observations, Suni antelope were regularly seen fighting with each other with extreme aggression, and although this is common for the species to engage in territorial bouts, reports of Suni antelope projecting their aggression towards people suggested that the effects of overpopulation and resource stress was reaching a tipping point. The study confirmed that the Aders' duiker display territoriality, and comparable with other duiker species an increase in the intensity of territoriality and aggression during overpopulation was observed (Kranz and Lumpkin, 1982; Bowland and Perrin, 1995).

The population dynamics on Mnemba Island, if left unmanaged, would follow a natural process of stochasticity. At the time of the investigation, the population had reached its maximum and would start to regulate itself through die-off – either through aggression or starvation (Prins et al., 2006; Robinson and Redford, 1991). The decision by the Department of Forestry and Non-renewable resources (DFNRR) in Zanzibar to actively manage the population on Mnemba Island, will benefit the initial aim of the project by increasing the surplus yield and allowing reintroduction of the surplus duiker offspring back onto Unguja. In the current study, a population survey on Mnemba was conducted in collaboration with the DFNRR. The results estimated that the maximum population oscillates around 25 and could under very favourable conditions reach a total of 30 duikers on the island, but with long term detrimental effects on the vegetation and the surplus yield. Any amount of duikers over a maximum 25 would see overlap of core ranges and drastic increases in violent clashes causing unnecessary die-off. The results from the population survey complimented the results from the home range analyses and supported the evidence that the maximum capacity of the island without considering the condition of the duikers or the vegetation peaks at 25 duikers. Furthermore, the aim is not to maintain the maximum density, but to increase productivity and reduce pressure on the vegetation, especially considering recent climatic changes experienced on the island and the sensitive nature of the microclimate. The result of bringing together home range data, population survey results, growth rate data and the aim of the breeding project, was an ecological carrying capacity estimate with Maximum harvest density of 13 duikers for Mnemba Island, which can be maintained by taking off no more than three duikers every two years (Jensen, 1975; Tobler et al., 2013; Plotz et al., 2016; Lyons et al., 2018; Jensen, 1975; Milner-Gulland and Mace, 1998; Morris and Mukherjee, 2000; Rachlow, 2008; Kuzyk et al., 2009; McLachlan and Defeo, 2018; Wildlife Campus, n.d.). The carrying capacity of the island might change in future as the island changes size and shape and the natural vegetation potentially moves into *Casuarina cunninghamiana* forest, or through propagation of stabilising species in the "erosion project" which is in full operation on the island.

As much as carrying capacity depends on spatial and vegetation resources, it is also influenced by the social and behavioural components of the population. As already noted, home range overlap was recorded in the spatial data as well as in the focal observation survey. For example, more than 34% of focal observation time involved three or more duikers in close proximity to one other. Literature suggested that the Aders' duiker lived in pairs, pairs with offspring, or in solitary (Hart, 2001). Although 66% of all foraging behaviour were observed to be solitary or in pairs, social congregation on Mnemba sometimes reached group sizes of up to 9 duikers. It was evident that multiple groups and individuals accessed the same resources on the island at different times of the day (Johnson et al., 2002). Although it is accepted that the same resources can be rotated among groups, once the population reaches a maximum density, pressure on the population reaches the levels of aggression and territorial fatalities such as what were recorded in this study. The need to reduce the population is critical to the success of this program, and the proposed Maintenance density of 13 duikers would still provide ample opportunity for social interaction while maintaining low impact on the vegetation.

The close proximity of so many Aders' duikers in an enclosed area provided a unique opportunity to study the social interaction and resource utilization for this species. Duikers have a unique diet among ungulates – affording them the opportunity to selectively seek out food items that are nutrient rich and less fibrous and alternating these foraging bouts with times of rest and rumination (Hart, 2001; Shipley, 2005). On average, the Mnemba duikers spent 39.4% of their daylight hours seeking out these food items, meeting their metabolic requirements through the adapted diet even under stressed conditions (Barrett, 2005; Jaman and Huffman, 2008). At maximum population density, one could have expected the duikers to be foraging for much larger portions of their day when resources were scarce, but the highly adapted diet, successful forage-selection and scramble competition strategies ensured that less than half their daytime hours were spent on foraging. A particular result that confirmed habitat segregation as a key strategy employed by the duiker population on Mnemba, was the outcome of gender differences in the activity peak data from focal observations. Males and females peaked in activity during opposite ends of the daylight hours. This strategy potentially contributed significantly to a reduction in competition for food patches and minimizing the effects of overpopulation on the carrying capacity for the island (Prins et al., 2006; Ruckstuhl, 2007). Additional activity pattern data was obtained from the high-resolution GPS tracking of one male and one female duiker over 12 months. These results added evidence that the female duikers' showed a vespertine peak (more active at dusk) while the male's demonstrated a matutinal peak (more active in the morning). The GPS tracking data serves as a valuable source of verification for the focal observations, and also serves to fill in the activity gaps during night-time hours when focal observations were not possible. The support for gender differences in activity peaks strengthened the study's findings that the Aders' duiker employs partial sexual segregation as a gender-based competition strategy. These findings raised further questions about underlying factors in energy requirements between male and female Aders' duikers. Reproduction cycles, social dynamics and territoriality played an important role in the differences in diel patterns for the species. Although it was concluded that both male and female Aders' duiker displayed bimodal diel patterns in dry and wet seasons, gender differences in energy requirements need to be investigated to fully understand the context of the current findings.

Seasonality further influenced fine scale behaviour of the duikers and was found to amplify the differences between males and females. Both focal and spatial data supported the trend that female Aders' duiker had a more pronounced bimodal diel pattern in the dry season, while the male duiker demonstrated weaker bimodal activity peaks. Dry seasons also indicated higher rates of solitary foraging. Extreme droughts could potentially reduce social cohesion and gathering, which in turn could exacerbate low rates of reproduction caused by low rainfall and forage quality (English et al., 2012; Ogutu et al., 2014). Yet, non-foraging congregation of large groups was noted in both dry and wet seasons, which shows that social cohesion is a very important factor in the social dynamic of the Aders' duiker.

Under the conditions of overpopulation and resource degradation, the resilient duikers still demonstrated the full repertoire of social, sexual and foraging behaviours that were reported in the multiple resources available on many other duiker species (as referenced in the preceding chapters). For example, the Mnemba duiker population was sedentary half the time during daylight hours, which is very much in line with findings of forest duikers in a much larger habitat (Newing, 1994). These activity patterns also agreed with the proposed foraging strategies and energy use for monomorphic antelope of the specific body size (between 7 and 12 kg) (Ansell, 1950; Dubost, 1980; Newing, 1994; Jarman, 1974; Skinner and Smithers, 1990). When Mnemba's duikers were not foraging, ruminating or resting, they were engaging each other (6.7% of the time), being vigilant (5.6% of the time), marking and patrolling territories (2.8% of the time) or travelling between areas (2.4% of the time).

The findings on Mnemba Island are interpreted within the specific conditions of the island, such as no natural predators or persecution and a limited and enclosed habitat. The lack of predators and hunting on Mnemba Island was noted as a key component in the success of the breeding project.

CHAPTER 10

CONCLUSION

The expectations of the Department of Forestry and Non-renewable Resources in Zanzibar, and the AndBeyond Safaris Conservation Management responsible for the management of Mnemba Island Lodge, was to establish a practical guide for managing the Aders' duiker population on the small island in such a way that the vegetation could recover from overpopulation and the island could sustain a suitable sized population indefinitely. The current study set out to address this problem through a series of investigations over an annual cycle, that would provide ecological data for the duiker species and a baseline for the vegetation habitat, which can be further translated into a scientific based management plan. Within the constraints of an isolated site location, the data collected during the field investigation provided ample information to fulfill the objectives of the study.

The baseline assessment for the island's vegetation habitat produced a list of 91 plant species. The classification of the species and growth forms resulted in four sub plant communities from two main communities, which roughly followed the physiognomic-physiographic delineation of the natural forest and the established pine forest (*Casuarina cunninghamiana*) on the sandy cay. It was concluded that Mnemba Island followed diversity trends of small sandy cays in the Indian Ocean, with species composition specific to the Zanzibar-Inhambane coastal forest mosaic (or Swahili coastal forest), as well as from small islands in close proximity to Madagascar, India and the African coastline (Nahonyo et al, 2002; Kindt et al., 2015; van Breugel et al., 2015a; van Breugel et al., 2015b; Yu and Lei, 2001; Losos et al., 2010). It was hypothesized that plant communities within the pine forest (*Casuarina cunninghamiana*) would show a lower species diversity than plant communities in the natural forested area. Differences in species diversity between the sub-communities tested statistically significant, and the trend showed a higher diversity in the natural forest, yet the overall difference between the two main communities did not test significant.

While the most abundant species on the island was *Eugenia capensis*, the most interesting species identification on the island was that of the *Pisonia grandis*. Numerous large specimens were found on the island, contributing to soil quality by stimulating the formation of phosphate and a peat like fermentation layer (Walker, 1991). This highly adaptable, drought tolerant species is important in all aspects of the island's ecology, including seabird breeding, soil health and particularly as a food source for Aders' duiker (Sharples and Cairney, 1998;

Woodroffe and Morrison, 2001; Batianoff et al., 2010; Walker, 1991). Mr. Roy Gereau, assistant curator at the Missouri Botanical Garden and the Tanzania Program Director, confirmed that apart from the current identification on Mnemba Island only two other records for this species along the East coast of Africa exist so far.

Once the vegetation survey provided the necessary baseline information for Aders' duiker habitat, the establishment of a carrying capacity for the island was crucial. This part of the study was fulfilled conducting a twelve-month GPS tracking survey of two individuals (one male and one female) on the island, a mark-recapture population survey to estimate the maximum density that had been reached over the ten years of proliferation, and the collection of instantaneous birth and death data over twelve months. Home range data from the tracking survey revealed that spatially, the island's natural vegetation could house eight mature duikers comfortably, without home range overlap between pairs or taking into account young offspring sharing these ranges. Range data also revealed that 25 core ranges theoretically fit side by side into the natural vegetation, without any overlap, at the time of the investigation. Population estimates and growth rate simulations confirmed that the duiker population had reached the size of 25 individuals, and that the growth rate was nearing equilibrium, approaching the island's maximum carrying capacity. The ecological carrying capacity was calculated form the population data and was set at a Maximum Sustainable harvest density of 13 duikers for the island's current extent of natural vegetation.

To complement the population and spatial data, an in-depth focal observation survey was completed over several field visits throughout the year. A comprehensive ethogram was developed and a fine-scale time-activity budget revealed that the duikers spent half their daylight hours being active of which 80% of the activity was dedicated to foraging (thus 40% of their daylight hours spent on foraging). The time activity budget in combination with the GPS tracking data confirmed the hypothesis that this duiker species would adhere to a bimodal diel pattern with crepuscular peaks. A significant difference in the male and female activity pattern however indicated that although both genders adhered to a crepuscular pattern, female duikers were slightly more active at dusk (a vespertine peak) and males more active at dawn (a matutinal peak). These findings have very important ecological implications for further research into the species' foraging and competition strategies. It also directs us to a related hypothesis set at the onset of the study: to test if this monomorphic antelope species shares the same foraging patterns between males and females (Gross et al., 1996, Ginnett and Demment, 1997; Bergman et al., 2001; Neuhaus and Ruckstuhl, 2004). The study found that Aders' duiker males spent 51% of their annual activity budget on foraging, while females only dedicated 35% of their annual activities to foraging. At first, this trend was not proven significant, but further analyses of the data produced significant differences between the genders across the different seasons. Recording these key seasonal differences in Aders' duiker ecology was one of the main objectives of the study, as was establishing the micro-climatic trends of the island. Weather data collected during the study provided important background information for interpreting such seasonal differences and for preparing a population management plan. Weather data analyses showed that the island is more sensitive to climate changes and at the time of the study, experienced much drier conditions than Unguja, especially compared to the west coast of Zanzibar island.

The study concluded that the monomorphic hypothesis for foraging patterns for this species could not be confirmed as the data showed that Aders' duiker females foraged more during the wet season compared to the dry season. This pattern was reversed for the Aders' duiker males. Additional seasonal data for all activity behaviour categories across seasons indicated that males were significantly much more active in the dry season with females displaying the opposite trend. Such gender and seasonal variation in behaviour is consistent with patterns for dimorphic antelope species (Muposhi et al. 2013). It was hypothesized that the effect of the seasonal differences would directly impact the home range sizes of the duikers (Dubost, 1980; Newing, 2001). This was indeed evident for both the GPS collard male and female duikers, with dry season home ranges being 25% smaller than wet season home ranges. An increase in home range overlap was also found to take place during the wet season. Both these findings were ascribed to the abundance of resources during the wet season as is explained by the Resource Dispersion Hypothesis (Gregory, 2017; McCullough et al., 2000; Johnson et al., 2002).

The goal to assess the duikers' food species was successful and the island was confirmed to be housing enough food species for the duikers to adjust their food selection according to the phenology of these plant species and still meet their metabolic intake throughout wet and dry seasons. The study also aimed to assess any direct and aggressive competition between the Aders' duiker and Suni antelope – no such evidence was recorded, but the pressure of overpopulation was observed in the form of aggressive territoriality among individuals of the same species. Broad recommendations for the management of the population and for further research would improve the surplus yield of duikers on Mnemba Island, to serve as an important breeding population for repopulating protected forest habitats on Unguja. The following recommendations should be considered:

- Continue erosion project to ensure the outside rim of the island becomes more stable and include additional rehabilitation of the pine forest (*C. cunninghamiana*) from the inside edge outward, where the natural forest and the pine forest meets, in order to increase the island's carrying capacity for the Aders' duiker.
- Remove the fast-breeding Suni antelope population in its entirety.
- If possible, move support structures for the hotel, such as staff accommodation, scuba tank compressor plant, laundry, and storeroom onto Unguja at Muyuni.
- Set up a committed effort to document all population growth records such as births, deaths, take-off, and new duikers that are introduced to the population.
- Reduce the duiker population to thirteen individuals while maintaining at least four pairs on the island. Remove three individuals every two years while maintaining breeding pairs and calculate the population growth based on removal capture survey data.
- Remove older pairs when duikers reach 8 to 10 years of age and replace with young duikers from Unguja.
- Record individual duiker data and collect genetic samples for diversity testing. Microchip all duikers on the island where possible. Ear tags are also an option for ease of identification and further research.
- Set up long term research projects for collecting information on breeding peaks, gestation periods and gender ratios.
- Establish a long term in-situ weather station for collection of climate data as part of a comprehensive climate change study.
- Where possible, initiate further research into the Aders' duiker's nutritional requirements and set up strategic small water points during the dry seasons.

The anticipated and any additional findings from the Aders' duiker ecology on Mnemba island closely reflected the findings of previous studies of Aders' duiker and other duiker species across Africa. The behavioural repertoire of the species agreed fully with studies of wild duikers. It is thus proposed that the findings from the current study could serve as a baseline for future captive and re-introduction projects of the species. Research findings could be extrapolated to other areas in and around Zanzibar, specifically when identifying additional natural habitat sanctuaries.

REFERENCES

ADCOCK, K. (2001a). Announcing the RMG Carrying Capacity model version 1.0 for black rhinos. *Pachyderm*, Jan—June: 99–100.

ADCOCK, K. (2001b). *RMG Black rhino carrying capacity model version 1.0: user's guide (evaluation draft)*. Harare. SADC Regional Programme for Rhino Conservation, pp. 1–64.

ADCOCK, K. (2009). *Status and Management of Black Rhino in South Africa and Namibia: April 2005 to March 2006*. Pietermaritzburg, South Africa. Rhino Management Group, 117 p.

AESCHLIMANN., A. (1963). Observations sur Philantomba maxwelli (Hamilton-Smith) une antilope de la foret eburneene. *Acta Tropica*, 20, pp. 341-368.

AFRODAD (2011). *Ecological debt: The case of Tanzania.* [Online] African Forum and Network on Debt and Development. Harare, Zimbabwe. Available: https://media.africaportal.org/documents/ecodebt_tanzania_final.pdf

AGRESTI, A. (2007). *An introduction to categorical data analysis*. Hoboken, NJ: Wiley.

AHRENDS A. (2005). *Patterns of degradation in lowland coastal forests in Coast Region, Tanzania*. Disseration (MSc). Ernst-Moritz-Arndt University of Greifswald.

AHRESTANI, F., HEITKONIG, I., and PRINS, H. (2012). Diet and habitat-niche relationships within an assemblage of large herbivores in a seasonal tropical forest. *Journal of Tropical Ecology*, 28, pp. 385-394.

AHUMADA, J., SILVA, C., GAJAPERSAD, K., HALLAM, C., HURTADO, J., MARTIN, E., MCWILLIAM, A., MUGERWA, B., O'BRIEN, T., ROVERO, F., SHEIL, D., SPIRONELLO, W., WINARNI, N. and ANDELMAN, S., (2011). Community structure and diversity of tropical forest mammals: data from a global camera trap network. *Philosophical Transactions of the Royal Society B, Biological Sciences*, 366(1578), pp. 2703-2711.

AIRY SHAW, H., (1952). On the Distribution of *Pisonia grandis* R. BR. (Nyctaginaceae), with Special Reference to Malaysia. *Kew Bulletin*, 7(1), p.87.

ALI, M. and SULAIMAN, M. (2006). *The causes and consequences of informal settlements in Zanzibar. Shaping the Change*, XXIII FIG Congress. Munich, Germany. October 8 – 13, 2006. pp. 1-17.

ALTMANN, J., (1974). Observational Study of Behavior: Sampling Methods. *Behaviour*, 49(3-4), pp.227-266.

AMIN, R., ANDANJE, S., OGWONKA, B., ALI, A., BOWKETT, A., OMAR, M. and WACHER, T., (2015). The northern coastal forests of Kenya are nationally and globally important for the conservation of Aders’ duiker Cephalophus adersi and other antelope species. *Biodiversity and Conservation*, 24(3), pp. 641-658.

ANDANJE S. and WACHER. T. (2004). *New Aders' duiker population*. IUCN/SSC Antelope Specialist Group. Gnusletter 23 (4-5)

ANDANJE S., ANDANJE, S., AMIN, R., BOWKETT, A., and WACHER, T. (2011b). *Update on the status of Aders’ duiker and a significant range extension for blue duiker on the east African coast*. IUCN/SSC Antelope Specialist Group. Gnusletter, 29(1).

ANDANJE, S., BOWKETT, A., AGWANDA, B., NGARUIYA, G., PLOWMAN, A., WACHER, T. and AMIN, R., (2011a). A new population of the Critically Endangered Aders’ duiker Cephalophus adersi confirmed from northern coastal Kenya. *Oryx*, 45(3), pp. 444-447.

ANDBEYOND (2014). *Mnemba Island - Historical changes in the size and shape of the island from 1973 to 2014*. AndBeyond Safaris. Sandton.

ANDBEYOND (2015). *AndBeyond and Sustainability Brochure*. AndBeyond Safaris. Sandton

ANSELL, W., (1965). Standardisation of Field Data on Mammals. *Zoologica Africana*, 1(1), pp. 97-113.

APIO, A. and WRONSKI, T. (2005). Foraging behaviour and diet composition of bushbuck (Tragelaphus scriptus Pallas, 1766) in Queen Elizabeth National Park, western Uganda. *African Journal of Ecology*, 43, pp. 225–232.

APLIN, D. (1998). *The report of the botanical survey of food plants of the Aders Duiker, (Cephalophus adersi) for its proposed reintroduction on Chumbe Island Nature Reserve, Zanzibar, East Africa*. February 1998. WWF Project AT104. UK: World Wide Fund for Nature.

ARCHER A. (1994). *A survey of hunting techniques and the results thereof on two species of duiker and the suni antelopes in Zanzibar.* Commission for Natural Resources, Zanzibar

ARCHER, A. and MWINYI, A. (1995). *Further Studies on the Two Duiker Species and the Suni Antelope in Zanzibar*. Ministry of Agriculture, Livestock and Natural Resources, Zanzibar.

ARTHURTON, R., BRAMPTON, A., KAAYA, C. and MOHAMED, S. (1999). Late Quaternary Coastal Stratigraphy on a Platform-Fringed Tropical Coast: A Case Study from Zanzibar, Tanzania. *Journal of Coastal Research*, 15(3), pp. 635-644 .

AUNG, M., MCSHEA, W., HTUNG, S., THAN, A., SOE, T., MONFORT, S. and WEMMER, C. (2001). Ecology and social organization of a tropical deer (*Cervus eldi thamin*). *Journal of Mammalogy*, 82(3,: pp. 836–847.

Australian Government (2017). *NVIS Fact sheet MVG 8 – Casuarina forests and woodlands*. [Online] Department of Environment and Heritage Protection. Commonwealth of Australia. Available: environment.gov.au

BAKER, D. and HOBBS, N., (1982). Composition and Quality of Elk Summer Diets in Colorado. *The Journal of Wildlife Management*, 46(3), p.694.

BALDUS R. (2004). *Africa's most endangered antelope lives in Zanzibar*. Gnusletter - Antelope Specialist Group 23, pp. 5-6.

BAÍLLOA, A. and CHACÓN, J. (2018). A survey and a new selection criterion for statistical home range estimation. *Quantitative Methods*, arXiv:1804.05129.

BALLOU, J., LEES, C., FAUST, L., LONG, S., LYNCH, C., LACKEY, L., and FOOSE, T. (2010). Demographic and genetic management of captive populations. *Wild Mammals in Captivity: Principles and Techniques for Zoo Management*. pp. 219-252.

BALLOU, J.D. and FOOSE, T.J. (1996). Demographic and genetic management of captive populations. In: D.G. Kleiman, S. Lumpkin, M. Allen, H. Harris, and K. Thompson . (Eds.);. *Wild mammals in captivity*. Chicago University of Chicago Press, USA. pp. 263–283.

BARNES R., SMITH D., BARNES D. and GERLACH J. (2008). Variation in the distribution of supralittoral vegetation around an atoll cay: Desroches (Amirante Islands, Seychelles). *Atoll Research Bulletin*, 565, pp.1-6.

BARNES, R. (2002). The bushmeat boom and bust in West and Central Africa. *Oryx,* 36, pp. 236-242.

BARRETT, A. (2005). *Foraging ecology of the vervet monkey (Chlorocebus aethiops) in mixed Lowveld bushveld and sour Lowveld bushveld of the Blydeberg Conservancy, Norther Province, South Africa*. Dissertation (Masters degree), University of South Africa.

BARRETT, A. (2009). *Spatial and temporal patterns in resource dispersion and the structure of range use and co-existence in a social omnivore Chlorocebus aethiops*. Dissertation (PhD). University of South Africa.

BARRETT, A., BROWN, L., BARRETT, L. and HENZI, P., 2010. A floristic description and utilisation of two home ranges by vervet monkeys in Loskop Dam Nature Reserve, South Africa. *Koedoe*, 52(1), pp. 1-12.

BARRETT, A., BROWN, L., BARRETT, L. and HENZI, S. (2006). Phytosociology and plant community utilisation by vervet monkeys of the Blydeberg Conservancy, Limpopo Province. *Koedoe,* 49(1), pp. 49–68.

BARUA, S. and PANHWAR, S. (2017). Maximum Sustainable Yield Estimates of Offshore Finfish in Bangladesh Marine Waters Using Non-Equilibrium CEDA Package. *Current Trends in Biomedical Engineering & Biosciences*, 2(4), pp. 1-6.

BATIANOFF, G., NAYLOR, G., FENSHAM, R. and NELDNER, V. (2010) Characteristics of Coral Cay Soils at Coringa-Herald Coral Sea Islands, Australia. *Pacific Science*, 64(2), pp.335–347.

BEASLEY, T. and SCHUMACKER, R. (1995). Multiple regression approach to analyzing contingency tables; Post hoc and planned comparison procedures. *Journal of Experimental Education*, 64, pp.79-93.

BECK, H. (2008). Tropical Ecology. *General Ecology*, 10, pp. 3616 - 3623.

BEECKMAN, H., GALLIN, E., and COPPEJANS, E. (1990). *Indirect gradient analysis of the mangal formation of Gazi Bay (Kenya),* 54, pp. 57-72.

BEENTJE, H. (1990). *Botanical assessment of Ngezi Forest, Pemba. Prepared for the Zanzibar Forestry Development Project of FINNIDA and the Finnish National Board of Forestry* - Unpublished report. Zanzibar, CHICOP.

BEIER, P. and MCCULLOUGH, D. (1990). Factors influencing white-tailed deer activity patterns and habitat use. *Wildlife Monographs*, 109, pp. 3 – 51.

BENNIE, J., DUFFY, J., INGER, R. and GASTON, K. (2014). Biogeography of time partitioning in mammals. *Proceedings of the National Academy of Sciences of the United States of America*, 111(38), pp. 13727-13732.

BERCOVITCH, F. and ZIEGLER, T. (1989). Reproductive strategies and primate conservation. *Zoo Biology*, 1, pp. 163-169.

BERGMAN, C., FRYXELL, J., GATES, C. and FORTIN, D. (2001). Ungulate foraging strategies: energy maximizing or time minimizing? *Journal of Animal Ecology*, 70, pp. 289–300.

BIRDLIFE INTERNATIONAL (2018). *Important Bird Areas factsheet: Jozani Chwaka Bay National Park*. www.birdlife.org [Accessed: 22 November 2018]

BIRDLIFE INTERNATIONAL (2019). *Country profile: Tanzania*. [Online] Birdlife International. Available: www.birdlife.org/datazone/country/tanzania. [Accessed: 26 May 2019]

BLACK, E., SLINGO, J. and SPERBER, K. (2003). An Observational Study of the Relationship between Excessively Strong Short Rains in Coastal East Africa and Indian Ocean SST. Monthly Weather Review, 131(1), pp.74-94.

BLAKE, S. and ROFF, C. (1988). *Honey Flora of Queensland*. Brisbane, Australia: Department of Primary Industries.

BLANCHARD, P. and FRITZ, H., (2008). Seasonal variation in rumination parameters of free-ranging impalas Aepyceros melampus. *Wildlife Biology*, 14(3), pp. 372-378.

BLARNEY, A. and JACKSON, W. (1956). The elusive little pin. *African Wildlife*, 10, pp. 295-299.

BOBO, K., KA MGAING, T., KA MDOU E., DZEFACK, C., (2015). Bushmeat Hunting in Southeastern Cameroon: Magnitude and Im pact on Duikers (Cephalophus spp.) *African Study Monographs*, Suppl. 51, pp. 119–141.

BOCHA, G. (2017). *How Boni Forest became the warzone it is today*. [Online] Nairobi: Daily Nation - 19 July 2017. Available: https://www.nation.co.ke/news/Boni-Forest-the-inside-story/1056-4022288-2kjqr4z/index.html [Accessed: 14 September 2018]

BODMER, R. and ROBINSON, J. (2004). *Evaluating the sustainability of hunting in the nootropics*, Chapter 19. In: SILIVIUS, K, BODMER, R. and FRAGOSO, J. (eds). People in Nature. Wildlife Conservation in South and Central America. Columbia University Press.

BODMER, R., FANG, T., MOYA, I., and GILL, R. (1994). Managing wildlife to conserve amazonian forests: Population biology and economic considerations of game hunting. *Biological Conservation*, 67(1), pp.29-35.

BOLAND, D., MONCUR, M. and PINYOPUSARERK, K. (1996): *Review of some floral and vegetative aspects to consider when domesticating Casuarina*. In: PINYOPUSARERK, K., J. W. TURNBULL and S. J. MIDGLEY (eds.) Recent *Casuarina* Research and Development, Proceedings of the Third International *Casuarina* Workshop Da Nang, March, 1996. Vietnam 4–7, pp. 17–25.

BONNELL, T, REYNA-HURTADO, R. and CHAPMAN, C. (2011). Post-logging recovery time is longer than expected in an East African tropical forest. *Forest Ecology and Management*, 261, pp. 855–864.

BOOTH V., CHAPMAN K. And WALMSLEY B. (2003). *Tanzania - Country Report*. [Online] SAIEA. Available: www.saiea.com/saieabook/tanzania1.pdf [Accessed: 20 November 2018]

BORCHERS, D., BUCKLAND, S. and ZUCCHINI, W., (2002). *Estimating Animal Abundance. Closed Populations*. Statistics for Biology and Health. London: Springer-Verlag.

BOWKETT, A., JONES, T., ROVERO, F., NIELSEN, M., DAVENPORT, T., HAWKINS, D., PLOWMAN, A. and STEVENS, J. (2014). Distribution and genetic diversity of the Endangered Abbott's duiker Cephalophus spadix in the Udzungwa Mountains, Tanzania. *Endangered Species Research*, 24(2), pp. 105-114.

BOWKETT, A., PLOWMAN, A., STEVENS, J., DAVENPORT, T. and VAN VUUREN, B. (2009). Genetic testing of dung identification for antelope surveys in the Udzungwa Mountains, Tanzania. *Conservation Genetics*, 10(1), pp. 251-255.

BOWKETT, A., ROVERO, F., and MARSHALL, A., (2008). The use of camera-trap data to model habitat use by antelope species in the Udzungwa Mountain forests, Tanzania. *African Journal of Ecology*, 46(4), pp. 479-487.

BOWLAND, A. and PERRIN, M. (1998) Food habits of blue duikersand red duikers in Kwazulu-Natal, South Africa. *Lammergeyer*, 45, pp. 1–16.

BOWLAND, A. (1990). The response of red duikers *Cephalophus natalensis* to drive counts. *Koedoe,* 33, pp. 47–53.

BOWLAND, A. and PERRIN, M. (1995). Temporal and spatial patterns in blue duikers *Philatomba monticola* and red duikers *Cephalophus natalensis*. *Journal of Zoology*, 237(3), pp. 487-498.

BOWMAN V. and PLOWMAN A. (2002). Captive Duiker Management at the Duiker and Mini-Antelope Breeding and Research Institute (Dambari), Bulawayo, Zimbabwe. *Zoo Biology,* 21, pp. 161–170.

BOYCE, M., HARIDAS, C. and LEE, C. (2006). Demography in an increasingly variable world. *Trends in Ecology and Evolution*, 21, pp. 141–148.

BRADY N., and WEIL, R. 2008. *The Nature and Properties of Soils*. 14th ed. Upper Saddle River, New Jersey: Prentice Hall Inc.

BRASHARES J.S. and ARCESE P. (1999) Scent marking in a territorial African antelope: I. The maintenance of borders between male oribi. *Animal Behaviour*, 57, pp. 1–10.

BRAUDE, S., CREWS J., STEPHENSON, C., and CLARDY, T. (2002). *The Ethogram and Animal Behaviour Research*. St. Louis: Washington University.

BRAUN-BLANQUET, J. (1964). *Pflanzensoziologie: Grundzüge der Vegetationskunde. 3rd ed.* Wien, Austria/New York, NY: Springer.

BREEDT A.C., DU PLESSIS R. and MEARNS K.F. (2016). *Waste characterisation and management at Mnemba Island Lodge (Zanzibar)*. Proceedings of the 23rd WasteCon Conference, 17-21 October 2016, Emperors Palace, Johannesburg, South Africa

BROWN S. and COOPRIDER, K. (2013). *Terminalia catappa*. U.S. Department of Agriculture, Cooperative Extension Service, University of Florida. Lee County Extension, Florida. Available: http://lee.ifas.ufl.edu/Hort/GardenPubsAZ/tropical_almond.pdf

BROWN, L., DU PREEZ, P., BEZUIDENHOUT, H., BREDENKAMP, G., MOSTERT, T. and COLLINS, N., (2013). Guidelines for phytosociological classifications and descriptions of vegetation in southern Africa. *Koedoe*, 55(1).

BROWN, M. and GORDON, D. (2008). In: JØRGENSEN, S., and FATH, B. (eds), *Encyclopedia of Ecology: Behavioral Ecology*, 4, pp. 3261-3264.

BRUNER-LORAND, J., (1965). Patterns of Mammalian Reproduction. Review of ASDEL, S. *Science*, 148(3671), pp. 826-826.

BUNNELL, F. and GILLINGHAM, M. (1985). Foraging behaviour: dynamics of dining out. In: HUDSON, R. and WHITE, R. (eds). *Bioenergetics of Wild Herbivores*, Florida, USA: CRC Press, Boca Raton. pp. 53–79.

BURGER, A. (2005). Dispersal and germination of seeds of *Pisonia grandis*, an Indo-Pacific tropical tree associated with insular seabird colonies. *Journal of Tropical Ecology*. 21(03), pp. 263 - 271.

BURGESS N. and CLARKE G. (eds.) (2000). *Coastal Forests of Eastern Africa.* IUCN, Gland, Switzerland and Cambridge, UK. xiii p443.

BURGESS N. and MUIR C. (eds) (1994). *Coastal Forests of Eastern Africa: Biodiversity and Conservation*. From the Proceedings of the Coastal Forests of Eastern Africa Workshop of 9 to 11 August 1993. Dar es Salaam, The Society for Environmental Exploration and The University of Dar es Salaam.

BURGESS N., DOGGART, N., DOODY, K., NEGUSSIE, G., SUMBI, P., PERKIN, A. (2003). New Information on the lowland coastal forests of eastern Africa. *Oryx*, 37, pp. 280–281.

BURGESS N.D. (1990). *Preliminary results of biological surveys in seven coastal forests of Tanzania - July to September 1998*. London: The Society for Environmental Exploration.

BURGESS, N., MWASUMBI, L., HAWTHORNE, W., DICKINSON, A. and DOGGETT, R., (1992). Preliminary assessment of the distribution, status and biological importance of coastal forests in Tanzania. *Biological Conservation*, 62(3), pp. 205-218.

BURGOYNE C., KELSO C. and MEARNS K. (2017) The impact of stakeholder relations on the Mnemba Island Marine Conservation Area, Zanzibar, Tanzania. *Tourism in Marine Environments*, 12(3–4), pp. 239–252

BURGOYNE, C., (2018). *Stakeholder Relations And Natural Resource Management: Case Studies From Ecotourism In Tanzania And South Africa.* Dissertation (PhD). University of Johannesburg.

BURT, W. (1943). Territoriality and home range concepts as applied to mammals. *Journal of Mammalogy,*24, pp. 346–52.

BUTLER. V. (2017). *Feeding ecology of the Greater Kudu (Tragelaphus strepsiceros) in the central Free State*. Dissertation (Master’s Degree). University of the Free State, Bloemfontein.

CADMAN, M., DE VILLIERS, C., HOLMES, P., REBELO, T., HELME, N., EUSTON BROWN, D., CLARK, B., MILTON, S., DEAN, R., BROWNLIE, S., SNADDON, K., DAY, L., OLLIS, D., JOB, N., DORSE, C., WOOD, J., HARRISON, J., PALMER, G., MAREE, K., MANUEL, J., HOLNESS, S., RALSTON, S. and DRIVE, A. (2016). *Fynbos Forum Ecosystem Guidelines for Environmental Assessment in the Western Cape Fynbos Forum*, Edition 2.

CAGNACCI, F., BOITANI, L., POWERL, R., and BOYCE, M. (2010). Animal ecology meets GPS-based radiotelemetry: A perfect storm of opportunities and challenges. Philosophical transactions of the Royal Society of London, Series B. *Biological sciences*, (365), pp. 2157-2162.

CALKINS, K (2005). Applied Statistics - Lesson 7 - Probability and Sampling / Distributions. [WWW] Andrews University, Michigan. (Available: https://www.andrews.edu/~calkins/math/edrm611/edrm07.htm#PROB)

CARLISLE, L. (2016). *Nets used during capture operation in April 2016* (Photo).

CARTER E. (1998). *Establishment of an Aders' duiker (Cephalophus adersi) Sanctuary on Chumbe Island, Zansibar, East Africa*. Final Technical Report. Zanzibar, CHICOP.

CARTER E. (1999). *The Aders' duiker translocation operation to Chumbe Island Coral Park: Report of Status and developments - September 1999*. Zanzibar: CHICOP.

CAUGHLEY, G. (1979). *What is this thing called carrying capacity*? In: BOYCE, M. and HAYDEN-WING, L. (eds). North American elk: ecology, behavior and management. The University of Wyoming, Laramie, pp 2–8.

CEPF (2005). *Ecosystem Profile: Eastern Arc Mountains & coastal Forests of Tanzania & Kenya July 31, 2003 (updated: March 2005)*. Arlington, Conservation International.

CEPF (2011). *Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya Region Program for Consolidation*, January 2011. Arlington, Conservation International

CHRISTIANSEN, F., RASMUSSEN, M. and LUSSEAU, D. (2013). Inferring activity budgets in wild animals to estimate the consequences of disturbances. *Behavioral Ecology*, 24(6), pp.1415-1425.

CLARKE G. (1995). Tanzania Coastal Forest Research Programme, Checklist of the Vascular Plants from 13 Coastal forests in Tanzania*. Frontier Technical report nr 15*. The Society for Environmental Exploration and The University of Dar es Salaam.

CLARKE G. and BURGESS, N. (2000). Coastal Forests of Eastern Africa. IUCN - The World Conservation Union. *International Union for Conservation of Nature and Natural Resources.*

CLEMSON, A. (1985). *Honey and pollen flora*. Melbourne, Australia. Inkata Press. iv + 263 pp.

CLIMATE-DATA.ORG (2018). *Zanzibar City Climate: Average Temperature, Weather By Month, Zanzibar City Water Temperature.* [Online] Climate-Data.org / AM OP / OpenStreetMap contributors. Available: *https://en.climate-data.org/africa/tanzania/zanzibar-urban-west/zanzibar-city-1019984/*. [Accessed: 24 October 2018]

CLUTTON-BROCK, T., IASON, G., ALBON, S. and GUINNESS, F. (1982). The effects of lactation on feeding behaviour and habitat use of wild red deer hinds. *Journal of Zoology*, 198, pp. 227–236.

COLYN, M., HULSELMANS, J., SONET, G., OUDÉ, P., DE WINTER, J., NATTA, A., NAGY, Z. and VERHEYEN, E. (2010). Discovery of a new duiker species (Bovidae: Cephalophinae) from the Dahomey Gap, West Africa. *Zootaxa*, 2637(1), pp.1-30.

COMPTON, J., (2001). Holocene sea-level fluctuations inferred from the evolution of depositional environments of the southern Langebaan Lagoon salt marsh, South Africa. *The Holocene*, 11(4), pp. 395-405.

COOK, R., MURRAY, D., COOK, J., ZAGER, P. and MONFORT, S. (2001). Nutritional influences on breeding dynamics in elk. *Canadian Journal of Zoology*, 79(5), pp. 845-853.

COOKE, S., HINCH, S., WIKELSKI, M., ANDREWS, R., KUCHEL, L., WOLCOTT, T. and BUTLER, P. (2004). Biotelemetry: a mechanistic approach to ecology. *Trends in Ecology & Evolution*, 19(6), pp. 334-343.

COOPER, W., (1978). Home range size and population dynamic. *Journal of Theoretical Biology*, 75(3), pp.327-337.

CROCKETTE, C. and HA, R. (2015). *Data Collection in the Zoo Setting, Emphasizing Behavior.* In: KLEIMAN, D., ALLEN, M. and THOMPSON, K. (eds). Wild Mammals in Captivity: Principles and TechniquesEdition: Second Edition. University of Chicago Press. Pp. 386-406.

DAGG, A., and FOSTER, J., (1982) *The Giraffe, Its Biology, Behavior and Ecology*. New York: Van Nostrand Reinhold Publishers.

DALERUM, F., LANGE, H., SKARPE, C., ROOKE, T., INGA, B. and BATEMAN, P. (2008). Foraging competition, vigilance and group size in two species of gregarious antelope. *South African Journal of Wildlife Research,* 38, pp. 138-145.

DAMUTH, J. (1981). Home range, home range overlap, and species energy use among herbivorous mammals. *Biological Journal of the Linnean Society*, 15(3), pp.185-193.

DANIELS C. (2004). *Ader's duiker progress and update, 2004*. Chumbe Island Coral Park. Zanzibar: CHICOP.

DANIELS C., MWINYI, A., and NYANGE, O. (2004). Monitoring of translocated Ader's duiker (*Cephalophus adersi*) on Chumbe Island, Zanzibar and their longterm future. *Paper presented at the International symposium on duiker and dwarf antelope in Africa, 17th – 20th February 2004*. Zanzibar, CHICOP.

DANSEREAU, P. (1951). Description and recording of vegetation upon a structural basis. *Ecology*, 32(2), pp. 172-229.

DARWIN, C. (1842). *The Structure and Distribution of Coral Reefs.* London: Smith Elder and Co.

DASMANN, R. (1964). *Wildlife Biology*. Wiley, New York. viii + 231 pp.

DAVIES, A., and BIRKENHAGER, B., (1990). Jentink's duiker in Sierra Leone - Evidence from the Freetown Peninsula. *Oryx,* 24(3), pp. 143-146.

DAVIES, G. and VANDEN BERGHE, E. (eds.) 1994. *Check-list of the mammals of East Africa*. Nairobi: East Africa Natural History Society.

DE BOER, W. and PRINS, H. (1990). Large herbivores that strive mightily but eat and drink as friends. *Oecologia*, 82(2), pp. 264-274.

DE VOS, D. NEL, R. SCHOEMAN, D., HARRIS, L. and DU PREEZ, D. (2019). Effect of introduced *Casuarina* trees on the vulnerability of sea turtle nesting beaches to erosion. *Estuarine*, *Coastal and Shelf Science,* 223, pp. 147-158.

DELVINGT, W., DETHIER, M., AUZEL, P. & JEANMART, P. (1997). *La chasse villageaoise Badjoue´, gestion coutumie`re durable ou pillage de la ressource gibier? In La foreˆt des hommes: Terroirs villageois en foreˆt tropicale africaine* (ed. DELVINGT, W.). Presses Agronomiques de Gembloux, Gembloux, Belgium. Pp. 65–92.

DE MARIGNAC, J. (2000). *Home range and diel movement pattern of subadult lemon sharks in Bimini, Bahamas*. (Master's Thesis). San Jose State University.

DEPARTMENT OF FORESTRY AND NON-RENEWABLE RESOURCES ZANZIBAR (2017). *Restructuring in the DFNR,* 21 August 2017. [Online] Minister of Agriculture, Natural Resources, Livestock and Fisheries, Zanzibar. Available: http://www.forestryznz.or.tz/index.php/newstory/12-news/68-dfnr-undergoes-restructing [Accessed: 1 July 2018]

DEPARTMENT OF FORESTRY AND NON-RENEWABLE RESOURCES ZANZIBAR (2018a). *Forest Conservation - Operational Target: Forest Conservation Areas*. [Online] Minister of Agriculture, Natural Resources, Livestock and Fisheries, Zanzibar Available: http://www.forestryznz.or.tz/index.php/programs/forest-conservation [Accessed 1 July 2018]

DETHIER, M. & GHUIRGUI, A. (1999). *Etude de la chasse villageoise dans le secteur Ouest (route Mambe´le´-Nde´le´) de la zone d'intervention du Projet ECOFAC*. Composante RCA, Bangui, Central African Republic.

DEVARANAVADGI, S., BASSAPPA, S., JOLLI, R., WALI, W. and BAGALI, A. (2013). Height-Age Growth Curve Modelling for Different Tree Species in Drylands of North Karnataka. *Global Journal of Science Frontier Research Agriculture and Veterinary Sciences*, 13(1), pp. 11-21.

DEWHIRST, O., EVANS, H., ROSKILLY, K., HARVEY, R., HUBEL, T. and WILSON, A. (2016). Improving the accuracy of estimates of animal path and travel distance using GPS drift-corrected dead reckoning. *Ecology and Evolution*, 6(17), pp. 6210–6222.

DI BLANCO, Y. and HIRSCH, B. (2006). Determinants of vigilance behavior in the ring-tailed coati (Nasua nasua): the importance of within-group spatial position. *Behavioral Ecology and Sociobiology*, 61(2), pp. 173-182.

DIERENVELD, E., MUELLER, P., and HALL, M. (2002). Duikers: Native Food Composition, Micronutrient Assessment, and Implications for Improving Captive Diets. *Zoo Biology*, 21, pp. 185–196.

DILLIS, C., BEAUDROT, L., FEILEN, K., CLINK, D., WITTMER, H., and MARSHALL, A. (2015). Modeling the Ecological and Phenological Predictors of Fruit Consumption by Gibbons (*Hylobates albibarbis*). *Biotropica*, 47(1), pp. 85–93.

DING, J., LIU, Z., SONG, Y., ZENG, Z., ZHANG, Q. and BRAVERY, B (2012). Rut-induced changes in the activity budgets of male tropical ungulates: Eld's deer on Hainan Island. *Current Zoology,* 58 (4), pp. 536–540.

DÕÂAZ-RUIZ, F., CARO, J., DELIBES-MATEOS, M., ARROYO, B., and FERRERAS, P. (2016). Drivers of red fox (Vulpes vulpes) daily activity: prey availability, human disturbance or habitat structure? *Journal of Zoology*, 298 (2), pp. 128-138.

DONNE J. (c.1623). *Meditation XVII.* [Online] Online Literature. Available: www.online-literature.com/donne/409/ [Accessed: 1 July 2018]

DOWNS, J., GATES, R., and MURRAY, A. (2008). Estimating carrying capacity for sandhill cranes using habitat suitability and spatial optimization models. *Ecological Modelling*, 214, pp. 284–292.

DOWNS, J., HELLERA, J., LORAAMMA, R., STEINA, D., MCDANIELA, C., and ONORATOB, D. (2012). Accuracy of home range estimators for homogeneous and inhomogeneous point patterns. *Ecological Modelling*, 225, pp. 66– 73.

DRAKE, D., MOTLEY, T., WHISTLER, W. and IMADA, C. (1996). Rain forest vegetation of 'Eua Island, Kingdom of Tonga. *New Zealand Journal of Botany*, 34(1), pp. 65-77.

DRUMMOND, R. (1975). A list of trees, shrubs and woody climbers indigenous or naturalised in Rhodesia. *Kirkia,* 10(1), pp. 229-285.

DU TOIT, J. and YETMAN, C. (2005). Effects of body size on the diurnal activity budgets of African browsing ruminants. *Oecologia*, 143(2), pp. 317–325.

DU TOIT, J., and YETMAN, C. (2005). Effects of body size on the diurnal activity budgets of African browsing ruminants. *Oecologia*, 143(2005), pp.317–325.

DUBI, A. (2000). Coastal Erosion, Chapter 1. In: NGUSARU, A., (Ed). *Tanzania Coastal Management Partnership: The Present State of Knowledge of Marine Science in Tanzania Synthesis Report*. Tanzania Coastal Management Partnership Support Unit, Science and Technical Working Group. pp. 5-42.

DUBOST, G. (1980). Ecology and Social-Behavior of the Blue Duiker - Small African Forest Ruminant. Zeitschrift Fur Tierpsychologie-*Journal of Comparative Ethology*, 54, pp. 205-266.

DUBOST, G. (1983). The Behavior of Cephalophus-Monticola Thunberg and Cephalophus-Dorsalis Gray, and Evolutive Situation of the Cephalophs among the Ruminants,2. *Mammalia*, 47, 281-310.

DUBOST, G. (1984). Comparison of the Diets of Frugivorous Forest Ruminants of Gabon. *Journal of Mammalogy*, 65, pp. 298.

DUBOST, G., and FEER, F. (1992). Reproductive-Cycles of Small Ruminants in Northeastern Gabon as a Function of Food Resource Variability. *Mammalia*, 56, pp. 25-43.

DUNBAR, R., KORSTJENS, A., and LEHMANN, J. (2009) Time as an ecological constraint. *Biological Reviews*, 84, pp. 413–429.

DUNHAM, K. and MURRAY, M. (1982) The fat reserves of impala Aepyceros melampus. *African Journal of Ecology*, 20, pp. 80-87.

DUNHAM, K., (1982). The foraging behaviour of impala Aepyceros melampus. *South African Journal of Wildlife Research*, 12, pp. 36–40.

DUVAT, V. (2018). A global assessment of atoll island planform changes over the past decades. *Wiley Interdisciplinary Reviews: Climate Change,* 10(1).

EAST, R. (1988). *Antelopes: Global Survey and Regional Action Plans: Part 1. East and Northeast Africa*. [Online] IUCN Publications Services Unit. Available: *http://data.iucn.org/* [Accessed: 14 June 2016]

EAST, R. (1999). African Antelope Database 1998. IUCN/SSC Antelope Specialist Group. *Occasional Paper of the IUCN Species Survival Commission No. 21.* Cambridge, UK: IUCN Publications Services Unit. Available: *http://data.iucn.org/* [Accessed: 14 June 2016]

EAVES, H. (2000). Animal Keepers Forum. *Journal of the American Association of Zoo Keepers Inc.* (July 2000). 27(11), pp. 497-505.

EKBLOM, A. (2004). *Changing landscapes: an environmental history of Chibuene, southern Mozambique.* Dissertation (PhD), Uppsala University.

ELFERS, S., (1988). *Element Stewardship Abstract for Casuarina equisetifolia Australian Pine*. The Nature Conservancy. Virginia, USA.

ENGLISH, A., CHAUVENET, A., SAFI, K and PETTORELLI, N. (2012). Reassessing the Determinants of Breeding Synchrony in Ungulates. *PLoS ONE,* 7(7), e41444. Available: doi:10.1371/journal.pone.0041444 [Accessed on: 14 June 2016]

ENSING, E., CIUTI, S., DE WIJS, F., LENTFERINK, D., TEN HOEDT, A., BOYCE, M., and HUT, R. (2014). Diaurnality and Crepuscularity: GPS Based Daily Activity Patterns in European Red Deer and

North American Elk (*Cervus elaphus*): Indication for a Weak Circadian Clock in Ungulates. *PLoS ONE,* 9(9), e106997. Available: doi:10.1371/journal.pone.0106997 [Accessed: 14 June 2016]

ESTES, R. (1974). *Social organization of the African bovidae*. IUCN Publications (N.S.), 24, pp. 166-205.

ESTES, R. (1991). *The Behavior Guide to African Mammals: including hoofed mammals, carnivores, primates.* Berkley: University of California Press.

EVES, H., STEIN, J, and BCTF. (2002). *BCTF Fact Sheet: Duikers and the African bushmeat trade*. Bushmeat crisis task force. Washington, DC. pp. 21.

EXPERT AFRICA (2012.) *Map of Tanzania's Coastline, showing Zanzibar, Pemba and Mafia islands*. [Online] Expert Africa. Available: www.expertafrica.com/tanzania/zanzibar-island/reference-map [Accessed on: 17 October 2018]

EYES ON AFRICA (2016). *Mnemba Island Lodge*. [Online] Eyes on Africa, Ltd © 2002-2016. Available: www.eyesonafrica.net/african-safari-tanzania/mnemba-island-lodge.htm. [Accessed on 22 November 2018]

FA, J., JUSTE, J., DEL VAL, J. and CASTROVIEJO, J. (1995). Impact of Market Hunting on Mammal Species in Equatorial Guinea. *Conservation Biolog*y, 9(5), pp. 1107-1115.

FAGAN, W., and LUTSCHER, F. (2006). Average dispersal success: linking home range, dispersal, and metapopulation dynamics to reserve design. *Ecological Applications*, 16, pp. 820–828.

FAO (2020). *Soil testing methods – Global Soil Doctors Programme - A farmer-to-farmer training programme*. [Online] FAO, ROME. Available: https://doi.org/10.4060/ca2796en

FARST, D., THOMPSON, D., STONES, G., BURCHFIELD, P. and HUGHES, M. (1980). *Maintenance and breeding of duikers Cephalophus spp at Gladys Porter Zoo.* Brownsville International Zoo, Yearbook 20, pp. 93-99.

FAURIE, A. and PERRIN, M. (1993). Diet selection and utilization in blue duikers *Cephalophus monticola* and red duikers *C. natalensis*. *Journal African Zoology*, 107, pp. 287-299.

FEER, F. (1988). *Strategies écologiques de deux éspèces de bovidés sympatriques de la forêt sempervirente africaine (Cephalophus callipygus et C. dorsalis): Influence du rythme d'activité*. Thesis (DSc). Université Pierre et Marie Curie, Paris

FEER, F. (1996). *Les potentialite´s de l'exploitation durable et de l'e´levage du gibier en zone forestie`re tropicale. In L'alimentation en fore˜t tropicale: interactions bioculturelles et perspectives de* *de´veloppement* (eds HLADIK, C., HLADKIK, A., RAGEZY, H., LINARES, O., KOPPER, G., and FROMENT, A.). UNESCO, Paris, France. pp. 1039–1061.

FENNESSY, J. (2004). *Ecology of desert-dwelling giraffe Giraffa camelopardalis angolensis in northwestern Namibia*. Thesis (PhD). University of Sydney, Australia.

FER, I., TIETJEN, B., JELTSCH, F. and WOLFF, C. (2017). The influence of El Niño–Southern Oscillation regimes on eastern African vegetation and its future implications under the RCP8.5 warming scenario. *Biogeosciences*, 14(18), pp. 4355-4374.

FERN, K. (2014). *Useful Tropical Plants Database.* [Online]. The Ferns. (Available: tropical.theferns.info/viewtropical.php?id=Sideroxylon+inerme). [Accessed: 2019-05-19]

FERRETTI, F., COSTA, A., CORAZZA, M., PIETROCINI, V., CESARETTI, G. and LOVARI, S. (2014). Males are faster foragers than females: intersexual differences of foraging behaviour in the Apennine chamois. *Behavioural Ecology and Sociobiology*, 68, pp. 1335–1344.

FIEDBERG, J. (2007). Kernel density estimators of home range: smoothing and the autocorrelation red herring. *Ecology,* 88(4), pp. 1059–1066.

FINKE, J. (2006). *The Rough Guide to Zanzibar* (2nd edition). New York: Rough Guides.

FINNIE, D. (2001). Aders' Duiker (Cephalophus Adersi) Discussion Document on the Potential of Establishing a Captive Breeding Centre at Jozani Forest Reserve. *Forestry Technical Paper 121.* CNR, Zanzibar.

FINNIE, D. (2002). *Ader's Duiker (Cephalophus Adersi) Species Recovery Plan* (Revised). Forestry Technical Paper No. 124. Zanzibar: DCCFF.

FINNIE, D. (2008). *Cephalophus Adersi*. *The IUCN Red List of Threatened Species 2008:* Version 2015.2. (Online) www.iucnredlist.org. Available: http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T4137A10455260.en or [Accessed: 26 August 2015]

FISKE, A. (2011). *The Aders's Duikers (Cephalophus Adersi) of Mnemba Island, Zanzibar: A Study of the Behavior and Diet of a Critically Endangered Species.* (Online). SIT Graduate Institute / SIT Study Abroad Digital Collections @ SIT. Collection Paper 1023. Available: http://digitalcollections.sit.edu/isp_collection/1023 [Accessed on: 15 April 2015]

FITZGIBBON, C., MOGAKA, H. and FANSHAWE, J. (1995) Subsistence Hunting in Arabuko-Sokoke Forest, Kenya, and Its Effects on Mammal Populations. *Conservation Biology,*9(5), pp. 1116-1126.

FITZSIMONS, F. (1920). *The natural history of South Africa*. Longmans: London.

FLEMING, C. and CALABRESE, J. (2017). A new kernel density estimator for accurate home-range and species-range area estimation. *Methods in Ecology and Evolution*, 8, pp. 571 - 579.

FLEMING, C., SHELDON, D., FAGAN, W., LEIMGRUBER, P., MUELLER, T., NANDINTSETSEG, D., NOONAN, M., OLSON, K., SETYAWAN, E., SIANIPAR, A. and CALABRESE, J. (2018). Correcting for missing and irregular data in home-range estimation. *Ecological Applications*, pp. 1003-1010.

FONSECA, A., VILLAÇA, R. and KNOPPERS, B. (2012). Reef Flat Community Structure of Atol das Rocas, Northeast Brazil and Southwest Atlantic. *Journal of Marine Biology*, 2012(4), pp. 1-10.

FORCHHAMMER, M., and BOOMSMA, J. (1995). Foraging strategies and seasonal diet optimization of muskoxen in West Greenland. *Oecologia,* 104, pp. 169–180.

FOSBERG, F., (1949). *Atoll Vegetation and Salinity*. Pacific Science, 3, January 1949.

FOSBERG, F., (1957). The Maldive Islands, Indian Ocean. *Atoll Research Bulletin No. 58.* Pacific Science Board, National Academy of Sciences, Washington. 37 p.

FOSBERG, F., THORNE, R. and MOULTON, J. (1961). Heron Island, Capricorn Group, Australia. I. Description of Heron Island. II. Vascular plants of Heron Island. III. Some Observations on the Tieron Island fauna. *Atoll Research Bulletin*, 82, pp. 5-14.

FOSTER, V., SARMENTO, P., SOLLMANN, R., TOÃRRES, N., JAÃCOMO, A., and NEGRÕES, N., FONSECA, C. and SILVEIRA, L. (2013). Jaguar and Puma activity patterns and predator-prey interactions in four Brazilian biomes*. Biotropica*, 45(3), pp. 373-379.

FREY, S., FISHER, J., BURTON, A. and VOLPE, J. (2017). Investigating animal activity patterns and temporal niche partitioning using camera-trap data: challenges and opportunities. *Remote Sensing in Ecology and Conservation*, 3(3), pp. 123–132.

GAILLARD J., DELORME, D. and JULLIEN, J. (1993). Effects of cohort, sex, and birth date on body development of roe deer (Capreolus- Capreolus) Fawns. *Oecologia*, 94, pp. 57 -61.

GARAMSZEGI, L. (2016). When limited availability of data meets with a thorough meta-analysis: a comment on Moore et al. *Behavioral Ecology*, (27, 2), pp. 375

GARCIA-REYES, M., MAYORGA-ADAMEET, G., MOULTON, M. and NADEAU, P. (2009). *Modeling of the Zanzibar Channel. Zanzibar Project Progress Report – 2009.* [Online] IRES: International Research Experiences for Students. Available: http://www.theissresearch.org/scientists/theiss/zanzibar/ProgressReport2009.pdf [Accessed on: 25 April 2018].

GAUTIER-HION, A., DUPLANTIER J., QURIS, R., FEER, F., SOURD, C., DECOUX, J., DUBOST, G., EMMONS, L., ERARD, C., HECKETSWEILER, P., MOUNGAZI, A., ROUSSILHON, C. and THIOLLAY, J. (1985). Fruit characters as a basis of fruit choice and seed dispersal in a tropical forest vertebrate community. *Oecologia*, 65, pp. 324–337.

GEIST, V. and WALTHER, F. (1974). *The Behaviour of Ungulates and its relation to management.* The Papers of an International Symposium held at The University of Calgary, Alberta, 2-5 November 1971. Canada.

GINNETT, T. and DEMMENT, M. (1997). Sex differences in giraffe foraging behavior at two spatial scales. *Oecologia*, 110, pp. 291- 300

GIRALDEAU, L. and CARACO, T. (2000). Social Foraging Theory. *Ecology,* 82(3), pp.

GIRARD, I., OUELLET, J., COURTOIS, R., DUSSAULT, C. and BRETON, L. (2002). Effects of sampling effort based on GPS telemetry on home-range size estimations. *Journal of Wildlife Management*, 66(4), pp. 1290–1300.

GITTLEMAN, J. and HARVEY, P. (1982). Carnivore home range size, metabolic needs and ecology. *Behavioural Ecology and Sociobiology,* 10, pp. 57-63.

GOLDBERG, W. (2016). Atolls of the world: Revisiting the Original Checklist. *Atoll Research Bulletin (*610), 28 June 2016. Smithsonian Institution. Washington.

GÖPPER, B. (2012). *The ecology of the Tsessebe, Damaliscus lunatus lunatus, in Borakalalo National Park, North West Province*. Dissertation (Masters Degree). University of Limpopo, Medunsa Campus.

GREGORY, T. (2017) *Home Range Estimation*. In: FUENTES, A. (eds). The International Encyclopedia of Primatology. Volume 3. [Online] John Wiley & Sons, pp. 1-4. Available: 10.1002/9781119179313.wbprim0177.

GRELLMAN, K. (2018). *A Disappearing Island: An Impact Assessment of Coastal Erosion on the Mnemba Island House Reef, Zanzibar*. [Online] Independent Study Project (ISP) Collection. 2870. Available: https://digitalcollections.sit.edu/isp_collection/2870

GRIFFIN, O. (2012). *Modelling the severity of deforestation in coastal Tanzania and a comparison of data sources*. Unpublished Thesis (MSc). Imperial College, London.

GROBLER, C., BREDENKAMP, G. and BROWN, L. (2006). Primary grassland communities of urban open spaces in Gauteng, South Africa. *South African Journal of Botany*, 72, pp. 367-377.

GROSS, J., ALKON, P. and DEMMENT, M. (1996). Nutritional ecology of dimorphic herbivores: digestion and passage rates in Nubian ibex. *Oecologia*, 107, pp. 170-178.

GROVES, C. and GRUBB, P. (2011). *Ungulate Taxonomy*. Baltimore: Johns Hopkins University Press.

GRUBBEN, G. (2008). *Plant Resources of Tropical Africa*. PROTA.

GUERRERO, D. (2000). Animal Keepers Forum. *Journal of the American Association of Zoo Keepers Inc,* 27(7), pp. 378.

GWYNNE, M. and WOOD, D. (1969). Plants collected on Islands in the Western Indian Ocean during a cruise of the M.F.R.V. "MANIHINE," September - October, 1967*. Atoll Research Bulletin*, 134, pp.1-15.

HAJI, S. (2010). *Water Balance Assessment in Unguja Island, Zanzibar, Tanzania*. Dissertation (Master's Degree). International Institute for Geo-Information Science and Earth Observation, Enschede, The Netherlands.

HAMEL, S. and CÔTÉ, S. (2008). Trade-offs in activity budget in an alpine ungulate: contrasting lactating and nonlactating females. Animal behaviour, 75, pp. 217-227.

HAMMERTON, J. (2001). *Casuarina*s in the Bahamas: a clear and present danger. *Bahamas Journal of Science*, 9, pp. 2–14.

HAN, L., BLANK, D., WANG, M., YANG, W., ALVES DA SILVA, A. and ALVES, J. (2019). Grouping patterns and social organization in Siberian ibex (Capra sibirica): feeding strategy matters, *Folia Zoologica*, 68(1), pp. 35-42.

HARESTAD, A., and BRUNNEL, F. (1979). Home Range and Body Weight--A Reevaluation. *Ecology*, 60(2), pp. 389-402.

HARCOURT, A. (1978). Activity periods and patterns of social interaction: a neglected problem. *Behaviour*, 66 (1-2), pp. 121-135.

HARRIS, S., CRESSWELL, W., FORDE, P., TREWHELLA, W., WOOLLARD, T. and WRAY, S. (1990). Home range analysis using radio-tracking data. A review of problems and techniques particularly as applied to the study of mammals. *Mammal Review,* 20, pp. 97 - 123.

HART, B. (1983). Hart, B. L. (1983). *Flehmen behavior and vomeronasal organ function*. In: SILVERSTEIN, R. and MULLER-SCHWARZE, D. (eds.). Chemical Signals in Vertebrates. Plenum, New York. pp. 87-103.

HART, B. and HART, L. (2001). *Duiker Behaviour* (Appendix J). In: WILSON, V. Duikers of Africa, Masters of the African forest floor. A study of Duikers - People - Hunting and Bushmeat. Chipangali Wildlife Trust (Wildlife Research Center), Duiker Research and Breeding Center, Zimbabwe.

HART, J. (2013a). Cephalophus leucogaster White-bellied duiker. In: KINGDON J. and HOFFMAN M. (Eds.) *Mammals of Africa* Vol. VI: Pigs, Hippopotamuses, Chevrotain, Giraffe, Deer and Bovids. Bloomsbury Publishing, London, pp 255–258.

HART, J. (2013b). Cephalophus natalensis Natal Red Duiker. In: KINGDON J. and HOFFMAN M. (Eds.) The *Mammals of Africa*. Volume VI: Pigs, Hippopotamuses, Chevrotain, Giraffes, Deer, and BovidsEdition: Bloomsbury Publishing, London.

HART, J. and HART, T. (1989). IUCN Antelope Specialist Group. *Gnusletter*, 8(2), pp. 7.

HARTLEY, D. and RIJALI, H. (2003). *Jozani Chwaka Bay Conservation Project*. Phase III (PIMS 1136). Project Terminal Review: 19 April - 3 May 2003. Zanzibar: UNDP – GEF Tanzania

HASSAN A. (2011). *Review of National Protected area board (NPAB) reconstituted with capacity to provide oversight and leadership*. Consultancy Final Report. Attorney General's Office, Zanzibar.

HEINICHEN, I. (1972). Preliminary Notes on the Suni, Nesotragus Moschatus and Red Duiker, Cephalophus Natalensis. *Zoologica Africana*, 7(1), pp.157-165.

HEMPSON, G., ILLIUS, A., HENDRICKS, H., BOND, W., VETTER, S., (2015). Herbivore population regulation and resource heterogeneity in a stochastic environment. *Ecology*, 96(8), pp. 2170–2180.

HEMSON, G., JOHNSON, P., SOUTH, A., KENWARD, R., RIPLEY, R. and MCDONALD, D. (2005). Are kernels the mustard? Data from global positioning system (GPS) collars suggests problems for kernel home-range analyses with LSCV. *Journal of Animal Ecology*, 74, (3), pp. 455-463.

HENDERSON, P. and SOUTHWOOD, T. (2016). *Ecological Methods*. 4th Ed. Chichester: Wiley Blackwell.

HERTEL, A., SWENSON, J, and BISCHOFA, R. (2017). A case for considering individual variation in diel activity patterns. Behavioral Ecology, 28(6), pp. 1524-1531.

HILL, M., VEL, T., HOLM, K., PARR, S. and SHAH, N. (2002). Cousin. *Atoll Research Bulletin*, 495(4), pp. 49-72.

HNATIUK, R. and MERTON, L. (1979). Vegetation of Aldabra, a reassessment. *Atoll Research Bulletin,* 239, pp. 1–21.

HODGKINSON, R and BALDING, S. (2003). Fruit Bats (Chiroptrea: Pteropodidae) as Seed Dispersers and Pollinators in a Lowland Malaysian Rain Forest. *Biotropica*, 35(4), pp. 491-502.

HOFFMANN, R. (1973). *The Ruminant Stomach: Stomach Structure and Feeding Habits of East African Game Ruminants*. East African Literature Bureau, Nairobi.

HOFFMANN, M. and BOWLAND, A. (2013). Cephalophus natalensis Natal red duiker. In: KINGDON J. And HOFFMANN M. (Eds.) *Mammals of Africa* Vol. VI: Pigs, Hippopotamuses, Chevrotain, Giraffe, Deer and Bovids. London: Bloomsbury Publishing, pp 258–261.

HOFMANN, T. and ROTH, H. (2003). Feeding preferences of duiker (Cephalophus maxwelli, C. rufilatus, and C. niger) in Ivory Coast and Ghana. *Mammalian Biology*, 68(2), pp. 65-77.

HU, S. and FEDOROV, A. (2017). The extreme El Niño of 2015–2016 and the end of global warming hiatus. *Geophysical Research Letter*, 44, pp. 3816–3824.

HUFFMAN B. (2016a). *Cephalophus Adersi: Aders' duiker*. [Online] Ultimate Ungulates. Available from: http://www.ultimateungulate.com/Artiodactyla/Cephalophus_adersiFull.html

HUFFMAN B. (2016b). *Ungulates of the World Species fact sheets*. [Online]. Ultimate Ungulates. Available from: http://www.ultimateungulate.com/Ungulates.html#Cephalophus [Accessed 3 May 2018]

HUFFMAN B. (2016c). *Neotragus moschatus: Suni Antelope*. [Online]. Ultimate Ungulates. Available from: www.ultimateungulate.com/artiodactyla/Neotragus_moschatus.html [Accessed 3 May 2018]

IIJIMA, H., and MAYUMI, U. (2016). Spatial heterogeneity in the carrying capacity of sika deer in Japan. *Journal of Mammalogy*, 97(3), pp. 734–743.

IKEDA, T., UCHIDA, K., MATSUURA, Y.,TAKAHASHI, H., YOSHIDA, T., KAJI, K. and KOIZUMI, I. (2016). Seasonal and Diel Activity Patterns of Eight Sympatric Mammals in Northern Japan Revealed by an Intensive Camera-Trap Survey. *PLoS ONE*, 11(10), pp. 1-16.

INNIS, A. (1958). The behaviour of the Giraffe, Giraffa camelopardalis, in the Eastern Transvaal. *Journal of Zoology*, 131 (2), pp. 245-278.

IPPC (2007). *Climate Change 2007: Synthesis Report*. PACHAURI, R.K and REISINGER, A. (eds.). Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC.

IPPC (2014). *Climate Change 2014: Synthesis Report*. PACHAURI R.K. and MEYER L.A. (eds.). Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC.

IUCN (2008a). *IUCN Red List of Threatened Species*. Version 2015.3.1 [Online] IUCN UK. Available: http://www.iucnredlist.org [Accessed 20 May 2015].

IUCN (2008b). *Nesotragus moschatus,* The IUCN Red List of Threatened Species. SSC Antelope Specialist Group. Version 2015.3.1. [Online] IUCN UK. Available: www.iucnredlist.org. [Accessed 26 August 2015].

IUCN (2017). *Cephalophus Adersi,* The IUCN Red List of Threatened Species. SSC Antelope Specialist Group. [Online] IUCN UK. Available: http://www.iucnredlist.org/details/4137/0. [Accessed 12 June 2018].

IUCN (2018a). *SSC Groups Critically Endangered Species*. [Online] IUCN UK. Available: https://www.iucn.org/ssc-groups/mammals/antelope-specialist-group/species-account/critically-endangered-species [Accessed 14 July 2018].

JAMAN, M. and HUFFMAN, M. (2008). Enclosure environment affects the activity budgets of captive Japanese macaques (Macaca fuscata). *American Journal of Primatology*, 70 (12), pp. 1133–1144.

JANSEN VAN VUUREN, B. and ROBINSON, T. (2001). Retrieval of four adaptive lineages in duiker antelope: evidence from mitochondrial DNA sequences and fluorescence in situ hybridization. *Molecular Phylogenetics and Evolution*, 20, pp. 409–425.

JARMAN, M. and JARMAN, P. (1973). Daily activity of Impala. *East African Wildlife Journal*, 11, pp. 75-92.

JARMAN, M. (1974). The Social Organisation of Antelope in Relation to Their Ecology. *Behaviour*, 48 (3/4), pp. 215-267.

JARSO, J. (2012). The East African Community and the Climate Change Agenda: An Inventory of the Progress, Hurdles, and Prospects. *Sustainable Development Law & Policy*, 12(2), pp. 19-24, 56-62.

JAVAID, A., KULESZ, M., SCHLÜTER, A., GHOSH, A., and JIDDAWI, N. (2016). Time Preferences and Natural Resource Extraction Behavior: An Experimental Study from Artisanal Fisheries in Zanzibar. *PLoS ONE*, 11, pp. 1-14.

JHALA, Y., and ISVARAN, K. (2016). Behavioural Ecology of a Grassland Antelope, the blackbuck Antilope cervicapra: Linking Habitat, Ecology and Behaviour" In: AHRESTANI, F. and SANKARAN, M. (eds.) The Ecology of Large Herbivores in South and Southeast Asia. Springer Nature Publication: Dordrecht, pp. 151-176.

JENNINGS, S., KAISER, M. and REYNOLDS, J. (2001). *Marine Fisheries Ecology*. Malden, MA: Blackwell Science.

JENSEN, A. (1975). Comparison of logistic equations for pop growth. *Biometrics*, 31(4), pp. 853-862.

JIDDAWI, N. and ÖHMAN, M. (2002). Marine Fisheries in Tanzania. *Ambio*, 31(7-8), pp. 518-527.

JOHNSON, D., KAYS, R., BLACKWELL, P. and MACDONALD, D. (2002). Does the resource dispersion hypothesis explain group living? *Trends in Ecology & Evolution*, 17 (12), pp. 563-570.

JOHNSON, R. and CHRISTENSEN, L. (2014). *Educational Research Quantitative, Qualitative, and Mixed Approaches, Fifth Edition*. California, SAGE Publications. 744 p.

JOHNSTON, A and ANTHONY, N. (2012). A multi-locus species phylogeny of African forest duikers in the subfamily *Cephalophinae*: evidence for a recent radiation in the Pleistocene. *BMC Evolutionary Biology,* 12 (120).

JOHNSTON, A. (2011). *Evolutionary Relationships Among Duiker Antelope* (*Bovidae*: *Cephalophinae*). Thesis (MSc), University of New Orleans.

JOHNSTONE, R., MUHANDO, C. and FRANCIS J. (1998). The Status of the Coral Reefs of Zanzibar: One Example of a Regional Predicament. *Ambio*, 27(8), pp.700-707.

KADNIKOVA, I., COSTA, R., KALENIK, T., GURULEVA, O., and YANGUO, S. (2015). Chemical Composition and Nutritional Value of the Mushroom Auricularia auricula-judae. *Journal of Food and Nutrition Research*, 3(8), pp. 478-482.

KAMUNDI, D. and VON STADEN, L. (2018). *Mimusops obtusifolia* Lam. National Assessment: Red List of South African Plants version 2020.1. Accessed on 2020/11/11

KANGA, E. (1999). *Survey of Aders' Duiker Cephalophus Adersi in Jozani Forest Reserve and in Ukongoroni, Charawe, Jambiani, Mtende, Kiwengwa and Michamvi Community forests, Zanzibar* (Unpublished report). Zanzibar: Commission for Natural Resources.

KANGA, E. (2002). *A conservation and recovery plan for Aders' duiker in Arabuko-Sokoke Forest, Kenya, October 2002*. Kenya: Kenya Wildlife Service.

KANGA, E. (2003). *Some ecological aspects and conservation of duikers in Arabuko-Sokoke Forest - Kenya*. Thesis (MSc). University of Nairobi.

KANGA, E. and MWINYI, A. (1999). *Population Survey of Zanzibar Mini Antelope (Unpublished Report)*. Tanzania: The Commission for Natural Resources, Zanzibar.

KARESH, W., HART, J., HART, T., HOUSE, C., TORRES, A., DIERENFELD, E., BRASELTON, W., PUCHE, H. and COOK, R. (1995). Health Evaluation of Five Sympatric Duiker Species (Cephalophus spp.) *Journal of Zoo and Wildlife Medicine*, 26(4), pp. 485-502.

KAZUNGU, K. (2018). *Mothers suffer as hospitals in Boni closed after Shabaab attacks*. [Online] Nairobi: Daily Nation - 22 August 2018. Available: https://www.nation.co.ke/counties/lamu/Mothers-suffer-Boni-dispensaries-closed/3444912-4723756-5tnn6uz/index.html [Accessed 14 September 2018]

KEENER, V, MARRA, J., FINUCANE, M., SPOONER, D. and SMITH, M. (eds.) (2012) *Climate Change and Pacific Islands: Indicators and Impacts*. Executive Summary of the 2012 Pacific Islands Regional Climate Assessment (PIRCA). Hawai, Island Press.

KENCH, P., OWEN, S and FORD, M. (2014). Evidence for coral island formation during rising sea level in the central Pacific Ocean. *Geophysical Union*, 41, pp. 820–827

KENCH, P., FORD, M., and OWEN, S. (2018). Patterns of island change and persistence offer alternate adaptation pathways for atoll nations. *Nanture Communications*, 9 (605), pp. 1 - 7.

KENCH, P., THOMPSON, D., FORD, M., OGAWA, H. and MCLEAN, R. (2015). Coral islands defy sea-level rise over the past century: Records from a central Pacific atoll. *Geology*, 43 (6), pp: 515–518.

KENT, M. (2012). *Vegetation description and analysis: A practical approach*. Oxford: Wiley-Blackwell. 428 p.

KENT, M. and COKER, P. (1997). *Vegetation description and analysis – a practical approach*. New York, John Wiley & Sons.

KHAN, A. (1993). Occurrence and importance of mycorrhizae in aquatic trees of New South Wales, Australia. *Mycorrhiza*, 3(1), pp. 31-38.

KIE, J., MATTIOPOULOS, J., FIEBERG, J., POWERLL, R., CAGNACCI, F., MITCHELL, M., GAILLARD, J., and MOOCROFT, P. (2010). The home-range concept: Are traditional estimators still relevant with modern telemetry technology?. Philosophical transactions of the Royal Society of London. Series B, *Biological sciences,* 365, pp. 2221-2231.

KIFFNER, C., and LEE, D. (2019). Population Dynamics of Browsing and Grazing Ungulates in the Anthropocene. In: GORDON, I., PRINS, H. (eds). The Ecology of Browsing and Grazing II. *Ecological Studies (Analysis and Synthesis)*, 239. Cham: Springer.

KINDT, R., VAN BREUGEL, P., ORWA, C., LILLESØ J-P., GRAUDAL, L., and JAMNADASS, R., (2015) *Useful tree species for Eastern Africa: a species selection tool based on the VECEA map*. Version 2.0. World Agroforestry Centre (ICRAF) and Forest & Landscape Denmark. http://vegetationmap4africa.org

KINGDON J. (1982). *East African Mammals: An Atlas of Evolution in Africa*. Vol. IIIC. London: Academic Press.

KINGDON J. (1997). *The Kingdon Field Guide to African Mammals.* London and New York: Academic Press.

KINGDON J. (2015). *The Kingdon Field Guide to African Mammals.* 2nd edition. London: Bloomsbury Publishing.

KINGDON J. and HOFFMAN, M. (Eds) (2013). *Mammals of Africa Volumes VI. Pigs, Hippopotamuses, Chevrotain, Giraffes, Deer and Bovids*. pp.248 - 249. *London: Bloomsbury Publishing*

KOHLI, M., SANKARAN, M, SURYAWANSHI, K., and MISHRA, C. (2014). A penny saved is a penny earned: lean season foraging strategy of an alpine ungulate. *Animal Behaviour*, 92, pp. 93-100.

KOLÁČKOVÁ, K., HEJCMANOVÁ, P., ANTONíNOVÁ, M., and BRANDL, P. (2011). Population management as a tool in the recovery of the critically endangered Western Derby eland Taurotragus derbianus in Senegal, Africa. *Wildlife Biology,* 17(3), pp. 299-310.

KOMBO Y.H. (2010). *Zanzibar Biodiveristy, Climate Change and energy crisis: Toward Zanzibar Environmental Policy Formulation.* The Department of Commercial Crops, Fruits and Forestry, Zanzibar.

KOMBO Y.H., BASHA A.U. and SULEIMAN R.H. (2013). *Implications of micro finance scheme on biodiversity conservation - Positive ideas turned into Negative Results: Lessons learned from Jozani National Park - Zanzibar*.

KOMERS, P., MESSIER, F., and GATES, C. (1992). Search or relax: the case of bachelor wood bison. *Behavioral Ecology and Sociobiology*, 31(3), pp. 192–203.

KRANZ, K. and LUMPKIN, S. (1982). Notes on the Yellow-backed duiker in captivity with comments on its natural history. *International Zoo Yearbook*, 22(1), pp.232-240.

KREBS, C. (1999). *Ecological methodology,* 2nd edition. Menlo Park, California: Addison-Welsey Educational Publishing.

KREBS, C. (2014). *Ecological Methodology*, 3rd edition. Department of Zoology, University of British Columbia.

KREBS, C. (2016). Estimating Abundance and Density: Mark-Recapture Techniques,Chapter 2. In: *Ecological Methodology*. Version 6. Department of Zoology, University of British Columbia.

KUENEN, P. (1933). Geology of coral reefs. *Snellius-Expedition Report*, 5, pp. 1–129.

KUZYK, G., COOL, N., BORK, E., BAMPFYLDE, C., FRANKE, A., and HUDSON, R. (2009). Estimating Economic Carrying Capacity for an Ungulate Guild in Western Canada. *The Open Conservation Biology Journal*, 3, pp. 24-35.

LANDE, R., ENGEN, S. and SAETHER, E. (2003). *Stochastic population dynamics in ecology and conservation*. Oxford University Press, Oxford. pp. i-x, 1–212.

LANSHAMMAR, F. (2007). *Report from the survey of Aders' Duikers on Chumbe Island the 7-9 September 2007*. Zanzibar: CHICOP

LANSHAMMAR, F. (2008). *Report from the survey of Ader's Duikers on Chumbe Island the 12th of February 2008*. Zanzibar: CHICOP

LANSHAMMAR, F. (2009). *Report from the survey of Ader's Duikers on Chumbe Island, 5-6th June 2009*. Zanzibar: CHICOP

LARKIN, R., and HALKIN, D. (1994). A review of software packages for estimating animal home ranges. *Wildlife Society Bulletin*, 22, pp. 274–287.

LAVER, P. (2005). *Kernel Home Range Estimation for ArcGIS, using VBA and ArcObjects*. User Manual (Beta v.2- 7 February, 2005). Department of Fisheries and Wildlife Sciences, Virginia Tech, Blacksburg.

LAWSON, D. (1989). The food habits of suni antelopes (Neotragus moschatus). *Mammalia: Artiodactyl, Journal of Zoology.* 217(3), pp. 441–448.

LE PENDU, Y., CIOFOLOF, I. and GOSSER, A. (2001). The social organization of giraffes in Niger. *African Journal of Ecology,* 38, pp. 78 - 85.

LEPAGE, D. (2018). *Birds of Zanzibar*. [Online] Denis Lepage. Available: https://avibase.bsc-eoc.org/checklist.jsp?region=Tzznza; Last modified: 2018-06-10. (Accessed on 22 November 2018)

LEUTHOLD, B. and LEUTHOLD, W (1978). Daytime activity patterns of gerenuk and giraffe in Tsavo National Park, Kenya. *African Journal of Ecology*, 16(4), pp. 231 - 243.

LICHTI, N. & SWILHART, R. (2011). Estimating utilization distributions with kernel versus local convex hull methods. *Journal of Wildlife Management*, 75(2), pp. 413-422.

LIM, E. and HENDON, H. (2017). Causes and Predictability of the Negative Indian Ocean Dipole and Its Impact on La Niña During 2016. *Scientific Reports*, 7. Available: https://www.nature.com/articles/s41598-017. 10.1038/s41598-017-12674-z.

LINDTSTEDT, S., MILLER, B., and BUSKIRK, S. (1986). Home range, time, and body size in mammals. *Ecology,* 67, pp. 413–418.

LINKIE, M. and RIDOUT, M. (2011). Assessing tiger-prey interactions in Sumatran rainforests. *Journal of Zoology*, 284(3), pp. 224-229.

LITVAITIS, J., and SHERBURNE, J. (1986). Bobcat habitat use and home range size in relation to prey density. *Journal of Wildlife Manage*, 50, pp. 110–117.

LOCHER, A., and LINDENBERG, M. (2016). *Home Range Creation and Analysis Using Geospatial Modeling Environment and ArcGIS Software*. Allendale, Grand Valley State University.

LONGAIR, S. (2016). *Cracks in the Dome: Fractured Histories of Empire in the Zanzibar Museum, 1897-1964*. Routledge, UK. 338 pp.

LOPEZ, J. and VAUGHAN, C. (2004). Observations on the role of frugivorous bats as seed dispersers in Costa Rican secondary humid forests. *Acta Chiropterologica* ,6, pp. 111–119.

LOSOS, J. and RICKLEFS, R. (eds) (2010). *The Theory of Island Biogeography Revisited.* Princeton, New Jersey.

LYONS, A., GAINES, W., SINGLETON, P., KASWORM, W, PROTCOR, M. and BEGLEY, J. (2018). Spatially explicit carrying capacity estimates to inform species specific recovery objectives: Grizzly bear (*Ursus arctos*) recovery in the North Cascades. *Biological Conservation,* 222, pp. 21–32.

MACDONALD, D. (2006). *The Encyclopedia of Mammals*. Oxford University Press, Oxford.

MACFARLANE, D., KINZER, A. and BANKS, J. (2015) Coupled human-natural regeneration of indigenous coastal dry forest in Kenya. *Forest Ecology Management*, pp. 1 - 11.

MACPHERSON, J., MACPHERSON, D., CARTER, E. (2002). *A study of the ecology and effects of a re-introduced population of Ader's duiker (Cephalophus adersi) on Chumbe Island*, Zanzibar. CHICOP.

MAJOLO, B., MCFARLAND, R., YOUNG, C. and QARRO, M. (2013). The Effect of Climatic Factors on the Activity Budgets of Barbary Macaques. *International Journal of Primatology,* 34, pp. 500-514.

MAPLE, T. and FINLAY, T. (1989). Applied primatology in the modern zoo. *Zoo Biology*, Supplement 1, pp. 101–116.

MARCAR, N., (1996). *Casuarina*s for salt-affected land. In: Pinyopusarerk K, Turnbull JW, Midgley SJ, eds. Recent *Casuarina* Research and Development. *Proceedings of the 3rd International Casuarina Workshop, Da Nang, Vietnam*. Canberra, Australia: CSIRO Forestry and Forest Products, pp. 180-186.

MARTIN, P., and BATESON, P. (1993). *Measuring behaviour: An introductory guide* (2nd ed.). Cambridge niversity Press, King's College, Cambridge.

MATTHEWS, K. (1990). A telemetric study of the home ranges and homing routes of copper and quillback rockfishes on shallow rocky reefs. *Canadian Journal of Zoology*, 68, pp. 2243-2250.

MBIJE, N., WAGNER, G., FRANCIS, J., ÖHMAN, M. and GARPE, K. (2002). Patterns in the Distribution and Abundance of Hard Corals around Zanzibar Island. *Ambio*, 31(7/8), pp. 609-611.

MCCLEERY, R., HOSTETLER, J., and OLI, M. (2013). Better off in the wild? Evaluating a captive breeding and release program for the recovery of an endangered rodent. *Biological Conservation*, 169, pp. 198–205.

MCCULLOUGH, D., PEI, K. and WANG, Y. (2000). Home Range, Activity patterns, of Reeves' Muntjacs in Taiwan. *Journal of Wildlife Management*. 64(2), pp. 430 - 441.

MCLACHLAN, A. and DEFEO, O. (2018). *The Ecology of Sandy Shores* (Third Edition). Elsevier Inc. Academic press. Available: https://www.sciencedirect.com/science/book/9780128094679.

MCNELLIE, M., DORROUGH, J. and OLIVER, I. (2019). Species abundance distributions should underpin ordinal cover-abundance transformations. *Applied Vegetation Science*, 22(3), pp. 361-372.

MELFI, V. and FEISTNER, A. (2002). A Comparison of the Activity Budgets of Wild and Captive Sulawesi Crested Black Macaques (Macaca Nigra). *Animal welfare*, 11(2), pp. 213-222.

MERWIN, M., MARTIN, J., WESTFALL, R., (1996). Provenance and progeny variation in growth and frost tolerance of *Casuarina cunninghamiana* in California, USA. *Forest Ecology and Management*, 79(3), pp. 161-171.

MILNER-GULLAND, E., and MACE, R. (1998). *Conservation of biological resources*. Wiley-Blackwell. 424 p.

MITCHELL, B. (1974). The forest flora of Christmas Island. *The Commonwealth Forestry Review*, 53(1,155), pp. 19-29.

MITCHELL, M., and POWELL, R. (2007). Optimal use of resources structures home ranges and spatial distribution of black bears. *Animal Behaviour,* 74, pp. 219–230.

MKUMBUKWA, A. (2014). *The History of Use and Conservation of Marine Resources in Zanzibar: Nineteenth Century to the Present*. Dissertation (PhD). University of Bayreuth.

MLIGO, C. (2015). Conservation of plant species diversity based on richness and evenness criteria in the Coast Forests of Tanzania (Online). *Journal of Environment and Ecology*, 6(1), pp. 1-20.

MUHANDO, C. (2009). Coral reef monitoring in Tanzania: an analysis of the last 20 years. *Western Indian Ocean Journal of Marine Science*, 8(2), pp. 203 – 214.

MOREAU, R. and PAKENHAM, R. (1941) The Land Vertebrates of Pemba, Zanzibar and Mafia: A Zoo-Geographical Study. *Proceedings of the Zoological Society of London, 14 November 1939, Series A. Vol. 110, Parts 3 and 4.* London. pp. 97-128.

MORRIS, D., and MUKHERJEE, S. (2000). Can we measure carrying capacity with foraging behavior? *Ecology*, 88, pp. 597-604.

MUCHAAL, P. & NGANDJUI, G. (1999) Impact of village hunting on wildlife populations in the western Dja Reserve, Cameroon. *Conservation Biology*, 13, pp. 385–396.

SHERMAN, K, OKEMWA, E., and NTIBA, M, (eds) (2009). *Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability and Management*. John Wiley & Sons. p.416.

MUPOSHI, V., MUVENGWI, J., UTETE, B., KUPIKA, O., CHIUTSI, S. and TARAKINI, T. (2013). Activity Budgets of Impala (Aepyceros melampus) in Closed Environments: The Mukuvisi Woodland Experience, Zimbabwe. *International Journal of Biodiversity, 2013, pp*. 1-8.

MUSTELIN, J. (ed)., ASSEID, B., HAJI, T., KHAMIS, M., KLEIN, R., MZEE, A. and SITARI, T. (2009). *Practical measures to tackle climate change: Coastal Forest buffer zones and shoreline change in Zanibar, Tanzania*. Turku University Department of Geography Publications B. Nr 13. Turku.

MWINYI, A (2016). *Zanzibar Aders' duiker conservation measures translocation attempts. Department of Forestry and Non- Renewable Natural Resources*. Unpublished.

MWINYI, A. (2006). *Zanzibar Aders' Duiker Conservation Measures: Translocation Attempts.* Unpublished report. Department of Natural Resources and Non-Renewable Resources Zanzibar.

MWINYI, A. and HIJA, A. (2008). *A Proposal for Suni Antelopes and Ader's Duiker Popuolation monitoring and relocation of Suni Antelopes from Mnemba to Unguja Island in Zanzibar*. Unpublished report. Department of Natural Resources and Non-Renewable Resources Zanzibar. Zanzibar.

MWINYI, A., MASUKA, S. and KLOIBER, U. (2012). ADER'S DUIKER (*Cephalophus adersi*) SURVEY REPORT Chumbe Island, 2nd June 2012. Zanzibar: CHICOP.

NAHONYO C., MWASUMBI, L., ELIAPENDA, S., MSUYA, C., MWANSASU, C., SUYA, T., MPONDA, B. and KIHAULE P. (2002). *Jozani - Chwaka Bay Proposed National Park Biodiveristy Inventory Report.* Department of Zoology and Marine Biology, University of Dar es Salaam. Tanzania.

NAKASHIMA, Y., INOUE, E. and AKOMO-OKOUE, E. (2013). Population density and habitat preferences of forest duikers in Moukalaba-Doudou National Park, Gabon. *African Zoology*, 48(2), pp. 395-399.

NANGLE, A. and SHENG, V. (2010). *Paradise Lost? Impact of Tourism and Public Use on the Mnemba House Reef.* Independent Study Project (ISP) Collection. Paper 826. Available online: http://digitalcollections.sit.edu/isp_collection/826

NEELAKANTAN, A. and JACKSON, C. (2007). *Abundance, distribution and habitat requirements of duiker (Cephalophus spp.) in the Arabuko-Sokoke Forest, Kenya: A pilot study using camera-traps to record the critically endangered Aders' duiker Cephalophus adersi*. (Internal report). BOWKETT A. and PLOWMAN A. (Eds.). UK: \Whitley Wildlife Conservation Trust.

NEKOLNY, S., DENNY, M., BIEDENBACH, G., HOWELLS, E., MAZZOIL, M., DURDEN, W., MORELAND, L., LAMBERT, J. and GIBSON, Q. (2017). Effects of study area size on home range estimates of common bottlenose dolphins Tursiops truncatus. *Current Zoology*, 63, pp. 693–701.

NEUHAUS, P. and RUCKSTUHL, K. (2004). Can the Activity Budget Hypothesis explain sexual segregation in desert Bighorn Sheep? *Behaviour,* 141, pp. 513-520.

NEWELL, N. and RIGBY, J. (1957). Geological studies on the Great Bahama Bank. *Society of Economic Paleonologists and Mineralogists, Special Publication*, 5, pp. 15–79.

NEWING, H. (1994). *Behavioural Ecology of Duikers (Cephalophus spp.) in Forest and Secondary Growth, Tal, Côte d'Ivoire.* Thesis (PhD). University of Stirling.

NEWING, H. (2001b). Bushmeat hunting and management: implications of duiker ecology and interspecific competition. *Biodiversity and Conservation,* 10, pp. 99–118.

NEWMAN, J., PARSONS, A., THORNLEY, J., PENNING, P. and KREBS, J. (1995) Optimal diet selection by a generalist grazing herbivore. *Functional Ecology*, 9, pp. 255–268.

NGANDJUI, G. and BLANC, C. (2000). Effects of hunting on mammalian populations in the western sector of the Dja reserve (Southern Cameroon). *Game and Wildlife Science*, 17, pp. 93–113.

NGOILE, M. (1990). Ecological baseline surveys of coral reefs and intertidal zones around Mnemba Island and Zanzibar Town. Commission of Lands and Environment. *Zanzibar Environmental Study Series*, 8, pp. 1-87. Zanzibar:

NIERING, W., (1956). Observations on Puluwat and Gaferut, Caroline Islands. *Atoll Research Bulletin,* 76, pp. 1 - 15.

NORBERG, R. (1977). An ecologigical theory on foraging time and energetic a choice of optional food searching method. *Journal of Animal Ecology*, 46, pp. 511–529.

NOSS, A. (1998). The impacts of cable snare hunting on wildlife populations in the forest of the Central African Republic. *Conservation Biology*, 12, pp. 390–398.

NOWAK, R. (1991). Walker's Mammals of the World. The Johns Hopkins University Press, Baltimore and London.

OCEAN POLICY RESEARCH FOUNDATION (2014). For The Better Conservation and Management of Islands and Their Surrounding Ocean Areas. *Contribution Paper for the Open Working Group on SDGs, January 2014.* Australian National Centre for Ocean Resources and Security - University of Wollongong.

OCHIENG' D., LUVANDA, A., WEKESA, C., MBUVI, M., and NDALILO, L. (eds) (2017). *Biodiversity Status of Arabuko Sokoke Forest, Kenya*. Nairobi, Kenya: Kenya Forestry Research Institute. 66 pp.

O'CONNELL, A., NICHOLS, J., and ULLAS, K. (eds.) (2011). *Camera Traps in Animal Ecology. Methods and Analyses*. Springer, Tokyo. 271 pp.

ODADA, E. (1993). The problem of coastal erosion and flooding in Eastern Africa. *Background paper presented at the workshop and Policy conference on integrated Coastal zone Management in East Africa,* April 1993*.* Arusha, Tanzania.

OGUTU, J., PIEPHO, H. and DUBLIN, H. (2014). Reproductive seasonality in African ungulates in relation to rainfall. *Wildlife Research*, 41, pp. 323–342.

ORBAN, B. (1995). *An ecological management plan for the Lionspruit Game reserve*. Dissertation (Masters Degree). University of Pretoria.

OWEN-SMITH, N. (1979) Assessing the foraging efficiency of a large herbivore, the kudu. *South African Journal Wildlife*, 9, pp. 102–110.

PAKIA, M. (2005). *African Traditional Plant knowledge today: An ethnobotanical study of the Digo at the Kenya Coast*. Dissertation (Masters degree). University of Bayreuth.

PAYNE, B. and & BRO-JØRGENSEN, J. (2016). Disproportionate Climate-Induced Range Loss Forecast for the Most Threatened African Antelopes. *Current Biology*, 26, 1200–1205.

PELLEW, R. (1984). The feeding ecology of a selective browser, the giraffe (Giraffa camelopardalis tippelskirchi). *Journal of Zoology*, 202(1), pp. 57-81.

PÉPIN, D., ADRADOS, C., MANN, C. and JANEAU, G. (2004). Assessing Real Daily Distance Traveled by Ungulates Using Differential GPS Locations. *Journal of Mammalogy*, 85, pp. 774-780.

PÉREZ-BARBERÍA, F. and GORDON, I. (1998). The influence of sexual dimorphism in body size and mouth morphology on diet selection and sexual segregation in cervids. *Acta Veterinaria Hungarica*, 46 (3), pp. 357-367.

PICKFORD, M. (2008). Middle Miocene vertebrate fauna from Pemba Island, Tanzania. *South African Journal of Science*, 104, pp. 231-237.

PINYOPUSARERK, K., WILLIAMS, E., LUANGVIRIYASAENG, V. and PURIYAKORN, B. (1996): Geographic variation in growth and morphological traits of *Casuarina equisetifolia*. In: K. PINYOPUSARERK, J. W. TURNBULL and S. J. MIDGLEY (Eds.). Recent *Casuarina* Research and Development. *Proceedings of the third International Casuarina Workshop Da Nang*, Vietnam 4–7, March 1996. pp 143–151.

PLOTZ, R., GRECIAN, W., KERLEY, G. and LINKLATER, W. (2016) Standardising Home Range Studies for Improved Management of the Critically Endangered Black Rhinoceros. *PLoS ONE,* 11(3). e0150571. https://doi.org/10.1371/journal.pone.0150571

POTGIETER, L., RICHARDSON, D., WILSON, J. (2014). *Casuarina*: biogeography and ecology of an important tree genus in a changing world. *Biological Invasions*, 16, pp. 609–633.

POWELL, R. and MITCHELL, M. (2012). What is a home range? *Journal of Mammalogy*, 93(4), pp. 948-958.

PRENDERGAST M.E. et al.(2016). Continental Island Formation and the Archaeology of Defaunation on Zanzibar, Eastern Africa. *PLoS ONE*, 11(2).

PRINS, H., DE BOER, W., VAN OEVEREN, H., CORREIA, A. MAFUCA, J. and OLFF, H. (2006). Co-existence and niche segregation of three small bovid species in southern Mozambique. *African Journal of Ecology*. 44(2). pp. 186–198.

QUINTON, B. (2016). The Effect of Home Range Estimation Techniques on Habitat Use Analysis. Dissertaion (Masters Degree). University of South Florida.

RACHLOW, J. (2008) Wildlife Ecology. In: JORGENSEN, S., and FATH, B. Encyclopedia of Ecology. Amsterdam ; Boston, Elsevier, pp. 3790-3794.

RAILS, K. (1969). Scent marking in Maxwell's duiker, Cephalophus maxwelli. *American Zoologist*, 9, p. 1071.

RAILS, K. (1973) Cephalophus maxwellii. Mammalalian Species, 31, pp .1–4.

RAMESH, T. KALLE, R. SANKAR, K. and QURESHI, Q. (2015). Role of body size in activity budgets of mammals in the Western Ghats of India. *Journal of Tropical Ecology*, 31(04), pp. 315–323.

RANSOM, J. and CADE, B. (2009). *Quantifying Equid Behavior—A Research Ethogram for Free-Roaming Feral Horses*. U.S. Geological Survey, Reston, Virginia.

RAYFIELD, B., MOILANEN, A., FORTIN, M. (2009). Incorporating consumer-resource spatial interactions in reserve design. *Ecological Modelling* 220, 725–733.

REDDELL, P., BOWEN, G., and ROBSON, A. (1986). Nodulation of *Casuarinaceae* in relation to host species and soil properties. *Australian Journal of Botany*, 34(4), pp. 435-444.

RENU. M., CHOURASIA, V. and SARAN, R. (2017). Diurnal and seasonal activity pattern of the Blackbuck (Antelope Cervicapra) In the Sorsan Grassland, Rajasthan. *International Journal of Recent Scientific Research*, 8(12), pp. 22496-22501.

REVOLUTIONARY GOVERNMENT OF ZANZIBAR (2005). Mnemba Island and Chwaka Bay Conservation Areas: A Preliminary Situational Assessment (July 2005). Prepared by EcoAfrica Environmental Consultants for the Department of Fisheries and Marine Resources.

REVOLUTIONARY GOVERNMENT OF ZANZIBAR (1999). *Towards Integrated Management and Sustainable Development of Zanzibar's Coast*. [Online] Department of Environment - Institute of Marine Sciences - Subcommission for Forestry Subcommission for Fisheries - Integrated Planning Unit , Zanzibar. Available: https://www.crc.uri.edu/download/ZAN_0056.pdf [Accessed on: Accessed on 26 August 2015].

REVOLUTIONARY GOVERNMENT OF ZANZIBAR (2012). *Marine and Coastal Environment Management Project (MACEMP), Zanzibar Coastal and Marine Tourism Plan, Finall Report, November 2012*. Ministry of Livestock and Fisheries, Zanzibar. pp. viii + 86.

RIVERS, P. (2012). The diet and behavior of Suni Antelope (Neotragus moschatus) on Mnemba Island, Zanzibar. *SIT Zanzibar: Coastal Ecology and Natural Resource Management*

ROBINSON, J. and REDFORD, K. (1991). Sustainable harvest of Neotropical forest mammals (Chapter 27). In: ROBINSON, J. and REDFORD, K (eds.) *Neotropical Wildlife Use and Conservation*. University of Chicago Press, Chicago. Pp. 415 - 428.

RODGERS W. and BURGESS, N. (2000). Taking conservation action. In: BURGESS, N., and CLARKE, G. (Eds.), *Coastal Forests of Eastern Africa*. Cambridge: IUCN Publications Services Unit. pp. 317–334.

RODGERS W. and SWAI I. (1988). Tanzania. In: R. East (Eds.), Antelopes: Global Survey and Regional Action Plans, Part 1: East & Northeast Africa. Gland, Switzerland: IUCN

ROLEČEK, J., TICHÝ, L., ZELENÝ, D., and CHYTRY, M. (2009). Modified TWINSPAN classification in which the hierarchy respects cluster heterogeneity. *Journal of Vegetation Science*, 20, pp. 596 - 602.

ROVERO, F. and MARSHALL, A. (2004): Estimating the abundance of forest antelopes by line transect techniques: a case from the Udzungwa Mountains of Tanzania. *Tropical Zoology*, 17, pp. 267-277.

ROVERO, F., JONES, T. and SANDERSON, J. (2005). Notes on Abbott's duiker (*Cephalophus spadix* True 1890) and other forest antelopes of Mwanihana Forest, Udzungwa Mountains, Tanzania, as revealed by camera-trapping and direct observations, *Tropical Zoology*, 18(1), pp. 13-23.

ROVERO, F., MARTIN, E., ROSA, M., AHUMADA, J. and SPITALE, D. (2014): Estimating species richness and modelling habitat preferences of tropical forest mammals from camera trap data. *Plos One*, 9(7).

RUCKSTUHL, K. (1998). Foraging behaviour and sexual segregation in bighorn sheep. *Animal Behaviuour*, 56, pp. 99–106.

RUCKSTUHL, K. (1999). To synchronise or not to synchronise: a dilemma for young bighorn males? *Behaviour*, 136, pp. 805–818.

RUCKSTUHL, K. (2007). Sexual segregation in vertebrates: proximate and ultimate causes. *Integrative and Comparative Biology*, 47(2), pp. 245–257.

RUCKSTUHL, K. and NEUHAUS, P. (2002). Sexual segregation in ungulates: A comparative test of three hypotheses. *Biological reviews of the Cambridge Philosophical Societ,* 77, pp. 77-96.

RUCKSTUHL, K. and NEUHAUS, P. (2009). Activity budgets and sociality in a monomorphic ungulate: the African oryx (Oryx gazella). *Canadian Journal of Zoology*, 87, pp. 165–174.

RUCKSTUHL, K., and FESTA-BIANCHET, M. (2001). Group choice by subadult male bighorn sheep: trade-offs between foraging efficiency and predator avoidance. *Ethology*, 107, pp. 161-172.

RUGG, D. and BUECH, R. (1990). Analyzing Time Budgets with Markov Chains. Biometrics, 46(4), pp. 1123-1131.

RUSSELL, E. (1931). Some theoretical Considerations on the “Overfishing” Problem. *ICES Journal of Marine Science*, 6(1), pp. 3–20

RYAN, C. and JAMMIESON, I. (1998). Estimating the home range and carrying capacity for Takahe (Porphyrio mantelli) on predator-free offshore islands: implications for future management. *New Zealand Journal of Ecology*, 22(1), pp. 17-24.

SALUM, L. (2009). Ecotourism and biodiversity conservation in Jozani–Chwaka Bay National Park, Zanzibar. *African Journal of Ecology*, 47(s1), pp.166 - 170.

SAMOILYSA, M., PABARIB, M., ANDREW, T., MAINA, G., CHURCHA, J., MOMANYIC, A., MIBEIA, B., MONJANEB, M., SHAHB, A., MENOMUSSANGAB, M. and MUTTAD, D. (2015). Resilience of Coastal Systems and Their Human Partners Ecological and social profile of coastal systems in Kenya, Mozambique and Tanzania. Nairobi, Kenya: IUCN ESARO, WIOMSA, CORDIO and *UNEP Nairobi Convention*. x + 74pp.

SAUNDERS S.P., CUTHBERT F.J. and ZIPKIN E.F. (2018). Evaluating population viability and efficacy of conservation management using integrated population models. *Journal of Applied Ecology,* 55, pp: 1380–1392.

SCHNABEL, Z. (1938). The Estimation of the Total Fish Population of a Lake. *The American Mathematical Monthly*, 45:6, pp. 348-352.

SCHRODT F. (2005). Estimating distribution and habitat associations of the endangered Aders'' duiker (Cephalophus Adersi): Implications of research and conservation. *University of Plymouth,* US.

SEAMAN, D., MILLSPAUGH, J., KERNOHAN, B., BRUNDIGE, G., RAEDEKE, K., and GITZEN, R. (1999). Effects of sample size on kernel home range estimates. *Journal of Wildlife Management*, (63)2, pp. 739–747.

SETON, E. (1909). *Life-histories of northern animals. An account of the mammals of Manitoba*. Charles Schribner's Sons, New York.

SHAGHUDE, Y. (2004). Shore morphology and sediment characteristics south of Pangani River, coastal Tanzania. *Western Indian Ocean Journal of Marine Science*. 3(2), pp 93 - 104.

SHARPE, D. (2015). Your Chi-Square Test is Statistically Significant: Now What? Practical Assessment. *Research & Evaluation*, 20(8), pp. 1-10.

SHARPLES, J. and CAIRNEY, J. (1998). Assimilation of inorganic nitrogen by a mycobiont isolated from *Pisonia grandis* R. Br. (Nyctaginaceae) mycorrhiza. *Mycorrhiza*, 7(5), pp. 255-60.

SHARPLEY, R., and USSI, M. (2014). Tourism and Governance in Small Island Developing States (SIDS): The Case of Zanzibar. *International Journal of Tourism Research*, 16(1), pp. 87 96.

SHEMSANGA, C. OMAMBIA, A. and GU, Y. (2010). The Cost of Climate Change in Tanzania: Impacts and Adaptation. *Journal of American Science*, 6(3), pp. 182-96.

SHEPHARD, C. (2016), Aders' duiker of Mnemba Island [Photograph]. At: Mnemba Island, Zanzibar. Unpublished.

SHEPHARD, F. (1948). *Submarine Geology*. New York: Harper, p. 348

SHI, J. and DUNBAR, R. (2009). Foraging ecology of feral goats on the Isle of Rum, NW Scotland. *Acta Theriologica Sinica*, 29(2), pp. 116 -124.

SHIPLEY, A. (2005). Nutritional physiology of duikers: A synthesis. In: GRAFFAM, W., HELLINGA, D., MASLANKA, M., and WARD, A. (eds). *Proceedings of the Sixth Conference on Zoo and Wildlife Nutrition.* AZA Nutrition Advisory Group, Omaha, NE.

SHIPLEY, L., GROSS, J., SPALINGER, D., HOBBS, N. and WUNDER, B. (1994). The scaling of intake rate in mammalian herbivores. *American Naturalist*, 143, pp. 1055–1082.

SIEX, K. (2011). *Protected Area Spatial Planning for Unguja and Pemba Islands, Zanzibar*. Wildlife Conservation Society (WCS) Africa Program, Zanzibar, For the World Wildlife Fund, New York.

SILVY, N. LOPEZ, R. and PETERSON, M. (2005). Wildlife marking techniques, Chapter 13. In: BRAUN, C. *Techniques for wildlife investigations and management* (6th Ed). The Wildlife Society, Bethesda, Maryland. Pp. 339-364.

SKINNER, J. and SMITHERS, R. (1990). *The Mammals of the Souther African Subregion*. University of Pretoria Press, Pretoria, 604-606.

SMITHERS, R. (1983). *The mammals of the southern African subregion*. Pretoria: University of Pretoria.

ST JOHN M. and ST JOHN O. (2017). Scuba Diving at the Mnemba Island in Zanzibar. [Online]. Drink Tea & Travel. Available from: www.drinkteatravel.com/diving-mnemba-island-zanzibar/ [Accessed on: 4 November 2018]

STAMPS, N. (2003). Out of the quagmire of plant defense hypotheses. *Quaterly Review of Biology*, 78(1), pp. 23–55.

STOCKLEY, G. M. (1941). *The Geology of the Zanzibar Protectorate and its relation to the East African Mainland*. Geology of Zanzibar Protectorate. pp: 233-240

STODDART, D. and FOSBERG, R. (1991). Phytogeography and vegetation of the reef islands of the Northern Great Barrier Reef. *Atoll Research Bulletin,* 349. pp. 1-19.

STODDART, D. and WALSH, R. (1979) Long-term climatic change in the western Indian Ocean. *Philosophical Transactions of the Royal Society of London*. Series B, 286, pp. 11–23

STODDART, D., and POORE, M. (1970). Geography and Ecology of Farquhar Atoll*. Atoll Research Bulletin,* 136, pp. 7-26.

STRATFORD, K. and STRATFORD, S. (2011). Fine-scale movements and use of space by spotted hyaena (Crocuta crocuta) on Ongava Game Reserve, Namibia. *African Journal of Ecology, pp. 1*-10.

SULLIVAN, K. (1984). The advantages of social foraging in downy woodpeckers. *Animal Behaviour*, 32(1), pp. 16–22.

SUMBI, P. (2002). Nairobi. Annex E: Tanzania country report – an overview of coastal forests management in Tanzania. *Eastern Africa Coastal Forest Programme Regional Workshop Report.* February 4-7, 2002. WWF-EAPRO. Pp. 36-41

SWAI, I. (1983). *Wildlife Conservation Status in Zanzibar*. University of Dar es Salaam, Tanzania.

SWANEPOEL, C., (2017). *Effect of coral reefs on wave attenuation and erosion: Mnemba Island, Zanzibar*. Dissertation (Masters' Degree). University of Kwazulu Natal.

SWANNACK, (2008). Growth Models In: JØRGENSEN, S. and FATH, B. (eds). *Encyclopedia of Ecology, Population Dynamics*. Elsevier. Pp. 1799 - 1805.

SWIHART, R. and SLADE, N. (1997). On Testing for Independence of Animal Movements. *Journal of Agricultural, Biological, and Environmental Statistics*, 2(1), pp. 48-63.

TAYAMA, R. (1952). *Coral reefs of the South Seas*. Bulletin of the Hydrographic Department, 11. Tokyo. pp. 1–292.

TAYLOR, J., BRAITHWAITE, C., PEAKE, J. and ARNOLD, E. (1979). Terrestrial faunas and habitats of Aldabra during the late Pleistocene. *Philosophical Transactions of the Royal Society of London*. Series B, 286, pp. 47–66.

TAYLOR, W., SKINNER, J. and KRECEK, C. (2006). The activity budgets and activity patterns of sympatric grey rhebok and mountain reedbuck in a highveld grassland area of South Africa. *African Journal of Ecology*, 44, pp. 431–437.

THE UNITED REPUBLIC OF TANZANIA (1990). *Tanzania Forestry Action Plan*. The United Republic of Tanzania, Ministry of Tourism, Natural Resources and Environment, 1990, xii, 128 pp.

THE UNITED REPUBLIC OF TANZANIA (1998). *National Forest Policy.* The United Republic of Tanzania, March 1998. Dar es Salaam, Government Printer, 59 pp.

THOMAS, O. (1918) XIII. A new duiker from Zanzibar. *Journal of Natural History*, 2(8), pp. 151-152. DOI: 10.1080/00222931808562355

TOBLER, W., HIBERT, F., DEBEIR, L., and RICHARD-HANSEN, C. (2013). Estimates of density and sustainable harvest of the lowland tapir Tapirus terrestris in the Amazon of French Guiana using a Bayesian spatially explicit capture–recapture model. Fauna & Flora International, *Oryx*, 2013, pp. 1–10.

TOLLINGTON, S. and EDWARDS, W. (2008). Distribution and habitat requirements of Aders' duiker (Cephalophus adersi) in the coastal forests of Kenya. [Internal report] BOWKETT A. And BOWMAN A. (Eds.) UK: Whitley Wildlife Conservation Trust.

TREWHELLA, W., HARRIS, S. and MCALLISTER, F. (1988). Dispersal Distance, Home-Range Size and Population Density in the Red Fox (Vulpes vulpes): A Quantitative Analysis. *Journal of Applied Ecology*, 25 (2), pp. 423-434.

TUCKER, C., RADZIO, T., STRICKLAND, J., BRITTON, E., DELANEY, D., and LIGON, D. (2014). Use of radio telemetry to detect nesting activity in ornate box turtles, Terrapene ornata. *American Midland Naturalist*, 171(1), pp. 79-89.

UNDERWOOD, R. (1982). Vigilance Behaviour in Grazing African Antelopes. *Behaviour*, 79(2/4), pp. 81-107.

UNESCO (2016). *Ecological Sciences for Sustainable Development - Jozani Chwaka Bay*. [Online] Available from: http://www.unesco.org [Accessed: 10 July 2018]

URAMA, K. and OZOR, N. (2010). Impacts of climate change on water resources in Africa: the role of adaptation. *African Technology Policy Studies Network, Climate Adaptation, pp. 1-*29.

US GOVERNMENT (2018). *Atoll Reef Structure*. [Online]. Nationial Oceanic and Atmospheric Administration. Available: https://oceanservice.noaa.gov [Accessed on: 5 November 2018]

UWEMAJO (2013). Community Behavioral Change (CBC): *Project proposal for GEF small grants programme 2013-2014*. Umoja wa Wenye Mashamba Jozani (UWEMAJO).

VAČKÁŘ, D., TEN BRINK, B., LOH, J., BAILLIE, J. and REYERS, B. (2012). Review of multispecies indices for monitoring human impacts on biodiversity. *Ecological Indicators,* 17, pp. 58–67.

VAN BREUGEL, P., KINDT, R., LILLESØ, J-PB., VAN BREUGEL, M. (2015b). Environmental Gap Analysis to Prioritize Conservation Efforts in Eastern Africa. *PLoS ONE,* 10(4): e0121444.

VAN BREUGEL, P., KINDT, R., LILLESØ, J-PB.,. BINGHAM, M., DEMISSEW, S., DUDLEY, C., FRIIS, I., GACHATHI, F., KALEMA, J., and MBAGO, F. (2015a) *Potential Natural Vegetation Map of Eastern Africa (Burundi, Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia).* Version 2.0. Forest and Landscape (Denmark) and World Agroforestry Centre (ICRAF). URL: http://vegetationmap4africa.org

VAN DER JEUGD, H. and PRINS, H. (2000). Movements and group structure of giraffe (Giraffa camelopardalis) in Lake Manyara National Park, Tanzania. *Journal of Zoology*, 251(1), pp 15-21.

VAN DER MAAREL, E. (ed.) (2009). *Vegetation Ecology*. [Online] Wiley-Blackwell. 408 pp. Available: https://www.wiley.com/en-us/9781444311198

VAN FLANDERN, T. and PULKKINEN, K. (1979). Low precision formulae for planetary positions. *Astrophysical Journal Supplement Series*, 41, pp. 391-411.

VAN VLIET N. and NASI R. (2008). Why do models fail to assess properly the sustainability of duiker (Cephalophus spp.) hunting in Central Africa? Fauna & Flora International, *Oryx*, 42(3), pp. 392–399.

VAZQUEZ, C., ROWCLIFFE, J. SPOELSTRA, K. and JANSEN, P. (2019). Comparing diel activity patterns of wildlife across latitudes and seasons: Time transformations using day length. Methods in Ecology and Evolution, 10, pp. 2057–2066.

VESEY-FITZGERALD, D. (1942). Further Studies of the Vegetation on Islands in the Indian Ocean. *Journal of Ecology*, 30(1), pp. 1-16.

VIQUERAT, S., BOBO, K., MÜLLER, M., KIFFNER, C., and WALTERT, M. (2012). Estimating forest duiker (Cephalophinae) density in Korup National Park: a case study on the performance of three line transect methods. *South African Journal of Wildlife Research,* 42(1), 10 p.

WALKER, T. (1991). *Pisonia* islands of the Great Barrier Reef. Part I. The distribution, abundance and dispersal by seabirds of *Pisonia grandis*. *Atoll Research Bulletin,* 350, pp. 1–23.

WALTER, W., FISCHER, J., BARUCH-MORDO, S. and VERCAUTEREN, K. (2011). What Is the Proper Method to Delineate Home Range of an Animal Using Today’s Advanced GPS Telemetry Systems: The Initial Step. *USDA National Wildlife Research Center - Staff Publications*, 1375, pp. 249-268.

WALL, J., WITTEMYER, G., LEMAY, V., DOUGLAS-HAMILTON, I. and KLINKERBERG, B. (2014), Elliptical Time-Density model to estimate wildlife utilization distributions. *Methods in Ecology and Evolution*, 5, pp. 780-790.

WATKISS, P., PYE, S., HENDRIKSEN, G., MACLEAN, A., BONJEAN, M., JIDDAWI, N., SHAGHUDE, Y., SHEIKH, M., and KHAMIS, Z (2012). The Economics of Climate Change in Zanzibar. *Study Report for the Revolutionary Government of Zanzibar*, Climate Change Committee.

WEATHER UNDERGROUND (2016a). *Zanzibar, Station ID: IMJINIMA3*; Station Key: 9b9685e0; MJINI MAGHARIBI, TZ. [Online]. Powered by the IBM Cloud. © Copyright TWC Product and Technology LLC 2014, 2018. Available at: www.wunderground.com. [Accessed 14 April 2017]

WEATHER UNDERGROUND (2016b). *Zanzibar, TZ - Station: Airport (HTZA)* (Elev 15m 6.22 °S, 39.22 °E). [WWW]. Powered by the IBM Cloud. © Copyright TWC Product and Technology LLC 2014, 2018. Available at: www.wunderground.com. [Accessed 14 April 2017]

WEBER, H., MORAVEC, J., and THEURILLAT, J., (2000). International Code of Phytosociological Nomenclature, 3rd edition. *Journal of Vegetation Science*, 1, pp. 739–768.

WEIGL, R. (2005). *Longevity of Mammals in Captivity: From the Living Collections of the World*, Kleine Senckenberg-Reihe 48. Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung. 214 pp.

WEINSTEIN, A., (1993). Provenance trials of *Casuarina cunninghamiana*, *Casuarina* glauca, and *Allocasuarina verticillata* in Israel. *Australian Forestry*, 56(1), pp. 34-37.

WERNER, D. and NEWTON, W. (eds) (2005). Nitrogen Fixation in Agriculture, Forestry, Ecology, and the Environment. Netherlands: Springer, 4, pp. 1-350

WESTHOFF, V. and VAN DER MAAREL, E. (1978). The Braun-Blanquet approach. In: WHITTAKER, R. (ed.) *Classification of plant communities*. Dr W Junk, The Hague: pp. 289-399.

WIAFE, E. and AMFO-OUT, R. (2012). Forest duiker (Cephalophus spp.) abundance and hunting activities in the Kakum conservation area, Ghana. *Journal of Ecology and the Natural Environment*, 4(4), pp. 114-118.

WICH, S., ATMOKO, S., SETIA, T. and VAN SCHAIK, C. (2008). Orangutans: Geographic Variation in Behavioral Ecology and Conservation. *Oxford Scholarship Online*. DOI: 10.1093/acprof:oso/9780199213276.001.0001.

WICKENS, G.E. (1979). Speculations on Seed Dispersal and the Flora of the Aldabra Archipelago. *Philosophical Transactions of the Royal Society of London*. Series B, Biological Sciences, 286(1011), pp. 85-97.

WIENS, H. (1962). *Atoll Environment and Ecology*. New Haven: Yale University Press. pp. 1-9

WIKUM, D. and SHANHOLTZER, G. (1978). Application of the Braun-Blanquet cover-abundance scale for vegetation analysis in land development studies. *Environmental Management*, 2(4), pp. 323–329.

Wildlife Campus (n.d.). Determining Browsing Capacity & Ecological Carrying Capacity Module # 13 – Component # 2 & 3. [Online] Wildlife Management Course. Available: https://www.wildlifecampus.com/

WILLIAMS, A., MASOUD, T. and OTHMAN, W. (1999). Community-based conservation experiences from Zanzibar. *International Institute for Environment and Development, Gatekeeper Serires,* SA80.

WILLIAMS, A., MWINYI, A., and SAID, J. (1996). A Population Survey of the Mini-antelope Aders' duiker *Cephalophus Adersi*, Zanzibar blue duiker *Cephalophus monticola sudevalli*, and *Suni Neotragus moschatus moschatus* of Unguja, Zanzibar. *Unpublished report to the Commission for Natural Resources, Zanzibar*.

WILLISCH, C. and INGOLD, P. (2007). Feeding or Resting? The Strategy of Rutting Male Alpine Chamois. *Ethology*, 113(1), pp. 97-104.

WILSON, D. and REEDER, D. M. (2005) (Editors). *Mammal Species of the World* (Third Edition). Johns Hopkins University Press, 2, 142 pp.

WILSON, V. (1987). *Action plan for duiker conservation*. IUCN/SSC Antelope Specialist Group and Chipangali Wildlife Trust.

WILSON, V. (2001). *Duikers of Africa: Masters of the African forest floor*. Zimbi Books, South Africa.

WILSON, V., SCHMIDT, J. and HANKS, J. (1984). Age determination and body growth of the Common duiker *Sylvicapra grimmia* (Mammalia). *Journal of Zoology*, 202, pp. 283-297.

WINGATE D. (2000). Strategies for successful biodiversity conservation and restoration on small oceanic islands: some examples from Bermuda. In: CALPE 2000: *Linking the fragments of paradise - An international conference on environmental conservation in small territories,* 28th September to 1st October 2000. Gibraltar, Gibraltar Ornithological & Natural History Society. Pp. 16–24.

WINNER, K., NOONAN, M., FLEMING, C., OLSON, K., MUELLER, T., SHELDON, D., and CALABRESE, J. (2018). Statistical inference for home range overlap. *Methods in Ecology and Evolution*, 9(7), pp. 1679-1691.

WOODROFFE, C. (2008). Reef-island topography and the vulnerability of atolls to sea-level rise. Global and Planetary Change. 62. pp: 77–96

WOODROFFE, C. And BIRIBO N. (2011). Atolls. In HOPLEY, D. (Ed.). *Encyclopedia of Modern Coral Reefs: structure, form and process*. The Netherlands: Springer. Pp. 51-71.

WOODROFFE, C. and MORRISON, R. (2001). Reef-island accretion and soil development on Makin, Kiribati, central Pacific. *Catena*, 44(4), pp. 245-261.

WORLD HEALTH ORGANIZATION (2002). *Global Solar UV Index: A Practical Guide.* Geneva, WHO.

WRONKSI, T. (2002). Feeding ecology and foraging behaviour of impala Aepyceros melampus in Lake Mburo National Park, Uganda. *African Journal of Ecology*, 40, pp. 205 - 211.

XIA, C., YANG, W., XU, W., XU, F., and BLANK, D. (2013). The characteristics of time budgets of male goitred gazelle in different rutting period stages. *Acta Theriologica Sinica*, 33(2), pp. 144-149.

YAMANO, H., KAYANNE, H. and CHIKAMORI, M. (2005) An Overview of The Nature and Dynamics of Reef Islands. *Global Environmental Research*, 9(1), pp. 9-20.

YOUNGE, A., NEGUSSIE, D. and BURGESS, N. (2002)*. Eastern Africa Coastal Forest Programme Regional Workshop Report. Produced for WWF-EAPRO.* February 4-7, 2002. Nairobi*.*

YU., A. and LEI., S. (2001). Equilibrium Theory of Island Biogeography: A Review. *USDA Forest Service Proceedings*, RMRS-P-21, Pp. 163–171.

ZAVALA-GARAY J., THEISS, J., MOULTON, M., WALSH, C., VAN WOESIK, R., MAYORGA-ADAME, C., GARCIA-REYES, M., MUKAKA, D., WHILDEN, K., and SHAGHUDE, Y. (2015). On the dynamics of the Zanzibar Channel. *Journal of Geophysical Research: Oceans,*120, pp: 6091–6113.

ZIPPIN, C. (1958). The removal method of population estimation. *Journal of Wildlife Management*, 22, pp. 82-90.

APPENDICES

12.1 Appendix A – The potential natural vegetation (PNV) map of Eastern Africa from **http://maps.vegetationmap4africa.org/docs.html**

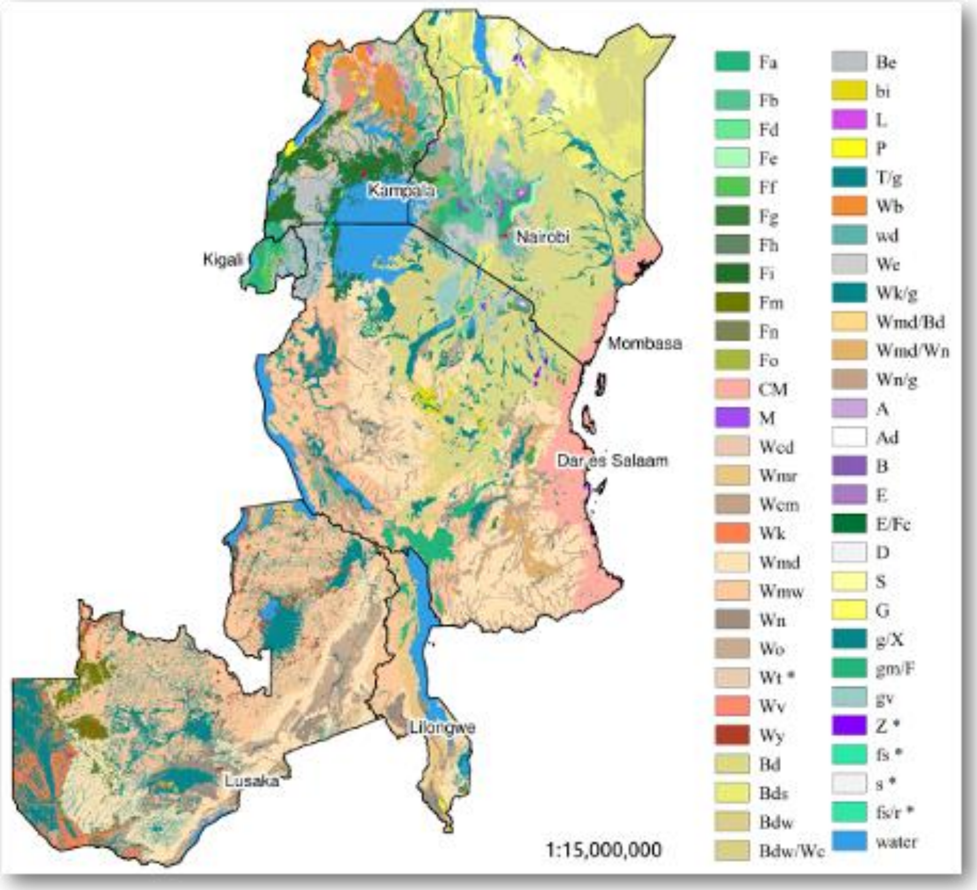


Figure 12-1: The potential natural vegetation (PNV) map of Eastern Africa

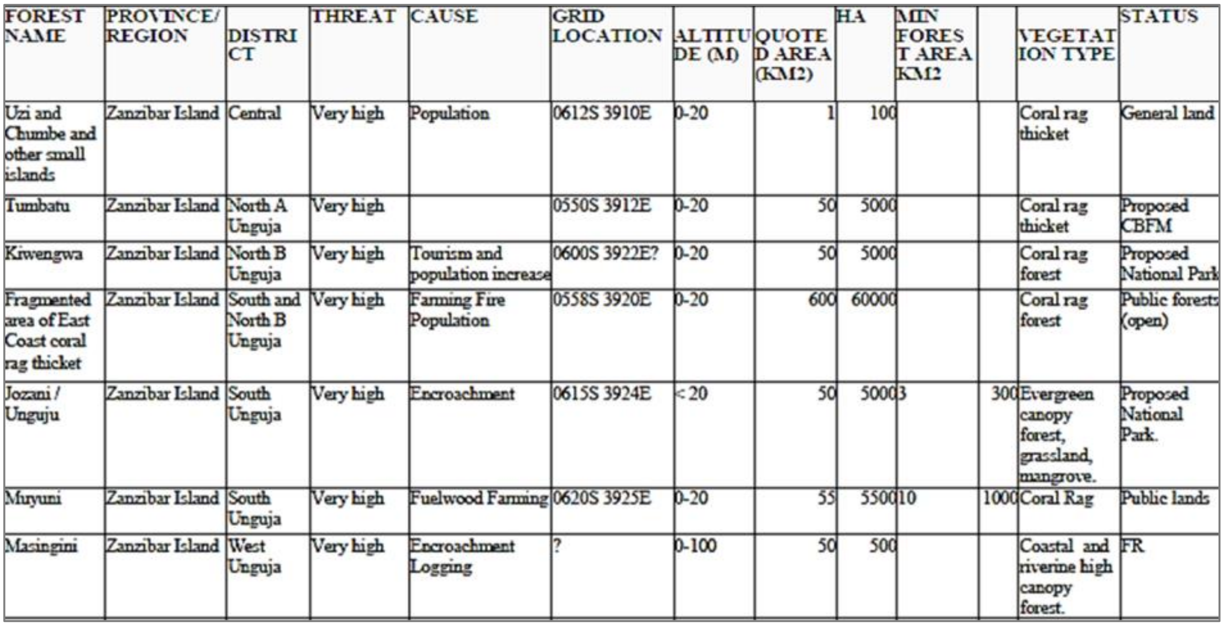
Legend code:

A Afroalpine vegetation
B Afromontane bamboo
Bds Acacia-Commiphora stunted bushland
Bd Somalia-Masai Acacia-Commiphora deciduous bushland and thicket
Be Evergreen and semi-evergreen bushland and thicket
bi Itigi thicket (edaphic vegetation type)
br Riverine thicket
CM Coastal mosaic
Da Afromontane desert
D Desert
E Montane Ericaceous belt
Fa Afromontane rain forest
Fb Afromontane undifferentiated forest
Fc Afromontane single-dominant Widdringtonia whytei forest
fc Zanzibar-Inhambane scrub forest on coral rag
Fd Afromontane single-dominant Hagenia abyssinica forest
Fe Afromontane moist transitional forest
fe Lake Victoria Euphorbia dawei scrub forest
Ff Lake Victoria transitional rain forest
Fg Zanzibar-Inhambane transitional rain forest
Fh Afromontane dry transitional forest
Fi Lake Victoria drier peripheral semi-evergreen Guineo-Congolian rain forest
Fm Zambezian dry evergreen forest
Fn Zambezian dry deciduous forest and scrub forest
Fo Zanzibar-Inhambane lowland rain forest
Fp Zanzibar-Inhambane undifferentiated forest
Fq Zanzibar-Inhambane scrub forest
fr Riverine forests
fs Swamp forests
Ft Lake Victoria Strychnos potatorum scrub forest
g Edaphic grassland on drainage-impeded or seasonally flooded soils
G Grassland
gv Edaphic grassland on volcanic soils
L Lowland bamboo
M Mangrove
P Palm wooded grasslands
R Riverine wooded vegetation (compound of fr, wr and br)
S Somalia-Masai semi-desert grassland and shrubland
T Termitaria vegetation
Wb Vitellaria wooded grassland
Wc Combretum wooded grassland
Wcd dry Combretum wooded grassland
Wcm moist Combretum wooded grassland
Wd Acacia-Commiphora deciduous wooded grassland
wd Edaphic wooded grassland
We Upland Acacia wooded grassland
Wk Kalahari woodland
Wmd Drier Miombo woodland
Wm Miombo woodland
Wmr Miombo woodland on hills and rocky outcrops
Wmt Zanzibar-Inhambane transition woodland
Wmw Wetter Miombo woodland
Wn North Zambezian undifferentiated woodland
Wo Mopane woodland and scrub woodland
Wt Terminalia sericea woodland
Wv Vitex-Phyllanthus-Sapium-Terminalia and Terminalia glaucescens woodlands
Wy Chipya woodland and wooded grassland
X Freshwater swamp
Z Halophytic vegetation

12.2 Appendix B - Threatened forest areas (2002) and forest corridors proposed (2011) for Unguja

Although Jozani Forest is the only National Park, there are other smaller forested areas of importance in Unguja. A total of 81 100 ha of forests are threatened.

Table 12-1: Threatened forest areas on Unguja (Zanzibar) (Sumbi, 2002).



FOREST NAME	PROVINCE/ REGION	DISTRICT	THREAT	CAUSE	GRID LOCATION	ALTITUDE (M)	QUOTED AREA (KM2)	HA	MIN FOREST AREA KM2		VEGETATION TYPE	STATUS
Uzi and Chumbe and other small islands	Zanzibar Island	Central	Very high	Population	0612S 3910E	0-20	1	100			Coral rag thicket	General land
Tumbatu	Zanzibar Island	North A Unguja	Very high		0550S 3912E	0-20	50	5000			Coral rag thicket	Proposed CBFM
Kiwengwa	Zanzibar Island	North B Unguja	Very high	Tourism and population increase	0600S 3922E?	0-20	50	5000			Coral rag forest	Proposed National Park
Fragmented area of East Coast coral rag thicket	Zanzibar Island	South and North B Unguja	Very high	Farming Fire Population	0558S 3920E	0-20	600	60000			Coral rag forest	Public forests (open)
Jozani / Unguju	Zanzibar Island	South Unguja	Very high	Encroachment	0615S 3924E	< 20	50	5000	3	300	Evergreen canopy forest, grassland, mangrove.	Proposed National Park.
Muyuni	Zanzibar Island	South Unguja	Very high	Fuelwood Farming	0620S 3925E	0-20	55	5500	10	1000	Coral Rag	Public lands
Masingini	Zanzibar Island	West Unguja	Very high	Encroachment Logging	?	0-100	50	500			Coastal and riverine high canopy forest.	FR

A network of linked forests and recommended corridors were identified for habitat conservation and wildlife protection. In total, five existing areas and one proposed area were identified and mapped, with six wildlife corridors linking the forest areas (Siex, 2011).

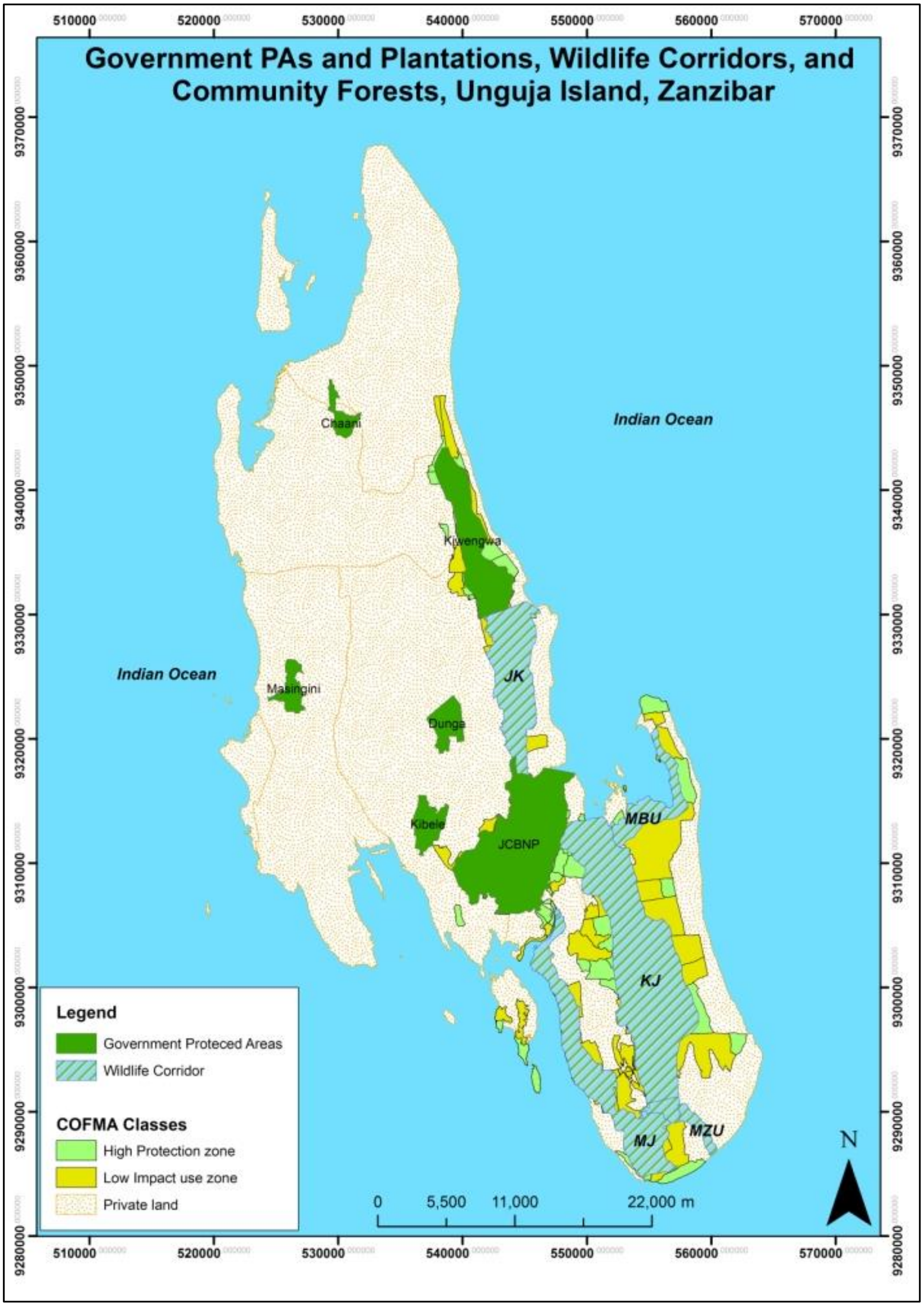


Figure 12-2: "*Government Protected Areas and Plantations, five Wildlife Corridors (JK, KJ, MJ, MBU, MZU) and Community "High Protection" and "Low Impact Use" zones, Unguja Island, Zanzibar*." Taken from Siex (2011), p20.

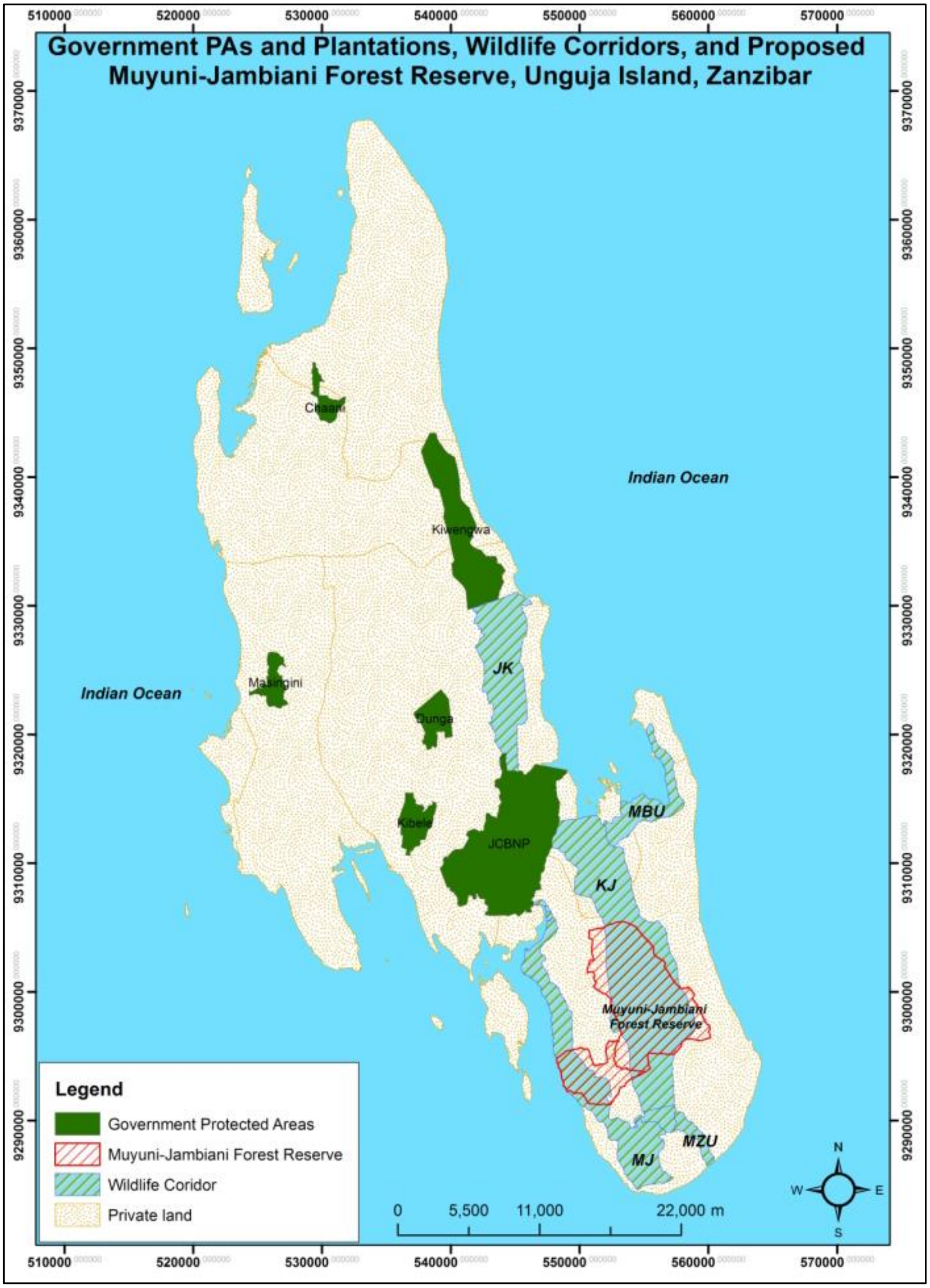


Figure 12-3: "*Government Protected Areas and Plantations, five Wildlife Corridors (JK, KJ, MJ, MBU, MZU), and the Proposed Muyuni-Jambiani Forest Reserve, Unguja Island, Zanzibar*." Take from Siex (2011), p21.

12.3 Appendix C - Classification of categories by the IUCN Red List

Classification of Species by the IUCN Red List considers nine distinct categories that are made up and evaluated based on key factors such as distribution, population size and fragmentation as well as population growth trends.

Taken from: https://www.iucnredlist.org/resources/classification-schemes

The Classification Schemes used in IUCN Red List assessments include:

Threats – to record past, ongoing and future threats to a taxon. For definitions, examples and guidance on the Threats Classification Scheme ver. 3.2

Stresses – to record how each threat impacts a taxon. For definitions, examples and guidance on the Stresses Classification Scheme ver. 1.1

Habitats – to record which habitats a taxon occurs in. For definitions, examples and guidance on the Habitats Classification Scheme ver. 3.1

Conservation Actions In Place – to record what conservation actions are already in place for a taxon. For definitions, examples and guidance on the Conservation Actions in Place Classification Scheme ver 2.0

Conservation Actions Needed – to record what conservation actions are needed for a taxon. For definitions, examples and guidance on the Conservation Actions Needed Classification Scheme ver. 2.0

Research Needed – to record what further research is needed on a taxon. For definitions, examples and guidance on the Research Needed Classification Scheme ver. 1.0

General Use and Trade – to record how a taxon is utilised and what level of trade occurs for the taxon. For the General Use and Trade Classification Scheme (including the Non-Consumptive Use scheme) ver. 1.0

Livelihoods – to record the importance of a taxon to human livelihoods. For the Livelihoods Classification Scheme ver. 2.0

Plant and Fungal Growth Forms – to record growth or life form to enable searches on the Red List web site for particular functional groups of plants (trees, shrubs, succulents, ferns, etc.) and fungi. For definitions and guidance on the Plant and Fungal Growth Forms Classification Scheme ver. 1.1

12.4 Appendix D – Plant species identified on Mnemba in 1989 and in this current study (2016/2017).

Table 12-2: Kiswahili names for 32 Plant species identified by Ngoile in 1989 on Mnemba Island, including the potential corresponding scientific names. Nr 9 and 32 seem to be a duplicate.

NGOILE 1989	Swahili name	Scientific name	Alternative Identification
1	Ndago ya pwani (a sage)	*Cyperus obtusiflorus*	
2	Upundi	Not identified	
3	Mwache	*Coco nucifera (likely)*	*Euphorbia hirta*
4	Mlakasa	*Ipomoea pres-caprae*	
5	Mpepe-kivundo / Mpepa-dume	*Maytenus spp.*	
6	Mkadi	*Pandanus kirkii*	
7	Mpumbu-paka	*Synaptolepis kirkii*	
8	Kiwavi (a climber)	*Tragia furialis*	
9	Mkaaga	*Eugenia capensis*	
10	Mrigwi	Not identified	
11	Mkolekwa / Mkolepwa	*Grewia glandulosa*	
12	Mkongwa (creeping plant)	*Anelima indehiscent*	
13	Mdimu-msitu	*Surregada zanzibarensis*	
14	Mvuru-vuru	*Mimusops obtusifolia*	
15	Mhan'gong'wa	*Psychotria spp*	
16	Mbubduki	*Bourreria petiolaris*	
17	Mpesu	*Tema orientalis*	
18	Mlimbo-makoa	*Mystroxylon aethiopicum (likely)*	*Hippocratea indica or Olea woodiana or Landolphia kirkii*
19	Mkogwa (creeping plant)	*Anelima spp*	
20	Kichango	*Rubia cordifolia*	
21	Gwede	*Encephalartos hildebrandtii*	
22	Mnywa (aclimber)	*Toddalia asiatica*	
23	Kongwa (a creeping plant)	*Commelina diffusa*	
24	Kindaramba	*Pemphis acidua*	
25	Mvinje	*Casuarina cunninghumiana*	
26	Mkwamba	*Fluggea virosa*	
27	Mtumbaku	*Ageratum conyzoides (likely)*	*Vernonia zanzibarica*
28	Mchunga wani	*Sonchus luxurians (likely)*	*Launaea cornuta*
29	Mtundang'ombe	*Sideroxylon inerme*	
30	Mkuju	*Ficus spp (likely)*	*Leucas spp*
31	Mchechepwa	*Abrus precatorius*	
32	Mkaaga (duplicate)	*Eugenia capensis*	

Table 12-3: All 91 Plant species identified on Mnemba Island in the current study.

Plant Species List for Mnemba Island - 2016/2017	**Family**	**Higher Classification**	**Distribution**
Abutilon spp	Malvaceae	DICOTYLEDONEAE	NATIVE
Acacia auriculiformis	Fabaceae	DICOTYLEDONEAE	INTRODUCED
Adenia gummifera	Passifloriacea	DICOTYLEDONEAE	NATIVE
Afroligusticum linderi	Apiaceae	DICOTYLEDONEAE	NATIVE
Anelima indehiscent	Commelinaceae	MONOCOTYLEDONEAE	NATIVE
Auricularia auricular-judae	Auriculariaceae	BASIDIOMYCOTA	NATIVE
Biddens pilosa	Asteraceae	DICOTYLEDONEAE	INTRODUCED
Boerhavia diffusia	Nyctaginaceae	DICOTYLEDONEAE	NATIVE
Boerhavia spp	Nyctaginaceae	DICOTYLEDONEAE	NATIVE
Bougainvillea spectabilis	Nyctaginaceae	DICOTYLEDONEAE	INTRODUCED
Bourreria petiolaris	Boraginaceae	DICOTYLEDONEAE	NATIVE
Brachiaria leersioides	Poaceae	MONOCOTYLEDONEAE	NATIVE
Caesalpinia bonduc	Fabaceae	DICOTYLEDONEAE	NATIVE
Capparis viminea	Capparacea	DICOTYLEDONEAE	ENDEMIC
Cassytha filiformis	Lauraceae	DICOTYLEDONEAE	NATIVE
Casuarina cunninghamiana	Casuarinaceae	DICOTYLEDONEAE	ALIEN
Chrysothrix spp	Chrysothricaceae	CHRYSOTHRICACEAE	NATIVE
Clerodendrum glabrum	Vebanaceae	DICOTYLEDONEAE	NATIVE
Coccinia grandis	Curbitaceae	DICOTYLEDONEAE	NATIVE
Coco nucifera	Palmae	MONOCOTYLEDONEAE	NATURALISED
Conyza newii	Asteraceae	DICOTYLEDONEAE	NATIVE
Cordia Subcordata	Boraginaceae	DICOTYLEDONEAE	NATIVE
Cyperus obtusiflorus	Cyperaceae	MONOCOTYLEDONEAE	NATIVE
Cyphostemma adenocaula	Vitaceae	DICOTYLEDONEAE	NATIVE
Dactyloctenium aegyptium	Poaceae	MONOCOTYLEDONEAE	NATIVE
Daedaleopsis confragosa	Polyporaceae	BASIDIOMYCOTA	NATIVE
Daldinia concentrica	Xylariaceae	ASCOMYCOTA	NATIVE
Dalechampia scandens	Euphorbiaceae	DICOTYLEDONEAE	NATIVE
Ecbolium ligustrinum	Acanthaceae	DICOTYLEDONEAE	NATIVE

Continue/

Plant Species List for Mnemba Island - 2016/2017	**Family**	**Higher Classification**	**Distribution**
Ehretia amoena	Boraginaceae	DICOTYLEDONEAE	NATIVE
Enteropogon macrostachyus	Poaceae	MONOCOTYLEDONEAE	NATIVE
Eragrostis ciliaris	Gramnaecea	MONOCOTYLEDONEAE	NATIVE
Euclea natalensis	Ebenaceae	DICOTYLEDONEAE	NATIVE
Eugenia capensis	Myrtaceae	DICOTYLEDONEAE	NATIVE
Evernia prunastri	Parmeliaceae	ASCOMYCOTA	NATIVE
Ficus ingens	Moraceae	DICOTYLEDONEAE	NATIVE
Ficus lutea	Moraceae	DICOTYLEDONEAE	NATIVE
Ficus polita	Moraceae	DICOTYLEDONEAE	NATIVE
Ficus scassellatii	Moraceae	DICOTYLEDONEAE	NATIVE
Fluggea virosa	Euphorbiaceae	DICOTYLEDONEAE	NATIVE
Fomitopsis pinicola	Fomitopsidaceae	BASIDIOMYCOTA	NATIVE
Grewia glandulosa	Tiliaceae	DICOTYLEDONEAE	NATIVE
Guettarda speciosa	Rubiaceae	DICOTYLEDONEAE	NATIVE
Halopyrum mucronatum	POACEAE	MONOCOTYLEDONEAE	NATIVE
Ipomoea pes-caprea	Convolvulaceae	DICOTYLEDONEAE	NATIVE
Ipomoea spp	Convolvulaceae	DICOTYLEDONEAE	NATIVE
Justicia capensis	Acanthaceae	DICOTYLEDONEAE	NATIVE
Kyllinga erecta	Cyperaceae	MONOCOTYLEDONEAE	NATIVE
Kyllinga platyphylla	Cyperaceae	MONOCOTYLEDONEAE	NATIVE
Ludia mauritiana	Salicaceae	DICOTYLEDONEAE	NATIVE
Maerua triphylla	Capparacea	DICOTYLEDONEAE	NATIVE
Maytenus heterophylla	Celatraceae	DICOTYLEDONEAE	NATIVE
Melanthera biflora	Asteraceae	DICOTYLEDONEAE	NATIVE
Mimusops obtusifolia	Sapotaceae	DICOTYLEDONEAE	NATIVE
Morinda citrifolia	Rubiaceae	DICOTYLEDONEAE	NATURALISED
Pandanus kirkii	Pandanaceae	MONOCOTYLEDONEAE	NATIVE
Panicum maximum	Poaceae	MONOCOTYLEDONEAE	NATIVE
Panicum repens	Poaceae	MONOCOTYLEDONEAE	NATIVE
Parmelia sulcata	Parmeliaceae	ASCOMYCOTA	NATIVE

Continue//

Plant Species List for Mnemba Island - 2016/2017	**Family**	**Higher Classification**	**Distribution**
Parquetina nigrescens	Asclepiadaceae	DICOTYLEDONEAE	NATIVE
Paspalum virgatum	POACEAE	MONOCOTYLEDONEAE	INTRODUCED
Pavetta stenosepala	Rubiaceae	DICOTYLEDONEAE	NATIVE
Pavonia species	Malvaceae	DICOTYLEDONEAE	NATIVE
Pemphis acidula	Lythracieae	DICOTYLEDONEAE	NATIVE
Phaeotrametes decipiens	Polyporaceae	BASIDIOMYCOTA	NATIVE
Phyllanthus amarus	Phyllanthaceae	DICOTYLEDONEAE	INTRODUCED
Pisonia grandis	Nyctaginaceae	DICOTYLEDONEAE	UNCLASSIFIED
Polyporus tubaeformis	Polyporaceae	BASIDIOMYCOTA	NATIVE
Polysphaeria parvifolia	Rubiaceae	DICOTYLEDONEAE	NATIVE
Psychotria psychotrioides	Rubiaceae	DICOTYLEDONEAE	NATIVE
Pupalia lappacea	Amarnthaceae	MONOCOTYLEDONEAE	NATIVE
Pycnoporus spp	Polyporaceae	BASIDIOMYCOTA	NATIVE
Ricinus communis	Euphorbiaceae	DICOTYLEDONEAE	NATIVE
Searsia natalensis	Anacardiaceae	DICOTYLEDONEAE	NATIVE
Rhynchosia sublobata	Fabaceae	DICOTYLEDONEAE	NATIVE
Scaevola sericea	Goodeniaceae	DICOTYLEDONEAE	NATIVE
Scutia myrtina	Rhamnaceae	DICOTYLEDONEAE	NATIVE
Secamone puntulata	Apocynaceae	DICOTYLEDONEAE	NATIVE
Sesbania bispinosa	Fabaceae	DICOTYLEDONEAE	NATIVE
Sideroxylon inerme	Sapotaceae	DICOTYLEDONEAE	NATIVE
Solanum viarum	Solanaceae	DICOTYLEDONEAE	ALIEN
Sporobolus virginicus	POACEAE	MONOCOTYLEDONEAE	NATIVE
Suregada zanzibarensis	Euphorbiaceae	DICOTYLEDONEAE	NATIVE
Suriana maritima	Surianaceae	DICOTYLEDONEAE	NATIVE
Synaptolepis kirkii	Thymaleaeae	DICOTYLEDONEAE	NATIVE
Tacca leontopetaloides	TACCACEAE	MONOCOTYLEDONEAE	NATIVE
Terminalia cattapa	Combretaceae	DICOTYLEDONEAE	NATURALISED
Toddalia asiatica	Rutaceae	DICOTYLEDONEAE	NATIVE
Trametes hirsuta	Polyporaceae	BASIDIOMYCOTA	NATIVE
Trema orientalis	Ulmaceae	DICOTYLEDONEAE	NATIVE
Xanthoria spp	Teloschistaceae	ASCOMYCOTA	NATIVE

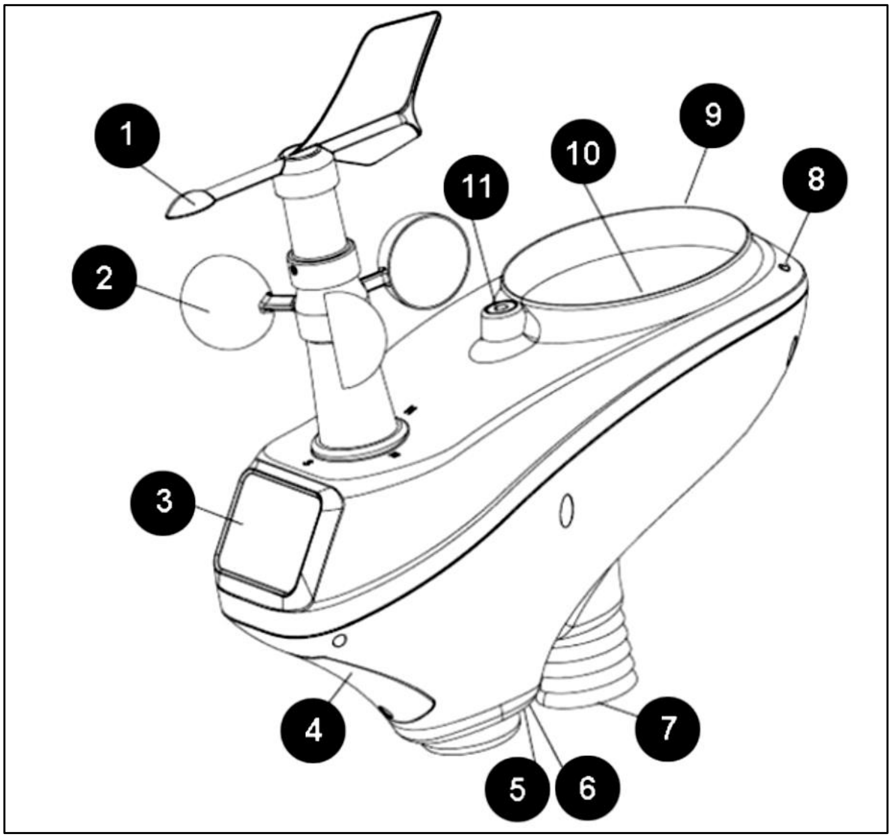
12.5 Appendix E – Mnemba weather station setup

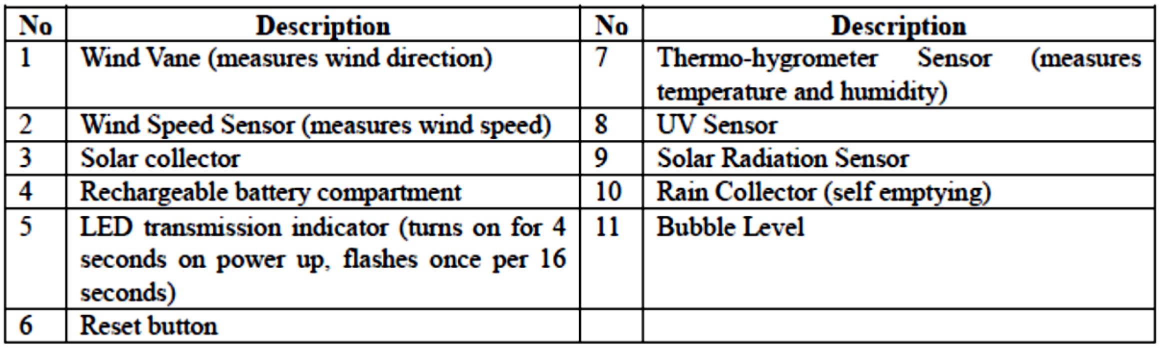
An impromptu Ambient Weather WS-1000-WiFi OBSERVER Solar Powered Wireless Wi-Fi Weather Station was procured from AWR Smith Process Instrumentation, South Africa, and erected above the height of the office roof with no obstructions or heat emitting surfaces close by.

Figure 12-4: Ambient Weather WS-1000-WiFi OBSERVER Solar Powered Wireless Wi-Fi Weather Station mounted on an 8-meter-high mast.

Figure 12-5: Weather Station mounted above the height of the office roof and clear of any obstructions.

Figure 12-6: Digital Weather consol displaying summary statistics from the Weather Ungeground cloud, where data from the on-site station was uploaded to.

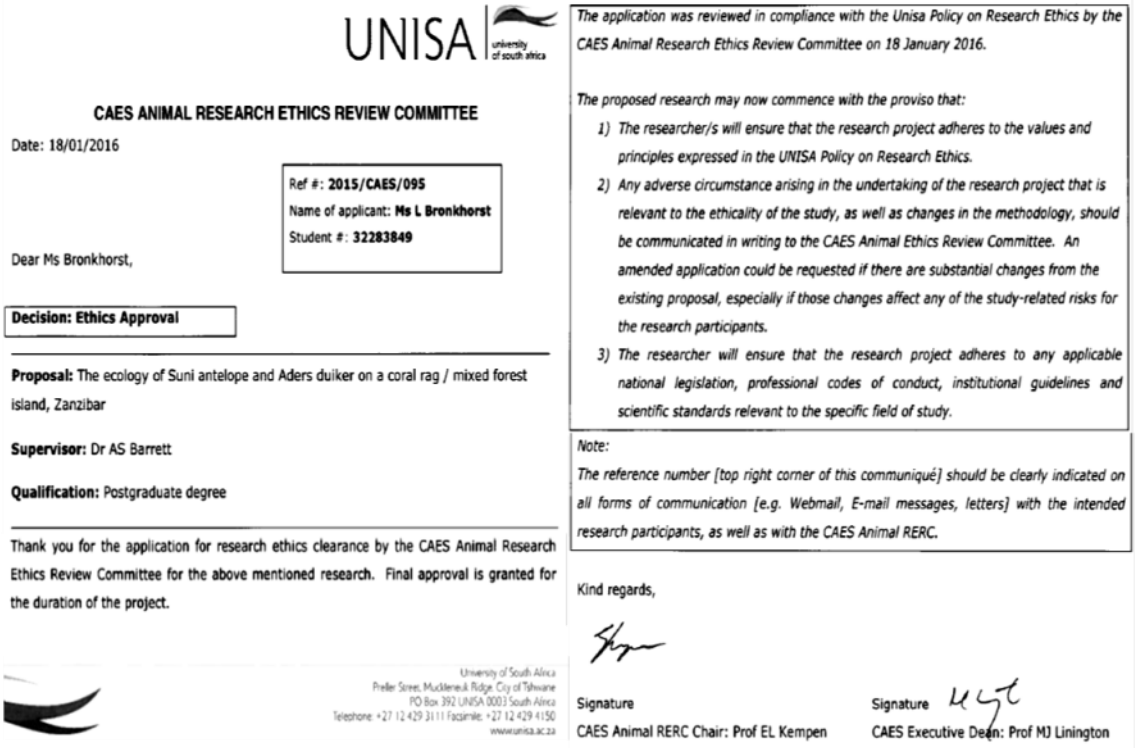




No	Description	No	Description
1	Wind Vane (measures wind direction)	7	Thermo-hygrometer Sensor (measures temperature and humidity)
2	Wind Speed Sensor (measures wind speed)	8	UV Sensor
3	Solar collector	9	Solar Radiation Sensor
4	Rechargeable battery compartment	10	Rain Collector (self emptying)
5	LED transmission indicator (turns on for 4 seconds on power up, flashes once per 16 seconds)	11	Bubble Level
6	Reset button		

Figure 12-7: Weather Station - Sensor Array Set Up

12.6 Appendix F - Ethics clearance, Research permit and Immigration legalities



UNISA
university of south africa

CAES ANIMAL RESEARCH ETHICS REVIEW COMMITTEE

Date: 18/01/2016

Ref #: **2015/CAES/095**
Name of applicant: **Ms L Bronkhorst**
Student #: **32283849**

Dear Ms Bronkhorst,

Decision: Ethics Approval

Proposal: The ecology of Suni antelope and Aders duiker on a coral rag / mixed forest island, Zanzibar

Supervisor: Dr AS Barrett

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Animal Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the project.

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Animal Research Ethics Review Committee on 18 January 2016.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Animal Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*

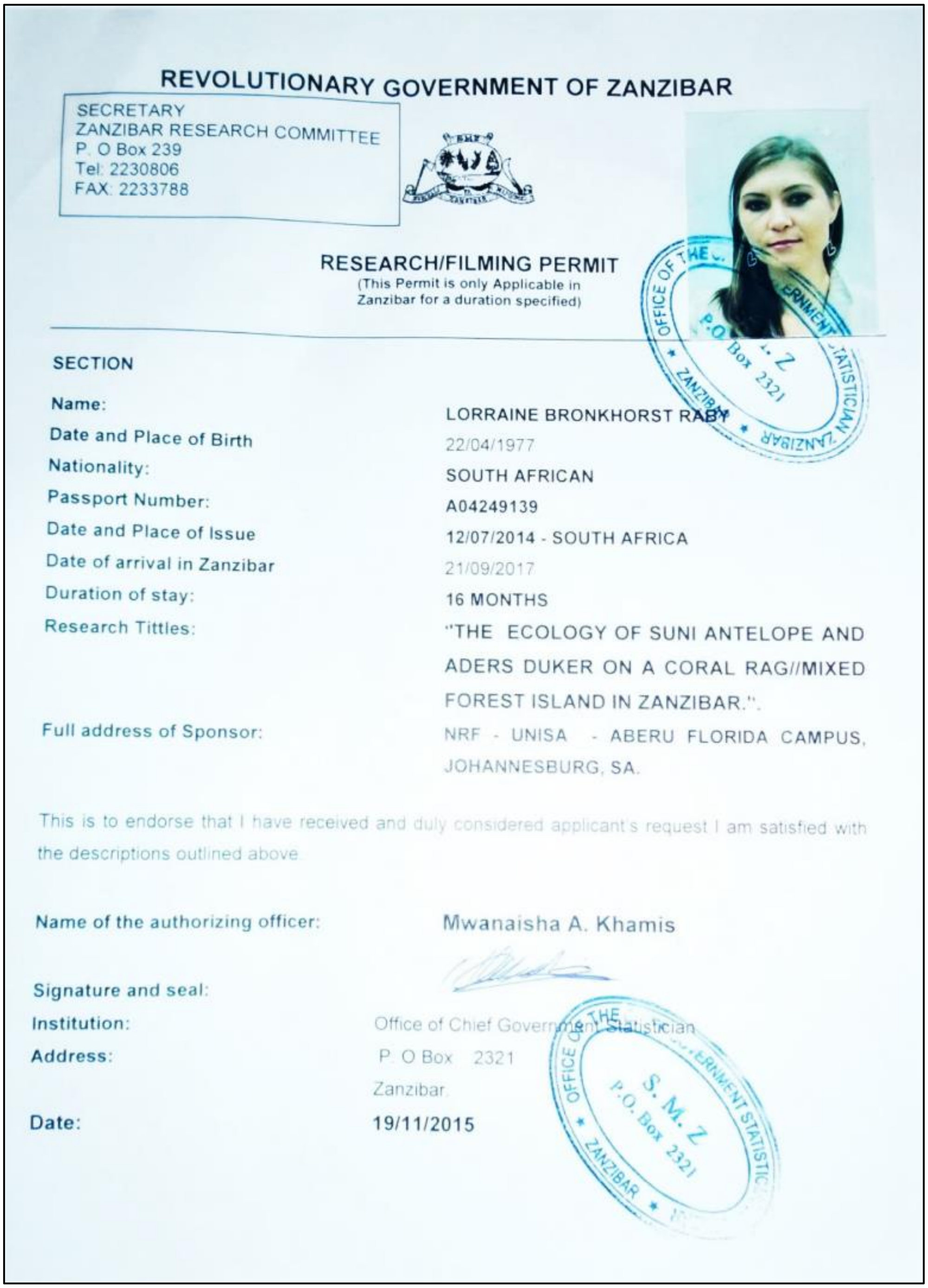
Note:
The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES Animal RERC.

Kind regards,

Signature
CAES Animal RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

Figure 12-8: Ethics clearance from the University of South Africa was registered under the reference 2015_CAES_095.



REVOLUTIONARY GOVERNMENT OF ZANZIBAR

SECRETARY
ZANZIBAR RESEARCH COMMITTEE
P. O Box 239
Tel: 2230806
FAX: 2233788

RESEARCH/FILMING PERMIT
(This Permit is only Applicable in
Zanzibar for a duration specified)

SECTION

Name:	LORRAINE BRONKHORST RABY
Date and Place of Birth	22/04/1977
Nationality:	SOUTH AFRICAN
Passport Number:	A04249139
Date and Place of Issue	12/07/2014 - SOUTH AFRICA
Date of arrival in Zanzibar	21/09/2017
Duration of stay:	16 MONTHS
Research Tittles:	"THE ECOLOGY OF SUNI ANTELOPE AND ADERS DUKER ON A CORAL RAG//MIXED FOREST ISLAND IN ZANZIBAR.".
Full address of Sponsor:	NRF - UNISA - ABERU FLORIDA CAMPUS, JOHANNESBURG, SA.

This is to endorse that I have received and duly considered applicant's request I am satisfied with the descriptions outlined above.

Name of the authorizing officer:	Mwanaisha A. Khamis
Signature and seal:	
Institution:	Office of Chief Government Statistician
Address:	P. O Box 2321 Zanzibar.
Date:	19/11/2015

Figure 12-9: Research permit - Zanzibar

SERIKALI YA MAPINDUZI YA ZANZIBAR
WIZARA YA KILIMO NA MALIASILI

Simu Nam: +255 (0)24 2238628
Fax: +255 (0)24 223 5991
E-mail: dccff@redcolobus.org.
Kumb. Yetu: IMMZ/..2/.17.27..

Idara ya Misitu na Maliasili Zisizorejesheka,
P. O. Box 3526, **Zanzibar - Tanzania**

Tarehe: 20/11/2015

KWA YEYOTE ANAEHUSIKA,

KUH: KUMTAMBULISHA MTAFITI WA PAANUNGA KATIKA KISIWA CHA MNEMBA, ZANZIBAR
(Mtafiti; Bibi Lorrane Bronkhost Raby)

Tafadhali kwa heshima husika na mada ya hapo juu.

Idara ya Misitu na Maliasili Zisizorejesheka Zanzibar imemruhusu mtajwa hapo juu, raia wa Afrika ya Kusini, mwanafunzi wa Shahada ya uzamivu (PhD), kutoka Chuo Kikuu cha Afrika ya Kusini, chini ya ufadhili wa *NRF-UNISA-ABEERU* (Florida Campus, Johannesburg, SA). Wakati akifanya utafiti wake ameruhusiwa kukamata Paanunga 2 (mke na dume) na Paa wekundu 2(mke na dume), ambao atawavalisha kidani kwa kila mmoja ili mtafiti aweze kujua mwendendo wa maisha ya wanyama hao kwa msaada wa kutumia mitambo ya nguvu za "*Satellite*".

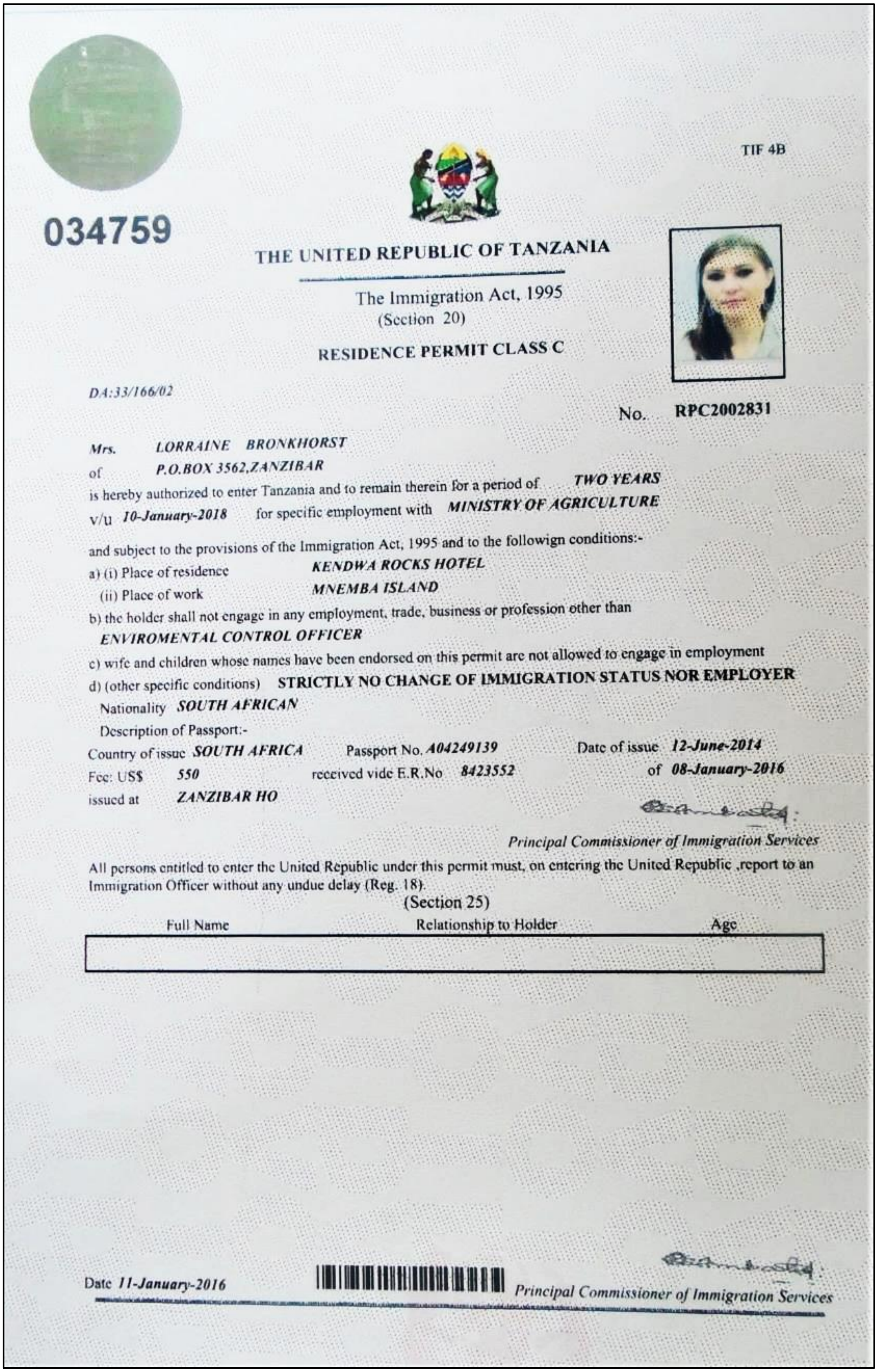
Mtafiti huyo atakuwepo nchini kukusanya taarifa za wanyama hao kwa kipindi cha 2015/2017. Ruhusa ya kufanya utafiti huo Mnemba-Zanzibar imetolewa na Afisi ya Makamo wa Pili wa Rais Zanzibar. Akiwa Zanzibar atakaa katika Hoteli ya *Kendwa Rock Hotel* na Kisiwani-Mnemba.

Paanunga walioko Mnemba walichukuliwa Mtende mwaka 2005 na kuachiliwa huru katika msitu wa Kisiwa hicho kwa lengo la kuwahifadhi wasipotee kutokana na uwindaji haramu. Utafiti huo utaifaidisha nchi/Zanzibar yetu kwa kujua tabia ya Paanunga na uwezekano wa kuwahifadhi katika maeneo mengine ya visiwa vodogo vidogo vya Zanzibar.

Ahsante,

Kassim, H. Madeweya,
Kny. Mkurugenzi,
Idaa ya Misitu na Maliasili Zisizorejesheka,
Zanzibar.

Figure 12-10: Research Registration with the Office of the Second Vice President, Zanzibar



034759

TIF 4B

THE UNITED REPUBLIC OF TANZANIA

The Immigration Act, 1995
(Section 20)

RESIDENCE PERMIT CLASS C

DA:33/166/02

No. **RPC2002831**

Mrs. *LORRAINE BRONKHORST*
of *P.O.BOX 3562,ZANZIBAR*
is hereby authorized to enter Tanzania and to remain therein for a period of *TWO YEARS*
v/u *10-January-2018* for specific employment with *MINISTRY OF AGRICULTURE*

and subject to the provisions of the Immigration Act, 1995 and to the followign conditions:-
a) (i) Place of residence *KENDWA ROCKS HOTEL*
(ii) Place of work *MNEMBA ISLAND*
b) the holder shall not engage in any employment, trade, business or profession other than *ENVIROMENTAL CONTROL OFFICER*
c) wife and children whose names have been endorsed on this permit are not allowed to engage in employment
d) (other specific conditions) **STRICTLY NO CHANGE OF IMMIGRATION STATUS NOR EMPLOYER**
Nationality *SOUTH AFRICAN*
Description of Passport:-
Country of issue *SOUTH AFRICA* Passport No. *A04249139* Date of issue *12-June-2014*
Fee: US$ *550* received vide E.R.No *8423552* of *08-January-2016*
issued at *ZANZIBAR HO*

Principal Commissioner of Immigration Services

All persons entitled to enter the United Republic under this permit must, on entering the United Republic ,report to an Immigration Officer without any undue delay (Reg. 18).

(Section 25)

Full Name	Relationship to Holder	Age

Date *11-January-2016*

Principal Commissioner of Immigration Services

Figure 12-11: Resident permit for duration of studies.

12.7 Appendix G – List of voucher samples and cover-abundance results for characteristic species on Mnemba Island

Table 12-4: A total of 52 Herbarium voucher specimens were filed at the Herbarium in the Zanzibar Natural History Museum, Stone Town.

Nr Sample	MNEMBA SPECIES CODE	VOUCHER LABEL	SCIENTIFIC NAME	FAMILY	LONG DMS - E	LAT DMS - S
1	MNE001	LRMNE2016-001	*Synaptolepis kirkii*	Thymaleaeae	39°22'58,518"	-5°49'13,764"
2	MNE002	LRMNE2016-002	*Clerodendrum glabrum*	Vebanaceae	39°22'58,692"	-5°49'13,404"
3	MNE003	LRMNE2016-003	*Pavonia spp*	Malvaceae	39°23'01.5"	-5°49'17.6"
4	MNE004	LRMNE2016-004	*Grewia glandulosa*	Tiliaceae	39°22'59,106"	-5°49'13,398"
5	MNE005	LRMNE2016-005	*Ecbolium amplexicual*	Acanthaceae	39°22'58,98"	-5°49'13,35"
6	MNE006	LRMNE2016-006	*Polysphaeria parvifolia*	Rubiaceae	39°22'59,202"	-5°49'13,248"
7	MNE006	LRMNE2016-006B	*Polysphaeria parvifolia*	Rubiaceae	39°22'59,412"	-5°49'13,134"
8	MNE007	LRMNE2016-007	*Maerua triphylla*	Capparacea	39°22'59,154"	-5°49'13,164"
9	MNE009	LRMNE2016-009	*Suregada zanibariensis*	Euphorbiaceae	39°22'59,49"	-5°49'13,062"
10	MNE009	LRMNE2016-009B	*Suregada zanibariensis*	Euphorbiaceae	39°22'59,13"	-5°49'16,056"
11	MNE010	LRMNE2016-010	*Psychotria spp*	Rubiaceae	39°22'59,658"	-5°49'12,792"
12	MNE011	LRMNE2016-011	*Maytenus heterophylla*	Celatraceae	39°22'59,844"	-5°49'12,576"
13	MNE012	LRMNE2016-012	*Secamone punctulata*	Apocynaceae	39°23'0,282"	-5°49'12,48"
14	MNE012	LRMNE2016-012B	*Secamone punctulata*	Apocynaceae	39°23'0,282"	-5°49'12,48"
15	MNE013	LRMNE2016-013	*Perotis patens*	Poaceae	39°23'1,398"	-5°49'11,766"
16	MNE014	LRMNE2016-014	*Ficus scasselati*	Moraceae	39°23'1,548"	-5°49'11,37"
17	MNE015	LRMNE2016-015	*Ficus polita*	Moraceae	39°23'2,856"	-5°49'11,466"
18	MNE016	LRMNE2016-016	*Sideroxylon inerme*	Sapotaceae	39°23'3,156"	-5°49'12,036"
19	MNE016	LRMNE2016-016B	*Sideroxylon inerme*	Sapotaceae	39°23'3,852"	-5°49'14,058"
20	MNE017	LRMNE2016-017	*Ficus lutea*	Moraceae	39°23'2,946"	-5°49'12,84"
21	MNE018	LRMNE2016-018	*Dalechampia scandens*	Euphorbiaceae	39°23'4,11"	-5°49'13,128"
22	MNE019	LRMNE2016-019	*Cyphostemma adenocaule*	Vitaceae	39°23'3,882"	-5°49'13,05"
23	MNE020	LRMNE2016-020	*Trema orientalis*	Ulmaceae	39°23'3,81"	-5°49'12,972"
24	MNE021	LRMNE2016-021	*Boerhavia diffusia*	Nyctaginacaea	39°23'4,026"	-5°49'12,78"
25	MNE023	LRMNE2016-023	*Scutia myrtina*	Rhamnaceae	39°22'56,178"	-5°49'15,834"
26	MNE024	LRMNE2016-024	*Mimusops obtusifolia*	Sapotaceae	39°22'56,406"	-5°49'15,726"
27	MNE025	LRMNE2016-025	*Ludia mauritiana*	Flacourtacea	39°22'57,204"	-5°49'16,338"
28	MNE026	LRMNE2016-026	*Cassytha filiformis*	Lauraceae	39°22'57,21"	-5°49'16,314"
29	MNE027	LRMNE2016-027	*Coccinia grandis*	Curbitaceae	39°22'58,65"	-5°49'15,942"
30	MNE028	LRMNE2016-028	*Pupalia lappacea*	Amaranthaceae	39°22'58,866"	-5°49'15,996"
31	MNE029	LRMNE2016-029	*Capparis viminea*	Capparacea	39°22'58,866"	-5°49'16,17"
32	MNE030	LRMNE2016-030	*Morinda citrifolia*	Rubiaceae	39°22'59,082"	-5°49'16,344"
33	MNE031	LRMNE2016-031	*Panicum maximum*	Poaceae	39°22'59,046"	-5°49'16,236"
34	MNE032	LRMNE2016-032	*Dactyloctenium aegyptium*	Poaceae	39°22'58,926"	-5°49'16,308"
35	MNE033	LRMNE2016-033	*Aneilema indehiscent*	Commelinaceae	39°22'58,902"	-5°49'16,362"
36	MNE034	LRMNE2016-034	*Pisonia grandis*	Nyctaginaceae	39°22'58,362"	-5°49'16,956"
37	MNE034	LRMNE2016-034B	*Pisonia grandis*	Nyctaginaceae	39°22'58,362"	-5°49'16,956"
38	MNE035	LRMNE2016-035	*Bourreria petiolaris*	Boraginaceae	39°23'1,794"	-5°49'17,526"
39	MNE035	LRMNE2016-035	*Bourreria petiolaris*	Boraginaceae	39°23'0,966"	-5°49'17,586"
40	MNE036	LRMNE2016-036	*Abutilon spp*	Malvaceae	39°23'1,44"	-5°49'17,478"
41	MNE038	LRMNE2016-038	*Melanthera biflora*	Asteraceae	39°22'58,332"	-5°49'18,486"
42	MNE039	LRMNE2016-039	*Eugenia capensis*	Myrtaceae	39°22'58,14"	-5°49'18,528"
43	MNE040	LRMNE2016-040	*Guettarda speciosa*	Rubiaceae	39°22'58,164"	-5°49'18,732"
44	MNE041	LRMNE2016-041	*Cordia subcordata*	Boraginaceae	39°22'57,966"	-5°49'19,074"
45	MNE041	LRMNE2016-041B	*Cordia subcordata*	Boraginaceae	39°22'55,848"	-5°49'17,652"
46	MNE042	LRMNE2016-042	*Ipomoea pes-caprea*	Convolvulaceae	39°22'56,754"	-5°49'19,254"
47	MNE043	LRMNE2016-043	*Sporobolus virginicus*	Poaceae	39°22'56,748"	-5°49'19,236"
48	MNE044	LRMNE2016-044	*Suriana maritima*	Surianaceae	39°22'55,092"	-5°49'18,396"
49	MNE046	LRMNE2016-046	*Pandanus kirkii*	Pandanaceae	39°22'55,932"	-5°49'17,55"
50	MNE047	LRMNE2016-047	*Ficus ingens*	Moraceae	39°22'55,806"	-5°49'17,676"
51	MNE047	LRMNE2016-047B	*Ficus ingens*	Moraceae	39°22'55,806"	-5°49'17,676"
52	MNE048	LRMNE2016-048	*Sesalpinia bundock*	Fabaceae	39°22'55,89"	-5°49'17,538"

Table 12-5: Relative cover-abundance of characteristic species for each of the main and sub plant communities on Mnemba Island.

Plant Community	Species	Cover-Abundance (%)	Plant Community	Species	Cover-Abundance (%)
1.	***Casuarina cunninghamiana***	**41.1**	**2.1**	***Scutia myrtina***	**2.1**
	Suriana maritima	9.5		*Pavetta stenosepala*	0.2
	Enteropogon macrostachyus	1.5		*Bourreria petiolaris*	0.2
	Evernia prunastri	0.3		*Ficus lutea*	0.1
	Brachiaria leersioides	0.1		*Psychotria psychotrioides*	0.1
	Ricinus communis	0.3		*Ficus polita*	0.1
	Rhynchosia sublobata	0.2		*Conyza newii*	0.0
	Aneilema indehiscence	0.2		*Justicia capensis*	0.1
	Dactyloctenium aegyptium	0.2		*Auricularia auricular-judae*	0.1
	Polyporus tubaeformis	0.3		*Xanthoria sp*	0.1
1.1	***Melanthera biflora***	**20.5**		*Ludia mauritiana*	0.1
	Panicum repens	0.4		*Phaeotrametes decipiens*	0.1
	Ipomoea pes-caprae	0.0		*Daldinia concentrica*	0.0
	Scaevola sericea	0.1		*Solanum viarum*	0.0
	Kyllinga erecta	0.1	**2.2**	*Clerodendrum glabrum*	**0.6**
	Sesbania bispinosa	2.2		*Daedaleopsis confragosa*	0.4
	Gymnosporia heterophylla	0.1		*Pavonia species*	0.3
1.2	*Bougainvillea spectabilis*	0.0		*Phyllanthus amarus*	0.2
	Chrysothrix sp	0.3		*Polysphaeria parvifolia*	0.3
	Fomitopsis pinicola	0.1		*Abutilon spp*	0.2
	Bidens pilosa	0.0		*Ipomoea spp*	0.1
	Panicum maximum	0.1		*Boerhavia diffusia*	0.1
2.	***Eugenia capensis***	**22.9**		*Kyllinga platyphylla*	0.1
	Mimusops obtusifolia	9.6		*Acacia auriculiformis*	0.0
	Pandanus kirkii	4.8		*Ehretia amoena*	0.1
	Secamone punctulata	1.7		*Parmelia sulcata*	0.1
	Cassytha filiformis	1.0		*Pycnoporus sp*	0.1
	*Grewia glandulosa**	1.5		*Trametes hirsuta*	0.1
	Maerua triphylla	0.3		*Boerhavia spp*	0.1
	Synaptolepis kirkii	0.4		*Morinda citrifolia*	0.1
	*Pisonia grandis**	3.1		*Coccinia grandis*	0.0
	Ecbolium ligustrinum	1.3		*Pupalia lappacea*	0.1
	*Suregada zanzibariensis**	0.3	**General**	***Sideroxylon inerme***	**1.8**
	Ficus scassellati	0.1		*Capparis viminea var orthacantha*	0.4
	Afroligusticum linderi	0.0		*Cyphostemma adenocaula*	0.4
	Cocos nucifera	0.0		*Eragrostis ciliaris*	0.0
	Adenia gummifera	0.0		*Terminalia catappa*	0.0
				Dalechampia scandens	**1.2**
				Cyperus obtusiflorus	0.1

12.8 Appendix H – Statistical analyses of differences between plant communities

Table 12-6: Mann-Whitney U Test for environmental differences between main communities on Mnemba. Alpha was set at 0.05. n1 = 8 and n2 = 16.

	Nr of Species	**Nr of Trees BHD>6 cm**	**Nr of Dead trees**
U	41.5	32.5	52
P (2-tailed)	0.166	0.053	0.461

	Total Cover	**Tree Cover**	**Shrub Cover**
U	48	6	28
P (2-tailed)	0.320	0.000*	0.027*

	Herb Cover	**GrassCover**	**Nonvegetated**
U	12	32	62.5
P (2-tailed)	0.001*	0.003*	0.923

	Tallest Tree	**Tallest Shrub**	**Average Diameter**
U	20	16.5	64
P (2-tailed)	0.006*	0.003*	1.000

	Rock Cover	**Litter Depth**	**Fermentation Depth**
U	52	45	32
P (2-tailed)	0.201	0.230	0.048

Table 12-7: Kruskal-Wallis Test for environmental differences between sub communities on Mnemba. Alpha was set at 0.05. The Degree of freedom was 3.

	Nr of Species	**Nr of Trees BHD>6 cm**	**Nr of Dead trees**
Chi-Square	10.928	4.954	11.822
P (2-tailed)	0.012*	0.175	0.008*

	Total Cover	**Tree Cover**	**Shrub Cover**
Chi-Square	1.371	12.956	7.126
P (2-tailed)	0.712	0.005*	0.068

	Herb Cover	**GrassCover**	**Nonvegetated**
Chi-Square	10.988	13.427	3.064
P (2-tailed)	0.012*	0.004*	0.382

	Tallest Tree	**Tallest Shrub**	**Average Diameter**
Chi-Square	11.257	10.534	7.180
P (2-tailed)	0.010*	0.015*	0.066

	Rock Cover	**Litter Depth**	**Fermentation Depth**
Chi-Square	2.445	10.149	4.256
P (2-tailed)	0,485	0,017*	0,235

12.9 Appendix I – Supporting material for Vegetation description

From the image below, it is evident that the large section of Mnemba Island that did not exist in the early 1970s, was created through the expansion of the *Casuarina cunninghamiana* forest (Plant Community 1.1 and Community 1.2).

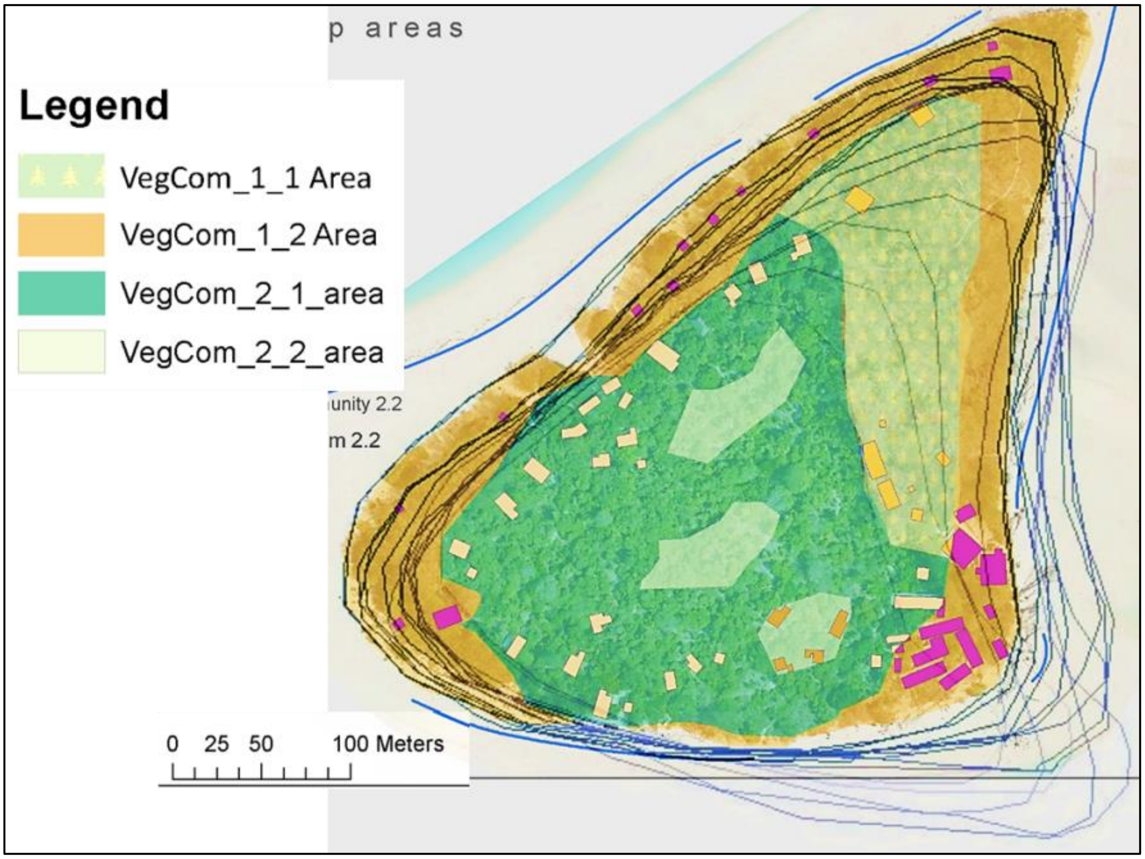


Figure 12-12: Vector polygons of Mnemba Island’s change in shape and size between 1973 and 2014 (AndBeyond, 2014) overlaid with the current study's vegetation imagery.

Another map indicating the vegetation boundaries in 2004 and 2011 (Figure 12-13) shows the changes in *Casuarina cunninghamiana* stands while natural vegetation boundaries remain relatively unchanged.

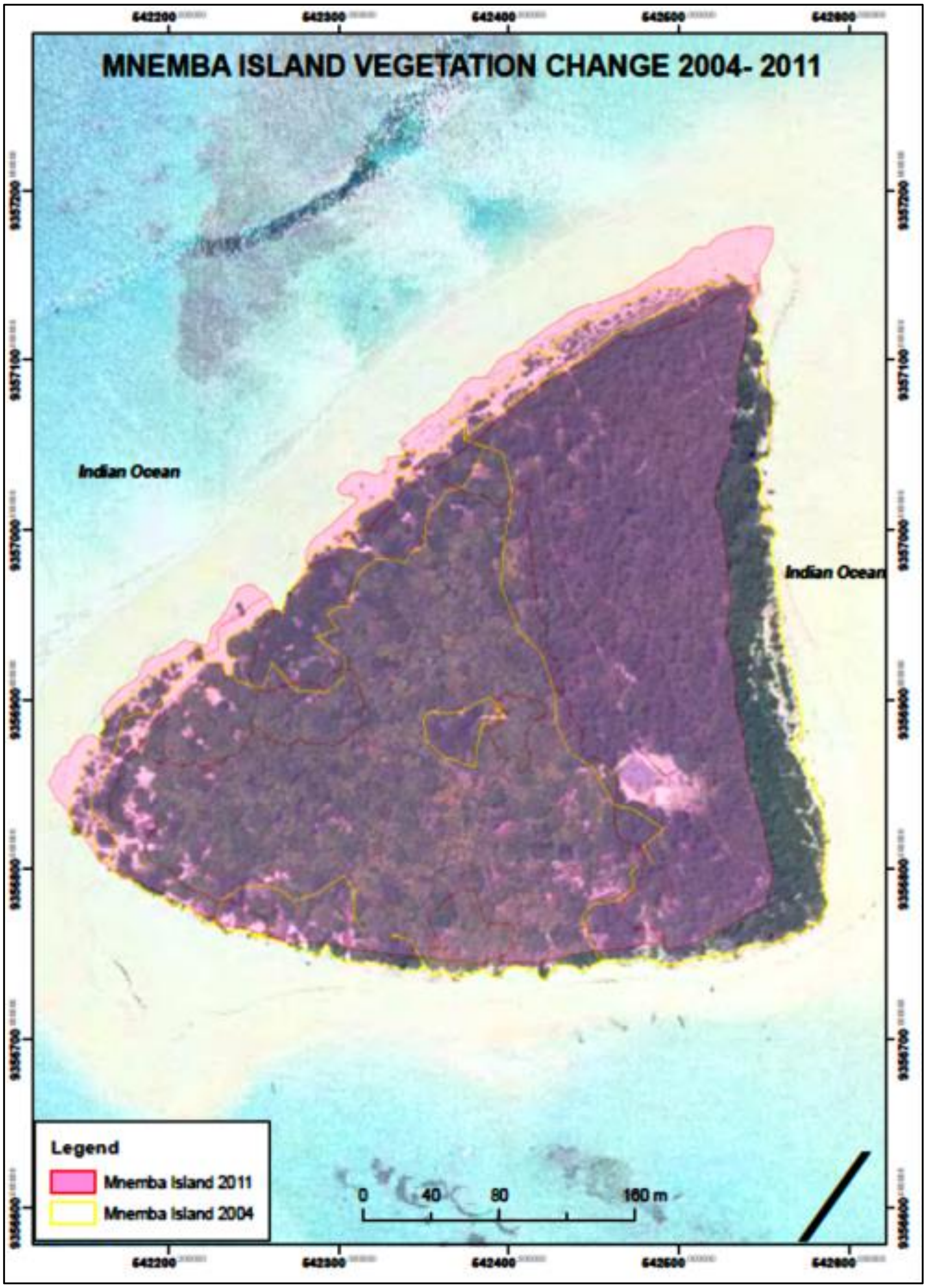


Figure 12-13: Mnemba Island Aerial view from 2004 to 2011.

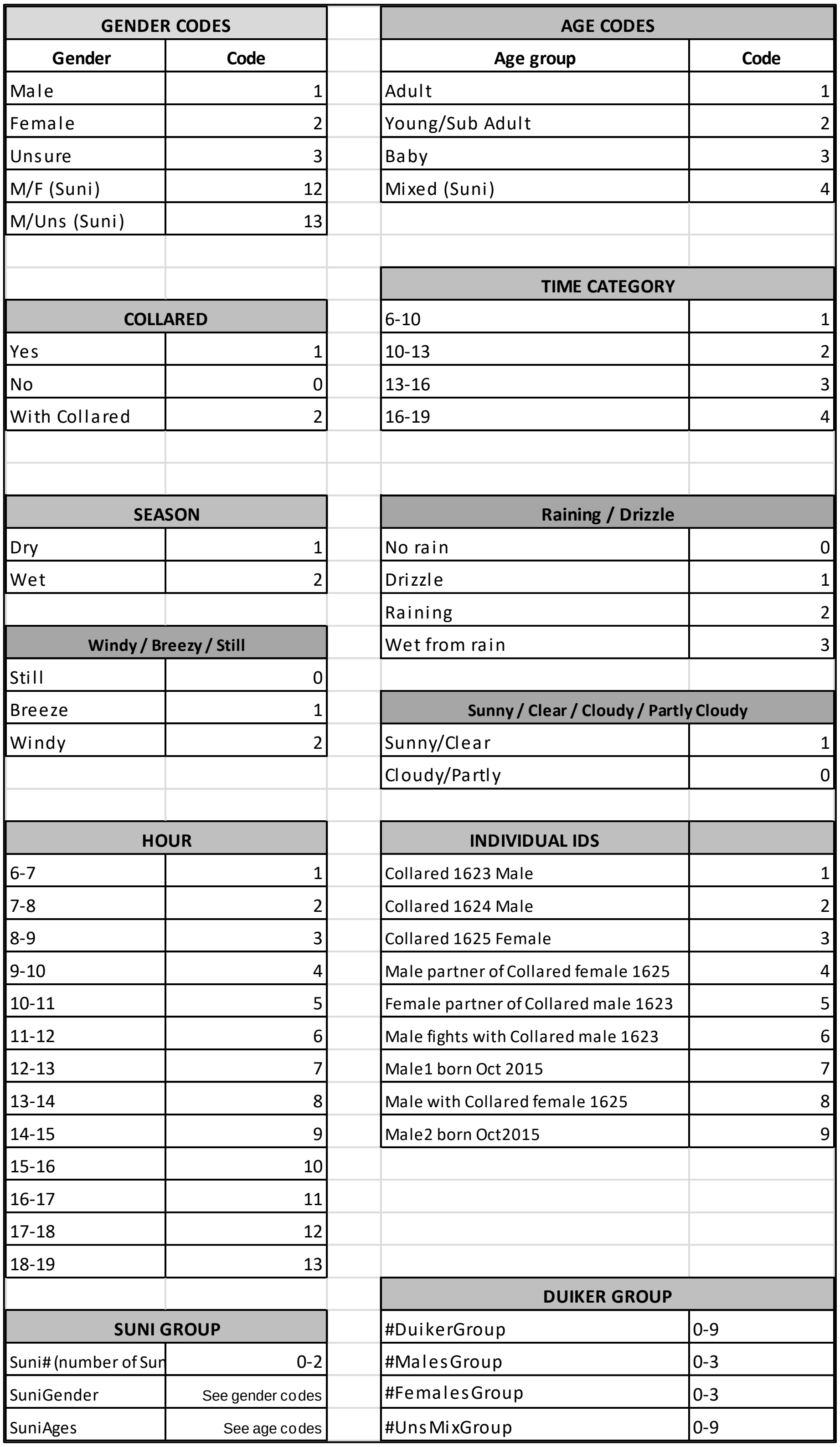
12.10 Appendix J – Aders' duiker Ethogram, survey variables and focal sampling track.

During focal observations, behaviour activities were selected from a list of pre-coded behaviour based on an all-inclusive Ethogram which was developed from literature studies (Innis, 1958; Leuthold and Leuthold, 1978; Dagg and Foster, 1982; Pellew, 1984; Le Pendu et al., 2001; van der Jeugd and Prins, 2000; Rivers, 2012) and preliminary observations during habituation sessions. The final Ethogram included a complete inventory of repertoires exhibited by the sub-population, grouped as Thirteen Main behavioural states and 47 Sub behavioural states (including the main states), of which 12 Sub states were further categorized into sub-sub states.

Table 12-8: Ethogram developed for Aders' duiker on Mnemba Island

Main State	Sub State	Sub-sub State
Drinking	Drinking	
Excretion	Defecating	
	Vigilant urinating	
Foraging	Engaging Foraging	
	Fast Foraging	
	Forage walking	
	Foraging and drinking	
	Slow Foraging	
	Territorial Foraging	
	Vigilant Foraging	
Lying down	Grooming Resting	
	Lying down	
	Resting	
	Resting with vigilance	
Ruminating	Ruminating	
	Ruminating Engaging	
	Ruminating Grooming	
	Ruminating resting	
	Ruminating resting with vigilance	
Running	Running	
	Vigilant Running	
Self Grooming	Self Grooming	
Vigilant	Vigilant Standing	
	Vigilant walking	
Social	Allogrooming	Being groomed
	Allogrooming	Grooming another
	Allogrooming	Mutual grooming
	Chasing	Being chased
	Chasing	Chasing
	Chasing	Mutual chasing
	Following	Being followed
	Following	Following
	Nursing	Being suckled
	Nursing	Suckling
	Sexual courting	Being courted
	Sexual courting	Courting female
	Protective	
	Social other	
Standing	Standing	
Taking shelter	Taking shelter	
Territory	Fighting Rutting	
	Investigative Urinating	
	Marking	
	Territory	
Travelling	Fast walking	
	Trotting	
	Walking	

Table 12-9: Additional variables included in the focal surveys.



GENDER CODES	
Gender	**Code**
Male	1
Female	2
Unsure	3
M/F (Suni)	12
M/Uns (Suni)	13

COLLARED	
Yes	1
No	0
With Collared	2

SEASON	
Dry	1
Wet	2

Windy / Breezy / Still	
Still	0
Breeze	1
Windy	2

HOUR	
6-7	1
7-8	2
8-9	3
9-10	4
10-11	5
11-12	6
12-13	7
13-14	8
14-15	9
15-16	10
16-17	11
17-18	12
18-19	13

SUNI GROUP	
Suni# (number of Sun	0-2
SuniGender	See gender codes
SuniAges	See age codes

AGE CODES	
Age group	**Code**
Adult	1
Young/Sub Adult	2
Baby	3
Mixed (Suni)	4

TIME CATEGORY	
6-10	1
10-13	2
13-16	3
16-19	4

Raining / Drizzle	
No rain	0
Drizzle	1
Raining	2
Wet from rain	3

Sunny / Clear / Cloudy / Partly Cloudy	
Sunny/Clear	1
Cloudy/Partly	0

INDIVIDUAL IDS	
Collared 1623 Male	1
Collared 1624 Male	2
Collared 1625 Female	3
Male partner of Collared female 1625	4
Female partner of Collared male 1623	5
Male fights with Collared male 1623	6
Male1 born Oct 2015	7
Male with Collared female 1625	8
Male2 born Oct2015	9

DUIKER GROUP	
#DuikerGroup	0-9
#MalesGroup	0-3
#FemalesGroup	0-3
#UnsMixGroup	0-9

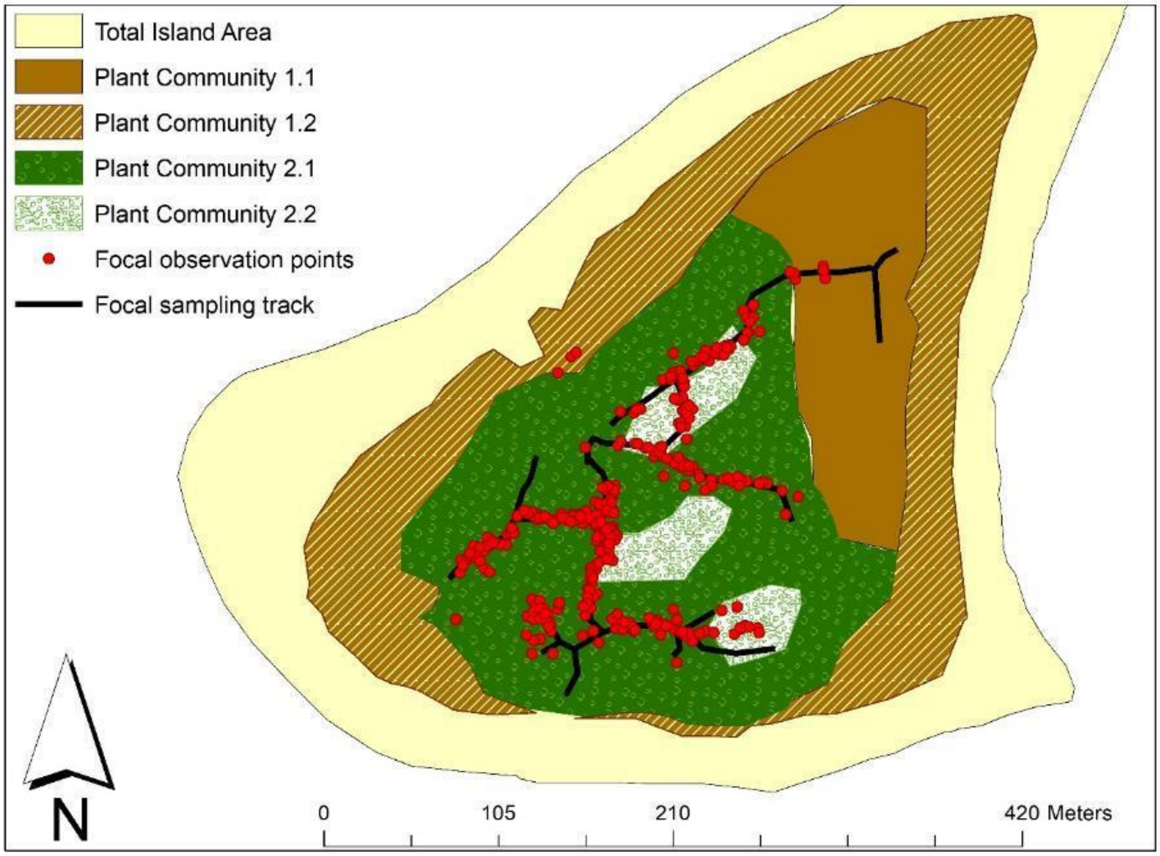


Figure 12-14: Focal observation points along the sampling track, overlaid with plant communities identified in the Vegetation survey

12.11 Appendix K – Food species identified during focal observations and combined list of Aders' duiker food species from all sources.

Table 12-10: The following 20 food species were identified from 14 plant families.

Auricularia auricular-judae	Auriculariaceae
Bougainvillea spectabilis	Nyctaginaceae
Capparis viminea	Capparacea
Cassytha filiformis	Lauraceae
Cordia Subcordata	Boraginaceae
Ehretia amoena	Boraginaceae
Eugenia capensis	Myrtaceae
Ficus lutea	Moraceae
Ficus polita	Moraceae
Ficus scassellatii	Moraceae
Grewia glandulosa	Tiliaceae
Guettarda speciosa	Rubiaceae
Mimusops obtusifolia	Sapotaceae
Pandanus kirkii	Pandanaceae
Pisonia grandis	Nyctaginaceae
Polysphaeria parvifolia	Rubiaceae
Sideroxylon inerme	Sapotaceae
Suregada zanzibarensis	Euphorbiaceae
Terminalia cattapa	Combretaceae
Toddalia asiatica	Rutaceae

Table 12-11: A list of 38 food plant species was compiled for Aders' duiker, from the current study and previous literature.

This study	Species
x	*Auricularia auricular-judae*
x	*Bougainvillea spectabilis*
x	*Capparis viminea*
x	*Cassytha filiformis*
x	*Cordia Subcordata*
x	*Ehretia amoena*
x	*Eugenia capensis*
x	*Ficus lutea*
x	*Ficus polita*
x	*Ficus scassellatii*
x	*Grewia glandulosa*
x	*Guettarda speciosa*
x	*Mimusops obtusifolia*
x	*Pandanus kirkii*
x	*Pisonia grandis*
x	*Polysphaeria parvifolia*
x	*Sideroxylon inerme*
x	*Suregada zanzibarensis*
x	*Terminalia cattapa*
x	*Toddalia asiatica*
-	*Ancylobotrys petersiana*
-	*Canavalia rosea*
-	*Canthium sp. (turkey berry bush)*
-	*Cassia occidentalis ? (Mkengajua - Kiswahili)*
-	*Clerodendrum spp. (Kipepe wazu -Kiswahili)*
-	*C. aethiopica (chasmanthe or cobra lily)*
-	*Diospyros consolatae (Mkuyukilemba - Kiswahili)*
-	*D. consolataei (Ebony tree)*
-	*E. schimperi (guarri bush)*
-	*Ficus sur*
-	*Fluggea virosa*
-	*Jasminum fluminense - (Muafu - Kiswahili)*
-	*Mystroxylon aethiopicum*
-	*Phymatodes scalopendria (Chanichakisimani?)*
-	*Pyrostria bibracteata*
-	*Tetracella littoralis*
-	*Grass sp*
-	*Uvariodendron kirkii*

12.12 Appendix L – Biological information

Duiker skull of a mature duiker that must have died on Mnemba Island some time before the study took place. The length of the horn measured 2.4 cm and the skull 13 cm in length. The specimen was donated to the Zanzibar Natural History Museum, Stone Town.

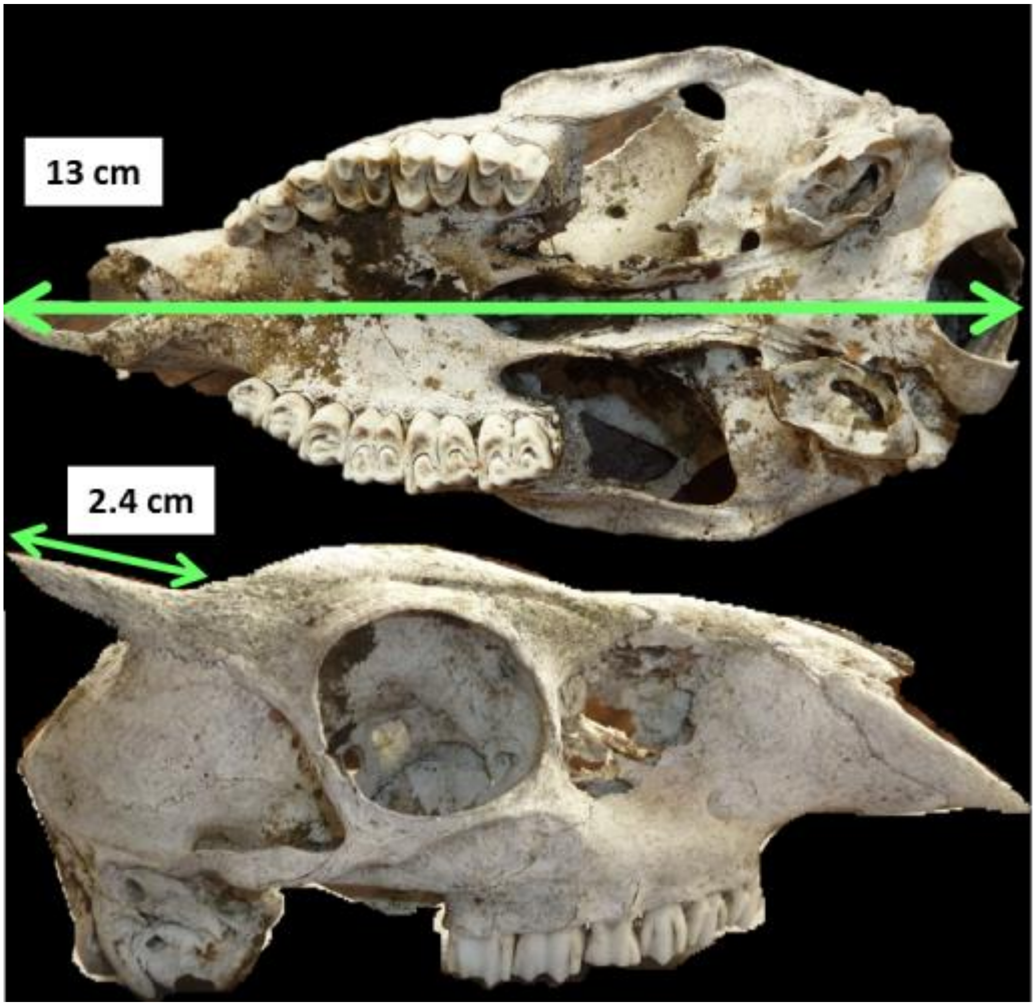


Figure 12-15: Duiker skull of a mature Aders' duiker.

A pelvic bone and one leg bone was found in the same vicinity as the skull. The pelvic bone measured almost 15 cm in length.

Figure 12-16: Pelvic bone of a duiker found on Mnemba Island.

Figure 12-17: Duiker spoor on Mnemba Island.

12.13 Appendix M – Historical Suni harvesting data in logistical growth graph & Logistic growth modelling for Aders’duiker, without and with harvesting

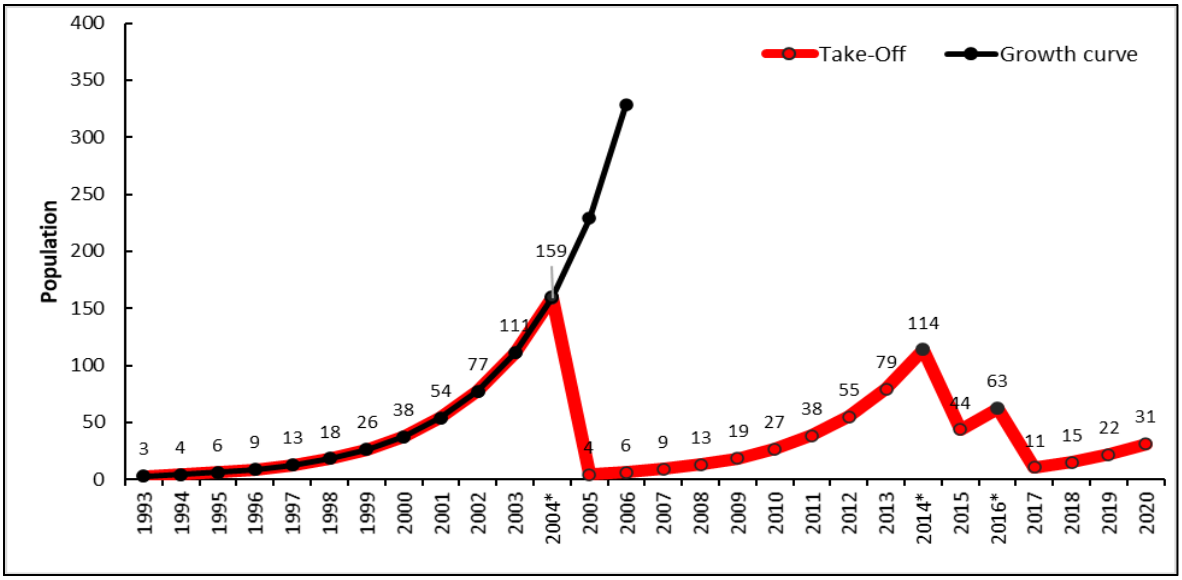


Figure 12-18: Suni antelope population growth curve and impact on population growth from harvesting data, for Mnemba Island. Harvesting and population data obtained from the Department of Forestry and Non-renewable Resources (DFNRR).

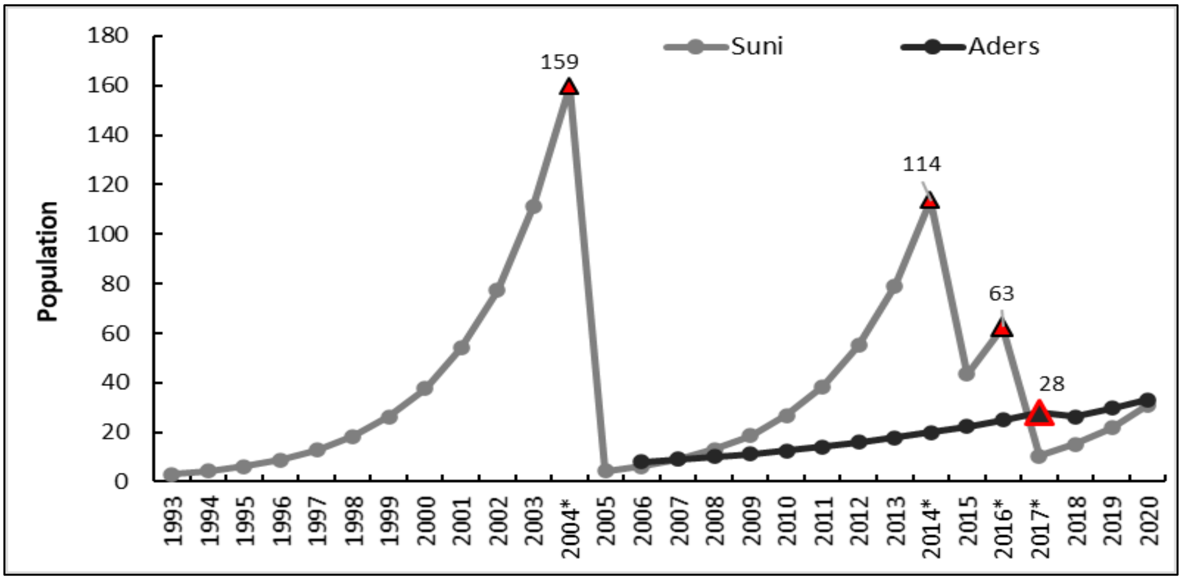


Figure 12-19: Overview comparison of population growth data including harvesting data, for Suni antelope and Aders’ duiker on Mnemba Island.

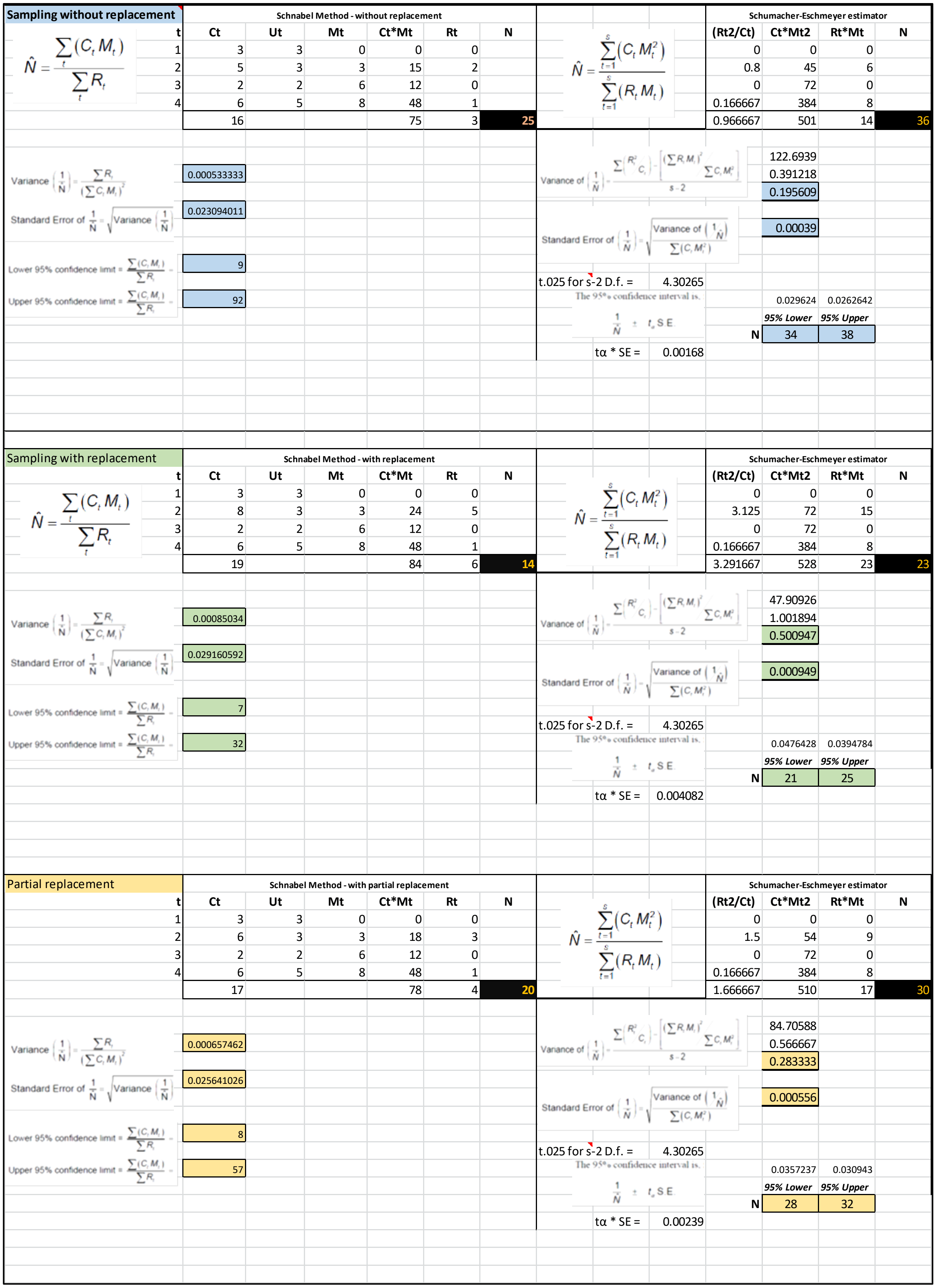
Table 12-12: Logistic growth modelling over 20 years, for different values of K (carrying capacity) and MSD (Maximum Sustainable harvest density) without harvesting through take-off

Logistic growth without take-off																													
		b- d=	**3**				**b- d=**	**3**				**b- d=**	**3**				**b- d=**	**3**				**b- d=**	**3**				**b- d=**	**3**	
pMax	**D_{est} at 2016**	**14**	**0,214**	**r_{max}**	**pMax**	**D_{est} at 2016**	**20**	**0,150**	**r_{max}**	**pMax**	**D_{est} at 2016**	**23**	**0,130**	**r_{max}**	**pMax**	**D_{est} at 2016**	**25**	**0,120**	**r_{max}**	**pMax**	**2016**	**30**	**0,100**	**r_{max}**	**pMax**	**2016**	**36**	**0,083**	**r_{max}**
4	**t**	**N**	**dN/dt**		**3**	**t**	**N**	**dN/dt**	**40%**	**3**	**t**	**N**	**dN/dt**	**40%**	**3**	**t**	**N**	**dN/dt**	**40%**	**3**	**t**	**N**	**dN/dt**	**40%**	**3**	**t**	**N**	**dN/dt**	**40%**
	0	8	1,29			0	8	1,80	**0,7**		0	8	1,96	**0,8**		0	8	2,04	**0,8**		0	8	2,20	**0,9**		0	8	2,33	**0,9**
	1	9	1,01			1	10	1,53	**0,6**		1	10	1,70	**0,7**		1	10	1,80	**0,7**		1	10	1,98	**0,8**		1	10	2,14	**0,9**
	2	10	0,79			2	11	1,30	**0,5**		2	12	1,48	**0,6**		2	12	1,58	**0,6**		2	12	1,78	**0,7**		2	12	1,96	**0,8**
	3	11	0,62			3	13	1,11	**0,4**		3	13	1,29	**0,5**		3	13	1,39	**0,6**		3	14	1,60	**0,6**		3	14	1,80	**0,7**
	4	12	0,49			4	14	0,94	**0,4**		4	14	1,12	**0,4**		4	15	1,22	**0,5**		4	16	1,44	**0,6**		4	16	1,65	**0,7**
	5	12	0,39			5	15	0,80	**0,3**		5	16	0,97	**0,4**		5	16	1,08	**0,4**		5	17	1,30	**0,5**		5	18	1,51	**0,6**
	6	13	0,30			6	15	0,68	**0,3**		6	17	0,85	**0,3**		6	17	0,95	**0,4**		6	18	1,17	**0,5**		6	19	1,38	**0,6**
	7	13	0,24			7	16	0,58	**0,2**		7	17	0,74	**0,3**		7	18	0,83	**0,3**		7	19	1,05	**0,4**		7	21	1,27	**0,5**
	8	13	0,19			8	17	0,49	**0,2**		8	18	0,64	**0,3**		8	19	0,73	**0,3**		8	21	0,95	**0,4**		8	22	1,16	**0,5**
	9	13	0,15			9	17	0,42	**0,2**		9	19	0,56	**0,2**		9	20	0,65	**0,3**		9	21	0,85	**0,3**		9	23	1,07	**0,4**
	10	13	0,12			10	18	0,35	**0,1**		10	19	0,48	**0,2**		10	20	0,57	**0,2**		10	22	0,77	**0,3**		10	24	0,98	**0,4**
	11	14	0,09			11	18	0,30	**0,1**		11	20	0,42	**0,2**		11	21	0,50	**0,2**		11	23	0,69	**0,3**		11	25	0,90	**0,4**
	12	14	0,07			12	18	0,26	**0,1**		12	20	0,37	**0,1**		12	21	0,44	**0,2**		12	24	0,62	**0,2**		12	26	0,82	**0,3**
	13	14	0,06			13	19	0,22	**0,1**		13	21	0,32	**0,1**		13	22	0,39	**0,2**		13	24	0,56	**0,2**		13	27	0,75	**0,3**
	14	14	0,04			14	19	0,18	**0,1**		14	21	0,28	**0,1**		14	22	0,34	**0,1**		14	25	0,50	**0,2**		14	28	0,69	**0,3**
	15	14	0,03			15	19	0,16	**0,1**		15	21	0,24	**0,1**		15	23	0,30	**0,1**		15	25	0,45	**0,2**		15	28	0,63	**0,3**
	16	14	0,03			16	19	0,13	**0,1**		16	21	0,21	**0,1**		16	23	0,26	**0,1**		16	26	0,41	**0,2**		16	29	0,58	**0,2**
	17	14	0,02			17	19	0,11	**0,0**		17	22	0,18	**0,1**		17	23	0,23	**0,1**		17	26	0,37	**0,1**		17	30	0,53	**0,2**
	18	14	0,02			18	19	0,10	**0,0**		18	22	0,16	**0,1**		18	23	0,20	**0,1**		18	27	0,33	**0,1**		18	30	0,49	**0,2**
	19	14	0,01			19	19	0,08	**0,0**		19	22	0,14	**0,1**		19	24	0,18	**0,1**		19	27	0,30	**0,1**		19	31	0,45	**0,2**
		14					**19**		**5**			**22**		**6**			**24**		**6**			**27**		**8**			**31**		**9**

Table 12-13: Logistic growth modelling over 20 years, for different values of K (carrying capacity) and MSD (Maximum Sustainable harvest density) with harvesting through take-off at intervals of 2 years. (t/o is take-off)

Logistic growth with take-off																													
		b-d=	**3**				**b-d=**	**3**				**b-d=**	**3**				**b-d=**	**3**				**b-d=**	**3**				**b-d=**	**3**	
MHD	**D_{est} at 2016**	**14**	**0,214**	**r_{max}**	**MHD**	**D_{est} at 2016**	20	**0,150**	**r_{max}**	**MHD**	**D_{est} at 2016**	23	**0,130**	**r_{max}**	**MHD**	**D_{est} at 2016**	**25**	**0,120**	**r_{max}**	**MHD**	**D_{est} at 2016**	30	**0,100**	**r_{max}**	**MHD**	**D_{est} at 2016**	36	**0,083**	**r_{max}**
7	**t**	**N-t/o**	**dN/dt**	**40%**	**10**	**t**	**N-t/o**	**dN/dt**	**40%**	**12**	**t**	**N-t/o**	**dN/dt**	**40%**	**13**	**t**	**N-t/o**	**dN/dt**	**40%**	**15**	**t**	**N-t/o**	**dN/dt**	**40%**	**18**	**t**	**N-t/o**	**dN/dt**	**40%**
t/o	0	8	1,29	**0,5**	***t/o***	0	8	1,80	**0,7**	***t/o***	0	8	1,96	**0,8**	***t/o***	0	8	2,04	**0,8**	***t/o***	0	8	2,20	**0,9**	***t/o***	0	8	2,33	**0,9**
	1	9	1,01	**0,4**		1	10	1,53	**0,6**		1	10	1,96	**0,8**		1	10	1,80	**0,7**		1	10	1,98	**0,8**		1	10	2,14	**0,9**
	2	10	0,79	**0,3**		2	11	1,30	**0,5**		2	12	1,66	**0,7**		2	12	1,58	**0,6**		2	12	1,78	**0,7**		2	12	1,96	**0,8**
	3	11	0,62	**0,2**	3	3	10	1,56	**0,6**		3	14	1,41	**0,6**		3	13	1,39	**0,6**		3	14	1,60	**0,6**		3	14	1,80	**0,7**
	4	12	0,49	**0,2**		4	11	1,32	**0,5**	2	4	13	1,50	**0,6**	2	4	13	1,46	**0,6**	1	4	15	1,54	**0,6**		4	16	1,65	**0,7**
	5	12	0,39	**0,2**	3	5	10	1,57	**0,6**		5	14	1,28	**0,5**		5	14	1,29	**0,5**		5	16	1,39	**0,6**		5	18	1,51	**0,6**
	6	13	0,30	**0,1**		6	11	1,34	**0,5**	3	6	13	1,53	**0,6**	3	6	13	1,49	**0,6**	2	6	15	1,45	**0,6**	1	6	18	1,47	**0,6**
	7	13	0,24	**0,1**	2	7	10	1,44	**0,6**		7	14	1,30	**0,5**		7	14	1,31	**0,5**		7	17	1,31	**0,5**		7	20	1,35	**0,5**
	8	13	0,19	**0,1**		8	12	1,22	**0,5**	3	8	13	1,56	**0,6**	2	8	13	1,40	**0,6**	3	8	15	1,47	**0,6**	3	8	18	1,48	**0,6**
	9	13	0,15	**0,1**	3	9	10	1,49	**0,6**		9	14	1,33	**0,5**		9	15	1,23	**0,5**		9	17	1,33	**0,5**		9	20	1,36	**0,5**
	10	13	0,12	**0,0**		10	12	1,27	**0,5**	2	10	13	1,43	**0,6**	3	10	13	1,44	**0,6**	3	10	15	1,49	**0,6**	3	10	18	1,50	**0,6**
	11	14	0,09	**0,0**	3	11	10	1,53	**0,6**		11	15	1,21	**0,5**		11	14	1,27	**0,5**		11	17	1,35	**0,5**		11	20	1,37	**0,5**
	12	14	0,07	**0,0**		12	11	1,30	**0,5**	3	12	13	1,48	**0,6**	3	12	13	1,48	**0,6**	3	12	15	1,51	**0,6**	3	12	18	1,51	**0,6**
	13	14	0,06	**0,0**	3	13	10	1,55	**0,6**		13	15	1,26	**0,5**		13	14	1,30	**0,5**		13	16	1,36	**0,5**		13	19	1,38	**0,6**
	14	14	0,04	**0,0**		14	11	1,32	**0,5**	3	14	13	1,52	**0,6**	2	14	13	1,38	**0,6**	3	14	15	1,52	**0,6**	3	14	18	1,52	**0,6**
	15	14	0,03	**0,0**	3	15	10	1,57	**0,6**		15	14	1,29	**0,5**		15	15	1,22	**0,5**		15	16	1,37	**0,5**		15	19	1,39	**0,6**
	16	14	0,03	**0,0**		16	11	1,34	**0,5**	2	16	14	1,40	**0,6**	3	16	13	1,43	**0,6**	3	16	15	1,53	**0,6**	3	16	18	1,52	**0,6**
	17	14	0,02	**0,0**	2	17	10	1,44	**0,6**		17	15	1,19	**0,5**		17	15	1,26	**0,5**		17	16	1,38	**0,6**		17	19	1,40	**0,6**
	18	14	0,02	**0,0**		18	12	1,22	**0,5**	3	18	13	1,46	**0,6**	3	18	13	1,47	**0,6**	3	18	15	1,54	**0,6**	3	18	18	1,53	**0,6**
	19	14	0,01	**0,0**	3	19	10	1,49	**0,6**		19	15	1,24	**0,5**		19	14	1,29	**0,5**		19	16	1,39	**0,6**		19	19	1,40	**0,6**
0		**14**		**2**	***25***		**35**		**11**	***21***		**36**		**12**	***21***		**35**		**11**	***21***		**37**		**12**	***19***		**38**		**13**
		0	*surplus*				**16**	*surplus*				**14**	*surplus*				**12**	*surplus*				**10**	*surplus*				**8**	*surplus*	

12.14 Appendix N – Population estimate calculations from Mark-recapture survey on Mnemba Island



Sampling without replacement

$$\hat{N} = \frac{\sum_t (C_t M_t)}{\sum_t R_t}$$

Schnabel Method - without replacement

t	Ct	Ut	Mt	Ct*Mt	Rt	N
1	3	3	0	0	0	
2	5	3	3	15	2	
3	2	2	6	12	0	
4	6	5	8	48	1	
	16			75	3	25

$$\hat{N} = \frac{\sum_{t=1}^{s} (C_t M_t^2)}{\sum_{t=1}^{s} (R_t M_t)}$$

Schumacher-Eschmeyer estimator

(Rt2/Ct)	Ct*Mt2	Rt*Mt	N
0	0	0	
0.8	45	6	
0	72	0	
0.166667	384	8	
0.966667	501	14	36

Variance $\left(\frac{1}{\hat N}\right) = \frac{\sum R_t}{(\sum C_t M_t)^2}$ 0.000533333

Standard Error of $\frac{1}{\hat N} = \sqrt{\text{Variance}\left(\frac{1}{\hat N}\right)}$ 0.023094011

Lower 95% confidence limit = $\frac{\sum(C_t M_t)}{\sum R_t}$ 9

Upper 95% confidence limit = $\frac{\sum(C_t M_t)}{\sum R_t}$ 92

Variance of $\left(\frac{1}{\hat N}\right) = \frac{\sum\left(\frac{R_t^2}{C_t}\right) - \left[\frac{(\sum R_t M_t)^2}{\sum C_t M_t^2}\right]}{s-2}$ 122.6939 0.391218 0.195609

Standard Error of $\left(\frac{1}{\hat N}\right) = \sqrt{\frac{\text{Variance of } \left(1/\hat N\right)}{\sum(C_t M_t^2)}}$ 0.00039

t.025 for s-2 D.f. = 4.30265

The 95% confidence interval is: $\frac{1}{\hat N} \pm t_\alpha \text{S.E.}$

tα * SE = 0.00168

	0.029624	0.0262642
	95% Lower	*95% Upper*
N	34	38

Sampling with replacement

$$\hat{N} = \frac{\sum_t (C_t M_t)}{\sum_t R_t}$$

Schnabel Method - with replacement

t	Ct	Ut	Mt	Ct*Mt	Rt	N
1	3	3	0	0	0	
2	8	3	3	24	5	
3	2	2	6	12	0	
4	6	5	8	48	1	
	19			84	6	14

$$\hat{N} = \frac{\sum_{t=1}^{s} (C_t M_t^2)}{\sum_{t=1}^{s} (R_t M_t)}$$

Schumacher-Eschmeyer estimator

(Rt2/Ct)	Ct*Mt2	Rt*Mt	N
0	0	0	
3.125	72	15	
0	72	0	
0.166667	384	8	
3.291667	528	23	23

Variance $\left(\frac{1}{\hat N}\right) = \frac{\sum R_t}{(\sum C_t M_t)^2}$ 0.00085034

Standard Error of $\frac{1}{\hat N} = \sqrt{\text{Variance}\left(\frac{1}{\hat N}\right)}$ 0.029160592

Lower 95% confidence limit = $\frac{\sum(C_t M_t)}{\sum R_t}$ 7

Upper 95% confidence limit = $\frac{\sum(C_t M_t)}{\sum R_t}$ 32

Variance of $\left(\frac{1}{\hat N}\right) = \frac{\sum\left(\frac{R_t^2}{C_t}\right) - \left[\frac{(\sum R_t M_t)^2}{\sum C_t M_t^2}\right]}{s-2}$ 47.90926 1.001894 0.500947

Standard Error of $\left(\frac{1}{\hat N}\right) = \sqrt{\frac{\text{Variance of } \left(1/\hat N\right)}{\sum(C_t M_t^2)}}$ 0.000949

t.025 for s-2 D.f. = 4.30265

The 95% confidence interval is: $\frac{1}{\hat N} \pm t_\alpha \text{S.E.}$

tα * SE = 0.004082

	0.0476428	0.0394784
	95% Lower	*95% Upper*
N	21	25

Partial replacement

Schnabel Method - with partial replacement

t	Ct	Ut	Mt	Ct*Mt	Rt	N
1	3	3	0	0	0	
2	6	3	3	18	3	
3	2	2	6	12	0	
4	6	5	8	48	1	
	17			78	4	20

$$\hat{N} = \frac{\sum_{t=1}^{s} (C_t M_t^2)}{\sum_{t=1}^{s} (R_t M_t)}$$

Schumacher-Eschmeyer estimator

(Rt2/Ct)	Ct*Mt2	Rt*Mt	N
0	0	0	
1.5	54	9	
0	72	0	
0.166667	384	8	
1.666667	510	17	30

Variance $\left(\frac{1}{\hat N}\right) = \frac{\sum R_t}{(\sum C_t M_t)^2}$ 0.000657462

Standard Error of $\frac{1}{\hat N} = \sqrt{\text{Variance}\left(\frac{1}{\hat N}\right)}$ 0.025641026

Lower 95% confidence limit = $\frac{\sum(C_t M_t)}{\sum R_t}$ 8

Upper 95% confidence limit = $\frac{\sum(C_t M_t)}{\sum R_t}$ 57

Variance of $\left(\frac{1}{\hat N}\right) = \frac{\sum\left(\frac{R_t^2}{C_t}\right) - \left[\frac{(\sum R_t M_t)^2}{\sum C_t M_t^2}\right]}{s-2}$ 84.70588 0.566667 0.283333

Standard Error of $\left(\frac{1}{\hat N}\right) = \sqrt{\frac{\text{Variance of } \left(1/\hat N\right)}{\sum(C_t M_t^2)}}$ 0.000556

t.025 for s-2 D.f. = 4.30265

The 95% confidence interval is: $\frac{1}{\hat N} \pm t_\alpha \text{S.E.}$

tα * SE = 0.00239

	0.0357237	0.030943
	95% Lower	*95% Upper*
N	28	32

The End