

An Integrated Ecosystem Management Framework for the Skeleton Coast-Iona Transfrontier Park



Otjinungua, Iona National Park (Photo by Vera De Cauwer)

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EXECUTIVE SUMMARY

The project “Co-designing conservation technologies for Skeleton Coast-Iona Transfrontier Conservation Area (Angola – Namibia)” (**SCIONA**) was implemented from 2018 to 2021 and funded by the European Union (FED/2017/394-802). The project was implemented in Namibia and Angola and led overall by the Namibian University of Science and Technology (NUST) together with the main implementing partner, the Instituto Superior de Ciências de Educação da Huíla (ISCED) (= the Higher Institute of Education Sciences of Huíla) in Angola. The SCIONA project’s overarching aim was to strengthen cross-border ecosystem management and wildlife protection in the newly established Iona – Skeleton Coast Transfrontier Park through co-designing and implementing conservation monitoring technology with the park authorities and surrounding communities.

This document addresses the Project aim by defining a management framework, a context for management decision-making, through highlighting the scientific perspective, broadening the knowledge base, and clarifying the connections of the ecological aspects to management. This includes a description of the main drivers and responders that make up the ecosystem, to support the selection of key indicators of ecosystem health. We used data collected during the SCIONA project for this study, complemented by dialogues with stakeholders and an extensive literature review.

The Transfrontier Park is ecologically an integrated part of the larger ecosystem that extends from the ocean across the hyper-arid zone, where the human footprint is relatively small, into the arid zone, where human influence is pervasive on various levels. The focus in this report is on the broader ecological region best defined as the Kaokoveld, and on both its human and natural inhabitants. The target audience for this report are the conservation authorities on both sides of the border, the various community conservation bodies (conservancy committees) and NGOs that are active in the region. Our focus is on the ecosystem that supports livelihoods, whether this is through the pastoralist lifestyle of the majority of the people living in the region, or through existing or future tourism opportunities that may be created through renewed attention to the management of the protected areas in both countries.

We describe the main factors that influence ecosystem structure and function, or represent important processes, in six thematic chapters (the role of water, biodiversity patterns, wildlife movement, human influence, the marine environment, and projected changes in climate). These six chapters collectively describe the management context, which is dealt with as a seventh chapter. The implications for monitoring, although really an integral part of management, are discussed in a separate chapter.

WATER AS A DRIVER OF ECOSYSTEM PROCESS

Water inputs arise from three sources: precipitation (summer rain showers with moisture from the Indian Ocean and fog, as strato-cumulous clouds formed over the Atlantic Ocean). Precipitation may at times cause episodic flows along ephemeral rivers and their smaller tributaries, where ephemeral pools remain for varying periods after a flood has subsided. Biota, including livestock, access surface water opportunistically along the rivers, but mostly at artificial water points (boreholes) or springs. Other sources are ephemeral saline pans along the coast, earthen dams and wells dug by people.

Precipitation increases as a sharp gradient from ~30 mm the coast to ~360 mm at the eastern boundary of the study area. This gradient affects an array of ecological factors, causing an equivalent gradient in primary

productivity and the relative amount of biomass along ephemeral drainage lines and rivers according to the position of their catchments. Most importantly, there is a basic water deficit along the whole of the gradient, with an aridity index of < 0.2 over most of the area, and < 0.03 in the hyper-arid zone along the coast. The ability of plants to endure the long dry spells during which the water deficit increases until water arrives in a short-duration pulse is the primary factor that determines resilience in the ecosystem.

Water flowing along the **Kunene River**, the only perennial river in the area, supports some thickets and riparian woodlands as well as some agricultural activities on narrow floodplains, mostly upstream from the Epupa Falls. The relatively small riparian woodlands and rocky thickets support rare bird and plant species, and the aquatic habitat is home to crocodiles (which is becoming increasingly threatened and cause conflict with humans) as well as to at least five endemic fish species and some unique invertebrates. The river's mouth is an important habitat for birds, freshwater soft-shelled turtles, marine green turtles and crocodiles. The riverine ecosystem remains threatened by the possible development of a large hydro-electric dam installation in the rocky section below Epupa.

Several **ephemeral rivers** cross the study area, the largest of which are the Curoca in Angola and the Hoarusib in Namibia. These rivers are often called "linear oases" and represent the most important biodiversity refuges in the Namib Desert, providing habitat for numerous species that would not normally occur in such an arid environment. The riparian woodlands are supported by alluvial aquifers that are periodically recharged by floods.

Several **perennial springs**, important resources for people (where water is palatable), their livestock and water-dependent wildlife, occur in the study area, even close to the coast. **Artificial water points** (boreholes and earthen dams) occur over most of the study area, and more are still in development. Especially the boreholes play a major role in making larger areas accessible for grazing by livestock and may be a key factor in the developing degradation over much of the area.

Advected fog, which is simply the strato-cumulous cloud layer (formed over the cold water of the Benguela Current) that shifts onto land, is the main source of moisture for a significant part of the biota of the hyper-arid coastline. This relatively predictable source of moisture supports a number of specialised biota, which have evolved an array of sometimes very innovative adaptations to access the free water.

BIODIVERSITY

The Kaokoveld is renowned for its biodiversity, with high levels of endemism in especially plants. For example, of the 234 indigenous woody species recorded in the SCIONA study area (both countries), 32 (14%) are endemic to the **Kaokoveld Centre of plant Endemism**. This Centre stretches from the Kuiseb River in the central Namib to Benguela in Angola, and eastwards to the escarpment. The high diversity can be explained by a sharp climatic gradient from the arid coast that is seasonally influenced by fog to a semi-arid and up to 2,500 m high mountainous escarpment. Part of this biodiversity hotspot is to some extent protected by the Transfrontier Park, but most of the Namibian part is situated in communal conservancies. Our work led to the description of four new plant species, an indication that there must be more waiting to be discovered. This emphasises the global importance of finding the right balance between human use and protection.

All three **floristic regions** of Namibia are represented in the study area, which is made up of five **vegetation types**. Although the definition of a habitat map was not a deliverable for our project, we used a random forest model to generate the first such **habitat map** of the region.

Two ongoing PhD studies supported by the SCIONA project represent the first attempt to focus on respectively the **microbes** and **arthropods** of a specific habitat type, the coastal hummocks. This habitat type is extensively distributed along the Namibian coast but is poorly known despite indications that it supports a highly diverse biota. Preliminary findings from these two studies are already confirming their uniqueness and vulnerability to threats such as coastal development. The SCNP-Iona Transfrontier Park can therefore play a large role in its protection.

WILDLIFE MOVEMENTS

As with most arid zone climates, the SCIONA study area shows high variability in primary production, a key factor that affects wildlife movements. Although many of the wildlife species here are adapted to survive the harsh and variable conditions, the primary response to rapid change is mobility – nomadic migrations are common. With increasing human activity in the region in general, effective space for such movements is decreasing. Based on literature and movement studies several wildlife species and as part of a collaborative study conducted for the MEFT, the Project therefore **defined corridors** that would allow effective movement of wildlife in response to variable conditions. The results **suggest two main movement corridors**, one of which, the Otjinhungwa corridor, could potentially be transboundary (movement across the Kunene has not yet been confirmed, but it is theoretically possible), and the other forms an east-west route into and out of the SCNP. The latter is especially important for giraffe, which need unfettered access to forage in the ephemeral rivers. Additionally, several smaller corridors allow local nomadic movements to and from ephemeral resources within secondary catchment landscapes. There is some congruence in corridor space between wildlife species, but fundamental differences in habitat requirements mean that species such as springbok will not overlap much with (e.g.) Hartmann's mountain zebra.

HUMANS

The main lifestyle in the region is transhumant and nomadic pastoralism (strictly speaking, both forms occur but for the sake of brevity we refer to both together as nomadic pastoralism). Nomadic pastoralism evolved in response to high variability in grazing resources. Nomadic movements to better rangelands allow vegetation a chance to recover and leads to the emergence of stability at a broader spatial and temporal scale. This effectively balances out the shorter-term fluctuations and is the key to the resilient nature of the lifestyle. The arid rangelands of the Kaokoveld have been utilised by pastoralists for at least two, and perhaps as many as four centuries. However, the human imprint has changed over time, most dramatically in the last fifty years as permanent water points were established below the escarpment. This expanded footprint of permanent water opened up pastures that were previously utilized only in exceptionally good rain years. In response, livestock numbers increased rapidly, declining only temporarily after major droughts (one of which at the end of the 1970s resulted in large stock losses). People are now semi-permanently occupying a part of the region where the mean aridity index is 0.04 to 0.05, and the annual average precipitation is only about 100 mm. The higher stocking densities have led to profound changes in centuries-old grazing rules and, together with seemingly more frequent droughts, was probably one of the main factors that put the rangelands on a trajectory towards degradation.

THE MARINE ENVIRONMENT

The Transfrontier Park borders the cold waters of the Benguela Current Large Marine Ecosystem that stretches from Cape Agulhas in South Africa in the south to about Moçâmedes (formerly Namíbe) in Angola, where it subducts under the warmer, tropical Angola Current at the seasonally shifting Angola-Benguela Front. Upwelling, with a strong cell off Cape Fria, underpins the high productivity of the Benguela ecosystem. The cold water is also the main reason why the coast is foggy, as ocean-generated strato-cumuluous clouds are advected onto land. Fog is a key factor that supports a uniquely adapted biota, with several species, ranging from insects to grass, that are adapted to this moisture source and whose geographic distribution is thus limited to the fog zone.

The SCIONA project focused on the terrestrial ecosystem of the study area (the marine zone adjacent to the park is not considered to be part of the Transfrontier Park). The developing regionally integrated marine spatial plan will include several transboundary Ecologically and Biologically Significant Marine Areas (EBSA's), including one that will cover the coastline of Iona and the northern coastline of Skeleton Coast National Park. This will be in addition to the previously established EBSA at Cape Fria, a foraging and breeding area for species like the Cape fur seal and the Damara Tern, which has a significant population here during specific periods of the year. It is also an important breeding site for Cape fur seals. Including the biodiverse Kunene River mouth, these areas of biodiversity significance form the basis for a proposed transfrontier marine protected area, which would include both the Namibe and Cape Fria EBSAs.

A critical concept that is intimately linked to the particular context of the Benguela upwelling along the Namibian coast is that of allochthony. The hyper-arid Namib Desert derives a significant proportion of the nutrients in the biotic component of its ecosystems from outside the Namib itself. This is an important driver of biodiversity patterns in especially hyper-arid deserts. There are little data available for the Namib on allochthonous transfers of specific elements, but it likely includes both the mineral elements themselves and organic matter (both plant detritus and dead animal tissues) borne on the wind or in surface water flows, as well as water itself, arriving in the form of floods or fog.

PROJECTED CLIMATE CHANGES

A compilation analysis of the WCRP Coupled Model Intercomparison Project - Phase 5 (CMIP5) data for historical (1950-1980), current (2006-2036) and future (2069-2099) scenarios for the SCIONA project area shows that both minimum and maximum temperatures will increase for both the intermediate and worst-case scenarios. These model results support the work by other researchers, but long-term outcomes are still highly uncertain because the effects of global warming on the Benguela Current, including the role of the strato-cumuluous deck over the Atlantic Ocean, are poorly understood. Surprisingly, both the intermediate and future modelled scenarios predict an increase in the annual rainfall in the Angolan section of SCIONA. Much of the current global discussion on climate change addresses the increase in extreme events, both in terms of flooding, drought and temperature extremes. For the study area, our models predict a slight decline in the early rain season (Oct-Dec) for both the intermediate (RCP 4.5) and worst case (RCP 8.5) scenarios, and an increase in the quantity of rain in either February or March. Based on global observations we can expect that these predicted differences are likely to result in more extreme events with flooding events potentially in February and March.

MANAGEMENT AND MONITORING

The current report is not a management plan. The protected areas on both sides of the border have existing management plans, and the Transfrontier Park will have its own. Conservancies often have their own management plans and there is no mechanism for a centrally implemented management plan outside the protected areas. Nevertheless, given the geographic focus of our project, we look at the issue from a regional perspective, and attempt to list and integrate themes that cross over boundaries, both those between the protected areas and their neighbours, and that between the two countries.

We deal with this constraint by purposely avoiding being prescriptive. We therefore do not provide detailed monitoring plans, because that level of detail is beyond our remit. Instead, we focus our contribution here on a discussion of topics that, in our opinion, should be addressed in some form or another in a management plan or plans that deal with conservation at a regional-landscape scale. The SCIONA project's geographic focus might be somewhat larger than what is generally considered for a "**protected landscape**", but the various threads that are woven into the fabric of the Kaokoveld and its residents (human and wildlife) can only be viewed and managed at this scale if it were to be successful.

The context for our discussions and recommendations for management is the preceding thematic description of key ecosystem components and processes. We do not specifically take each aspect through to management, but they do inform the discussions. The main topics of importance for management are water, land degradation, proposed indicators for monitoring, flagship species, invasive alien species, human-wildlife conflict and response to climate change. Of these, water and degradation are easily the most pressing issues to solve, at least outside the protected areas, and our discussion here focuses on identifying the constraints and possible solutions. With wildlife movements being such an important process for the maintenance of this system, we recommend several indicator species that will provide the manager with a robust assessment of the health of this process. We also include plant species that we consider to be sensitive indicators of climate change and recommend some actions that will mitigate against the effect of climate change on biodiversity. Finally, we highlight the role that our paraecologists played in the implementation of the project and the skills they gained.

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BACKGROUND

The project “Co-designing conservation technologies for Skeleton Coast-Iona Transfrontier Conservation Area (Angola – Namibia)” (**SCIONA** or “**the Project**”) commenced in February 2018. It was funded by the European Union (FED/2017/394-802) and, after a no-cost extension of the original contract, came to an end in June 2021. The project was implemented in Namibia and Angola, and led overall by the Namibian University of Science and Technology (NUST) with as the main implementing partner the Instituto Superior de Ciências de Educação da Huíla (ISCED) (= the Higher Institute of Education Sciences of Huíla) in Angola.

The SCIONA project’s overarching aim was to strengthen cross-border ecosystem management and wildlife protection in the newly established Iona – Skeleton Coast Transfrontier Park through co-designing and implementing conservation monitoring technology with the park authorities and surrounding communities. The current document addresses the Project’s overarching aim by defining a *management framework*. We did this by expanding on a literature study undertaken early in the project (De Cauwer, 2019) which involved collecting and evaluating ecosystem information, adding data and results obtained during the SCIONA project. Since our study was not primarily a scientific investigation of ecosystem dynamics, the baseline description relied on published information and as such was not an exhaustive review.

In the context of natural resource management, there are no formal definitions for the concept of a management framework. In a business management concept, it has been defined as “a combination of interlinked items that support a particular approach to a specific objective” (Budler & Trkman, 2019). In their sense it is a process of developing memes (the “items”) within a collective understanding of the management space. This clearly has little utility for us. However, in proposing that our report will comprise a management framework, we envisioned something similar to Budler & Trkman’s (2019) “combination of interlinked items”, in service of an understanding of the ecosystem’s functioning in such a way that we can, by measuring specific variables (i.e. “indicators”) obtain an evidence-based impression of ecosystem health.

We therefore approached the concept of a management framework as a description of the main drivers and responders that make up the ecosystem (analogous to an “ecological baseline”), that must in turn serve as justification for the definition of key indicators of ecosystem health that are measurable within the constraints of available management capacity (government as well as conservancies) and available information. Set within an adaptive management framework, this constituted our framework.

The current report is not a management plan. The protected areas on both sides of the border have existing management plans, and the Transfrontier Park will have its own. Conservancies often have their own management plans and there is no mechanism for a centrally implemented management plan outside the protected areas. Nevertheless, given the geographic focus of our project, we look at the issue from a

regional perspective, and attempt to list and integrate themes that cross over boundaries, both those between the protected areas and their neighbours, and that between the two countries. In defining the ecosystem factors that are key to management, we have therefore assumed a set of more general objectives that can be summarised as *socio-economic development that requires a healthy ecosystem*.

The title of this document refers to the Transfrontier Park, but the Park is ecologically an integrated part of the larger ecosystem that extends from the ocean across the hyper-arid zone where the human footprint is relatively small and into the arid zone, where human influence is pervasive on various levels. It was virtually impossible to understand the ecosystem dynamics of the Transfrontier Park without also understanding the arid matrix it is embedded in. As such, and because opportunities created by biodiversity conservation for the development of neighbouring communities need to be maximised and placed in their appropriate human context, our focus in this report is on the broader ecological region best defined as the Kaokoveld¹, and on both its human and natural inhabitants. In describing the main components of the ecosystem in Sections 1 to 6, we place a strong emphasis on the human component in the form of nomadic pastoralism and land degradation. We believe that the health and productivity of the rangelands that are all outside protected areas are as important as that inside the protected area for the region's sustainable future.

¹ The issue of what to call the geographic area that the SCIONA project focused on, is a difficult one to solve. None of the various geographic names encapsulate the whole focal area well. In Namibia, the Kunene Region is much larger than our study area, while the other commonly encountered name, Kaokoland is a Namibian colonial leftover referring to a Homeland in the apartheid system. In 1992, Kaokoland ceased to exist as an administrative unit. The former Kaokoland became part of the Kunene Region and within this administrative unit is called Kunene North, or Epupa and Opuwo constituencies. Neither of these options fit the SCIONA focus very well. On the Angolan side, the study area focused on Iona National Park, situated in Namibe province, and Monte Negro, a village just outside the southeastern point of the park in the Cunene province. An expansion of the park in this south-east corner is proposed in the Integrated Management Plan of Iona.

The focus of the SCIONA Project is on synergy between biodiversity conservation and the communities adjacent to the Parks. Although the [Kaokoveld Desert Ecoregion](#) (Dinerstein et al., 2017; Figure 1) is both longer from north to south and narrower from east to west, it stretches across the international boundary and includes both arid and hyper-arid zones. It is thus conceptually closer in meaning to the project's implicit focus on a region sharing a set of ecological properties, with the protected areas serving as anchors for development. We therefore use the term **Kaokoveld** when referring to our project's geographic focus, which lies roughly between the Angolan Curoca River in the north, the Namibian Hoarusib River in the south, and Swartbooisdrif on the Kunene River in the east.

INTRODUCTION

Straddling the Kunene River (Rio Cunene in Angola) that drains the western highlands of Angola, the north-western Kunene Region in Namibia and the south-western Namibe Province of Angola together form an enigmatic desert landscape that has attracted the attention of explorers and adventurers for centuries (Owen-Smith, 1972) (Figure 1). The numerous shipwrecks in the seas along its coast (the origin of the popular name Skeleton Coast), and the extreme climate have given it a romantic allure as a harsh, unforgiving and inhospitable region, populated only by the hardiest of wildlife. The region has come to be personified by expansive, hazy vistas with large mammal species such as the desert-adapted oryx and springbok.

Its popular image is not just the result of marketing; a promotion as a last wilderness where wildlife, rugged landscapes and adventure awaits². The Transfrontier Park does fit the IUCN definition for wilderness, being a large area of unmodified to slightly modified land, that has retained its natural character and influence, and is protected and managed to preserve its natural condition. Mittermeier et al. (2003) applied the wilderness concept beyond protected areas and showed that most of the Kaokoveld is part of one of the 24 main global wilderness areas, the Miombo-Mopane woodlands. Nature seems to be unbound in the vast landscape, and when looking beyond the obvious large ungulates to smaller and sometimes more cryptic organisms, there is a lot to be appreciated. The Kaokoveld supports remarkable numbers of endemic species, and high levels of micro-endemism, across several groups, making it one of the southern African region's most important harbours of biodiversity. The Kaokoveld's biodiversity is attractive in itself. However, contrary to popular belief about arid ecosystems, the biodiversity also plays an essential role in maintaining multiple ecosystem functions and services that are particularly vulnerable to climate change because of the general water scarcity Pravalie, 2016).

However, wilderness does not necessarily mean an absence of human influence. The Kaokoveld has been home to humans since at least the early stone age (Smith, 2000 and references therein; Vogelsang et al., 2002). Relatively few archaeological studies have been conducted in the SCIONA study area (Eichhorn & Vogelsang, 2007) and surrounding regions (Smith, 2000) but the available evidence supports the overall pattern that has been described for the Namib. It is a pattern of widespread presence of Pleistocene (early stone age) hunter-gatherers who retreated to escarpment refugia during particularly dry times, associated with the Last Glacial Maximum, but expanded again into the lower-lying arid regions as climatic conditions improved (Kinahan, 2020). More critically, and more relevant for this report, between 1,500- and 2,000-years BP³ livestock appeared in Namibia⁴.

² See for example <https://www.travelnewsnamibia.com/news/explore-kaokoland-and-the-wild-northwest/> and <https://www.facesofthenamib.com/activities/seven-rivers-of-kaokoland/>

³ Most of the information on the pre-history of the Namib comes from Namibia, because of a relative paucity of archaeological work in Angola. In a recent review, De Matos et al. (2021) show that Pleistocene sites dominate the southwestern part of Angola, including our study region. However, there is no reason to suspect that the advent of pastoralism was different in Angola to what it was in Namibia.

⁴ A cave near Outjo, just outside our study area, provides some of the most compelling evidence for this significant step in cultural development (Smith, 1995; 2000).

This was not yet the advent of true pastoralism⁵, which arose only several hundred years later, but it does signify that the connection of humans with this arid ecosystem and with their livestock and land is old and deep and has endured and survived natural and political disasters, even up to recent times (Bollig, 2000).

As in many of the world's arid zones, the dominant form of farming in this region is still pastoralism (Eisold et al., 2006), an ancient form of agriculture that developed in response to extreme variability in rainfall and plant productivity (Vetter, 2005). The dominance of a grazing system that depends on the freedom to move livestock herds in search of forage means that we cannot understand ecosystem structure and function if we view it only as a wilderness populated by wild animals where humans intrude at times. To fully comprehend the ebb and flow of energy and nutrients through this system, and the vulnerability of this ecosystem to climate change, we must include humans and their livestock as integral components. The arid rangelands of the Kaokoveld have been utilised by pastoralists for at least two centuries (Bollig & Gewald, 2000), but the human imprint has changed over time. The change has perhaps been most dramatic in the last fifty years as ovaHimba settlements expanded to areas below the escarpment (Owen-Smith, 1972) following the expansion of permanent water points in a decades-long borehole drilling programme (Bollig, 2013). It is thus unlikely that even a small part of the Kaokoveld, including much of the hyper-arid zone, can be found in its "natural" state absent of human influence (Bollig & Schulte, 2007).

However, the convergence of several factors ranging from recent multi-year droughts to the continuing unthinking development of water resources that draw large herds into previously inaccessible areas (Bollig, 2013), the latter driven by the basic and understandable need of each livestock owner to grow their herd, has – maybe unsurprisingly – led to serious degradation over large areas. The degradation problem is not a uniquely Namibian phenomenon – globally, pastoralist communities and the pastoralist way of life is threatened with land degradation as mobility declines and herd sizes tend to grow (Nori et al., 2005). Researchers from several disciplines have been warning about a potential catastrophe in the Kaokoveld for decades. For a long time, the predicted socio-economic collapse failed to materialise, but it is clear even to the casual observer that this problem has accelerated in the last five to ten years. One cannot escape the feeling that the region is sitting on an ecological precipice, that a mere nudge of a degree Celsius of warming, or a drought that lasts only a month or two longer, might push it over an edge with disastrous consequences for the people, the wildlife and the services they obtain from the ecosystem (Pravalie, 2016).

⁵ Pastoralism refers to a form of animal husbandry where livestock are allowed to roam freely on open rangelands. It is one of the most widespread forms of agriculture in the world, occurring on all continents except Antarctica and covering almost 25% of the world's land area (Dong, 2016). It is a complex form of adaptive natural resource management that still is practiced in more than 100 countries, supporting about 200 million households and herds of nearly a billion animals that account for about 10% of the world's meat production (FAO, 2001). Transhumance and nomadic pastoralism are two of three forms of pastoralism (the third is sedentary production; Weber & Horst, 2011) that are principally practiced in arid and semi-arid rangelands. Transhumance refers to a relatively stable pattern of movement between a home base and a small number of dry season pastures (e.g., mountain tops), while nomadism is characterized by continual movement of livestock in search of forage. In the case of nomadism no permanent home base is established, and movement is not pre-defined but highly adapted to current conditions (Weber & Horst, 2011). The ovaHimba (and other Namibian pastoralist groups) practice a mixed form of these two types. In this document we use the term nomadic pastoralism to refer to this mixed form in the Kaokoveld.

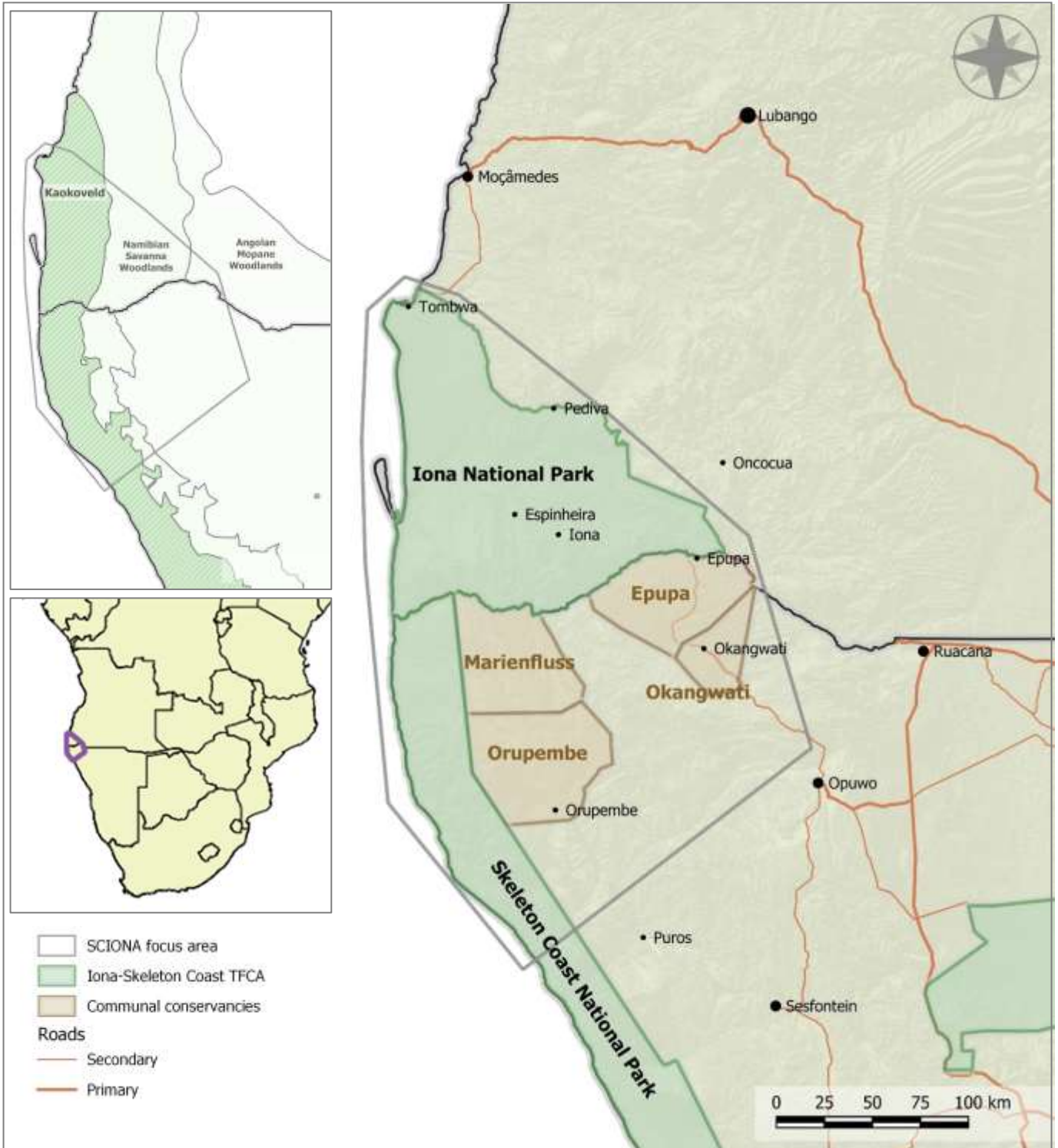


Figure 1. The SCIONA study area. Inset upper left shows the location of the three main Terrestrial Ecoregions (Dinerstein et al., 2017), with the Kaokoveld in green.

This is an exceptionally difficult problem to solve, playing out in a socio-political context and involving a range of stakeholders well beyond only the ovaHimba community. Solving this problem is also outside the remit of the SCIONA Project, but the opportunities that are created by community-based natural resource management in partnership with conservation authorities in two countries, allied to the established Transfrontier Conservation movement, may hold at least part of the development answer⁶. Making a contribution to the success of this potential set of solutions is in fact within the SCIONA remit.

Although the current report was originally conceived as a management plan of a kind, events have overtaken that goal. An Integrated Management Plan was developed for Iona National Park in 2016 as part of an EU – UNDP – GEF project and translated from Portuguese to English by the SCIONA project. A new management plan was developed in 2021 for SCNP under the NamParks 5 project (see MEFT, 2021 for the draft MP). The recent development of the management plans has meant that we can now focus on adding value through highlighting the scientific perspective, on broadening the knowledge base and on clarifying the connections of the ecological aspects to management. We can now also focus on the areas surrounding the SCNP, which is not dealt with in any detail by either the integrated Transfrontier MP or the Management Plan for the SCNP. In this way, the current report gives flesh to the landscape vision articulated by MEFT (2021). We hope that a scientific description of the structure and function of the arid ecosystem here will serve as a framework and context for management decision-making.

We have divided the report into two main parts, covering eight topics. In contrast to conventional baseline descriptions that start with accounts of the atmosphere, geology, soils, flora and fauna, we chose to approach the topic thematically. To do this, we identified eight themes, that are each explored from a functional perspective. The first part, comprising seven sections, sketches what are, in our opinion, the main ecological factors that are relevant for a broad understanding of the Kaokoveld ecosystem, its functioning, and its vulnerabilities.

We start the story with a discussion on water as a critical driver, exploring the meaning of variability in fog, precipitation, and flooding as the drivers of variability in ecosystem properties.

The story of the Kaokoveld cannot be told without a description of its biodiversity – it is rich in endemic species and in unique communities of taxa ranging from microbes, through invertebrates, to plants and larger wildlife that occupy an assortment of habitats from coastal dune hummocks to ephemeral rivers and mountaintops. This focus on **species, their habitats and their biogeography** forms our second theme. Related to this but requiring a specific focus as a critical process that determines the survival of several mammals, is the third theme of **wildlife movement, corridors and migration**. The nature of these movements, and their relationship with and response to human settlement patterns clearly have several implications for conservation management of the region.

⁶ In this regard it is important to note that the recently published draft Management Plan (MP) for the Skeleton Coast National Park (SCNP) explicitly envisions an “*interconnected conservation landscape east, west, north and south of the Coastal Parks dominated by biodiversity- and conservation-friendly forms of land use and economic activity that does not degrade landscape qualities and mitigates against the impacts of climate change on biodiversity, restores and maintains landscape connectivity and generates incremental conservation and developmental benefits through cooperation and coordination amongst stakeholders. This landscape will be open-ended and driven by conservation opportunities*” (MEFT, 2021).

The fourth theme investigates the **role that humans play** in determining ecosystem properties, specifically through the nomadic pastoralist lifestyle, the expansion of pastoral ranges, and increases in livestock herds. In the fifth theme, we summarise properties of the **marine ecosystem**. This description is based principally on work from other authors, but we additionally highlight the connections between the marine and terrestrial ecosystems, a unique feature of the Namib Desert that is driven by the Benguela upwelling system and its influences on climate. In the sixth theme, we explore the **implications of climate change** for the Kaokoveld ecosystem. The second-to-last theme is a cross-cutting topic on management, including an explanation of the implications of the first part (Sections 1 to 6) for the **management** of both protected areas and pastoral rangelands. This section includes a description of the increasingly evident **land degradation** that appears to be closely related to expansion of water points and coinciding droughts. We end the report with the final theme, being a proposal for monitoring approaches.

Appendix 1 is a brief description of the current climate of the Kaokoveld and surrounding regions and represents the context for Section 7.7. Appendices 2 and 3 are lists of the region's plant and mammal species respectively, and Appendix 4 describes the aerial survey of wildlife and livestock done for the current project.

1 PARCHED: WATER AS A DRIVER OF LIFE AND PROCESS

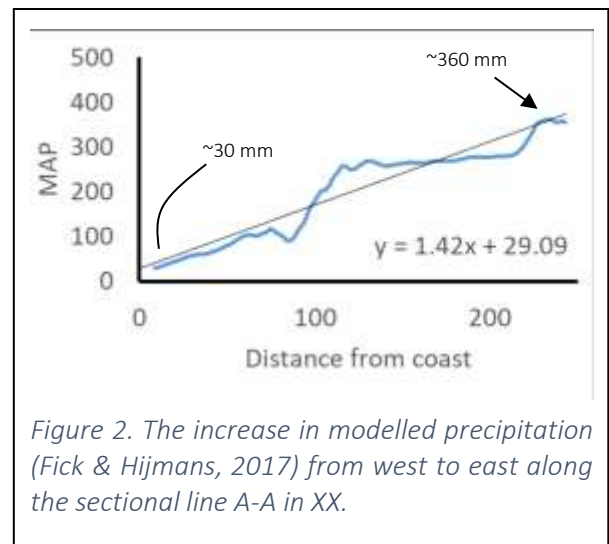
1.1 BEING DRY IS ABOUT WATER INPUTS, ARIDITY AND DROUGHT

It goes without saying that water is the most critical determinant of dryland ecosystem function. Water is unique among natural resources because it controls how other resources are used (Pratt, 1997), on a range of scales.

Water inputs into the Kaokoveld ecosystem arise from three sources. Precipitation arrives principally as atmospheric water in the form of summer rain showers or fog. Rain is derived from moisture that enters the region across the sub-continental landmass from the Indian Ocean as part of the southern African weather system, while fog is simply low-altitude stratocumulus clouds that form over the Atlantic Ocean and are then advected onto land (Andersen et al., 2019; Spirig et al., 2019). Surface inputs of free water arrive as episodic flows along ephemeral rivers and their smaller tributaries (and associated ephemeral pools that remain for varying periods after a flood has subsided), and surface water points. The latter occur as natural springs that vary in volume, consistency and quality over time and space, as ephemeral pans that are most often highly saline especially along the coast, in earthen dams constructed in a few places, wells dug by people, and water pumped from several boreholes (Figure 3).

1.2 WATER ARRIVES AS RAIN, BUT MOST OF IT EVAPORATES

Precipitation is distinctly seasonal (Figure 3; see also Appendix 1), even at the coast where long-term Mean Annual Precipitation (MAP) is close to 30 mm and shows a marked southwest-northeast gradient in long-term average annual rainfall (Figure 2; Figure 3). The sharp gradient, which represents an average of 1.4 mm increase in MAP per km from east to west, is a critical factor that determines the relative habitat suitability and survival potential for all animals and plants. Long-term weather data for the region is not easy to obtain. The MAP for Kamanjab, a town that is located ~200 km to the southeast of Opuwo, has shown a generally downward trend in rainfall from the early 1940's to the end of the previous century (Figure 4). No other stations in the study area, including the SASSCAL Weathernet stations (<http://www.sasscalweathernet.org/>) have long-term data. Data derived from satellite images, such as the CHIRPS dataset, can show long-term trends and does show that MAP was below average for most of the period 2011 - 2020 in the Kaokoveld, with exception of the rain season 2014 - 2015 (Thompson, 2021).



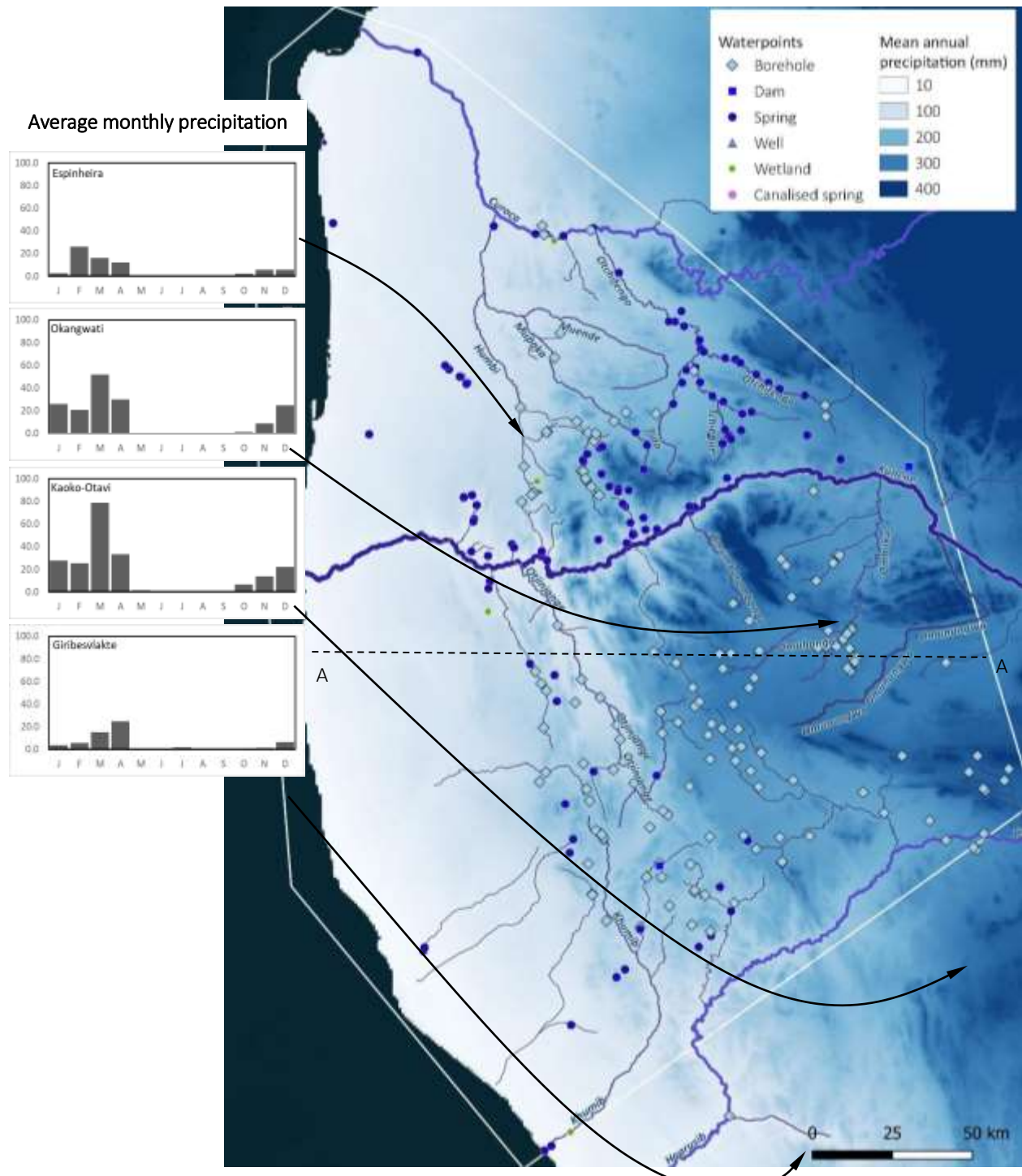


Figure 3. Main moisture inputs, except fog, into the Kaokoveld (study area outlined in a thin white line) and the average monthly precipitation at four weather stations. (Map: V. De Cauwer)

The source for the spatial precipitation pattern was the WorldClim database (Fick & Hijmans, 2017) and average monthly rainfall since ~2016 at the four weather stations were downloaded from <http://www.sasscalweathernet.org/>. Because of variations in station downtime, the latter is based on 2 – 5 years data for the different stations. Boreholes, wells and springs on the Namibian side were obtained from Jeff Muntifering (KREA), the Atlas of Namibia or digitised on Bing aerial photos. Water points on the Angolan side were obtained from Bruce Bennett (African Parks) or digitised on Bing aerial photos. The rivers' line thickness provides a subjective indication of their relative size, with the thickest ones indicating the presence of more frequent and larger flooding due to higher chances of rainfall in their catchments, or by having a larger catchment. Section A-A was used to determine the rate of increase in precipitation with distance from the coast.

Other aspects of precipitation, such as the spatial distribution of rainfall in the wettest quarter and the coefficient of variation in rainfall are described in Appendix 1, together with relevant patterns of other synoptic variables.

The basic statistics about precipitation however tell only a part of the story. At an ecosystem scale, it is not only the amount of water or its seasonality that affects life. The proportion of water that is lost to evaporation compared to what is received as precipitation is arguably more important because it determines the net soil moisture and thus the rate and magnitude of nutrient capture and cycling through the ecosystem and the total amount of plant and animal biomass that can be supported (Safriel et al., 2005; Jiao et al. 2016; Liu et al. 2019).

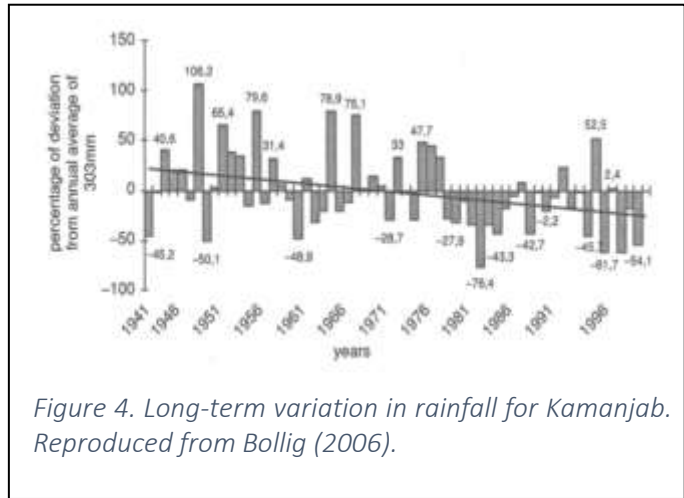


Figure 4. Long-term variation in rainfall for Kamanjab. Reproduced from Bollig (2006).

A full water balance includes more than simple precipitation. Soil water content (SWC) is ultimately determined by effective precipitation, which is the total precipitation less the rainwater that is intercepted by the canopy and litter, minus all forms of evaporation and transpiration. It is clear that the study region’s soils, and thus its vegetation is severely stressed, with remarkably low minima in soil water content fraction and thus high levels of vegetation stress (Figure 5).

The ratio of precipitation to evapotranspiration provides a handy index of dryness, or aridity, that summarises the net effect of the soil water balance. Although several such indices have been proposed, the most widely used is the Aridity Index (AI); the long-term mean of the ratio of mean annual precipitation to mean annual evapotranspiration (MAP/MAE), which was defined by UNEP for the World Atlas of Desertification (Middleton & Thomas, 1997). MAE is usually modelled as mean annual potential evapotranspiration (PET) (Zomer et al., 2008). AI values lower than 1 indicate an annual moisture deficit.

Drylands are defined as areas with $AI \leq 0.65$ —that is, areas in which annual mean PET is at least ~ 1.5 x greater than MAP. Drylands are generally considered to comprise of four types—dry subhumid, semiarid, arid, and hyper-arid—reflecting an increasing level of aridity or moisture deficit. Conventionally, the four subtypes are divided as ranges of the AI (Table 1). Ecosystems with index values above 0.65 are considered to be humid.

Table 1. Aridity Index value ranges for the four dryland types.

| Dryland type | Aridity index range | Evaporation as approximate multiple of precipitation |
|---------------|----------------------|--|
| Hyper-arid | $AI \leq 0.03$ | > 33 times |
| Arid | $0.03 > AI \leq 0.2$ | 33 – 5 times |
| Semi-arid | $0.2 > AI \leq 0.5$ | 5 – 2 times |
| Dry sub-humid | $0.5 > AI \leq 0.65$ | 2 – 1.5 times |

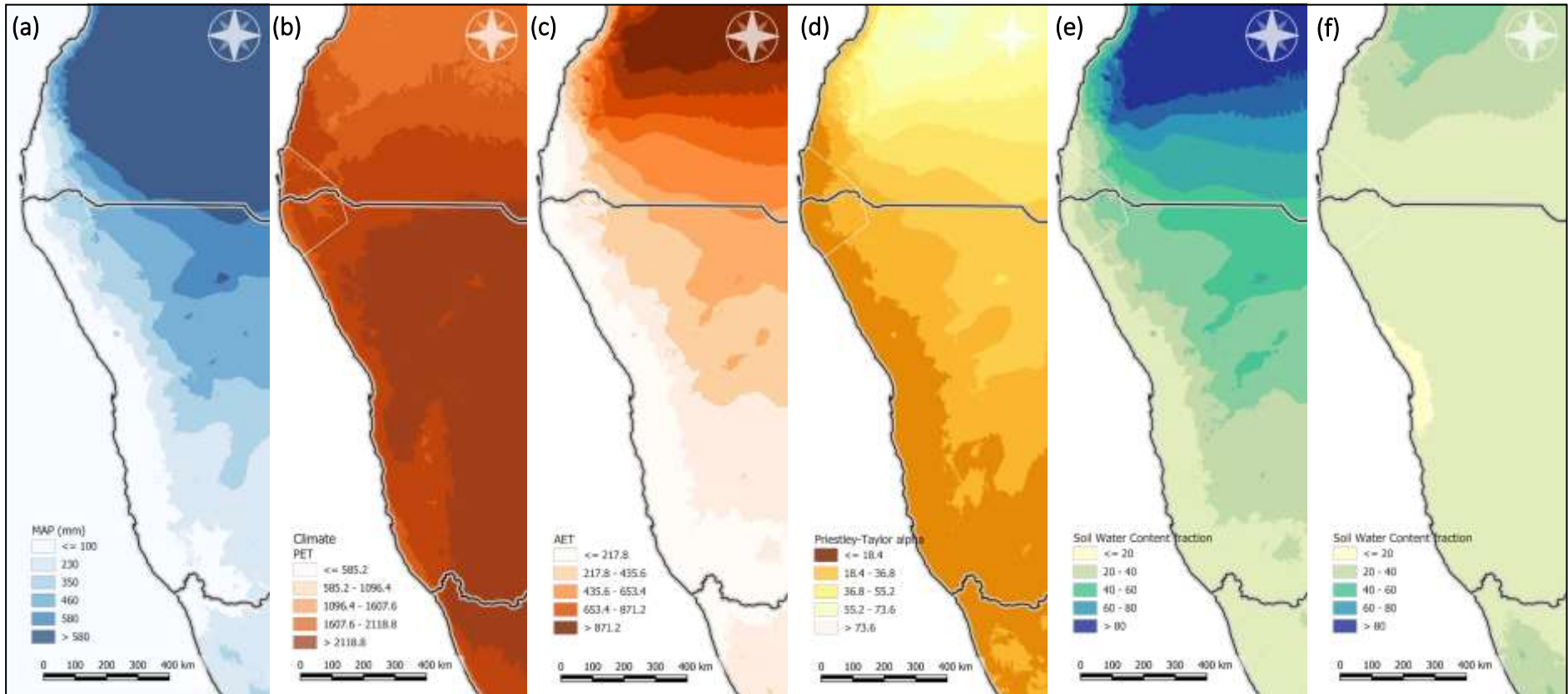


Figure 5. Spatial distribution of selected variables that contribute to soil water balance. (a) Mean annual precipitation (MAP), (b) Potential evapotranspiration (PET), (c) Actual Evapotranspiration (AET), (d) Priestley-Taylor's Alpha index (a measure of water stress experienced by plants), (e) maximum Soil Water Content fraction (April) and (f) minimum Soil Water Content fraction (October). The SCIONA study area is outlined in a faint white line.

The source for the PET, AET, Alpha index and soil water content data is the CGIAR-CSI Global Soil-Water Balance Database (Trabucco & Zomer, 2010), downloaded from <https://cqiarcsl.community>. Mean Annual Precipitation data were sourced from the WorldClim database (Fick & Hijmans, 2017). Other factors that contribute to the annual energy balance and thus to the calculation and modelling of PET are several temperature variables – please see Appendix 2 for more detail on their distribution.

The whole of Namibia is dryland ($AI \leq 0.65$), and more than half (~62%) is arid or hyper-arid (Figure 6). Most of the Kaokoveld is classified as hyper-arid and arid, with only a small part of our study area ranging into the semi-arid zone (Figure 6). The lower the aridity index of a region the greater the water resources variability and scarcity in time, and the more vulnerable the area is to desertification (Berdugo et al., 2020).

The most important implication of an $AI < 0.2$ is thus that there is an extreme soil water deficit for most of the year that is only relieved when water arrives during short duration pulses in the rainy season, followed by a longer and more gradual decline as some of it is stored as groundwater but the majority is lost to evapotranspiration. It is the ability of the plants to overcome the seasonal asymmetrical pattern of the increase and subsequent decline of soil moisture, as well as prolonged droughts, that determine the resilience of the ecosystem.

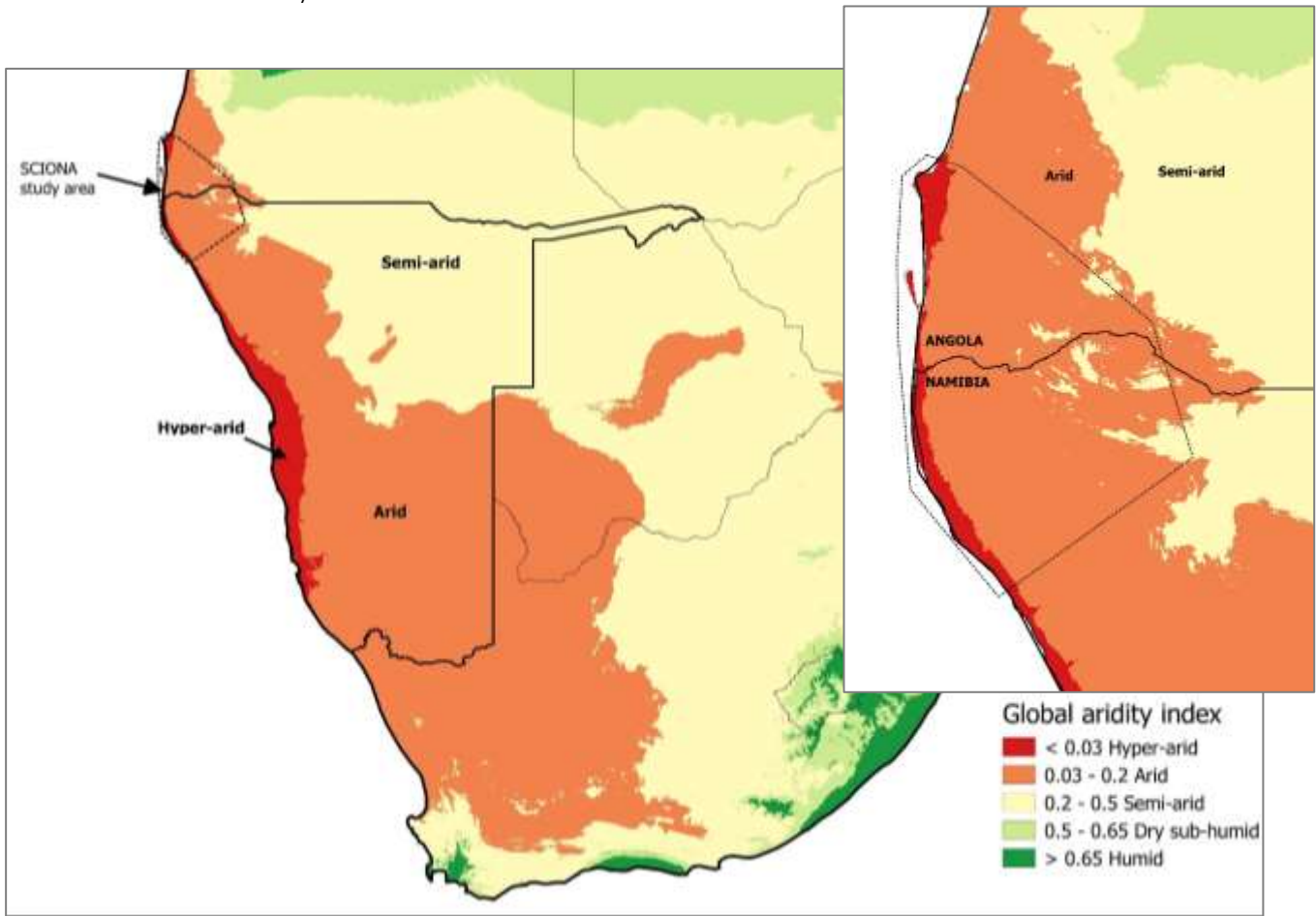


Figure 6. Southern African dryland types.

The source of the AI data is the CGIAR-CSI Global-Aridity and Global-PET Database (Zomer et al., 2008; Trabucco & Zomer, 2018), downloaded from <https://cgiarcsi.community/data/global-aridity-and-pet-database/>.

Our understanding of the properties of arid zone precipitation pulses and their role in functional processes such as nutrient cycling and plant productivity have improved (Snyder & Tartowski, 2006), but we do not yet understand the behaviour of structural ecosystem properties on the brink of sudden shifts to alternative stable states very well (Berdugo et al., 2020). Additionally, the partitioning of soil water between

evaporation from bare soil and transpiration by plants, a key input into predictions of ecosystem behaviour under increased temperatures and more variable and extreme events, is still poorly known (Loik et al., 2004).

Overall, we still know remarkably little about past changes in the spatial pattern of aridity in Namibia – has aridity increased in extent and has the AI of certain areas decreased (become more arid)? These past changes and their relationship to ecosystem health, together with expected future increases in aridity (Huang et al., 2017; Berdugo et al., 2020) will have major implications for food security for the Kaokoveld’s pastoralists.

1.3 RIVERS: WATER FROM ANGOLA, FLOODS, DAMS AND RIPARIAN FORESTS

Rivers are the lifeblood of the desert, transporting water and replenishing resources, and providing habitat to a diversity of organisms. The study region contains both a perennial and several ephemeral rivers. The two countries and parks are in fact separated by the only perennial river in the study area: the Kunene River or Rio Cunene, whose valley forms an oasis in the arid ecosystem. The basic and relatively simple hydrological difference between rivers that flow year-round (i.e., perennial) and those that flow episodically with floods of varying magnitudes (ephemeral) belies the vast differences in their ecologies.

The **perennial Kunene River** is approximately 1,050 km long, with a catchment of 106,500 km², of which ±92,400 km² lies in Angola and 14,216 km² in Namibia (Paterson, 2007; Midgeley 1966; Morant, 1996; Greenwood, 1999; BCLME, 2007; Strohbach, 2008). On average, about 5.5 km³ water flows down the Kunene annually (Robertson et al., 2012), transporting around 9 million tons of sediment (Garzanti et al., 2017). The river is impounded in three places upstream of the Ruacana diversion weir in Namibia: the Angolan Gove, Matala, and Calueque Dams (Figure 8). The Gove and Calueque dams were built in the early 1970s as part of the Ruacana power scheme to regulate the flow of water and allow the generation of electricity on a more constant basis.

The maximum discharge recorded did occur during the SCIONA project: a flow of 2004 m³.s⁻¹ on 16 February 2020 at Ruacana (Figure 7). Rainfall in the upper Cunene resulted in the opening of the sluice gates of the three Angolan dams that had reached full storage level. Water levels increased very quickly over a very short period in mid-February. The flow a week before was only 709 m³.s⁻¹.

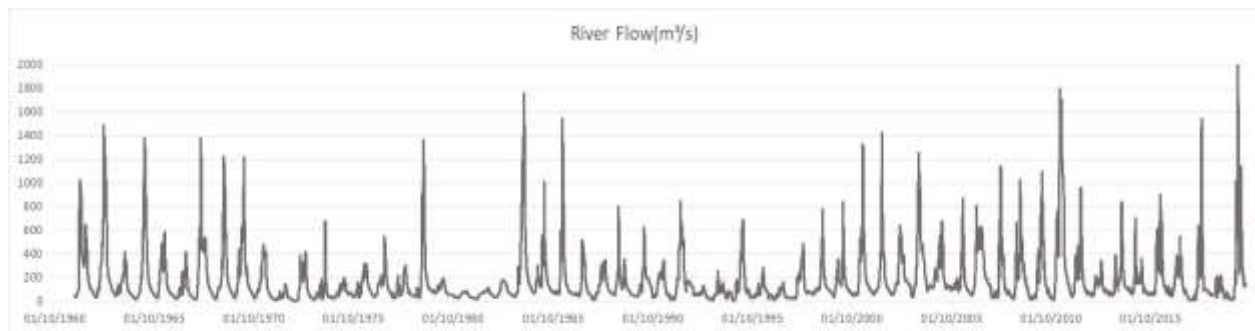


Figure 7. Kunene River flow at Ruacana (Source: NamPower).

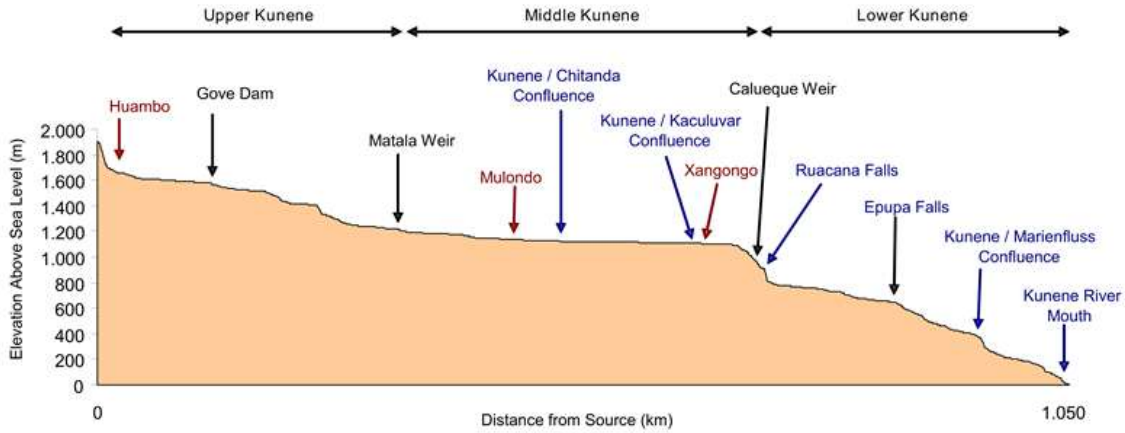


Figure 8. Kunene River elevation profile. Source: downloaded from the Kunene River Awareness Kit (http://www.kunene.riverawarenesskit.com/kunenerak_com/en/management.htm), attributed to ANH Group.

For most of its course along the international border, it is a relatively fast-flowing river along a steep gradient (Figure 8) confined to narrow rocky gorges (Hay et al., 1997), with only a few, relatively small floodplains and riparian habitats. The latter is concentrated upstream from Epupa and are almost all used for the cultivation of crops by ovaHimba communities resident along the River valley (9). Along the rocky gorge sections (see e.g. Figure 9b and d) vegetation is sparse, with some denser stands upstream of all significant rapids (e.g. Figure 9e) and small sandy beaches and boulder traps sometimes supporting a few trees or thickets, particularly along the section bordered by the Kunene erg (sand sea) (Figure 9d). This is a fundamentally different kind of habitat from what can be found in the Angolan floodplains upstream of the Caleque dam, where the lower gradient and slower flows result in a braided channel pattern with ~5 km or more-wide marshy floodplains (Figure 9; Hay et al., 1997) and more diverse bird, reptile and aquatic communities. It is therefore true that the smaller floodplains and even smaller pockets of vegetation in a few scattered locations along the rocky gorges play a minor ecological-functional role when viewed in the context of the whole river's biodiversity. Yet the riparian woodlands and forest along the stretch upstream from Epupa is the habitat for some rare bird species (e.g. the Cinderella Waxbill *Estrilda thomensis*), while the small pockets of vegetation along the lower Kunene support some extremely rare plant species (e.g. the newly described *Syzygium kuneneense*; Swanepoel et al., 2021a). Although the riparian habitats along the lower Kunene ranked low for bird endemism, they ranked high for diversity (Robertson et al., 1998), reflecting their value for bird species that would not normally occur in the arid zone.

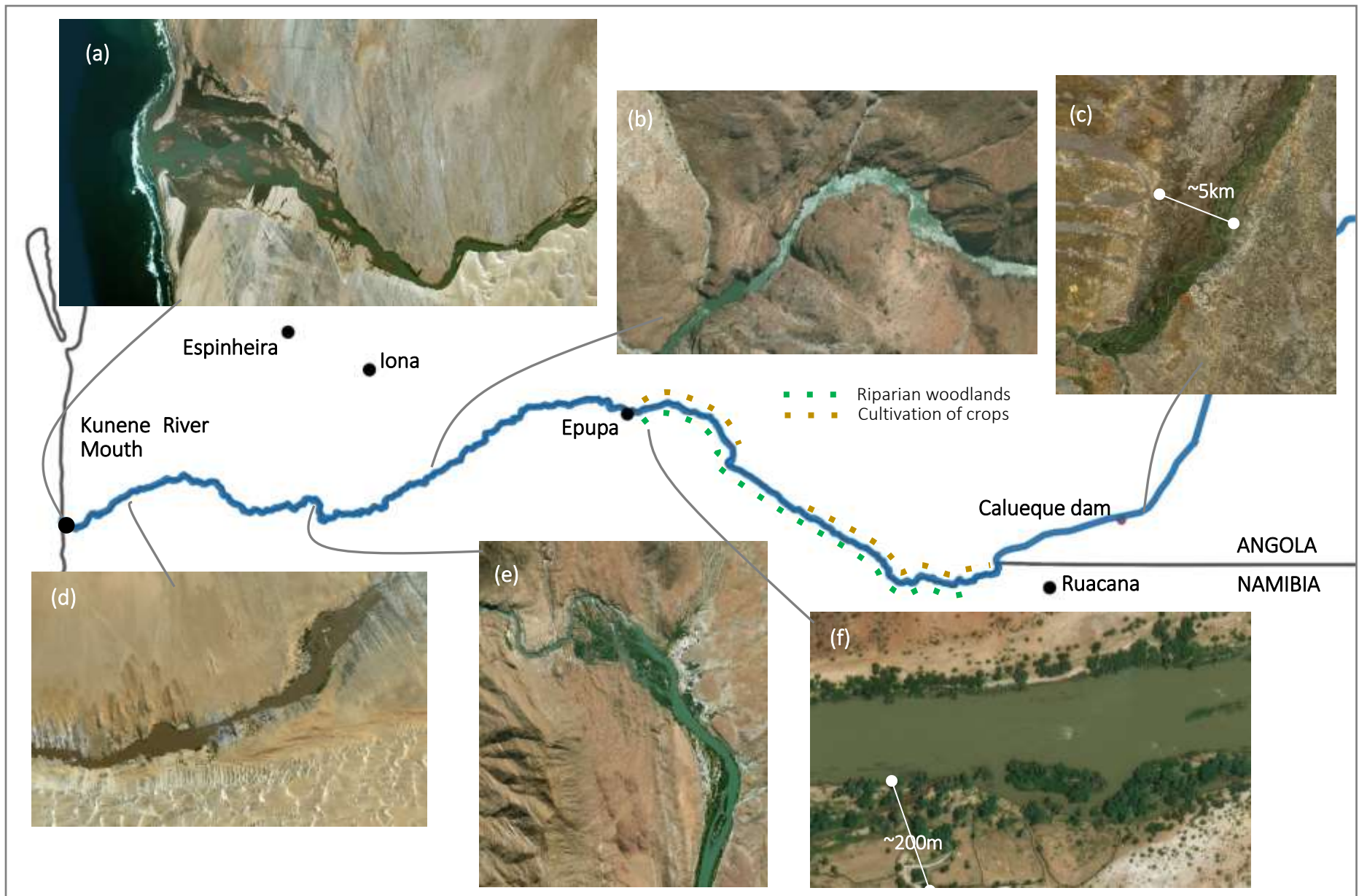


Figure 9. Habitats along the middle and lower Kune River. The stretches of river that contains significant riparian woodlands and where crops are cultivated (on both sides of the river) are indicated in green and brown dashed lines respectively.

Nevertheless, most of the lower Kunene's biodiversity character is linked to the aquatic habitat, principally fish, invertebrates and crocodiles (Simmons et al., 1993; Hay et al., 1997; de Moor et al., 2000; Lyet et al., 2016). The Kunene system is not particularly rich in fish assemblages, but it represents the southern limit of several species and at least five endemics occur (Hay et al., 1997). Five species are limited to the section below Ruacana, but the diversity generally declines from Ruacana to the river mouth, probably because such a large part of this section is fast-flowing (Hay et al., 1997). Crocodiles occur along the full length of the river, with most smaller individuals found above Epupa (Lyet et al., 2016). Recently crocodiles have been increasingly targeted by local communities because of the increasing incidence of human-wildlife conflicts as crocodiles prey on livestock and people.

The Kunene River Mouth furthermore plays a large role as a habitat for migrating birds, several Namibian red data bird species, breeding crocodiles and the largest concentration of freshwater Nile soft-shelled turtle (occurring here at the southern limit of its range) and marine green turtles in Namibia (Simmons et al., 1993; Paterson, 2007); it is thus considered to be a biodiversity hotspot along the coast (Barnard & Curtis, 1998). The mouth lacks estuarine benthic fauna, marine and estuarine plankton, and marine fish species (Carter & Bickerton 1996; Morant & Carter 1996; BCLME 2007), which indicates that it acts as a river mouth rather than an estuary, according to the classification of Whitfield (2001).

Namibia has considered the installation of another hydropower scheme at Epupa, further downstream. The hydropower scheme would require the flooding of a large part of the Kunene valley. Impact assessments were performed and the Epupa site was compared with a site near the Baynes Mountains (Corbett, 1999). The dam was never established, but the concept has recently experienced a resurgence, being the subject of a number of articles in the popular press. Plans for a hydropower scheme are unlikely to be shelved permanently, even though there are several good ecological reasons why it could have significant downstream impacts on not only the riparian and aquatic ecosystems, but also on communities that depend on its floods and natural resources. Critically, one of the largest threats is that we still know little about the effects of damming and regulated flows on populations of specialised fish species (Hay et al., 1997) or of aquatic invertebrates (de Moor et al., 2000). The simple diversion weir used at Ruacana had an immediate negative effect on recruitment in three downstream fish species (Holtzhausen, 1991, cited by Simmons et al., 1993). Likely, the characteristic extreme fluctuations in daily river level, caused by the release of water at Ruacana when daily energy demand is highest, have also had major impacts on a range of other taxa.

The dams can also reduce water flow during critical dry years, affecting riverine vegetation, and resulting in the dieback of large *Faidherbia albida* and *Combretum imberbe* trees as has been observed in South Africa (O'Connor, 2001). Dieback of *F. albida* was observed downstream of Otjiningua during the SCIONA project. It is not clear to what extent the dams have affected the annual floods and the consequent yearly availability of grazing in the waterlogged areas near the Kunene. Malan and Owen-Smith (1974) report that the Himba rely on this grazing for their cattle during the winter months, sometimes even up till October in very dry years.

Almost thirty years ago Simmons et al. (1993), said "the Kunene is Namibia's third -largest and most poorly studied river", and this, unfortunately, remains true today. In view of the remaining and increasing threats to the Kunene ecosystem's health, it is critical that these knowledge gaps are filled to allow appropriate monitoring and management of the health of this unique perennial riverine ecosystem.

All other rivers within the study area are **ephemeral rivers**. The largest within Iona National Park is the Curoca, almost a perennial river, forming the northern border. Other important ephemeral rivers are mainly northward-flowing, into the Curoca. They include the Otchifengo that forms part of the eastern boundary of the park, the Humbe, Muende, Mupaka, and Thieque (Ministério do Ambiente, 2016; GIS data Bruce Bennett). Within the SCNP part of the study area, the ephemeral rivers are westward-flowing; there are from south to north the Khumib, Sechomib, Nadas, Munutum, and Engo (Ondusengo) Rivers. The Sechomib, Nadas and Munutum widen into small alluvial fans where their valleys leave the hills (Miller, 2008, p. 25-36, 25-37, 25-38). The rivers originate in the highlands beyond the escarpment and do not always reach the sea.

So-called 'Benguela Niño' events – when the South Atlantic is warmer than normal and the Inter-Tropical Convergence Zone progresses further south – bring higher than normal rainfalls to the Kaoko highlands which result in high-magnitude flash floods that last several days (Jacobson et al., 1995; Krapf et al., 2003; Stollhofen et al., 2014), for example in 1982 and 1995. These floods, usually from February to April, do not only bring water, but also sediments and nutrients to the lower reaches of the ephemeral rivers. Where ephemeral rivers are barred by dunes, most flows terminate in flat inter-dune playas or active fan systems, forming short-lived wetlands. Only exceptional floods in the rivers with the larger catchments can break through the dunes. The ephemeral rivers are of vital importance for supporting biodiversity in the hyper-arid environment. Riparian vegetation and relatively shallow groundwater in alluvial aquifers – which occasionally surface as springs – provide 'linear oases' to both resident and migrating wildlife, from where they undertake grazing forays. Biodiversity is higher along the river courses than in the surrounding desert (Figure 10).



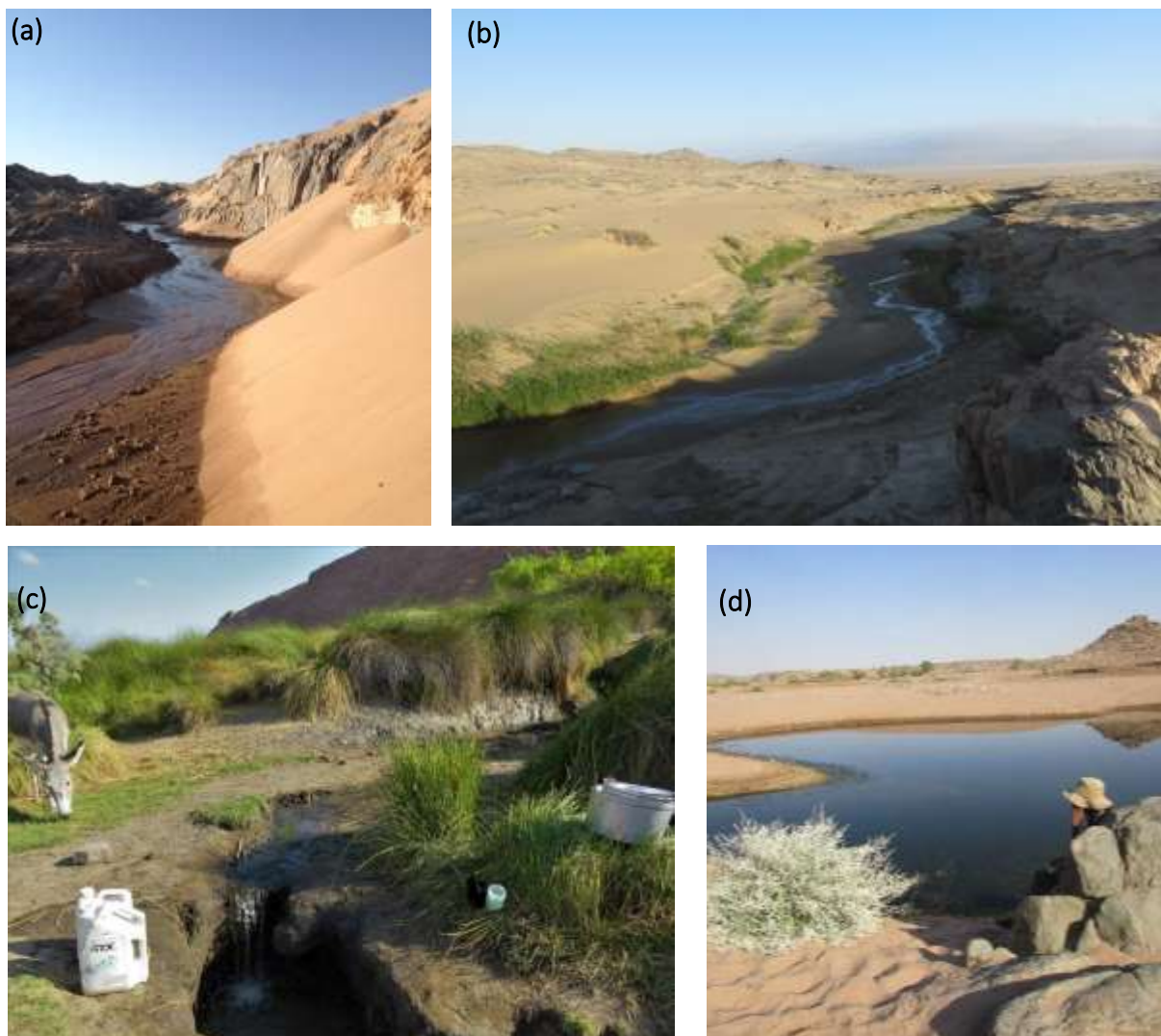
Figure 10. An example of the riparian habitats along the larger ephemeral rivers – here it is the Hoarusib River. The woodlands along these rivers represent a linear penetration by elements from the wetter hinterland into the true desert. As such they are critical for the support of biodiversity here.

1.4 NATURAL WATER POINTS: PERENNIAL SPRINGS

There are several ephemeral springs within the Namibian part of the study area; the Okau, Sarusas, Oasis, Auses, Ganias, Soutvlei, and Hoaswater springs (Ministry of Environment and Tourism, 2013). Okau is a spring on the Munutum River, near Cape Fria (Figure 11a,b). In the communal areas east of Skeleton Coast Park, there are hot springs west of Okangwati (Schneider, 2004), as well as springs at Ombivango, Omutati, Okapaizirwa, Omuatjivingo, Otjihaa, Omuatjinguma, Orupembe, Sanitatas, Otjijanjasemo, Omayuru, Ondova, Okangwati, Ogams (Sanitatas area), Okakuyu (Ehama area), Oryeheke (Epupa area) and Etanga (Christelis & Struckmeier, 2011).

In Iona National Park, there is also an Okau spring, situated about 2 km north of the Otjiningua rapids on the Kunene (Figure 11c). There are hot springs in Pediva, east of Salondjamba (Figure 11d). Dispersed through central and eastern Iona are springs, wells and water pumps, although only some have a permanent water flow. Iona village is supplied by canalised waters from springs in the Tchamalindi Mountains. Various sites along the Curoca and Otchifengo rivers offer permanent surface water (Ministério

do Ambiente, 2016). A few springs are present in the desert zone of the park, providing much-used waterholes for large mammals.



*Figure 11. (a) (b) Okau spring in the SCNP, Namibia (Photos by Vera De Cauwer & Nicky Knox). (c) Okau spring near Otjinungua (Photo by Wessel Swanepoel). (d) Pediva hot spring with *Aerva leucura* plant in front (Photo by Vera De Cauwer).*

Springs found in the normally dry streambeds of ephemeral rivers play a disproportionately large role as oases in the surrounding hyper-arid landscape. They occur where impermeable underlying geological formations such as dykes refract groundwater upwards (Watson & Lemon, 1985). The upwelling waters can be either fresh or brackish.

1.5 HUMAN-MADE WATER POINTS: THE EXPANSION OF BOREHOLES

Boreholes and wells were established in the central, south-eastern and southern areas of Iona since the 1970's, making this entire zone accessible to livestock, although it is not suitable for cattle (Huntley, 2017, Ministério do Ambiente, 2016). They will require regular maintenance, unlike the older, hand driven waterpumps established on the east side of Iona (Figure 12).

Recently established boreholes and wells in the central, south-eastern and southern areas of Iona have made the entire sub-zone accessible to livestock, although it is not suitable for cattle (Ministério do Ambiente, 2016) Figure 12). The Namibian part of the Kaokoveld is characterised by a large number of boreholes that were drilled by the government in several waves over the last 70-odd years. Most of these were drilled from the 1950s into the 2000s and resulted in a dramatic expansion of available grazing area and subsequent growth in the livestock herds (see Sections 4 and 5 for a detailed discussion on the relationship between permanent water and grazing). The boreholes will also have benefited water-dependent wildlife species such as Hartmann's mountain zebra, but it is unclear to what extent this has led to changes in their population. Borehole yields are on the low side, except for some of those drilled in the semi-arid zone in the far eastern parts of the old Kaokoland.

The availability of data on borehole yields and quality have declined markedly over the last twenty years or so. It is therefore not possible to do more detailed analyses of the role that boreholes have played, relative to drought, in exacerbating land degradation processes. Before the modern era, surface water was only available seasonally and access to pastures followed this seasonal pattern. This variability is an important aspect that could determine the health of arid-zone ecosystems. Ecologically, when a critical resource such as water varies in time and space, stability in both livestock numbers and ecosystem integrity could emerge over larger spatio-temporal scales – this is in fact one of the key features of a non-equilibrium system. Clearly there can be no doubt that the stabilisation of water supply between seasons and over space must lead to the loss of integrity of the grazing resource base.



Figure 12. Waterpump north-east of Monte Negro, just outside Iona NP (Photo by Vera De Cauwer).

1.6 A SPECIAL KIND OF MOISTURE: FOG AND THE BIOTA OF THE HYPER-ARID ZONE

The Namib Desert borders the cold Benguela Current, one of the world’s major continental Eastern Boundary Upwelling Systems (EBUS). These regions – the California, Peru, Canary and Benguela systems – are influenced by the subtropical anticyclones, which produce alongshore upwelling-inducing winds (Chavez & Messie, 2009). Upwelling brings cool, nutrient-rich waters to the surface, driving productive marine and xeric terrestrial ecosystems. Three features that occur in all the EBUS – advected warmer air, cold water and a stable inversion layer – mean that stratus clouds and fog are prominent features in all.

Almost unique among these systems, the Namib is uniformly dry along its ~1,000 km north-south length (Lancaster et al., 1984). In the driest part of the Namib, fog precipitation exceeds rainfall and is therefore a more reliable source of water than rain for the desert biota (Pietruszka & Seely, 1985; Shanyengana et al., 2002). The Namib is furthermore home to three large ergs or sand seas, including the Kunene dune field in the Kaokoveld (Seely, 2012), that support a diverse fauna and flora dependent on fog as a moisture source (Henschel & Seely, 2008; Mitchell et al., 2020).

Fog in the Namib may be radiative or advected onto land (Olivier, 1992). The latter includes sea fog (low-level fog formed over the ocean), but principally refers to the marine stratus clouds that consistently form over the south-east Atlantic (Figure 13) and are driven onto land by winds associated with a coastal low-pressure system (Andersen et al., 2019). Fog occurs along almost the entire southern African coastline, from Cape Town to Bentiaba in Angola (Figure 14). The Namib’s land surface, unique among the four major EBUS, has an average elevation gradient of only 1%. This particularly sets it apart from the otherwise similar Atacama Desert of South America, where the steeply rising land intercepts stratus clouds at much higher altitudes. In the Namib, fog is formed when cloud layers occurring between 200 and 600 m a.m.s.l. below an inversion layer are advected onto land in the early mornings before sunrise until a few hours after sunrise (Figure 17; Andersen et al., 2019). The stratus clouds need to form at relatively low altitudes to reach the land surface; clouds forming under a higher temperature inversion thus often never reach ground level (17).

In the central Namib, where most fog measurements have been made, a distinct seasonal cycle is evident with two main fog “seasons”. During the winter (April to ~August), fog events increase near the coast (< 100 m altitude), while

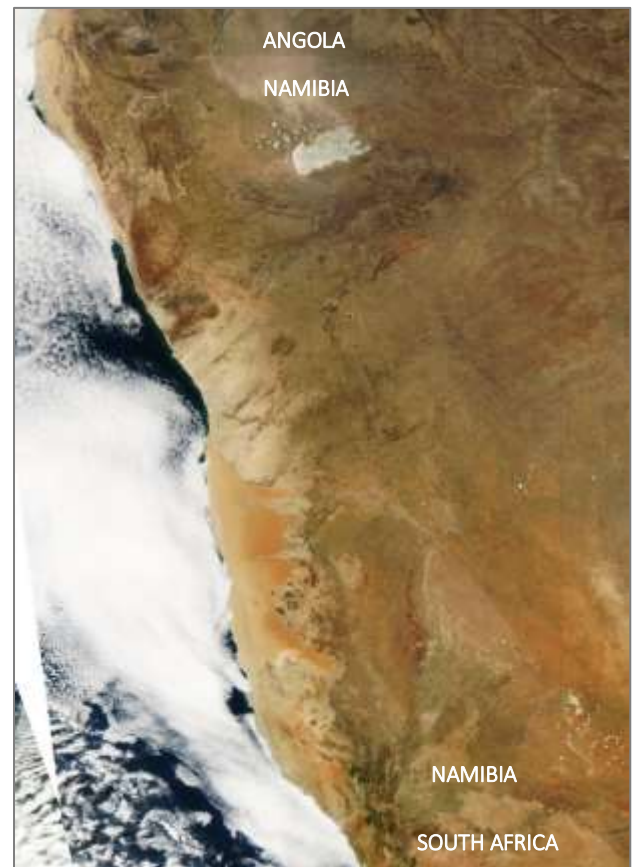


Figure 13. A satellite image of Namibia showing the presence of a stratocumulus cloud deck over the Atlantic Ocean, abutting onto the land surface. Where it hits land, it is experienced as fog.

the maximum frequencies are measured inland (> 300 m altitude) during the start and end of summer (~August to October, with a second peak in December and January) (Andersen et al., 2019).

The seasonal fog cycle is the result of a change in cloud base height, which furthermore affects the timing of fog occurrence at different distances from the coast. Coastal locations experience fog from about 15:00 but inland locations only much later (Figure 16). Fog appears at ~40 – 60 km from the coast at around 20h30 in the central Namib and at around 18h00 in the northern Namib-Kaokoveld. Fog usually lasts until an hour or two after sunrise, so the Kaokoveld will effectively experience a longer period of wetness with each fog event. However, this is partially offset by the relatively lower fog frequency over most of the study area, at least as this was measured using a fog and low-cloud detection algorithm on visible and infrared data by Andersen & Cermak (2018). The daily cycle of humidity that is induced by fog is well illustrated by the SCIONA data collected at the Serra Cafema Camp of Wilderness Safaris at the Kunene River, about 50 km from the coast (Figure 15)

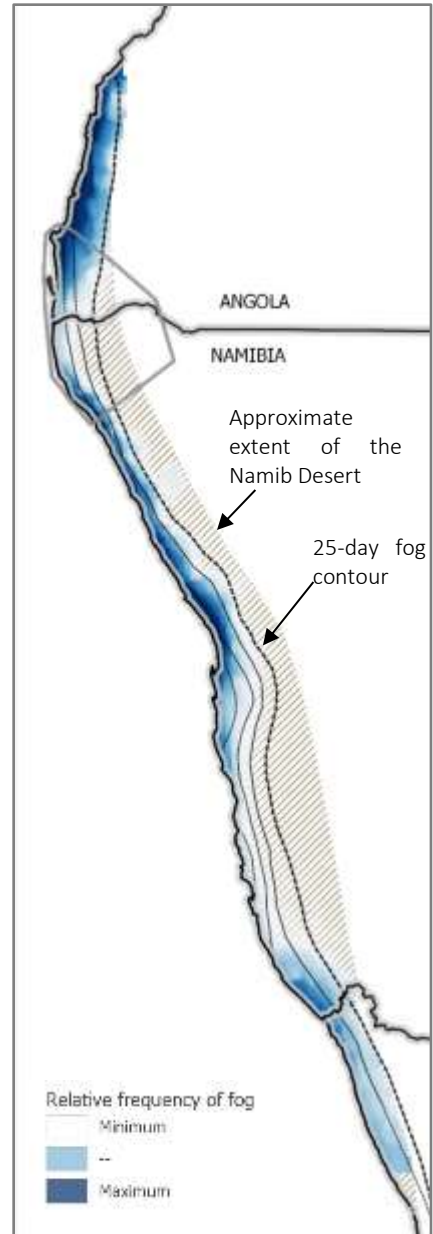


Figure 14. The pattern of fog along the SA-Namibia-Angolan coast, relative to the approximate extent of the Namib Desert (converted from data from Andersen & Cermak, 2018 and Mitchell et al., 2020). The 25-day fog contour is based on data from Mendelsohn et al. (2002).

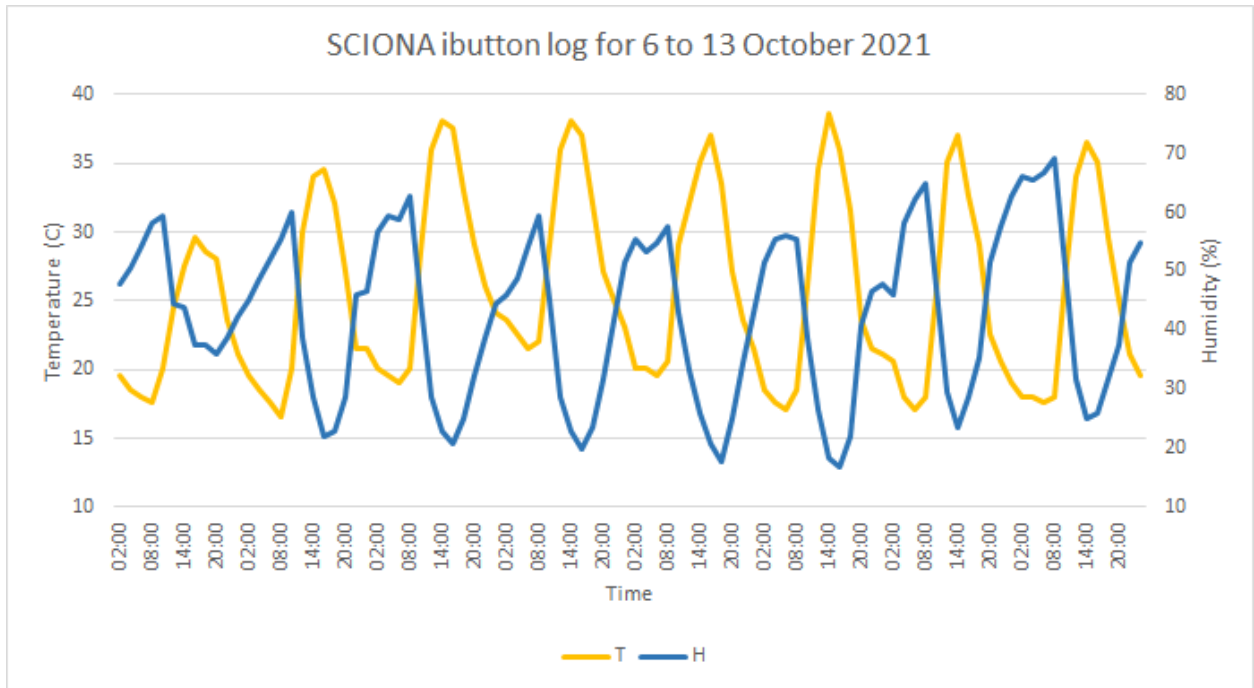


Figure 15. Typical daily cycles of temperature and relative humidity for October. Data were collected with a hygrochron (*i-Button*) at Serra Cafema.

Fog is most often encountered on the low-lying coastal plains, which is why the north-western corner of the study area experiences a relatively high frequency of fog (Figure 14). The timing of fog occurrence, and thus the total duration of ground-level wetness, plays a large role in the ecophysiology of several Namib species (Mitchell et al., 2020).

For organisms, it is not the absolute volume of moisture that is important, but the reliability of its supply. In the Namib, fog is a much more reliable source of moisture for Namib biota than rain (Pietruszka & Seely, 1985), which has in fact slightly increased in volume but decreased in frequency and become more variable in the central Namib over the last four decades (Eckardt et al., 2013; Mitchell et al., 2020). As a result, the Namib, which has a remarkably long arid history associated with the late Miocene development of the Benguela Upwelling System (Siesser, 1980; Ward and Corbett, 1990), hosts a number of endemic species that have adapted to fog as a primary source of moisture (Mitchell et al., 2020). Although these adaptations allow organisms to access all non-rainfall atmospheric water, including dew, fog is probably the largest (by far) component that is accessible to the biota (Mitchell et al., 2020).

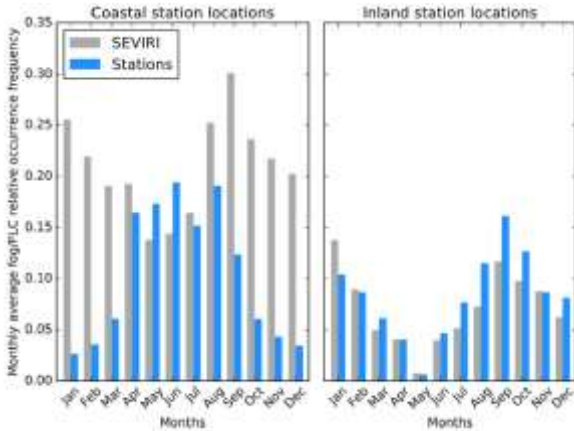


Figure 16. Monthly averaged relative fog frequencies at coastal and inland weather stations of the Gobabeb Fognet sensor array (Helmschrot et al., 2014). Graphs were reproduced from Andersen et al. (2019).

In a landmark review of all the fauna that utilise fog water either opportunistically or obligately, Mitchell et al. (2020) discuss the various adaptations of Namib biota, ranging from tiny insects to large mammals, to access and ingest fog water, and to overcome the physiological challenge of consuming low-osmolality fluid. Apart from opportunistic harvesting of free water in droplet form from any available surface by species with a range of body sizes, some highly specialised adaptations have been developed. The most widely known of these is perhaps the fog-basking behaviour by the beetle species *Onymacris unguicularis* (that made the cover of Nature; Hamilton & Seely, 1976), a species that also occurs in the Kunene erg, together with three or more *Lepidochora* beetle species that dig trenches and drink fog water from the trench ridges. Adaptations go well beyond behaviour, though. Species with a mass < ~100 mg struggle to overcome the surface tension on a droplet of water and may even drown stuck inside it. These smaller species, such as the zygomentan *Ctenolepisma terebrans* and the larvae of the tenebrionid beetles *Onymacris plana* and *O. marginipennis* may access fog water in its vapour phase through hygroscopic surfaces in a rectal “cryptonephridial” complex. Larger species tend to be more opportunistic in their use of fog water, but even species as large as the springbok (*Antidorcas marsupialis*) utilise fog water through metabolic and pre-formed water in their plant food, which in turn utilise fog water directly.

In addition to the fauna reviewed by Mitchell et al. (2020), several plant species are known to utilise fog water, sometimes exclusively so. A medium-size mound of the dune grass *Stipagrostis sabulicola* (Figure 17) has been shown to harvest up to 5 litres of water per fog event (Ebner et al., 2011), making it almost entirely independent of rain (it may require rain to germinate and establish a robust tussock). The forb *Trianthema hereroensis* goes one step further, absorbing fog water through its leaves (Seely et al., 1977), an adaptation that may be more common than generally thought as there is also some evidence that foliar uptake of water occurs in the tree species *Faidherbia albida* and *Euclea pseudebenus* (Wang et al., 2019), both of which are common in or near western ephemeral rivers, including those of the Kaokoveld. The pencil bush (*Arthroa leubnitziae*), a shrub that occurs only in the fog zone of the central Namib, takes up not only the fog water itself, but also the marine-origin nutrients in it (Gottlieb et al., 2019).

While Namib fog is important to sustain populations, it does not normally allow populations to grow; for this, we need rain. Rainfall is a key driver of population irruptions for several species across many taxa. Fog, on the other hand, is critical to bridge the very long inter-rain periods, not only for individuals to survive longer, but also for populations to remain relatively stable during long periods without rainfall (Seely et al., 2005). It probably plays an important factor in the existence of the fynbos vegetation encountered on the mountain top of Serra Cafema in Iona.



*Figure 17. The dune grass *Stipagrostis sabulicola* in its natural environment in the dunes of the central Namib erg in the fog zone.*

While most research on fog and its role in supporting a diverse and unique biota have been done in the central Namib, most of the adaptations are likely to also be found in the Namib of the Kaokoveld. The Namib appears to be unique amongst foggy deserts in hosting such a diverse array of species that have fully adapted to this water source. The critical dependence of so many of them on fog suggests that this system might be extremely sensitive to changes in wetness or frequency of fog.

2 DIVERSITY IN PLANTS, MICROBES AND ARTHROPODS

2.1 VEGETATION UNITS, ENDEMISM AND FUNCTIONAL IMPORTANCE IN PLANTS

2.1.1 Kaokoveld Centre of Endemism

The SCIONA study area is part of the Kaokoveld Centre of Endemism, one of the world's hotspots of biodiversity and species endemism and considered to be among the last terrestrial wildernesses (Craven 2002, Mittermeier *et al.*, 2003). The exact extent of this Centre of Endemism is not known, but in its broadest definition, it stretches from the Kuiseb River in west Central Namibia to Benguela in Angola from the Atlantic Ocean to the escarpment in the east (Craven 2009, Swanepoel pers. obs.). Elevation ranges from sea level to 2050 m at Serra Cafema and 2573 m in the southern Kaokoveld on the Brandberg. The mountain ranges stretching from southern Angola to northern Namibia form the Ovahimba highlands (Owen-Smith 2010).

The high biodiversity of the Kaokoveld Centre of Endemism can be explained by a rapid transition from the arid coast that is seasonally influenced by fog to a semi-arid and mountainous escarpment area with mountain tops rising to 2500 m. Part of this hotspot is to some extent protected by the Transfrontier Park, but most of the Namibian part is situated in communal conservancies, including the four target communities, but also others such as Otjitanda, Sanitatas, Purros and Etanga. Conservation in such biodiversity hotspots becomes of global importance considering the world's increasing species extinction and defaunation (loss of abundance) (Dirzo *et al.*, 2014; McCauley *et al.*, 2015; Young *et al.*, 2016).

Because of the size, remoteness and inaccessibility of the Kaokoveld, new species continue to be found over the last decennia. For example, four new plant species were described during the project (Swanepoel and De Cauwer 2019, Swanepoel *et al.* 2019, 2021a, 2021b) (Figure 18). The full extent of species richness and endemism of the Kaokoveld Centre of Endemism is not yet understood. There is especially very limited biodiversity information on Iona National Park. During the colonial era, research on the country's biodiversity was limited, while little field research could be done during the war years, which started with Angola's independence in 1975 up till 2002. From then on, biodiversity research increased but coverage of the remote regions of Angola, including Iona National Park, remains weak. Highlights were the biodiversity survey to the Tchamalindi mountains, organised by Brian Huntley in 2009 (Huntley *et al.* 2019) and a herpetological survey (Ceríaco *et al.* 2016).



Figure 18. *Osteospermum namibense*, a new species from the northern part of the Namib Desert described in Swanepoel *et al.*, 2021b (Photo by Vera De Cauwer).

The study area of the SCIONA project is smaller than the Kaokoveld Centre of Endemism, covering less than half of it¹. For example, the Otjihipa, Baynes and Zebraberg mountains, where many endemic species were described, are outside the study area.

2.1.2 Vegetation types, distribution and their importance for wildlife

All three floristic regions of Namibia are represented in the study area: the Karoo-Namib in the west, the Zambezi region in the east, and in between the Kalahari-Highveld transition zone (White 1983, Maggs et al. 1998). The vegetation in these floristic regions consists of (Table 1, Figure 19):

- **The Namib Desert:** a strip of 30 to 60 km wide stretching along the coastline of the study area and consisting of sand dunes and gravel plains with very sparse vegetation, mainly desert-adapted plants on hummocks and rocky outcrops. The rocky outcrops and inselbergs provide a habitat for plants that do not occur elsewhere and shelter for many animal species (MEFT, 2021). The hummocks provide micro-habitats to microbes and arthropods in the desert (more info in 2.2 and 2.3). Wildlife in the Namib Desert consists mainly of oryx and ostrich, and depending on rainfall, springbok,
- **Pro-Namib:** the transition zone from desert to shrubland, which includes gravel plains and open shrubland that can become grassland after good rains, as well as rocky outcrops with relatively more woody vegetation, succulents and animals. For most of the study area, the pro-Namib includes the escarpment with an abrupt increase in elevation. This zone is characterised by many endemic plants and a high plant and reptile bio-diversity,
- **Mopane shrubland:** the shrub vegetation in the higher rainfall zones of the east is dominated by mopane (*Colophospermum mopane*). In the north of Iona National Park, this includes the escarpment zone, situated further inland than in the south. Although this area is optimal for most fauna, there is hardly any wildlife because it is shared with people and their livestock. Especially large mammals are rare, while carnivores such as cheetah, leopard, and brown hyena are attracted to the livestock,
- **Riverine vegetation:** the relatively dense vegetation along the Kunene, the only perennial river, as well as the larger non-perennial rivers, such as the Curoca, Hoarusib, and the Khumib. This vegetation is also present where the larger rivers cross the Namib Desert and is essential for the survival of large mammals, including elephants, giraffe and carnivores, especially lion, cheetah, and leopard. In the Namibian part of the study area, they form movement corridors for large mammals such as elephant and giraffe (MEFT, 2021),
- **Afromontane vegetation:** the tree and shrub savanna on the highest mountaintops, especially those with elevation above 1500 m. It is characterised by a high plant and reptile biodiversity, as described by the report of the SCIONA mountain biodiversity survey. The vegetation provides refuge to some large mammals such as kudu, while Himba herders rely largely on its dry, often still perennial, grasses during winter (Malan and Owen-Smith 1974).

Table 1. Comparison of ecoregions and vegetation types of literature (Barbosa 1970, White 1983, Olson et al. 2001, Burke et al. 2002). Mean altitude is extracted from the Shuttle Radar Topography Mission (SRTM) (NASA JPL 2013)

| | Coastal area | | Highland |
|--|--------------|--|----------|
| | | | |
| | | | |
| | | | |

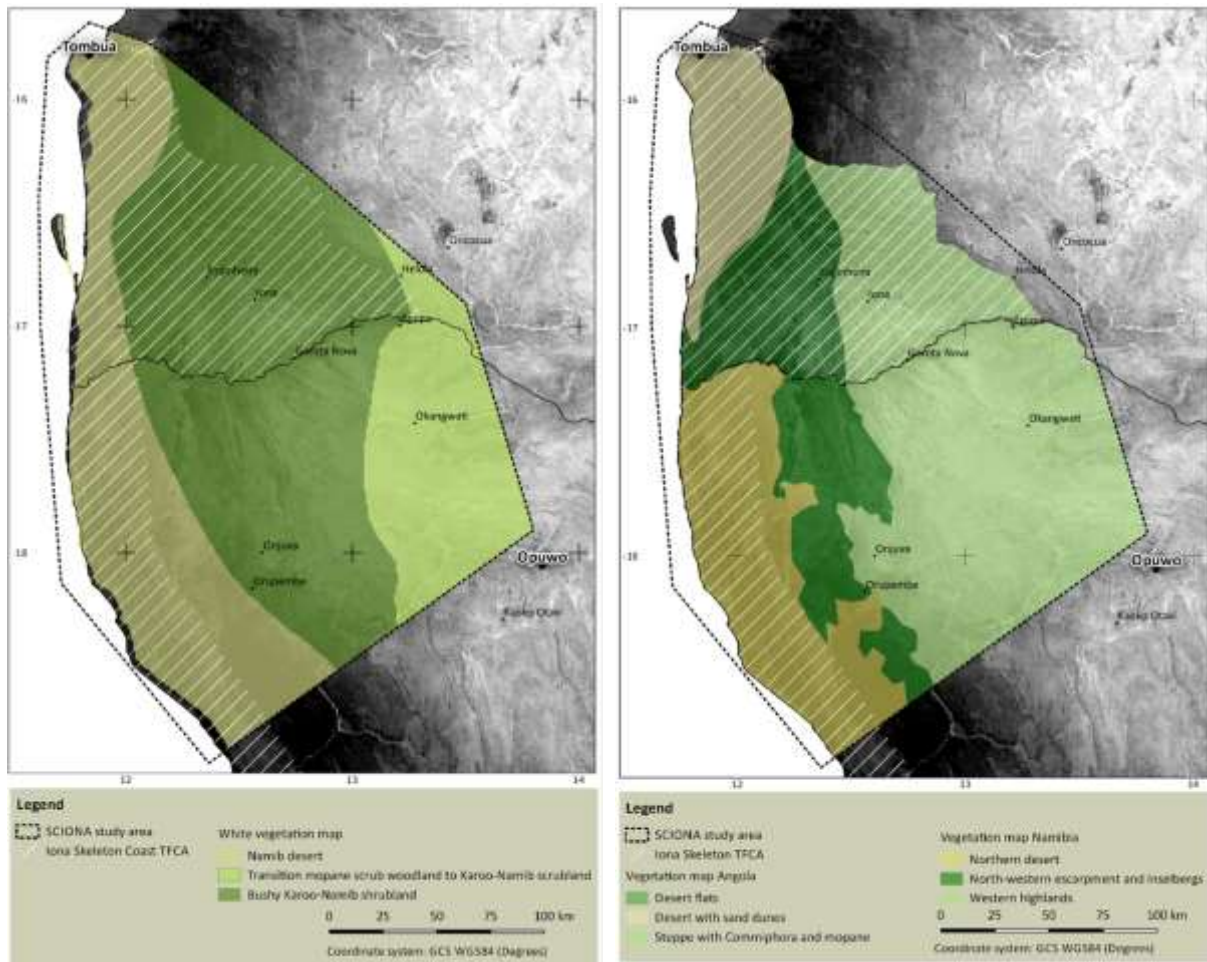


Figure 19. (a) Vegetation map of White (1983) (b) Vegetation maps of Namibia (Burke et al. 2002) and Angola (Barbosa 1970). Both maps have a MODIS Enhanced Vegetation Index for August averaged over 2000 – 2018 in the background (Map: V. De Cauwer).

No detailed vegetation or habitat map exists for the Transfrontier Park. Prof Norbert Jürgens of the University of Hamburg is working on a vegetation map for the desert zone of Iona National Park, while one of the Angolan SCIONA students is working on a description of the vegetation in the central zone of Iona National Park. Machine learning methods do allow the creation of a detailed habitat map of the Transfrontier Park. A Random Forest model with a resolution of 10 m was generated to illustrate this possibility (Figure 21). The model is based on satellite data of Sentinel and MODIS Land Surface Temperature in combination with other environmental data such as climate and topography and is trained with observations made during fieldwork and on Bing high-resolution images. The draft habitat map will be further finetuned as part of a research project.

2.1.3 Plant biodiversity and distribution

The Kaoveld is a recognized centre of plant diversity (WWF/IUCN, 1994). The flora of the Centre includes about 1600 species in nearly 550 genera in 130 families (Craven 2009). At least 20 new species have been described since.

During the SCIONA project, we assessed the distribution of all shrubs and trees – woody species - within the study area, which forms only a small part of the Kaokoveld Centre of Endemism. There are at least 234 indigenous woody species recorded in the SCIONA study area, of which 183 were observed during SCIONA field trips (Appendix 2). One of these species, described as part of the research done through the SCIONA project is *Syzygium kuneneense*, a small tree or shrub that grows among rocks on the floodplain and banks of the lower Kunene River (Figure 20) (Swanepoel et al. 2021a). Only 38 woody species were recorded in Skeleton Coast National Park (SCNP), while 161 species were recorded in Iona National Park. Of the four Namibian conservancies, Epupa showed the highest biodiversity in woody plants with 152 species, and Marienfluss the least with 60 species. The complete woody species list is added in Appendix 2.



Figure 20. Mature flowering tree of *Syzygium kuneneense* near the Kunene River, Namibia, a new species described during the SCIONA project (Photo by Wessel Swanepoel).

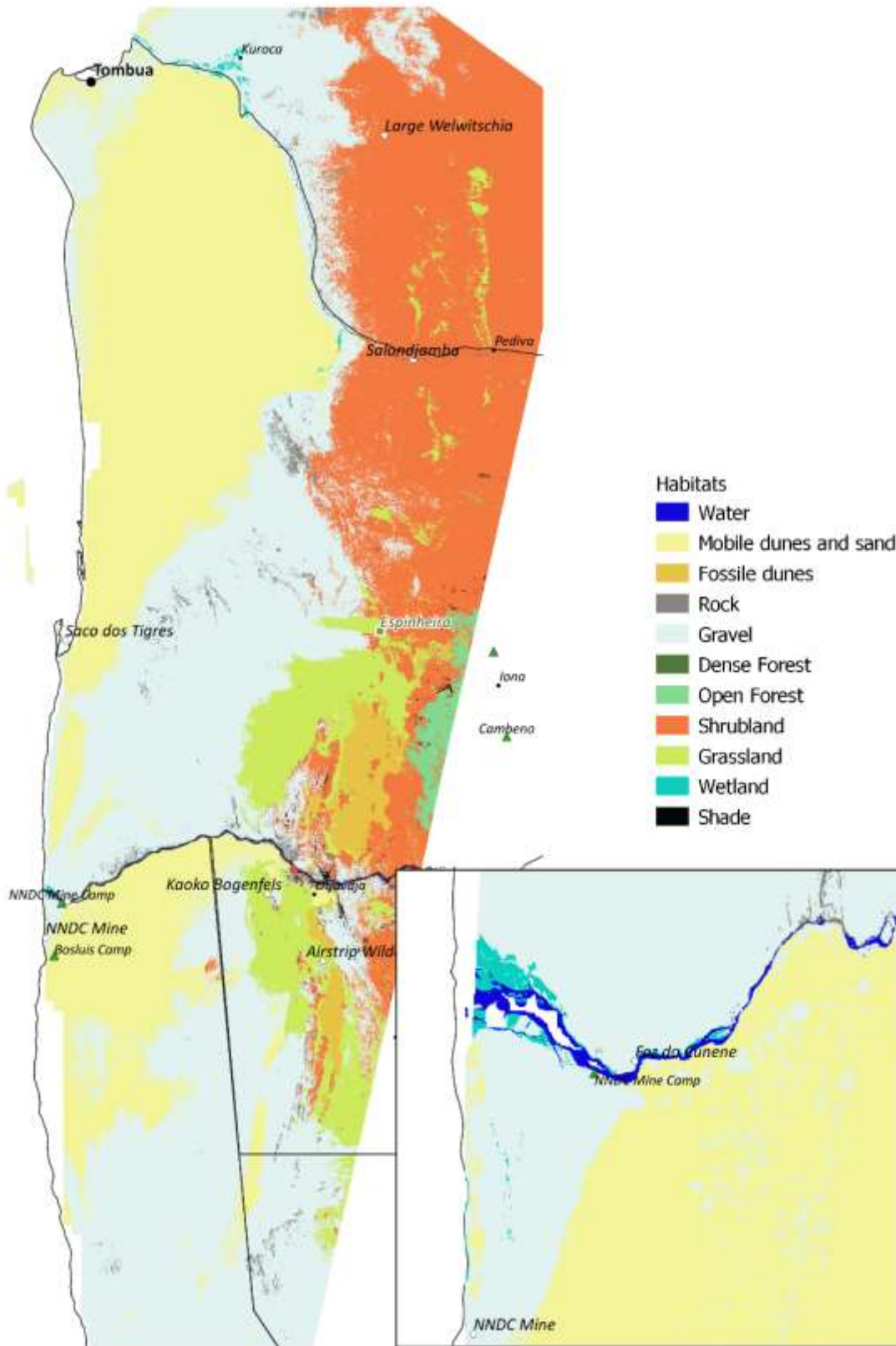


Figure 21. Draft habitat model for the western part of the study area. The inset shows the Kunene River mouth (Model: V. De Cauwer). Shade refers to the shade side of high mountains where there is no satellite reflectance.

Other vascular plants were recorded opportunistically during the project. This includes three new species that were described for SCNP. They are the succulent shrublets *Euphorbia rimireptans* (Figure 22), *Crassothonna agaatbergensis*, and *Osteospermum ambience* (Swanepoel and De Cauwer 2019, Swanepoel *et al.* 2019, 2021b).

The distribution ranges of many plant species are not known within the study area, especially not in the two national parks. For example, during a short SCIONA visit of three days to the Kunene mouth in 2020, 36 plant species were found that were not recorded in the Namibian national herbarium for that area (SCIONA: Kunene Mouth and Skeleton Coast National Park. Internal Field trip report 2020) (Figure 23). At least 15 new species were recorded for Angola during the project; they include amongst others *Senegalia montis-usti*, *Commiphora oblanceolata*, *Commiphora otjihipana*, *Commiphora schimperi*, *Dombeya kirkii*, *Erythrina decora*, *Euphorbia leistneri*, *Euphorbia monteiroi* subsp. *brandbergensis*, *Maerua kaokoensis*, *Portulacaria kaokoensis*, *Portulacaria kuneneana*, and *Sesamothamnus leistneri*.



Figure 22. Left: *Euphorbia rimireptans*, a newly described species (Photo by Vera De Cauwer). Right: *Euphorbia kaokoensis*, a rare Kaokoveld endemic (Photo by Alma Möller).



Figure 23. *Grangea maderaspatana* along the Kunene River near the mouth, the first record of this pantropical species in the Kaokoveld (Photo by Vera De Cauwer).

2.1.4 Plant Endemism

Of the list with more than 1000 vascular plants described by Craven (2002), only 24 were endemic to the area. Since then, many endemic species were described for the Kaokoveld Centre of Endemism (Swanepoel 2005, 2006a, 2006b, 2007, 2008, 2015, 2019, 2020, van Jaarsveld and Swanepoel 2007, Swanepoel and Kolberg 2011, Van Jaarsveld and Swanepoel 2012, Swanepoel *et al.* 2015, 2021b, Swanepoel and Van Jaarsveld 2019). The SCIONA project described another four endemic species (Swanepoel and De Cauwer 2019, Swanepoel *et al.* 2019, 2021a, 2021b).

Of the 234 indigenous woody species recorded in the SCIONA study area, 32 are endemic to the Kaokoveld. Most of these 32 endemics are found in both Angola and Namibia. A few are only found in Namibia (*Euphorbia otjingandu*, *Hymenodictyon kaokoensis*, *Petalidium kaokoense*, *Sesbania sesban*) and one only in Angola (*Euphorbia curocana*), but it may be only a matter of time and research budgets before they are found on the other side of the border.

Because many new species were recorded for Angola during the SCIONA project, several species previously recorded as Namibian endemics, became near-endemics. This includes amongst others *Senegalia montis-usti* and *Euphorbia leistneri* (Figure 24).



Figure 24. *Senegalia montis-usti* in Iona National Park, near Pediva. This is the first record of the species in Angola, which was previously recorded as a Namibian endemic, where it grows along the escarpment (Photo by Vera De Cauwer).

2.2 MICROBES: EVEN THE SOIL IS DIVERSE

The hyper-arid zone is an extreme environment. Soils have little organic matter, as primary productivity is limited, and vegetation cover is present primarily in isolated ‘hummocks’ where shifting sands accumulate around vascular plants. This system has a limited diversity of higher plants and animals (Scola et al., 2017), due to long periods of desiccation, strong winds, low nutrient status and high temperature fluxes (Pointing & Belnap, 2012). As a consequence of the limited macrofauna diversity in this extreme system, soil microbes have been recognized as key players in critical processes (such as nitrogen cycling, carbon cycling, soil formation, litter decomposition process etc.) needed to maintain ecosystem functioning and soil quality (Lüneberg et al., 2018; Maestre et al., 2015; Makhalanyane et al., 2015; Cowan et al., 2014; Stomeo et al., 2013; Fierer et al., 2012; Pointing & Belnap, 2012; Zak et al., 2003). The taxonomic diversity of soil microbial communities, surprisingly, is higher than initially assumed in desert soils, encompassing a number of key taxa. In this hyper-arid system, the bacterial community consists of over 35 phyla, among which Actinobacteria, Proteobacteria, Firmicutes, Bacteroidota, Chloroflexi, Planctomycetota, Myxococcota, Gemmatimonadota, Verrucomicrobiota and Acidobacteriota phyla are the most abundant. The fungal community is dominated by Ascomycota, Basidiomycota and a large number of unclassified phyla, due to the underrepresentation of environmental sequences in the UNITE database. Fungal taxonomic diversity has not been surveyed comprehensively in desert environments globally. A PhD study supported by SCIONA is one of the few studies to use next-generation high-throughput sequencing to assess fungal taxonomic diversity in the Namib Desert soils. In this hyper-arid system, soils from plant hummocks have higher α -diversity (species richness and evenness) of microbial communities in comparison to bare soils, with some bacterial families such as Pseudomonadaceae occurring exclusively in soils from the plant hummocks and not in the bare soils. This is corroborated by prior studies that show the intimate associations of Pseudomonadaceae with plants. Thus, this suggests that any changes in vegetation cover in this system may affect the soil microbial structure, which may then reduce microbial taxonomic diversity. Reduction in microbial taxonomic diversity may lead to reduced microbial functional capacity, which, in turn affects key ecosystem functions and resilience.

2.3 ARTHROPODS

Insects make up over 80% of the total biomass of land animals and are the most diverse and successful life forms on earth (Cranshaw & Redak, 2013). They are important components of terrestrial systems, contributing significantly to biodiversity and ecosystem structure and function (Picker et al., 2002), and occur at all levels of the food web (Seymour & Dean, 1999). In the hyper-arid Namib Sand Sea south of the SCIONA study area, they have been attributed an important role as plant decomposers in a detritus-based ecosystem. Main detritivores are beetles and termites, but also fungi (Jacobson et al., 2015).

Additionally, members of some insect groups live in the soil or use soil as a substrate for eggs and other inactive life stages (Higgins et al., 2014), helping soil formation by moving and mixing huge amounts of soil as they tunnel (Cranshaw & Redak, 2013). The diversity, richness and composition of insects and their associated functions vary within and between ecosystems (Holm & Edney, 1973), and may shift under changing environmental factors, such as temperature, precipitation as well and vegetation structure. This is particularly true for sensitive ecosystems such as the hyper-arid deserts.

Southern African insect diversity is poorly discussed in the literature with only specific references made to very discrete biomes or ecological niches. The Namibian Biodiversity Database (NBD) indicates that there

are 8064 insect species found in Namibia of which 121 are endemic (Irish, n.d.). No overview studies of the insect biodiversity exist for the Kaokoveld Centre of Endemism, Iona National Park, or the Skeleton Coast. There are very specialised focused studies on specific groups of insects but the holistic view of the insect assemblages in the area is unknown. During the SCIONA project, a study of the insect assemblages of the coastal dune hummock habitat (Figure 25) was started. Dune hummocks are small aeolian dunes formed by sand deposits in and around pioneer plants (Hesp, 1989). They form small fields, often associated with only one or two plant species. The main species around which hummocks are formed are nara (*Acanthosicyos horridus*), dollar bush (*Tetraena/Zygophyllum stapffii*), *Salsola* spp., Brakspekbos (*Tetraena/Zygophyllum simplex*), and pencil bush (*Arthroaerua leubnitziae*). The hummocks develop by a combination of the growth and development of the plant which forms the foundation of the hummock and the accumulation of sand around the plant which stimulates sand trapping ability and overall growth of the dune hummock (Elliott et al., 2000). This development is very slow and dune hummocks are therefore very sensitive to destruction by physical activities (Irish, 2013b). In terms of fauna, coastal dune hummocks are distinct from surrounding habitats and several species are restricted to only these habitats. Examples of these species include *Onymacris marginipennis*, a near-endemic beetle found from the central Namib as far north and Namibe in Angola (Penrith, 1975), and *Onychosis gracilipes*, a near endemic beetle found from Lüderitz to Tombua in Angola (Penrith, 1977). Despite being scattered over a long latitudinal range, coastal dune hummocks make up only a small portion of the total area of the Kaokoveld as their fields only stretch about 30 m inland. Hence, any endemic species found in the coastal dune hummocks can already be considered as threatened (Irish, 2013b, 2013a, no date).



Figure 25. Hummocks with *Salsola* spp. in Skeleton Coast National Park (Photo by Alex Derr).

From studies done by John Irish on the coastal dune hummocks of the central Namib as part of environmental impact assessments for various projects (Irish, 2013a; 2013b), he found that 94 known endemic insect species in the area can be classified as threatened according to IUCN guidelines. Fifty-seven of these species can be considered critically endangered, 30 species are endangered and 7 are vulnerable

(Irish, n.d.). There is a pressing need to conduct studies on the insect assemblages along the length of the coastal dune hummock system. A study was therefore initiated under the greater SCIONA project to determine the insect assemblages of hummocks along the Skeleton Coast. We expect high levels of endemism and several new species. Additionally, we will resolve north-south biogeographical patterns and determine the conservation status and level of threat that anthropogenic disturbances will bring, with the overall aim of informing conservation management and defining appropriate monitoring indicators.

3 WILDLIFE: ROAMING IN AN EVER-MORE CONSTRICTED SPACE

Corridors facilitate wildlife movement which are known to improve genetic diversity, enhancing resilience against global change (Heller and Zavaleta, 2009; Wilson and Provan, 2003). Where corridors have been established for specific species, the improvement in gene-flow and resilience has often been observed in entire communities and not only target species (Christie and Knowles, 2015). Mobility between isolated populations has the added advantage of realising viable population sizes in species of low overall number (Christie and Knowles, 2015; Cushman et al., 2013).

The SCIONA area shows extreme fluctuation in environmental and climatic conditions. Figure 27⁷ illustrates the variability in NDVI (normalised difference vegetation index, a remote sensing measure of plant productivity), which is here a surrogate for variability in available vegetation for herbivorous mammals, and consequently variation in predators of these species. In addition to the seasonal variation between the growing and non-growing seasons, Figure 26 illustrates good seasonal plant growth over 2016-18, followed by almost non-existent growth during the drought of 2019-21. The graph does not illustrate the spatial variability in conditions, which is even more volatile.

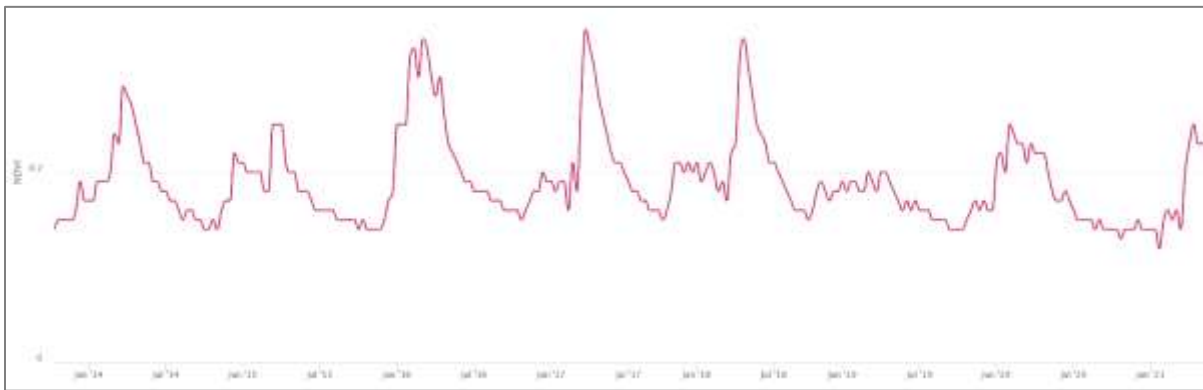


Figure 26. Variability in NDVI between March 2013 and May 2021 as adapted from Time series viewer, n.d.).

Although many of the wildlife species in SCIONA (Appendix 3) are uniquely adapted to survive the harsh and variable conditions, the primary response to rapid change is mobility (McNeely, 2003; Rumiano et al., 2020). Countering any potential anthropogenic fragmentation of landscapes and habitats is therefore critical to maintain ecological processes as well as wildlife movement areas (Galvin et al., 2008).

In preparation for the revision of the management plan for the Skeleton Coast Park, MEFT commissioned a study to identify wildlife movement corridors in the Kunene Region between the SCNP and surrounding areas (Figure 27). Data collected by the SCIONA project fed into the corridor assessment.

⁷ Time series viewer [WWW Document], n.d. URL <https://proba-v-mep.esa.int/applications/time-series-viewer/app/app.html> (accessed 4.1.21).

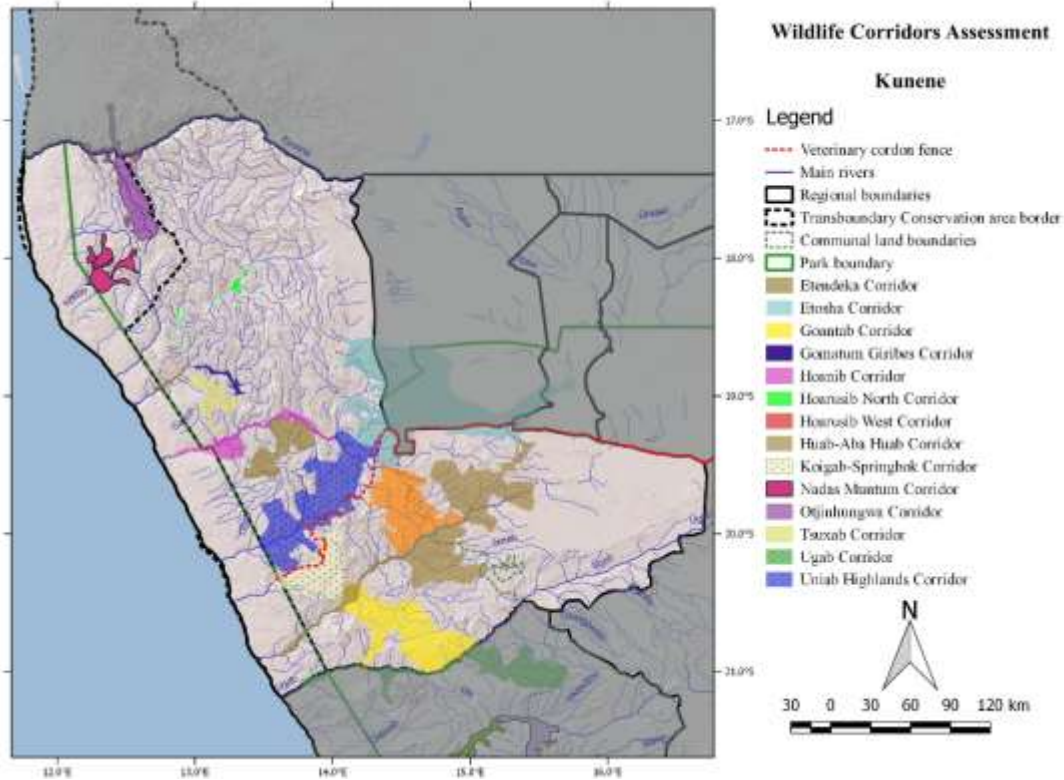


Figure 27. Proposed movement corridors in the Kunene Region for inclusion into the draft Skeleton Coast Park management plan (MEFT, 2021).

Within the SCIONA portion of the Kunene Region, MEFT (2021) proposed two wildlife movement corridors. The first is the transboundary Otjinhungwa corridor. Throughout the SCIONA project, the Marienfluss area received well-below average rainfall, resulting in low wildlife numbers. However, following effective rainfall, the Marienfluss is known to produce productive grazing, and attracts large herds of wildlife (Owen-Smith, 2011). Although this was not confirmed during the SCIONA project, it is probable that wildlife occasionally moves across the Kunene into the INP. Understanding this movement through telemetric studies of motile wildlife species (e.g. springbok and Hartmann’s zebra) is needed. Looking at the corridor assessment for Hartmann’s zebra (Figure 28a), gemsbok (Figure 28b) and springbok (Figure 28c) it is possible that recolonisation of plain habitats in southern Iona took place from populations traversing the Kunene.

The second proposed corridor is the Nadas-Muntum (MEFT, 2021). This corridor was observed after assessing the home ranges and movement patterns of giraffe from telemetric studies undertaken by SCIONA in collaboration with the Giraffe Conservation Fund (GCF), as well as conservancy game counts (Figure 29). Feeding resources for giraffe in the study area are extremely limited, and the forage along the riverbeds provide a lifeline to them and other wildlife (Hamutenya, 2021).

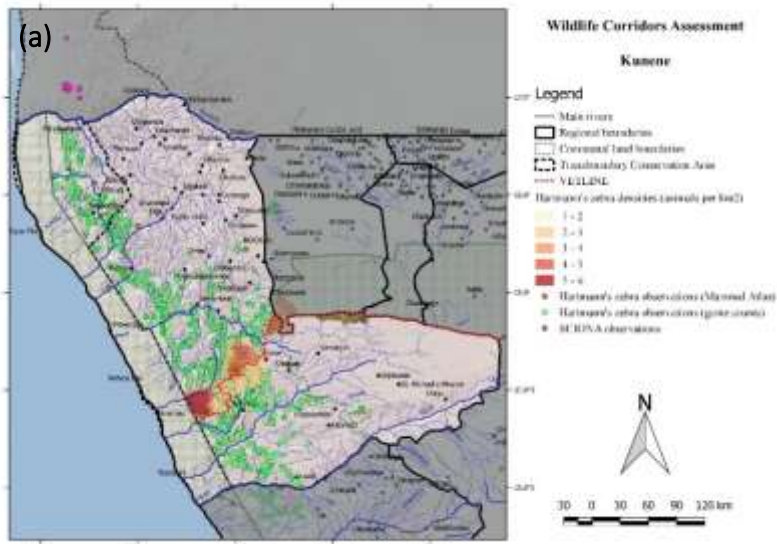
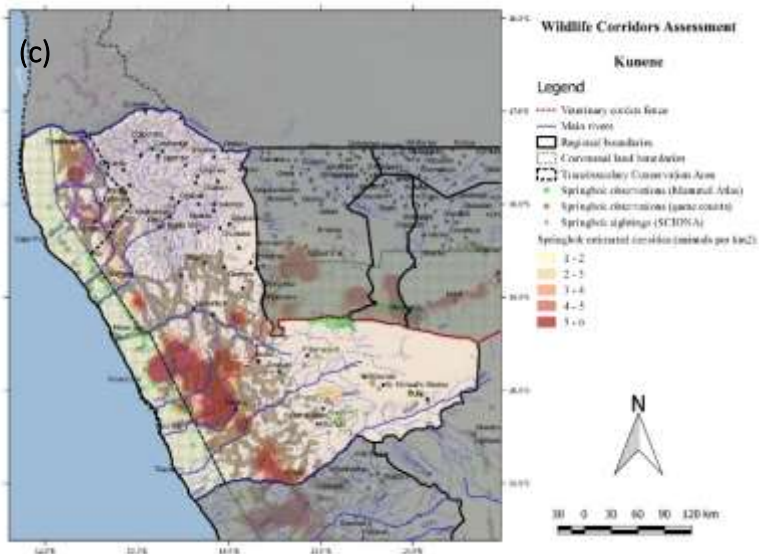
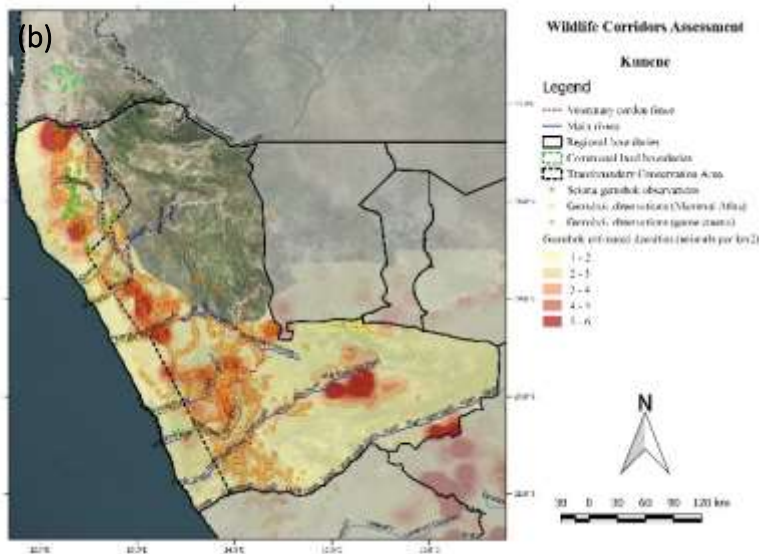


Figure 28. An assessment of potential corridor routes for Hartmann's zebra (a), gemsbok (b), and springbok (c).



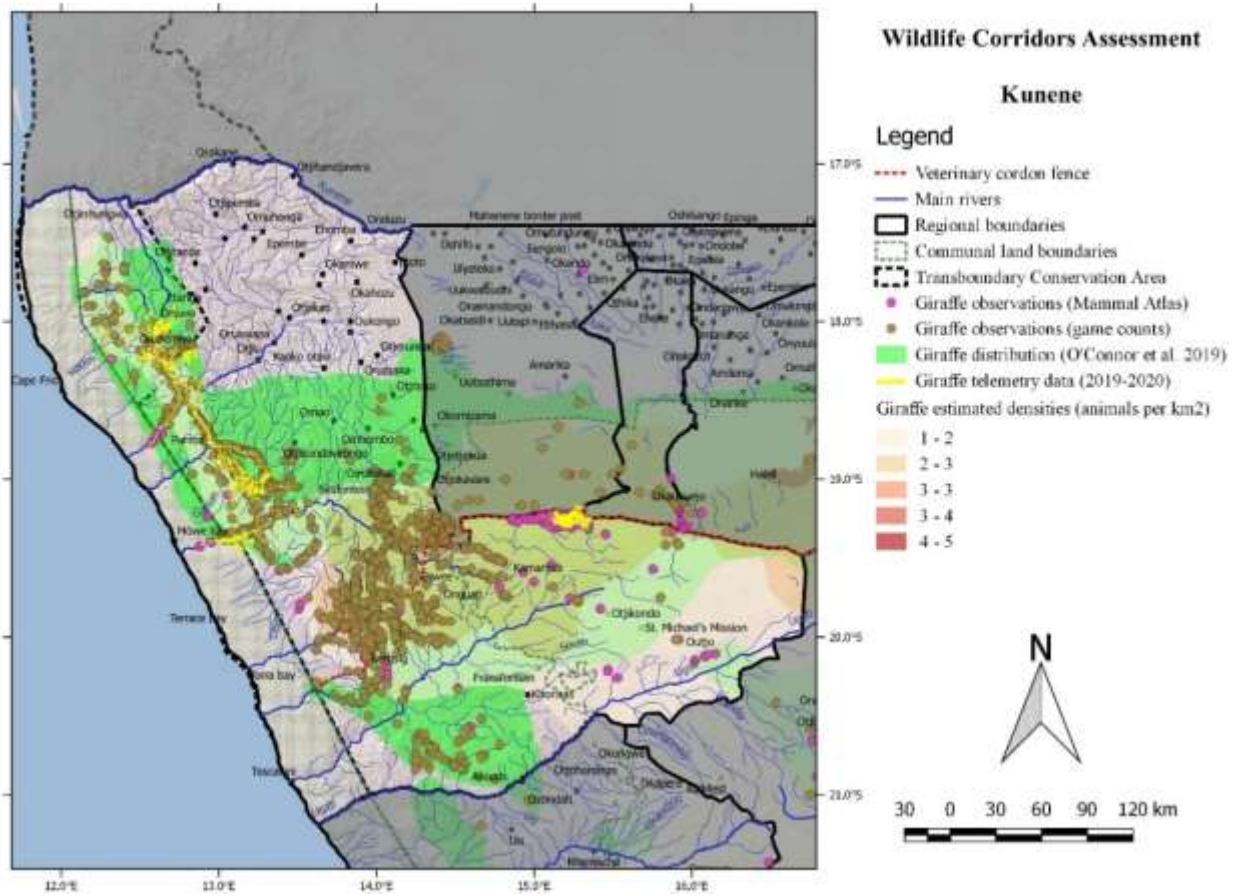


Figure 29. Giraffe sightings and telemetry data for the Skeleton Coast Park and adjacent landscapes in Namibia's Kunene Region (MEFT 2021).

4 HUMANS: TRANSHUMANCE AND NOMADIC PASTORALISM IN THE KAOKOVELD

Nomadic pastoralism developed in response to the high variability in resource availability encountered in drylands. As such, mobility is a core feature that sets it apart (Vetter, 2005 and references therein). Theoretically, the free-ranging opportunistic use of periodically abundant grazing, and consequent implicitly defined rest periods for large parts of the range is an energetically conservative and sustainable system, with minimal long-term impacts on vegetation composition and productivity except in piospheres around permanent water (see e.g., Ward et al., 1998; Sullivan 1999). When mobility is not curtailed, and in the absence of too many outside influences, it is also quite successful at ensuring long-term access to natural resources while contributing to sustainable development goals (Zinnstag et al., 2016) and the regulation of ecosystem services (Seid et al., 2016).

But nomadic pastoralism evolved well beyond a subsistence economy into a culturally defined dynamic lifestyle (Weber & Horst, 2011), that has had varying degrees of success in adapting to its larger geopolitical context over the last few decades (Pratt et al. 1997). Although pastoralism has the tools to respond to a range of drivers (e.g., switches between pure pastoralism and agropastoralism as the economics and environment demands are common – Mace et al., 1993), its dependence on livestock defines certain hard limits, such as available land and labour, within which survival is possible.

Mobility is a key feature (Weber & Horst, 2011). For various reasons, including a general trend of increasing sedentarization, reduction in available rangeland, increased population density, climatic disasters such as multi-year droughts, and political constraints, the mobility of nomadic pastoralists around the world have declined markedly (Niamir-Fuller, 1999). These changes represent major threats to the nomadic pastoralist lifestyle but also, more importantly from our perspective, to the integrity and resilience of the natural resource base on which it depends so intimately (Weber & Horst, 2011).

This is particularly relevant in Namibia and Angola, where a mix of transhumance and nomadic pastoralism is the main lifestyle of the ovaHimba (and related groups) of the arid Kaokoveld (Bollig, 2006). The ubiquity of pastoralists and their herds across most of the arid zone of our study area in Namibia, and the growing presence of people in the Iona National Park in Angola means that human resource consumption is the dominant driver of the ecosystem in our study area in terms of structure, composition and function. It is thus surprising to learn that the Kaokoveld pastoralism in its modern guise is relatively new and largely the result of governmental and other influences since the 1950s.

4.1 HISTORY OF NOMADISM IN THE KAOKOVELD

From the beginning of the colonial era, one of the most important direct tactics of government to control native populations was to restrict movement and trade. During the German colonial era and subsequently, under South African control, the mobility of pastoralists and their trading with neighbours to the north and east was curtailed by several iterations of policies that aimed to isolate and exert political control over the Himba (Bollig, 2013). These original policies severely impacted the ability of the ovaHimba to respond to environmental disruptions and probably posed a larger risk to survival than seasonal or annual resource scarcity. In general, it served to exacerbate the effects of severe droughts, with a number of catastrophic

famines that could have been avoided had the ovaHimba been free to move and trade (Bollig, 1997; 2000; 2013).

A second and longer lasting change came soon after the ascendancy of Apartheid in South Africa in 1948. In the 1950s, official policy shifted focus to “modernisation” of agriculture in the so-called “Native Reserves” in order to improve food output. The Odendaal Commission of 1963 aimed to give semi-independence to the Kaokoland and recommended the drilling of boreholes as the key to a modernisation of agriculture and economic development here, to open up “under-exploited pastures” in the vast arid savannas of the Kaokoveld (Bollig, 2013). From a handful of waterholes created through blasting in the 1930s, the numbers of boreholes and the area covered then increased rapidly: 136 holes were drilled in the 1960s, 128 in the 1970s, 57 in the 1980s and 40 in the 1990s (Bollig, 2013). Drilling activity post 2000 is not well-documented, but the programme has continued until relatively recently (albeit at a slower rate) (D. Sarma, personal communication). Even a recent project which aimed to improve rangeland integrity and restore aspects of traditional pastoral management drilled more holes (IPA, 2020). Perhaps the most important feature of the post-1960 drilling programme was that the majority of the holes were drilled in the arid zone, where the aridity index ranges between 0.03 and 0.2 (Figure 14; see also Section 1.1 for a description of the aridity index) indicating a large water deficit and thus an ecosystem that is vulnerable to disturbance over the long term.

Unsurprisingly, people followed the newly available surface water, establishing permanent residence over large areas below the escarpment (Bollig, 2013). Coming on the back of a decade of above-average rainfall in the 1950s (Bollig, 2006), the expansion of water sources in the period after 1960 also saw the largest increase in cattle numbers, from about 65,000 in 1960 to a high of 218,000⁸ in 2006 (Figure 30). The impact of such dramatic growth in the availability of surface water for livestock was profound, with one of its most pervasive effects being a fundamental change in rangeland management rules. To understand this change, and its ecological effects, it is necessary to understand how the ovaHimba manage their common pool resource of grazing⁹ and how this has changed over the last century.

Two different periods of pasture management can be defined: pre- and post-1950. Before 1950, the Kaokoveld population was small and many people still employed a mixture of hunter-gatherer and pastoralist lifestyles, only establishing a pastoral mode of production by the 1920s (Bollig, 2013). Human presence was probably limited mostly to the semi-arid zone above the escarpment, with very little use of grazing resources on the lower-lying plains (Owen-Smith, 1972). The pre-1950 system of land tenure and grazing rotation was entirely driven by the seasonal occurrence of water in rangelands away from permanent water sources.

Bollig (2013) reports on the system used by people in the Epupa - Omuramba area (Figure 31). The key feature was a movement of mobile livestock camps to distant pastures during the rainy season, when

⁸ This period of sustained growth was interrupted by a devastating drought that started around 1977, and reached its zenith in 1982, when about 90% of the herd died (Figure 29).

⁹ In contrast to the popular perception of the “tragedy of the commons”, in most cases common pool resources are managed in a sustainable way through a set of rules that all members of the community ascribe to (Behnke, 1998; Bollig & Schulte, 1999, Bollig & Gewald, 2000; Harring, 2001). The incentives for following rules are complex and involve an array of cultural and economic constructs such as the location of a home base with graves of ancestors, the cattle patronage system and the dual system of inheritance.

seasonal water sources such as pans and pools in ephemeral drainages offered enough water. In these distant areas, cattle were grazed in orbits around the seasonal water until pools and other rain-dependent water sources became dry and the mobile cattle camps had to retreat to settlements near permanent water along rivers and at permanent wells. In many ways this transhumant system perfectly mimicked the way in which large wild herbivores would move seasonally across a catenary drainage gradient (Du Toit, 2003).

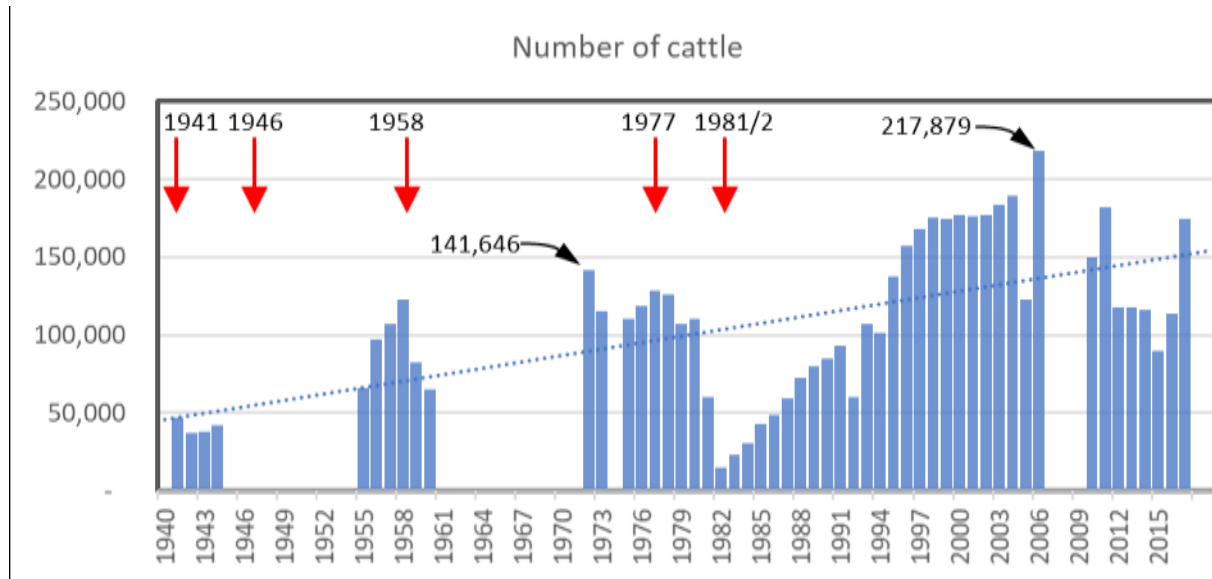


Figure 30. Cattle numbers in the Kaokoveld between 1940 and 2017. Data were sourced from the Directorate of Veterinary Services internal files and Bollig (2013), who consulted earlier publications for the period before 1970.

The trend line shows an average increase of about 1,380 animals per year over the whole period. Note that the data after 2006 may contain errors. Red arrows indicate approximate dates of droughts that were intensive enough to make it into the oral tradition (Bollig, 2006). Two recorded droughts, one in 1915 and one in 1929/30, preceded the period covered by the graph but no records of cattle numbers or losses exist (Bollig, 2006).

Important features of this period were that 1) the group of users and managers of specific pasture resources was clearly defined and numerically small, 2) households held tenure rights in specific places that had permanent water and, 3) perhaps the most crucial feature from an ecological perspective, the absence of permanent water over most of the area significantly reduced mobility and meant that large tracts of land were not used at all or used very seldom.

Bollig (2013) quotes local informants who claimed that rules of resource protection as such were not necessary as people were few, with fewer livestock than today. Additionally, ephemeral water sources in the rainy-season grazing areas had usually dried up a few months after the rains, bringing a rapid end to the exploitation of these pastures and a naturally enforced an annual period of ecological rest. This intensive grazing of outlying pastures for only three to four months during the growing period favoured perennial grasses (Bollig, 2013), which could easily recover lost biomass during the resting period when soil moisture would still have been adequate for growth.

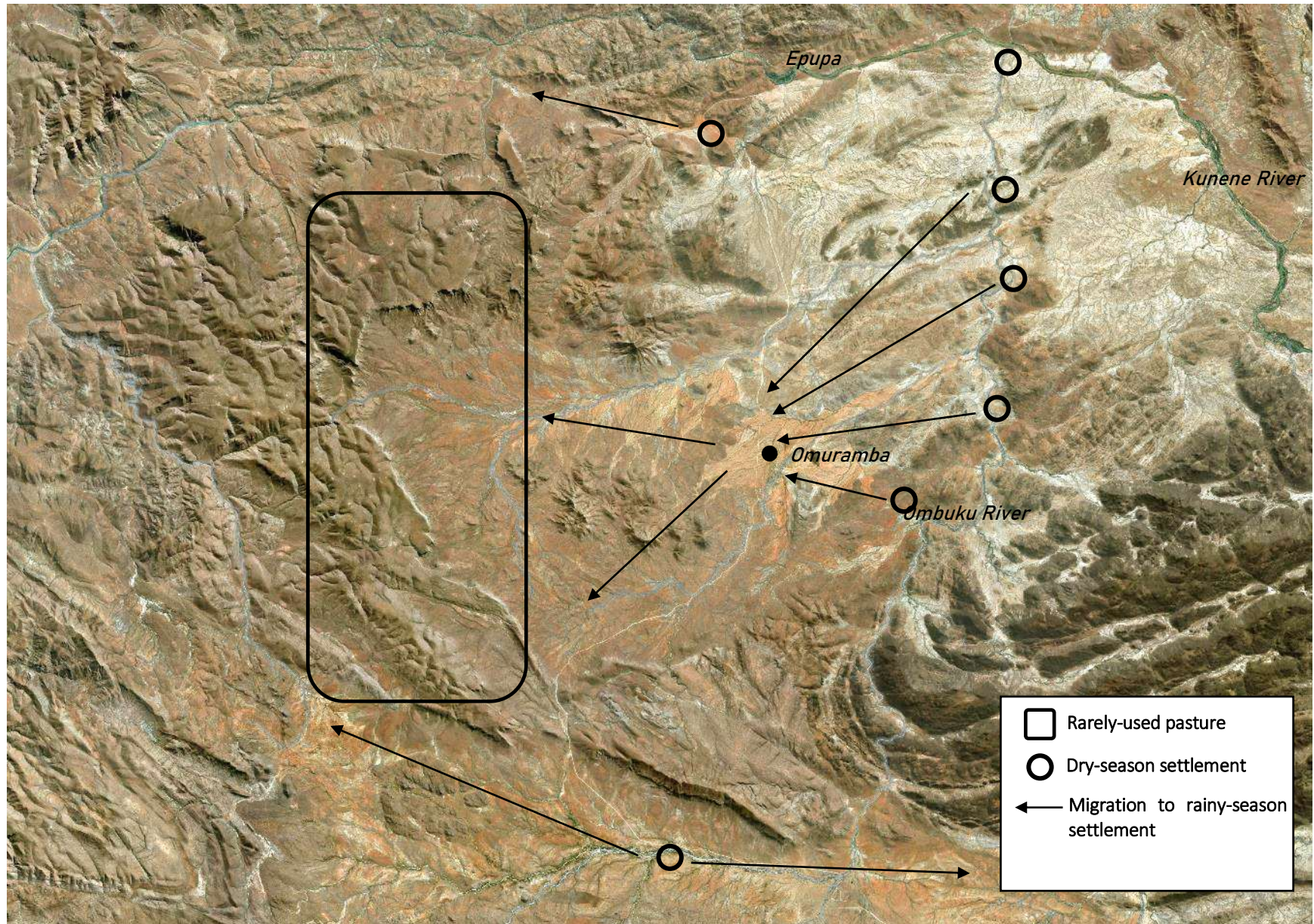


Figure 31. Map of pastoral tenure and mobility in wider Omuramba-Epupa before 1960. Redrawn from Bollig (2013). During the rainy season, households from Ombuku River migrated to Omuramba with their large cattle herds and then further west where they grazed the cattle until the water sources in these areas had dried up. They then returned to the Ombuku River, where water could easily be found in the river's sandy deposits. Large parts of the western rangelands were very seldom grazed.

The post-1950s drilling programme caused a comprehensive change to this tenure and management system. The boreholes which were located in former dry-season grazing areas and a network of roads connecting them led to a reversal in mobility patterns (Bollig, 2013). In the Epupa – Omuramba – Omuhonga region, Bollig (2013) recorded the development of water resources at several localities in what used to be rainy-season pastures, as well as along the Omuhonga and Ombuku rivers (Figure 32) and a consequent change in the grazing rotation system. What had once been seldom-used wet-season pastures now became dry-season range, grazed continuously for long periods. Main settlement areas changed: Omuramba, an ephemeral drainage with a strong borehole, replaced Ombuku, a place with permanent water at a perennial river where people retreated only during the height of the dry season. Importantly, the 1960s and 1970s also saw a dramatic increase in cattle numbers, reaching and staying over 100,000 head for a decade or longer. Whereas before, in the 1950s, with cattle not exceeding 50,000 head, large areas remained unused and ecologically intact, the huge regional herd now needed all available grazing. By the 1970s, Malan and Owen-Smith (1974) report that much of the Namibian Kaokoveld is severely overgrazed, with the result that perennial grasses are scarce and only present far away from permanent water and large areas are bare during most of the year.

By the 1990s, Bollig and others (Behnke, 1998; Bollig, 1997; Bollig & Schulte, 1999) described what they considered to be the traditional grazing system of the ovaHimba, which now included a set of usage rules designed to protect the grazing resource in the face of a much higher density of cattle and small livestock. The system is too complex to describe here (see Bollig, 1997, 2006 and 2013, and Bollig & Schulte, 1999 for a comprehensive description), but the rules, apart from reversing the mobility pattern, also led to a change in vegetation. Because outlying pastures could not be grazed during the rainy season, annual grasses were not disturbed during their main growing period. The rules of ‘good grazing’ also protected annual grasses on dry-season pastures until they had seeded, thus ensuring their reproduction. In contrast, perennial grasses were intensively grazed during a period of low soil moisture which severely impacted their ability to recover before the next rainy season. It explains why all pastures rapidly switched from being dominated by perennial grasses to dominance by annuals. Animal production thus became inextricably tied to a grass type whose production was much more sensitive to drought than that of perennials, which could rely on belowground reserves during low rainfall years (Bollig, 2013).

The loss of perennial grasses leads to a decrease in system resilience, and thus represent an environmental risk that must be managed through careful application of complex grazing rules. To this can now be added an additional and underappreciated risk. Whereas before the crucial property of pastoralism here – mobility – was a key and successful risk minimisation strategy during even severe droughts, more animals and more households with more complex tenure rights meant drastically fewer options to find drought relief grazing (Bollig, 2013). These two risks had thus effectively stressed the whole grazing ecosystem to a point where degradation was almost inevitable. Unsurprisingly, Bollig found widespread disobedience to the rules and breakdown in the system of reciprocity upon his return to the Epupa-Omuramba community in the early 2000s (Bollig, 2013). What had been perceived in the 1990s to be a traditional and stable pasture management and land tenure system turned out to have only existed for a few decades. It represented a transient period of stability in a larger sequence of social-ecological change that appear to be as much about upheavals and change as continuity.

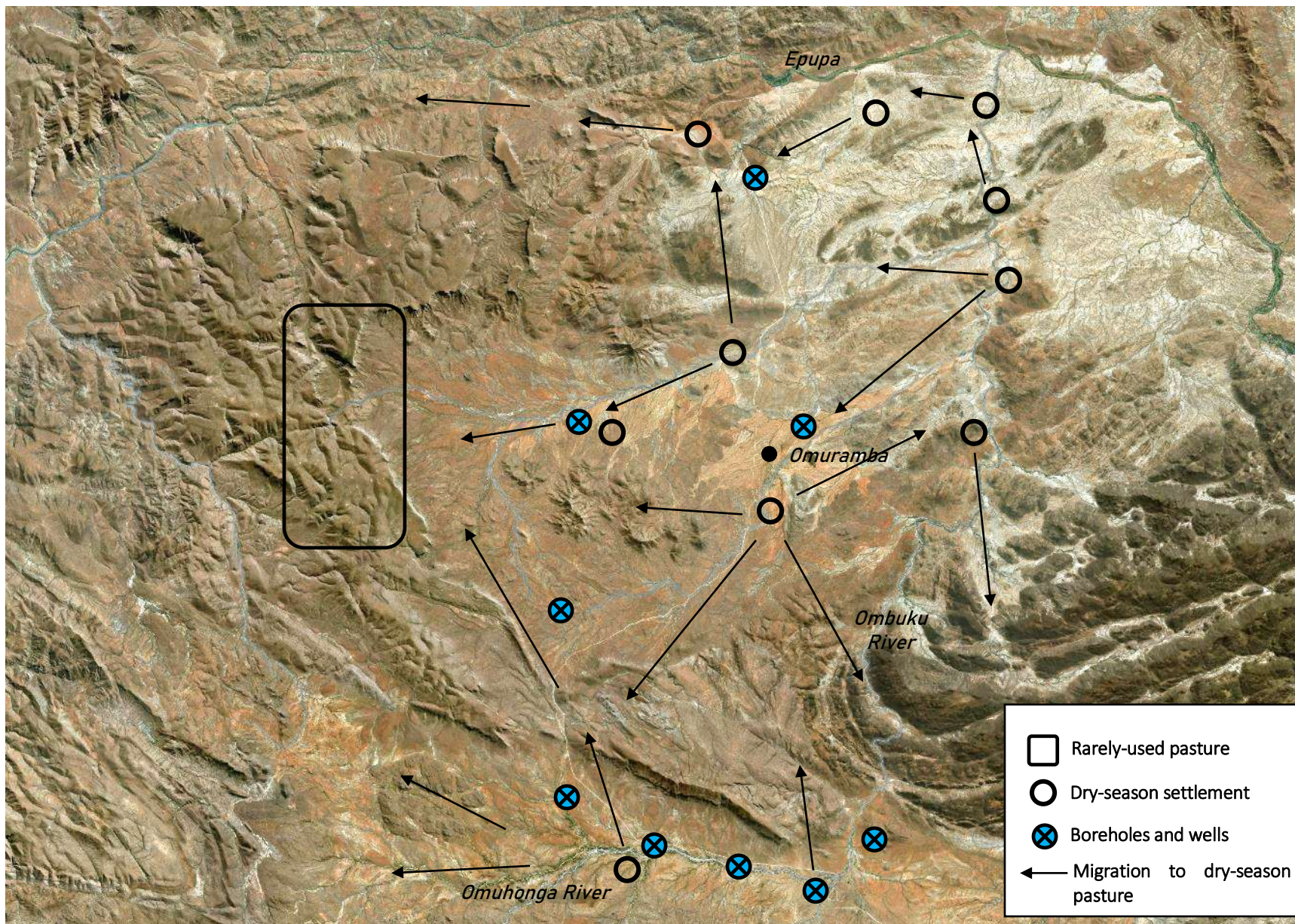


Figure 32. Map of pastoral tenure and mobility in wider Omuramba-Epupa in the 1990s. Redrawn from Bollig (2013).

This situation has not improved in the intervening period. There are no recent data-based regional-scale assessments of the state of land degradation, and functioning, or of livestock distribution and numbers. A recent and ongoing drought has contributed to a large-scale loss of vegetation cover, bedevilling any attempt at unravelling the proximate and distal causes of degradation. Yet the fact of degradation is evident to the eye for anyone who cares to look and represent the dominant resource management problem to solve for the study area and wider region. We discuss this topic further in Section 4 below.

4.2 SPATIAL PATTERNS OF NOMADISM IN THE KAOKOVELD

The nomadic groups in the study area use the areas where livestock fodder is available and do not venture into the desert zones, unless close to the Kunene and Curoca rivers. In Iona, the most western kraals and signs of human settlements, excluding those along the Kunene and Curoca, occur from a longitude of 12.19° and east wards (Figure 33), similar to settlement on the Namibian side of the Kunene. Table 2 shows how they occur right up to the edge of the hyper-arid zone, where rainfall is on average 100 mm per year.

Table 2. Environmental data of the zone with the most western kraals and huts in Iona National Park, a strip of about 35 km wide (12.19° - 12.5° longitude; Figure 33). The MAP is mean annual rainfall derived from WorldClim 2 (Fick & Hijmans, 2017) and the Aridity Index from the CGIAR-CSI Global-Aridity database (Zomer et al., 2008; Trabucco & Zomer, 2018).

| Variable n (number) | Huts/houses 101 | Kraals 661 |
|--------------------------------|----------------------------|-----------------------|
| Aridity Index | | |
| Min | 0.03 | 0.03 |
| Mean | 0.04 | 0.05 |
| Max | 0.09 | 0.11 |
| Altitude (m) | | |
| Min | 168 | 166 |
| Mean | 333 | 443 |
| Max | 1055 | 1200 |
| MAP (mm) | | |
| Min | 63 | 63 |
| Mean | 95 | 110 |
| Max | 188 | 221 |

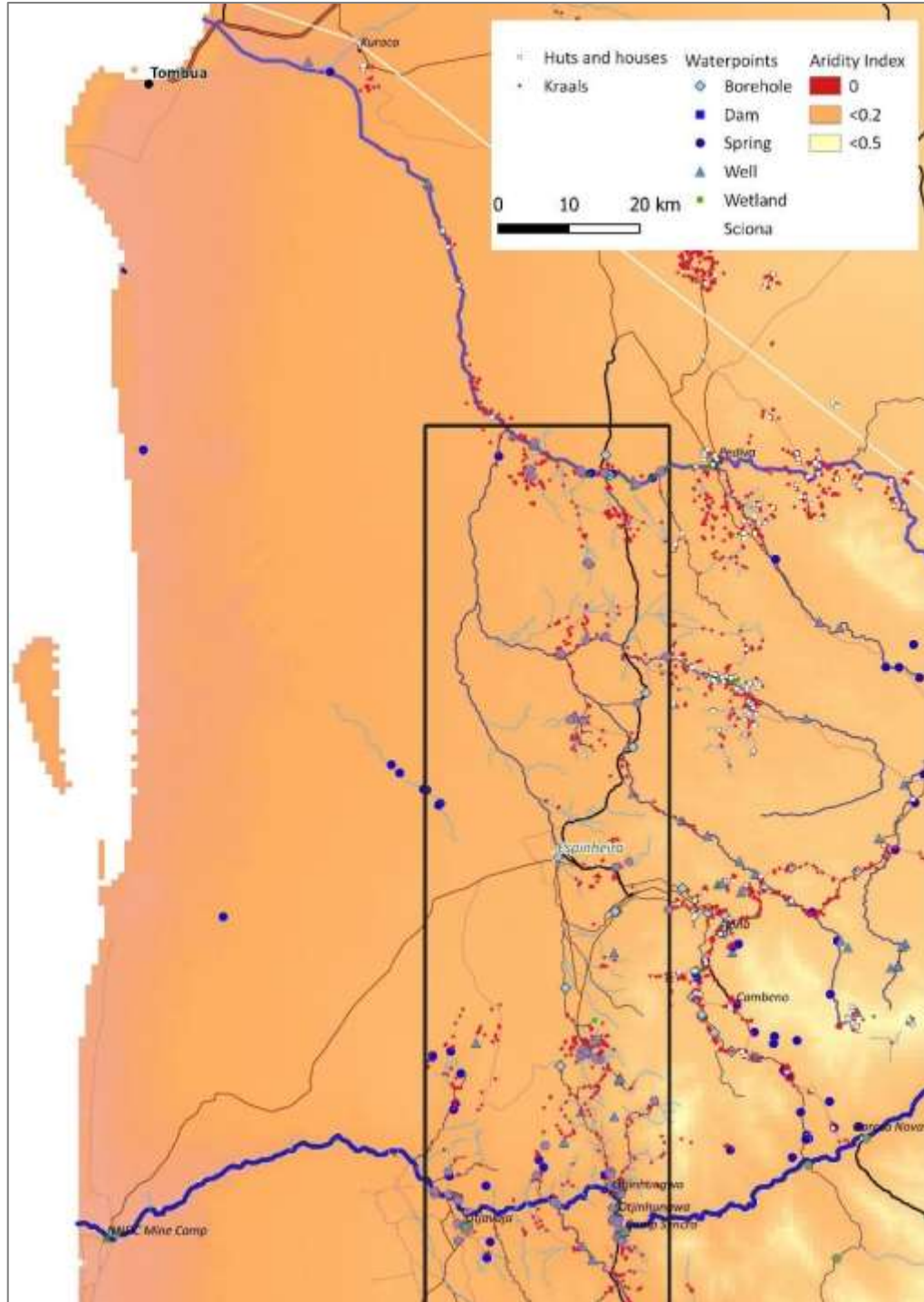


Figure 33. Herder and settlement patterns in the driest area of Iona National Park. The frame indicates the area with the most western huts and kraals (12.19° to 12.5° longitude). (Map: V.De Cauwer)

5 THE MARINE ENVIRONMENT

The SCIONA project focused on the terrestrial ecosystem of the Skeleton Coast – Iona Transfrontier Park. The marine zone adjacent to the park is not considered part of the Park. Hence, this chapter will only introduce the marine ecosystem and focus on the interaction between marine and terrestrial ecosystems. The BCC commissioned a coastal biodiversity survey of Skeleton Coast. The results of the survey are reported in Kreiner et al. (2019).

5.1 EBSA's

Currently, the Benguela Current Commission is driving a regionally integrated marine spatial plan, that will include several transboundary Ecologically and Biologically Significant Marine Areas (EBSA's), which falls under provisions of the Convention on Biological Diversity. An EBSA is not a protected area but is subject to comprehensive monitoring and restrictions on resource extraction (MEFT, 2021). An Angolan-Namibian task team is working on recommendations for the management of the Namibe EBSA, which will include the coastline of Iona and the northern coastline of Skeleton Coast National Park (Figure 34).

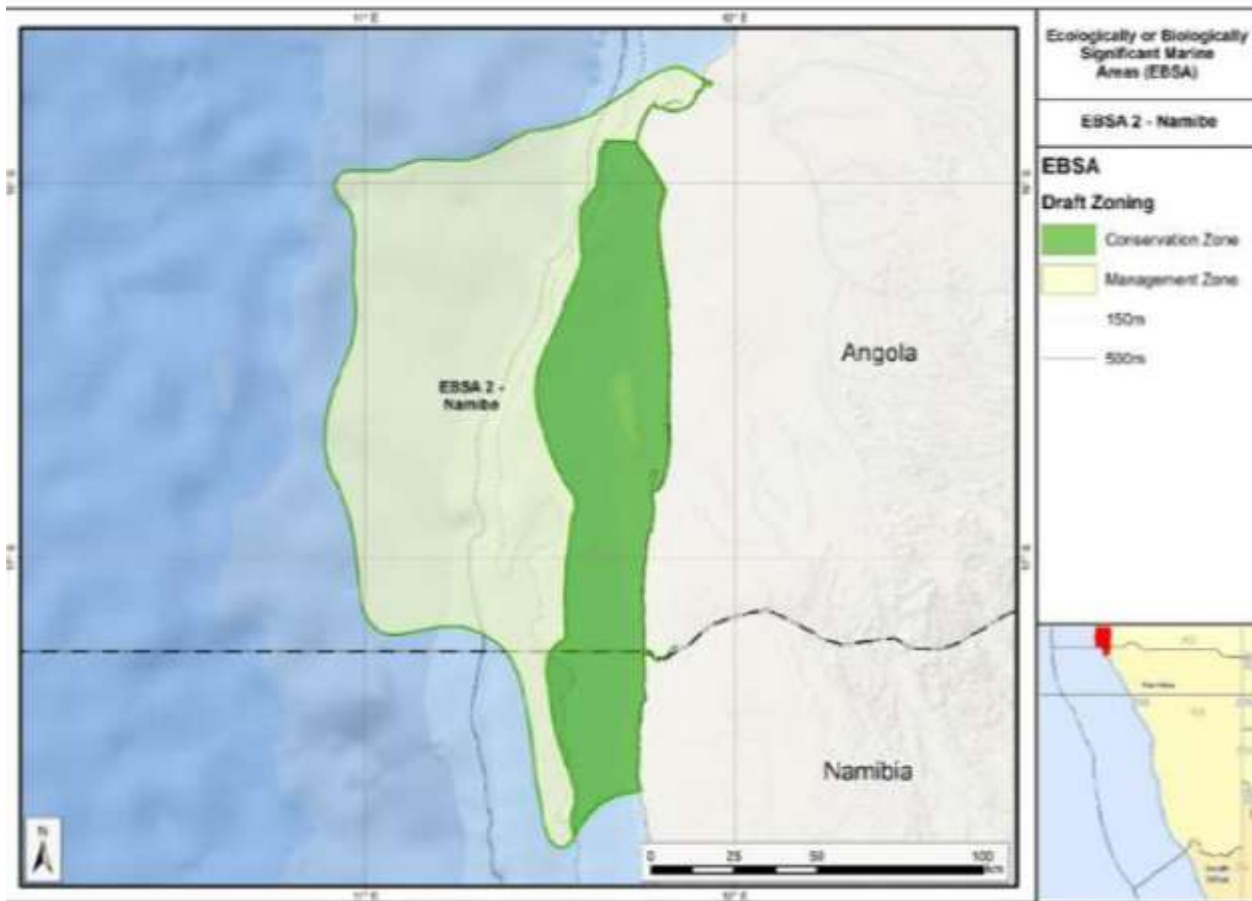


Figure 34. Draft zoning for the Namibe EBSA (Source: Erich Maletzky, Ministry of Fisheries and Marine Resources Namibia).

The Namibian Ministry of Fisheries and Marine Resources (MFMR) established an EBSA at Cape Fria (MEFT, 2021), 50 km south of the border with Angola¹⁰. The EBSA includes Cape Fria and the small prominent bay of Angra Fria to its north. This area is important for ocean productivity because it contains an intense upwelling cell, second only to that found at Lüderitz, over the narrowest part of the Namibian continental shelf. Consequently, several top predators use this area as a foraging ground. The EBSA extends 100 km along the shore, with a width of 40 km in its northern part (where seals forage), and 5 km in the south (where Damara Terns forage). The upwelling cell also marks the northern boundary of the Benguela Current. Cape Fria thus falls within a diverse biogeographic transition zone (an ecotone), supporting species at both the northern and southern limits of their distributions. The area is critical for aggregations of almost the entire global population of Damara Tern, a Benguela System endemic, during specific periods of the year, and is an important breeding site for Cape fur seals.

5.2 BENGUELA CURRENT

The TFCA borders the Atlantic Ocean. The cold waters form part of the Benguela Current Large Marine Ecosystem that stretches from Cape Agulhas in South Africa in the south (35°S) to about Moçâmedes (former Namíbe) in Angola in the north (15°S), where it subducts under the warmer, tropical Angola Current at the seasonally shifting Angola-Benguela Front. The Benguela Current forms the eastern leg of the anti-clockwise South Atlantic Gyre. It flows north along the Namibian coast at a speed of 10 – 30 cm, with a counter bottom-current flowing southward near the edge of the continental shelf. Upwelling, with a strong cell off Cape Fria, underpins the high productivity of the Benguela ecosystem. Strong upwelling events result in plumes of cold water extending up to 30-50 nautical miles offshore towards the northwest (Shannon 1985). During late summer and autumn, when southerly winds are weaker, the Benguela upwelling system also weakens and warmer water from the tropical, more saline Angola Current intrudes further south (Sakko, 1998).

The marine biodiversity, driven and supported by the Benguela upwelling system and its associated processes and the unique conditions created by the interface with the tropical Angola Current, is still largely unprotected. This is the motivation for the recent proposal to establish a transfrontier marine protected area (MEFT, 2021). In its most ambitious guise, this protected area will encompass all the biodiversity zones from the Namibe EBSA in the north to the Cape Fria EBSA in the south, including the freshwater interface of the Kunene River mouth.

The continental shelf is between 100-140 km wide, narrowing to only 30 km off the Kunene River Mouth. The Walvis Ridge separates the Angola Basin from the Cape basin and presents an obstruction to deep ocean circulation. The Walvis Ridge is a submarine mountain chain of extinct volcanoes from off Cape Fria to the mid-Atlantic Ridge in the direction of Tristan da Cunha and Gough Island, with a length of more than 2,500 km and height of more than 4,000 m above the abyssal plain (Robertson et al., 2012).

¹⁰ The description of the basis for the establishment of the Cape Fria EBSA is sourced from <https://cmr.mandela.ac.za/Research-Projects/EBSA-Portal/Namibia/Cape-Fria>

5.3 COASTLINE

Since the epeirogenic uplift of the continental margin after separation from South America, sea levels have fluctuated widely between +200 m (above current sea level) around 70Ma and -400 m about 30Ma. Sea level was ± 120 m lower and the coastline 10-50 km further west 18,000 years ago during the last glacial maximum, when much water was locked up in polar ice caps. Some 5,500 years ago, sea level was 1.5 m higher than now (Robertson et al., 2012; Sieser & Dingle, 1981). During the current era ('Anthropocene), sea levels on the Namibian coast have risen, on average, about 1.87 mm per year since 1959 (Mather, Garland & Stretch, 2009; Brundrit, 1995). Though coastal erosion happens in places and is likely to be exacerbated by sea level rise due to climate change, many parts of the Namibian coastline are aggregating. The tidal range is ± 1.4 m.

The Skeleton Coast coastline has no deep, sheltered inlets; just some small bays north of (rocky) headlands. Several elongated coastal salt pans are found parallel to and just inland of the coastline. Coastal geomorphology is greatly affected by a pair of strong wind-driven wave swell-regimes, one originating in the Atlantic Storm Belt (the 'Roaring Forties') in the Southern Ocean and the other generated by the South Atlantic Anticyclone. They produce a persistent, northward longshore current along the inner continental shelf that forms a powerful littoral transport system, stretching from Cape Town to the Gulf of Guinea (Robertson, et al., 2012; Garzanti et al., 2014). Wave fronts meet the shore obliquely. Wherever they encounter a rocky headland, waves are refracted and lose some of their energy and thus their ability to keep sediment in suspension and motion (Garzanti et al., 2014). Sand is deposited as northward-pointing sand spits, and in J-bays behind headlands.

The fresh water plume from the Kunene River mixes with seawater and creates estuarine conditions in the coastal waters just north of the river mouth (BCLME, 2007). Satellite imagery reveals a 100 km² plume of warm, nutrient-rich river water extending NNW into the Atlantic Ocean in March (Simmons et al., 1993) (Figure 35). The northward-flowing longshore current ensures that fresh river water has no noticeable influence on the marine environment south of the mouth.



Figure 35. Kunene River Mouth. (Source: Sentinel, Map: V.De Cauwer).

5.4 ALLOCHTHONY

A critical concept that is intimately linked to the particular context of the Benguela upwelling along the Namibian coast is that of allochthony. The hyper-arid Namib Desert derives a significant proportion of the nutrients in the biotic component of its ecosystems from outside the Namib itself (Polis et al. 1997). This phenomenon, known as *allochthony*, is an important driver of biodiversity patterns in especially hyper-arid deserts (Bornkamm 1987). Generally, organisms and communities of organisms respond linearly to a supply of nutrients from outside, but the effects of allochthonous inputs can be modified by the simultaneous occurrence of resource pulses such as episodic rainfall, or by species interactions.

The marine-land transfer of nutrients occurs with particular intensity in areas such as the Namib coast where highly productive coastal waters (a result of the cold Benguela upwelling) are juxtaposed with unproductive terrestrial habitats (Seely 1984; Polis & Hurd 1996). There are little data available for the Namib on allochthonous transfers of specific elements, but it likely includes both the mineral elements themselves and organic matter (both plant detritus and dead animal tissues) borne on the wind or in surface water flows, as well as water itself, arriving in the form of floods or fog (Jacobson et al., 1999; 2000).

The transfer of nutrients from the marine environment to the land is perhaps the most obvious and discrete forms of allochthony that exists (Polis & Hurd, 1996). The agents of ocean-land nutrient transfer are sea birds, mammals, shore drift of algae mats (and carrion), and wind (Polis & Hurd 1996). Several concentrations of seabird colonies (Boyer & Hampton 2001), as well as a large seal colony at Cape Cross (Kirkman 2010) imply that this is indeed an important process driving biological diversity on the Namib coast. For example, through decomposition of excreta and other wastes, the Cape Cross seal colony produces ca. 25-70 tonnes of airborne biologically active NH_3 per year (Theobald et al. 2006), probably providing a nearby terricolous lichen field with its nitrogen requirements.

In contrast to the paucity of data on ocean-land nutrient transfers through biotic agents in the Namib, the relationship of marine-derived subsidies to the occurrence of gypsum is relatively well understood (Bowker et al. 2011). Some of the most extensive pedogenic gypsum deposits in the world occur in the central Namib in a ca 50-70km band parallel to the coast; as shallow pedogenic gypsum crusts in the desert pavement and as hydromorphic saltpan and mudflat gypsum (Heine & Walter 1996; Eckardt et al. 2001). The occurrence of gypsum is closely associated with the occurrence of the diverse lichen communities of the central Namib.

6 PROJECTED CHANGES IN CLIMATE AND THEIR IMPLICATIONS

Climate change studies suggest that globally and specifically in sub-Saharan Africa the drylands will be strongly affected (IPCC 2007, 2014; Spinoni et al., 2014). Drylands have been expanding over the last 60 years and are predicted to expand further under climate change in the 21st Century (Huang et al., 2017). Few studies have focused on Namibia and even fewer on the Kaokoveld region. The most comprehensive recent report for Namibia (Dirkx et al., 2008) and modelling studies (Engelbrecht et al., 2015; Archer et al. 2018) show recent historical and predicted general warming trends but variable results for rainfall. More germanely perhaps, a study by Engelbrecht & Engelbrecht (2016) predicts a wide expansion of the hot desert zone in the Köppen-Geiger climate zone classification in warming. The lower the aridity index of a region the greater the water resources variability and scarcity in time, and the more vulnerable the area is to desertification (Berdugo et al., 2020).

Unfortunately, there are no estimates for Namibia or southern Africa of how the hyper-arid and arid zones may expand – this is a more relevant issue since the definition of aridity is based on a fundamentally important ecological factor namely the ratio of precipitation to potential evapotranspiration. This ratio is basically an integrated estimate of the net potential soil moisture and will drive vegetation patterns, primary productivity (Wei et al., 2019) and thus also livelihood sustainability.

A compilation analysis of the WCRP Coupled Model Intercomparison Project - Phase 5 (CMIP5¹¹) data for historical (1950-1980), current (2006-2036) and future (2069-2099) (Figure 36) for the SCIONA project area show that both the minimum and maximum temperatures for both the intermediate and worst case scenarios show future warming within the area (Figure 36 Column 2 &3, rows b-e). These model results would support the work of Dirkx et al. (2008), Turpie et al. (2010), Engelbrecht et al. (2015) and Archer et al. (2018). There is still however long-term uncertainty for this area linked to the changes of the Benguela Current. Currently there is ongoing research within the ORACLES, CLARIFY and AEROCLOSA projects that are trying to understand the role of the strato-cumulous deck over the Atlantic Ocean and what role this may then play in the climate models along the Namibian and Angolan coastlines. The findings of this would be expected within the next 5 years.

In terms of the predicted annual rainfall it is shown that there has been a slight decline across the study area within the current period when compared to the historical values, but both the future model scenarios predict an increase in the annual rainfall in the Angolan section of SCIONA, but little difference to the historical values in the Namibian section of SCIONA (Figure 36 Column 1, rows b-e). Much of the current global discussion on climate change addresses the increase in extreme events, both in terms of flooding, drought and temperature extremes. In breaking down the modelled annual rainfall patterns (Figure 36) and looking at a monthly scale (Figure 37) for six SASSCAL weather stations within

¹¹ The WCRP Coupled Model Intercomparison Project - Phase 5 (CMIP5) - CLIVAR Exchanges Special Issue, No. 56, Vol 16, 32pp, 2011

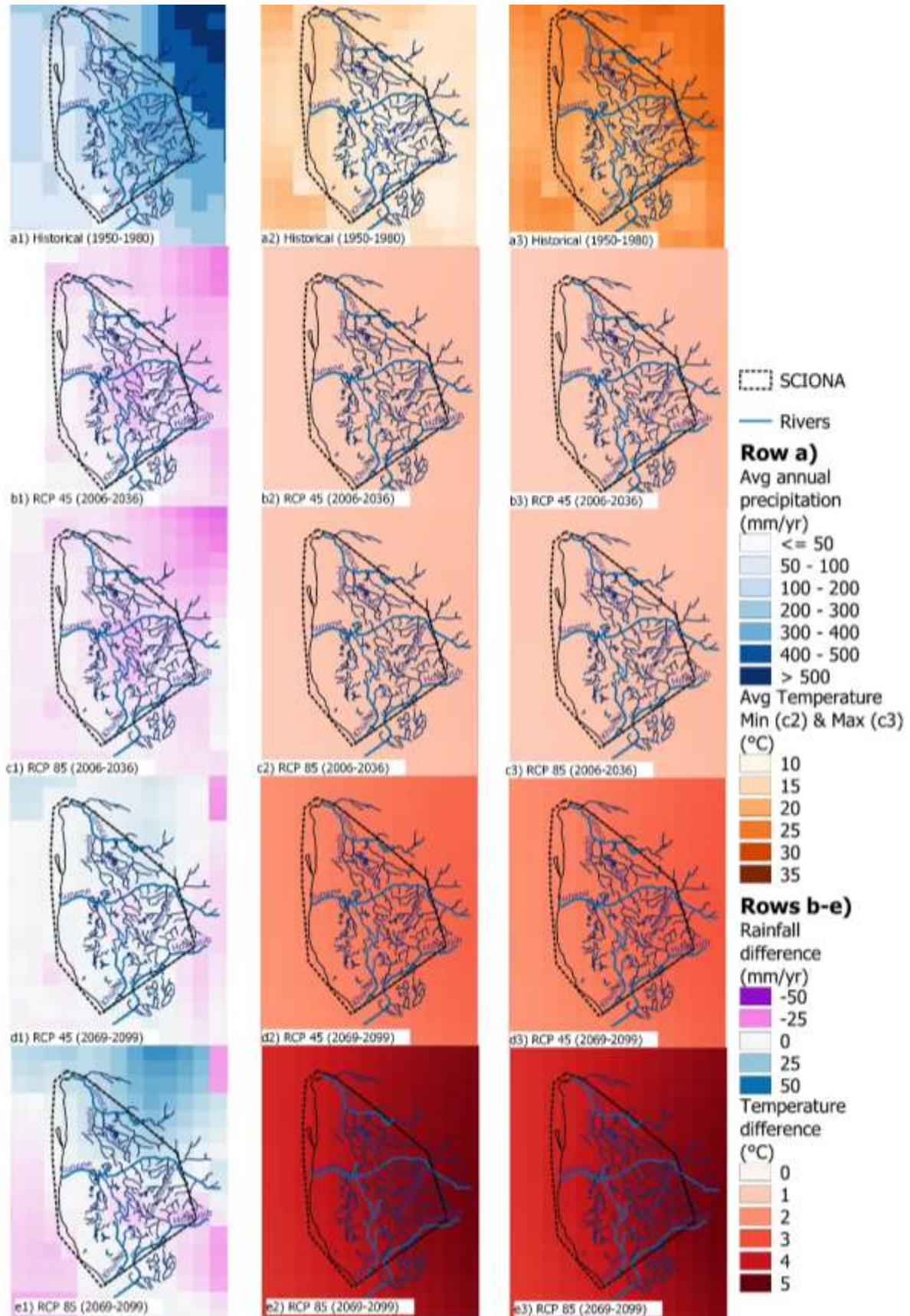


Figure 36 (previous page). Modelled historical (1950-1980) averages (Row a) for Annual Rainfall (Column 1), Minimum Temperature (Column 2) and Maximum Temperature (Column 3) derived from averaging the 21 WCRP - Coupled Model Intercomparison Project - Phase 5 (CMIP5) models. From these historical averages a difference was taken based on the calculated combined CMIP5 model averages derived for Current (2006-2036) (row b & c) and Future (2069-2099) (row d & e) periods based on two Representative Concentration Pathway (RCP) scenarios (Intermediate RCP 4.5 (row b & d) and Worst-case RCP 8.5 (row c & e)) applied to the current and future periods.

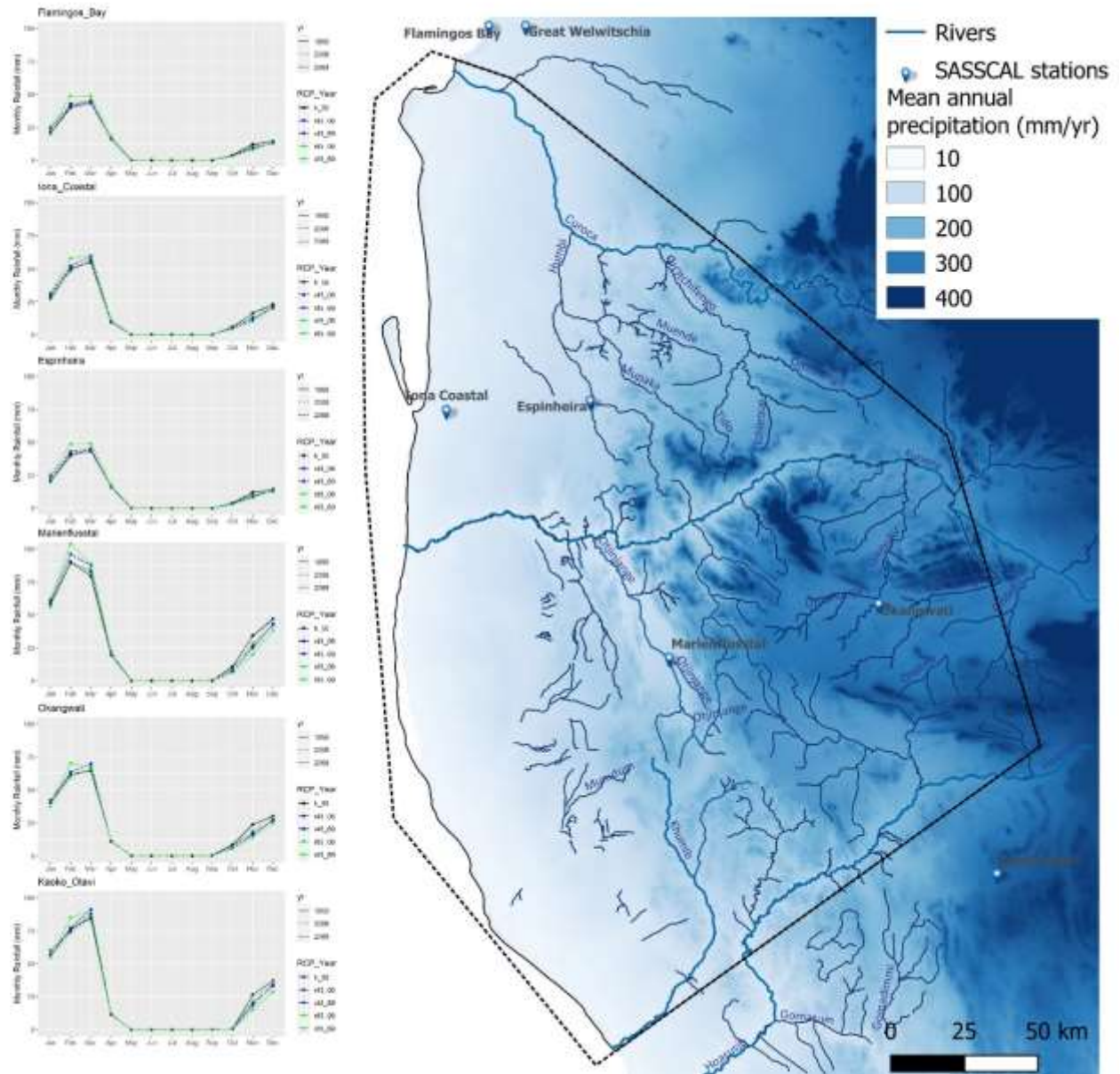


Figure 37. The long term mean annual precipitation, with the location of the current SASSCAL weather stations. For each of these stations the average monthly rainfall based on the 21 WCRP - Coupled Model Intercomparison Project - Phase 5 (CMIP5) models for historical (1950-1980), current (2006-2036) and future (2069-2099) periods applied on two Representative Concentration Pathway (RCP) scenarios (Intermediate RCP 4.5 and Worst-case RCP 8.5) is presented in the respective plots.

or close to the SCIONA study area, there is predicted to be a slight decline in the early rain season (Oct-Dec) and for both the intermediate (RCP 4.5) and worst case (RCP 8.5) scenarios, and an increase in the quantity of rain in either February or March. Based on global observations we can expect that these predicted differences are likely to result in more extreme events with flooding events potentially in February and March. It must be noted that the rainfall modelling integrates all precipitation forms (fog and rain), given the importance of fog to this area, it is vital to understand what might happen to this resource in the future.

The projected temperature increase will place pressure on species, and particularly on those that are range-restricted or occur in the mountains, where the temperature gradient is large. Namibia's western escarpment, a major topographic feature in the SCIONA study area, is therefore highlighted as a habitat that will be negatively impacted by climate change (Turpie et al., 2010). Impacts will probably be first visible for the range-restricted plant and insect species but can affect most animal and plant species in the study area. During the SCIONA project, we modelled the potential effect of climate change on the distribution of three key plant species with large distribution ranges: *Acanthosicyos horridus* (nara), *Commiphora wildii* (wild myrrh), and *Welwitschia mirabilis*. The models illustrate that the distribution areas increase for all three species (Figure 38; Figure 39; Figure 40). However, it is not clear how climate change will affect the occurrence of fog at the Namibian and Angolan coast and hence, we did not include fog in the models. If the current fog frequency is included in the modelling, the distribution area of *Commiphora wildii* is expected to decrease slightly under future climatic scenarios (Figure 41).

The critical dependence of many species on fog suggests that the western Kaokoveld might be extremely sensitive to changes in wetness or frequency of fog. Fog is ultimately the result of the cold Benguela upwelling and disruptions in the upwelling because of climate change will have significant negative impacts on a part of the region's biodiversity that is utterly unique. Regional predictions for the future frequency of fog are needed to better predict the effect of climate change on species in the hyper-arid and arid zones of the study area.

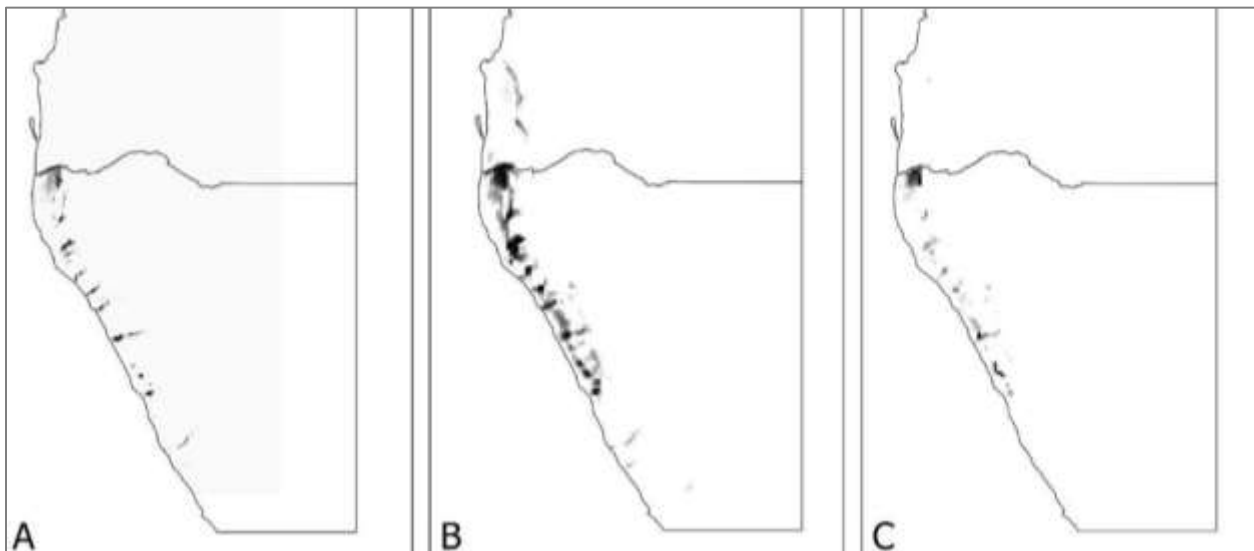


Figure 38. Current and future (2081-2100) distribution scenarios for !nara (*Acanthosicyos horridus*). A. is the current distribution; B. uses emission data from low emission scenario SSP126 and C. from high emission scenario SSP585. A minimum threshold of 10 percentile training presence was applied to outline species distribution (Modelling: A. Fillipus).

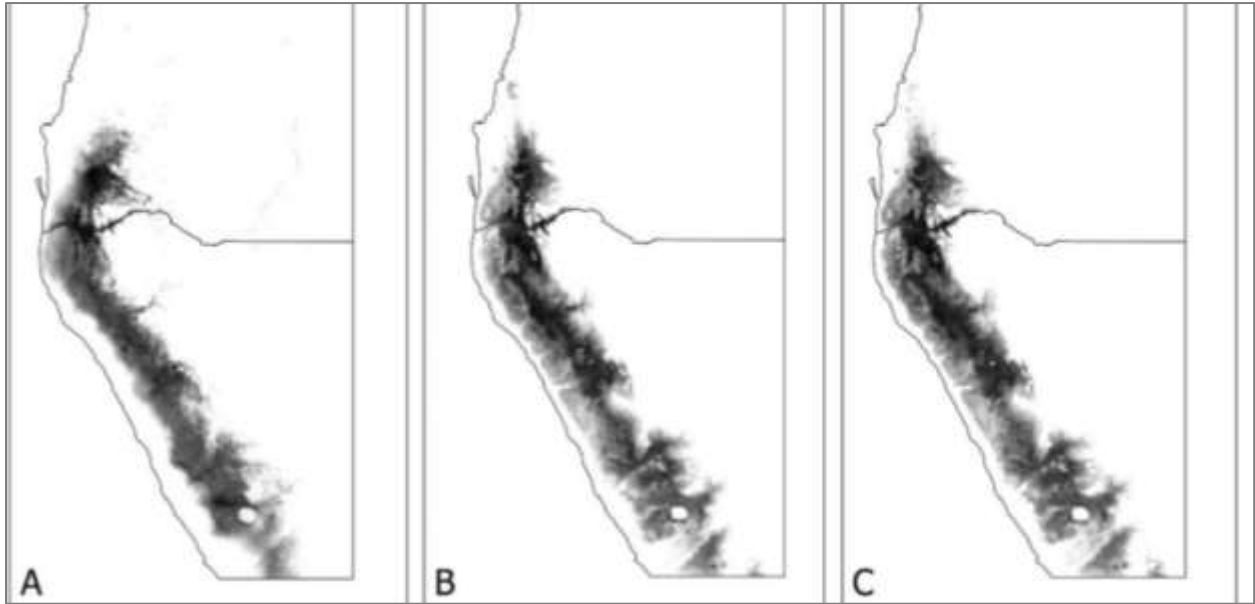


Figure 39. Current and future (2081-2100) distribution scenarios for Namibian myrrh (*Commiphora wildii*). A. is the current distribution, B. uses emission data from low emission scenario SSP126 and C. from high emission scenario SSP585. A minimum threshold of 10 percentile training presence was applied to outline species distribution (Modelling: A. Fillipus).

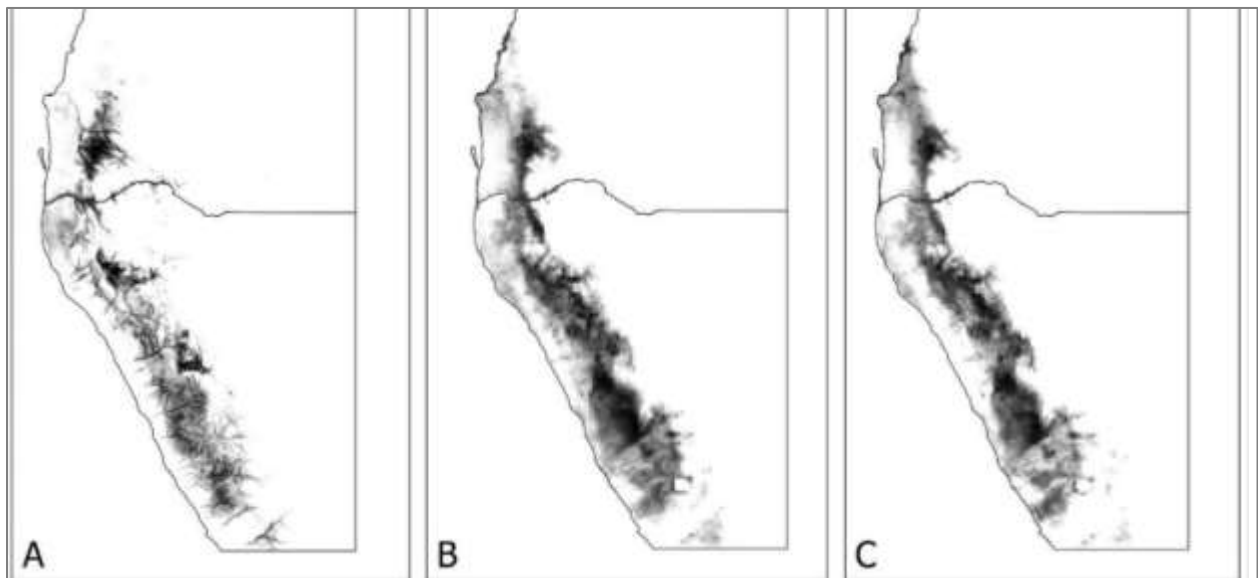


Figure 40. Current and future (2081-2100) distribution scenarios for *Welwitschia mirabilis*. A. is the current distribution, B. uses emission data from low emission scenario SSP126 and C. from high emission scenario SSP585. A minimum threshold of 10 percentile training presence was applied to outline species distribution (Modelling: A. Fillipus).

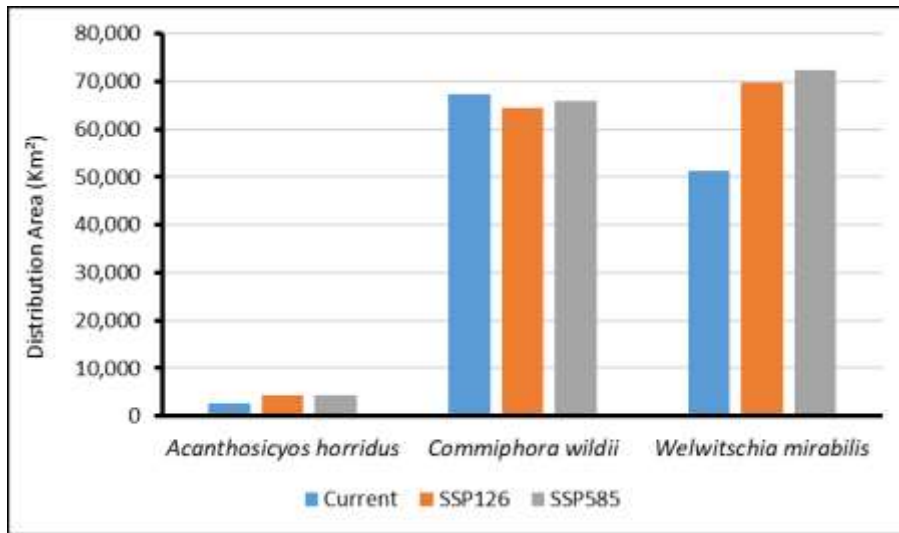


Figure 41. Distribution areas of three species in the SCIONA study area for current and future climatic scenarios when the current fog occurrence was included (Fillipus, 2021).

If the future climate modelling outlined in Figure 36 and Figure 37 we presume this will have significant impacts not only on the Western Escarpment as suggested by Turpie et al. (2010) but may have broader impacts in particular on vegetation within the region. The later onset, and decreased quantity of rainfall at the start of the rainy season would result in a later vegetation greening. This would have significant knock-on effects to both the pastoralists utilising the area, and to the movement of wildlife. An increase in the minimum and maximum temperatures might increase risk of heat stress in animals, but what is not clear from these annual average temperature values is whether we might expect extreme heating/cooling events and it is these extreme events, which are of greater concern to animal and human livelihoods than the long-term averages.

7 MANAGEMENT

The current report is not a management plan. The protected areas on both sides of the border have existing management plans, and the Transfrontier Park will have its own. Conservancies often have their own management plans and there is no mechanism for a centrally implemented management plan outside the protected areas. Nevertheless, given the geographic focus of our project, we look at the issue from a regional perspective, and attempt to list and integrate themes that cross over boundaries, both those between the protected areas and their neighbours, and that between the two countries.

We deal with the constraint that this large geographic focus brings by purposely avoiding being prescriptive. We do not provide detailed monitoring plans, because that level of detail is beyond our remit. Instead, we focus our contribution here on a discussion of topics that, in our opinion, should be addressed in some form or another in a management plan or plans that deal with conservation at a regional-landscape scale. The SCIONA project's geographic focus might be somewhat larger than what is generally considered for a "protected landscape", but the various threads that are woven into the fabric of the Kaokoveld and its residents (human and wildlife) can only be viewed and managed at this scale if it were to be successful.

The context for our discussions and recommendations for management is the preceding thematic description of key ecosystem components and processes. We do not specifically take each aspect through to management, but they do inform the discussions. The main topics of importance for management are water, land degradation, proposed indicators for monitoring, flagship species, invasive alien species, human-wildlife conflict and response to climate change. Of these, water and degradation are easily the most pressing issues to resolve, at least outside the protected areas, and our discussion here focuses on identifying the constraints and possible solutions. With wildlife movements being such an important process for the maintenance of this system, we recommend several indicator species that will provide the manager with a robust assessment of the health of this process. We also include plant species that we consider to be sensitive indicators of climate change and recommend some actions that will mitigate against the effect of climate change on biodiversity.

7.1 WATER

7.1.1 Water management is about balancing the needs of people and the ecosystem

The future of the Kaokoveld and its surrounding regions is largely a function of what will happen to precipitation and temperature, and how the needs of the arid ecosystem and people are balanced. From a geographically explicit management perspective we have no control over the former, but it will be an important modifier of how we approach the latter.

The issue of water management occurs at two main levels: single water points (wells, boreholes, springs [Figure 42], and ephemeral pools) and river catchments. Within the latter there is a clear divide between the perennial Kunene and the rest, which are all ephemeral. Ephemeral rivers in turn can be divided between those that have catchments in the arid zone (relatively infrequent flooding, less dense riparian vegetation) and those that originate in the moister semi-arid zone (more frequent and intense flooding, dense riparian woodlands are common). There is an additional sharp geographic divide in management issues between the hyper-arid protected areas, which support relatively small populations of water-

independent wildlife, and the majority of the rest of the study area, which almost all falls into the arid zone and support significant populations of people and their livestock.

7.1.2 Water management issues in the hyper-arid protected areas

Small numbers of large water-dependent species (e.g., elephant and giraffe) may occasionally reach into the protected areas, but these movements will mostly be limited to the ephemeral river courses and water access will be of relatively minor importance here. Water management in the protected areas would almost entirely be limited to keeping all natural springs free from disturbances to allow water-dependent species unfettered access. The abstraction of water for human and livestock use in the arid zone may of course also affect the production of springs in the protected areas should the water table be lowered as a result. As such the management of artificial water in the arid zone has implications for water management in the protected areas.

7.1.3 Water management issues in the populated arid zone

Ironically, in a pastoralist lifestyle the needs of people and ecosystem are so closely related that they could be seen as the same thing. This close relationship is captured in the term *social-ecological system*, which refers to the interdependence and functional connectivity between humans and their environment (Berkes & Folke, 1998). In an arid system this interdependence is nowhere more critically defined than through the medium of water.

People and their livestock need water for physiological maintenance, but they also need intact and robust grazing resources, which is in turn an ecosystem need¹². Water management is therefore intimately linked to range management, and the topic of water provision and use flows seamlessly into the topics of stocking density, transhumance and land degradation.

Absent of significant technological inputs, from a systems perspective this interdependence contains several stabilising (negative) feedbacks that lead to resilience. For example, if open water declines, the physiological needs of livestock dictate that they have to move elsewhere, preventing further consumption of vegetation and thus allowing a “resting period” during which plants can recover.

The historical resilience of pastoralist systems has strong support (Behnke, 1998a; Bollig & Schulte, 1999, Bollig & Gewalt, 2000; Harring, 2001). However, there are numerous ways in which the perceived and realised needs of people could diverge from that of the ecosystem. The provision of surface water through the drilling of boreholes is a classic example of the introduction of a positive, non-stabilising feedback into the system. Successive Namibian governments drilled boreholes in several waves since the 1950s (see Figure 43; there are no similar data available for the Angolan side), dramatically expanding the area available for grazing and thus leading to a steady growth in livestock herds that has been punctuated only by a handful of severe droughts. Water that is available all the time in a fixed place forces a more intense and longer-lasting period of defoliation, thus shortening or entirely removing the vegetation resting period. As a result, vegetation cover declines, evaporation increases, and soil water balance enters a negative spiral.

¹² We use the concept of “ecosystem need” here as if the ecosystem is a living unit that strives for homeostasis.

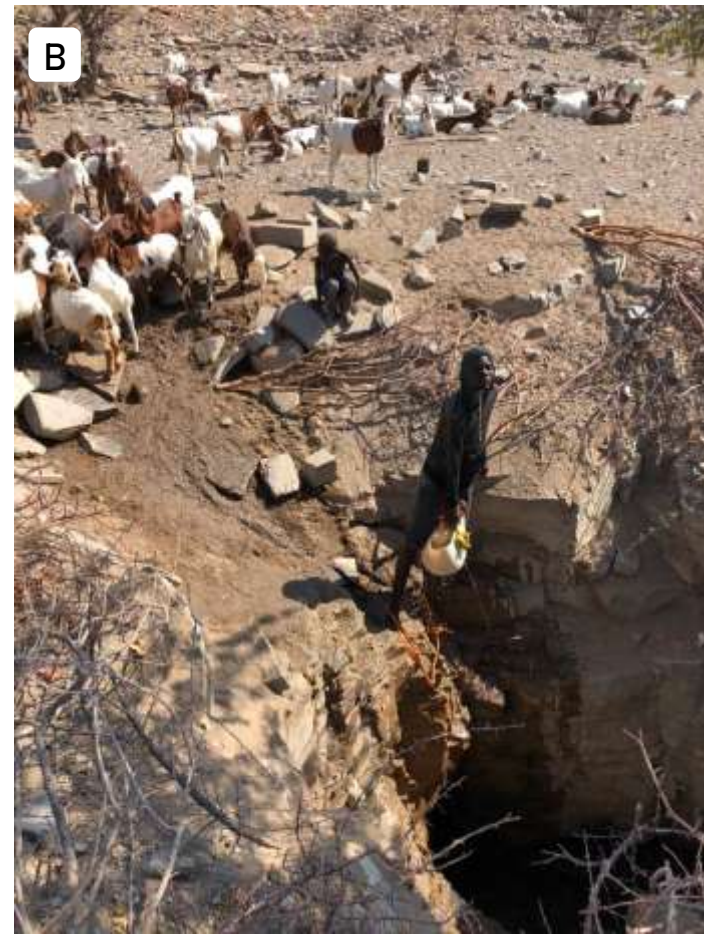


Figure 42. A) Cattle drinking at a trough at Okavare, south of Opuwo. This is an example of the numerous boreholes that have been provided by the government to support pastoralist farmers in the region. B) A herder taking water from a hand-dug well to water his goats in the Sanitatas Conservancy. C) Sheep and goats drinking from the spring at Okorosave. (Photos by Theo Wassenaar).

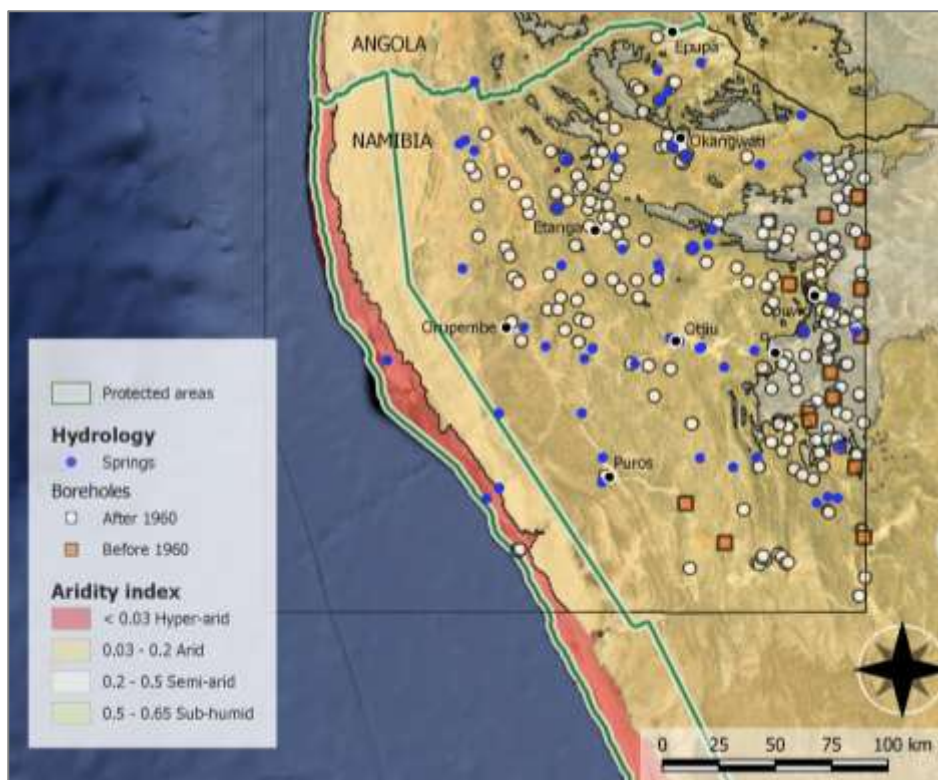


Figure 43. Boreholes were drilled during different periods from the 1950s on. This map shows only data for Namibia, as there are no equivalent data for Angola.

Although there is little hard data available, most scientists, and the ovaHimba pastoralists themselves, accept that the Kaokoveld rangeland condition has declined over the past two to three decades or so (Behnke, 1998b) and that the decline can be ascribed to “overstocking” and “overgrazing”. However, the issue is about more than just the number of large stock units per hectare. Many studies have shown that these arid systems can be remarkably productive, that appropriate, adaptive grazing management can lead to resilience (Behnke, 1998a). A rigid “stocking rate” approach, based in an equilibrium conceptual environment and with an inflexible aim to optimise economic yield, has failed in pastoralist systems where stocking thresholds tend to be higher than in commercial systems and degradation is conceptually more difficult to define (Behnke, 1998a).

Much has however happened in the period between the studies of the 1990s (Behnke, 1998a; Bollig & Gewald, 2000; Bollig, 2013) and now, including a steady growth in livestock numbers and a continuing borehole drilling programme (GOPA, 2014), which, together with a crippling recent drought, have led to effective stocking densities that are comparatively off the scale. There is no up-to-date field-based data on rangeland status, and no in-depth studies that have attempted to provide a broad definition of degradation in such conditions. It is nevertheless self-evident that the relationship between grazing and water lies at the heart of the rangeland’s dynamics and that the way in which this relationship perceived and managed is critical for not only the recovery of productivity, but also for long-term sustainability.

It is outside the current report's mandate to define explicit management actions or structures for such an effort. Nevertheless, it might be possible to parse the larger problem into a smaller number of more manageable ones, if the overall goal remains within the sphere of a social-ecological system. To do this, we need to recognise the most critical feature of water in arid systems: more than just being scarce, it is extremely variable in time and across space.

At the climate scale, the pattern of precipitation (or, more frequently, its absence) and changes therein, determines variation in primary productivity across several seasons.

At the local scale, the unpredictability of rainfall in a specific part of the range determines whether livestock will have enough food to ensure survival, maintenance, and reproduction, or whether the herds have to be moved elsewhere. This multi-scale variability defines the reality that a pastoralist herder must navigate to survive from one season to the next. Logically, the appropriate response here, one that has evidently worked for centuries, is not the artificial stabilization of access to water, but to exercise the option to move should the situation warrant it.

However, current observations suggest that the old range management system does not function anymore (IPA, 2020). There have been no critical studies to determine the scope of the problem, nor its main drivers. Yet there is enough circumstantial evidence to suggest that the provision of artificial water across the largest part of the study area has downgraded the role that the key limiting factor of livestock's physiological needs used to play in determining rest periods. Given the likely critical role that constant water availability plays in setting ecosystems on a degradation trajectory, it is reasonable to propose that this might be a management point. But it is not clear whether it would be possible to manage artificial water supply in such a way as to control rangeland recovery periods.

7.1.4 What are the options to use boreholes as a management tool?

By management tool we refer to the theoretical option of managing boreholes on a finer scale, to switch them off in particular seasons, or to regulate their production to simulate a variable water source such as an ephemeral spring. This would theoretically decrease the predictability and thus allow vegetation recovery. The role that unpredictability of critical resources plays in causing ecosystem heterogeneity – and thus increasing resilience and stability at system scale – is well-established, also for artificial water sources such as boreholes (see for example Owen-Smith, 1996; James et al., 1999; Parker & Witkowski, 1999; Gaylard et al., 2003; Nangula & Oba, 2004)

It is however an open question whether it is even possible to manage artificial water points anymore in a system with so many competing interests and where political ecology adds an additional layer of uncertainty. Water management requires inputs and agreement on purpose from many layers of society, and across several authorities. Most importantly, decisions have to come from the pastoralist communities themselves (Behnke, 1998a) and interventions from outside have to be consistent with the interests of the local land users. In Namibia some attempts have been made at borehole management, notably as an outflow of the NOLIDEP project, where communities were consulted on the best placement of new boreholes and they were requested to cover at least half of the costs of drilling (Behnke, 1998a; 1998b). The thesis of this approach was that traditional knowledge of rangeland resources is superior to that of external experts. By expecting the community to cover at least part of the costs, the project forced a limit on the size (capacity) of the water installations. By allowing the community to locate the installation, they

prevented external parties from drilling new holes in the most convenient places to them, which has a larger chance of resulting in degradation (Behnke, 1998b).

The Community-Based Rangeland and Livestock Management (CBRLM) project, also implemented in Namibia, attempted a similar approach from 2010 to 2014, with varying success (GOPA, 2014). Their findings, and those of the evaluation team a while later (IPA, 2020) suggest that the main challenges in water management are closely related to issues of grazing management. Starting in the 1990s, the government has slowly turned over control of water resources to community water associations, but formal sanctions on access to water (which is indirectly linked to grazing access) changed to traditional means of sharing based on kinship and other factors (Behnke, 1998a; Schnegg & Linke, 2015; 2016; Schnegg & Bollig, 2016). While many farmers recognized their role in causing a decline in range productivity, it was difficult to enforce grazing rules and rules on access to water evenly. Additionally, both the NOLIDEP project (Behnke, 1998a; 1998b) and the CBRLM project (GOPA, 2014), recognized the critical importance of having sound grazing management in place before a water source is installed; both projects expressed some doubts whether this is possible in the long term, but have not ruled it out.

The installation of smaller capacity water infrastructure could of course be viewed as a way to partially achieve the aim of limiting the number of animals that can be supported by a single borehole, but it has its own constraints and can probably be circumvented fairly easily. The problem of the effect of boreholes on rangeland integrity does not have an obvious solution and it is not even sure whether the link between water and rangeland condition is widely accepted. Management of borehole production for the purpose of managing rangeland health should thus perhaps not be attempted before there is widespread acceptance of such a concept, and agreement by all players to keep by the rules.

7.1.5 Other artificial water sources

Boreholes are of course not the only artificial surface water sources. Earthen dams (not including structures erected at springs to provide easy access to water for livestock) play a significant role in a surprising number of places in the study area, specifically for providing water during the wet season to allow access to grazing resources away from their dry-season range (Behnke, 1998a). However, these dams are all rain-fed and as such they have a limited capacity to supply livestock for more than two seasons or so, depending on their capacity. The low rainfall also means there is a limited potential for proliferation; they are thus self-limiting in a way. More importantly, although they play a clearly important management role to expand access to grazing in different seasons, it is difficult to see how they may be used as a tool to manage the sustainability of range utilisation, because the likelihood of them having captured any water is directly related to highly variable rainfall.

7.1.6 Climate change and water

It goes almost without saying that climate change has the potential to cause significant impacts to water sources across the whole region, including the SCIONA study area, with most of these expected to be negative (see Section 6). There has been very little attention paid to the region encompassing the SCIONA study area, so we must rely on general impressions gleaned from less accurate global circulation models (Dirkx et al., 2008). These models predict a range of possible effects, with impacts that may range from reduced flooding frequencies or durations to more frequent massive floods, to decreased aquifer re-charging. In terms of management issues to address, climate change is the primary motivation for implementing a regional groundwater and flood monitoring system, including monitoring sites across the whole rainfall gradient.

7.2 LAND DEGRADATION

7.2.1 Hyper-arid zone along the coast

The desert pavements, inland soil crusts and saltpans in the desert zone are highly sensitive to physical disturbance, often with no recovery. Desert pavements are the mechanical crusts of stone fragments formed by the wind on gravel (Coetzee, 2021b). Abiotic soil crusts are primarily gypsum soil crusts that originated over millions of years from sulphur eruptions in the Atlantic Ocean (see Chapter 5). Biotic soil crusts primarily consist of lichens bound to gypsum soil crusts or rock debris, gravel or sand (Coetzee, 2021b). The protection of these soils is one of the main reasons why combatting of illegal off-road driving was given the highest priority in the new management plan of SCNP (MEFT, 2021).

A soil map was created for SCNP during the SCIONA project (Figure 44). Most mapping units in the northern SCNP are desert or yermic soils with low organic matter content, light soil colours, and the presence of desert pavement. Other evidence of aeolian activity include ventifacts (wind-shaped gravel, stones, rocks). Only one occurrence of gypsisols could be confirmed north of Terrace Bay, to the southwest of Agate Mountain. The presence of a strong upwelling cell offshore from Cape Fria, together with the prevailing strong southerly/south-westerly wind suggests that more gypsisols will occur in that area. More information on the geomorphology and soils can be found in two reports compiled for the SCIONA project (Coetzee 2021a, 2021b) and posted on the website at <http://sciona.nust.na/project-outputs>.

7.2.2 Arid zone

Drylands' defining feature of water scarcity puts them at disproportionate risk to all forms of land degradation. Africa, with ~75% of its surface area classified as dryland (Pravalie, 2016), is thus particularly vulnerable. Pravalie (2016) considered it the continent's most severe environmental problem, and it is most often associated with unsustainable range management.

In Section 4 we described how a reversal in the rotational grazing system of the ovaHimba after the 1950s and the subsequent increase in cattle numbers could eventually lead to the collapse of the pasture management rules and subsequent degradation as observed in the early 2000s by Bollig (2013). By then, the grazing resource had been impoverished, and vegetation cover of all growth forms had markedly declined. Even the more palatable and productive annual grass species were being replaced by robust, low-yielding species. This fundamental change in pasture management and pastoral movement was exacerbated by a trend of sedentarization, lack of opportunities for marketing animals and, perhaps most importantly, at least two droughts since the late 1990s (Bollig, 2013).

At least, that is what was found by Bollig in the early 2000s. Almost twenty years later, a general decline in rangeland condition is abundantly clear even on casual observation (Rothauge, 2014). A healthy non-equilibrium system could be expected to retain most of the plant species after being grazed, even though canopy cover might have declined. Seeds and rootstock and soil health should be such that biomass can rapidly increase after rain. In the Kaokoveld, over large parts of the range, this is not the case anymore (Figure 45; Figure 46). The ovaHimba are clearly aware of this situation and agree that the loss of soil and vegetation cover is currently a key risk for them that they struggle to buffer against (Bollig & Schulte, 1999; Bollig, 2013; Inman et al., 2019; 2020).

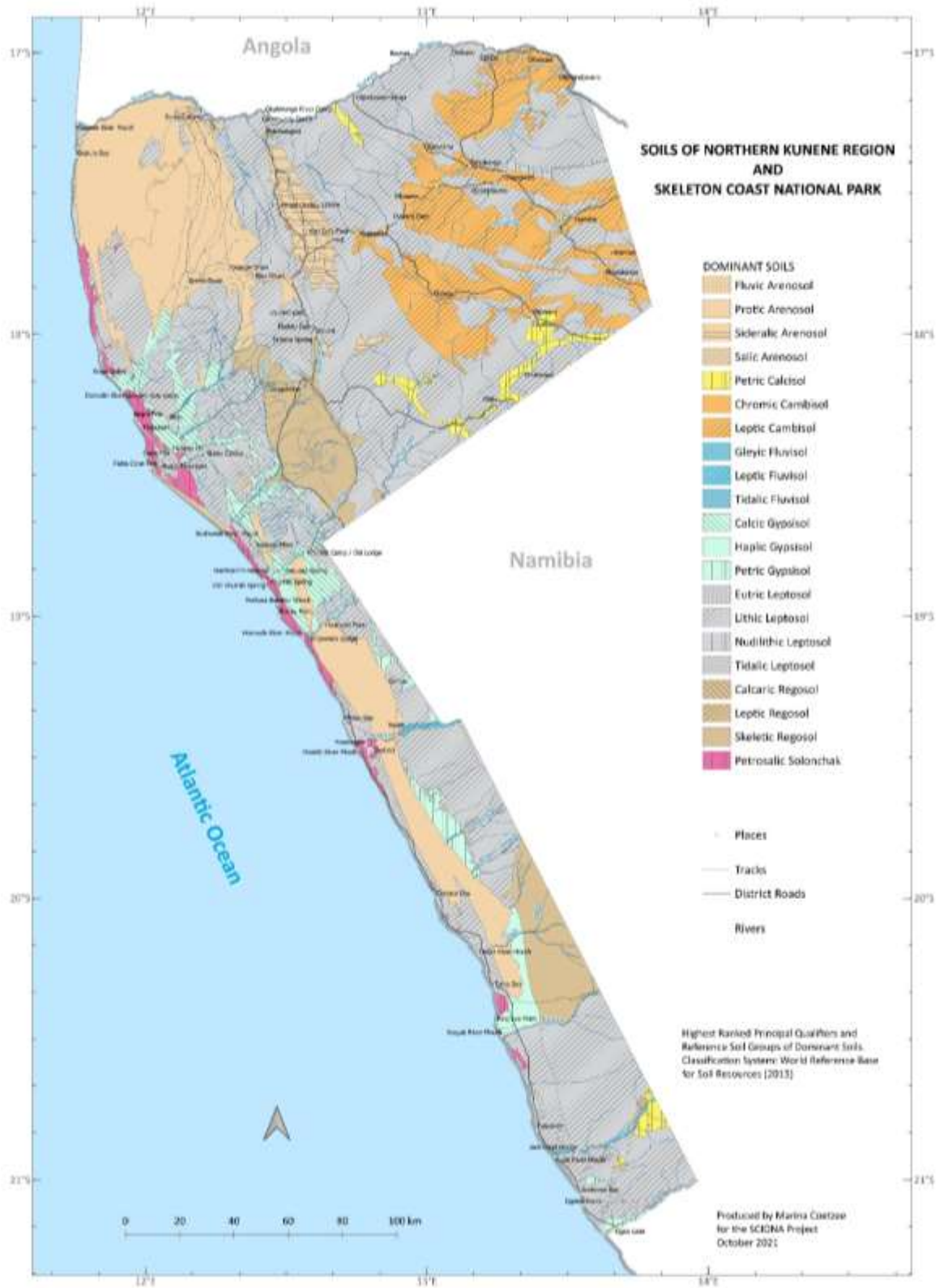


Figure 44. Soils of the Skeleton Coast National Park and SCIONA project area in Namibia (Coetzee, 2021a)

Still, there is frustratingly little published data about the extent, type, severity or, most importantly, the mechanisms of degradation, especially on a regional scale. This lack of information and solid data matters because it is difficult to design sustainable solutions without an understanding of the ecological and biological mechanisms that led to vegetation and topsoil loss. Land degradation and restoration in the Kaokoveld are inextricably linked to grazing. Any discussion on the mechanisms or magnitude of degradation must start in the context of the natural dynamics of arid ecosystems¹³. In the rangeland science literature of the 1980s and 1990s the degradation issue was phrased as a critical question of whether arid rangelands were in equilibrium and required tightly managed conservative stocking rates far below ecological carrying capacity, or never in equilibrium (“non-equilibril”) and the concept of stocking rate did not apply (Vetter, 2005).

While interesting theoretically, this argument is important because it has implications for policy. Proponents of the non-equilibril view argued that pastoralist range management approaches have adapted to this variability in a way that would prevent a long-term decline in productivity (Sullivan, 1999; Sullivan & Rohde, 2002). Livestock were thus not the cause of observed instances of desertification. Yet, there were many instances where the interaction between herbivores and plants led to catastrophic and irreversible loss of plant material (Illius & O’Connor, 1999) and obvious degradation.



Figure 45. Erosion just south of Opuwo (Photo by Wessel Swanepoel).

¹³ Earlier theoretical concepts of the ecology of species communities (groups of species that tend to occur together) assumed that the species’ densities are relatively stable (in “equilibrium”), maintained by inter- and intra-specific “biotic” interactions within the constraints presented by a constant abiotic environment. Ecosystems are viewed as isolated and closed biotically-driven systems, with species densities gradually tending towards (or “equilibrating” to) a stable set of possible values. Their population sizes could be said to be density dependent. The end-point, or “climax”, of this tendency towards equilibrium is a balanced community which is stable through time unless disturbed by forces that are external to the closed biotic system.

Driven by different perspectives from the fields of rangeland science and anthropology, the issue of whether semi-arid and arid ecosystems are equilibril or not was the subject of an intense debate in the range management literature in the 1980s and 1990s (see Vetter, 2005 for a review of the topic). The classic, European equilibrium perspective with its emphasis on stocking rate and carrying capacity was clearly a bad fit for the dynamic arid savanna systems where rainfall was variable enough that livestock numbers at any given place could never increase to the point where they affected the vegetation. The vegetation was thus “uncoupled” from the herbivores, being mostly a function of stochastic climatic trends and the herbivores, in turn, were buffered against climatic variability by high spatial variability in productivity. Such a system can be described as non-equilibril (or in dis-equilibril), without any definable climax state.

At the time, it seemed as if the viewpoints in this debate were diametrically opposed, the differences highlighted by different approaches from the ecologists, rangeland scientists and social anthropologists that were participating in debate. In practice however, arid rangelands are probably a mix of systems and the strength of the coupling between herbivores and their grazing resource more likely fall on a gradient that is a function of both rainfall variability and the relative proportions of key and non-equilibrium resources (Illius & O’Connor, 1999; Derry & Boone, 2010).



Figure 46. Examples of severe degradation on the Namibian side of the Kaokoveld. A: Mopane trees standing on pedestals near Okakuyu; B: perennial grass tussock with exposed roots in the wind-eroded middle Marienfluss; C: pedestal island in valley near Onganga, showing the extent of topsoil loss (Mr Koruhama is standing on the subsoil while pointing to the B-horizon); D: algal soil crust, preventing water infiltration (taken near Otjitanda). (Photos by Theo Wassenaar).

Clearly it will not help to view these complex systems through such simple opposing models. The debate did however serve to highlight the importance of a mechanistic understanding of system drivers and responses to design effective policy and practical and sustainable responses to degradation. Since restoration of degradation in the Kaokoveld will undoubtedly require adaptations in range management, it is necessary to construct new models that include factors that are external to the livestock-plant-climate interaction, such as human population increase, social-political changes, and the availability of permanent water.

The most glaring gap, however, is the lack of a regional baseline value for the history, severity, extent and forms of degradation. While some workers consider land degradation here as a recent phenomenon, its historical provenance and trajectory is largely unknown. The last national estimate of land degradation was done by Klintonberg & Seely in 2004, and even they admitted that it was just a first approximation. The underlying dynamic of arid ecosystems is dominated by “slow” variables (Reynolds et al., 2007) such as e.g. soil fertility and integrity. These variables have long turnover times and possess thresholds or tipping points that, when crossed, could result in a regime shift. It is this potential for a large shift in system state that represents the risks that social and climate change pose for the socio-ecological system of the arid and semi-arid Kaokoveld of Namibia and Angola.

The lack of good information on past, current and likely future degradation, and how these are related to plant water stress, grazing and recovery/restoration potential prevent a confident assessment of the risk of a regime shift.

Various lines of evidence thus point to the fact that the region is, environmentally, approaching a potentially calamitous and irreversible loss of the productive vegetation base that maintains the pastoralist system. Not understanding the likelihood and mechanics of such a regime shift will put the Kaokoveld region in a particularly vulnerable position. Responding or adapting to a profound regime/system state shift is difficult and expensive (Reynolds et al., 2007) and requires, at a minimum, knowledge of the drivers and their dynamics and a robust assessment of the risks that it will happen.

7.3 INDICATORS OF ECOSYSTEM STRUCTURE AND FUNCTIONING

The best measure of conservation management success is the conservation of the ecosystem and its biodiversity. This can be evaluated through a systematic approach that includes prioritising and monitoring of indicators of ecosystem structure and functioning.

Often, indicators are a set of keystone species. Broadly defined, keystone species are important linkages in ecosystems where their loss to a system results in the loss of many other species (Bond, 1994; Mills et al., 1993). A keystone species thus has a disproportionately large effect on the ecosystem relative to its biomass through many different processes such as trophic interactions, pollination, or habitat modification (Power et al. 1996, Jordan 2009). Key stone species form an important component of sustainable ecosystem management and nature conservation. For the selection of keystone species, there must be some reasonable evidence that a particular indicator is a proxy of something larger than itself – hence the definition of the larger part is almost more important. For example, the population dynamics of a top-level predator may appear to be a very sensitive indicator of the health of the ecosystem in which it occurs, but because these species tend to be vulnerable to a range of other disturbances, they are not necessarily a good proxy for the ecosystem’s overall health, and might be a better indicator of human pressure on the system. Key primary consumers may include better keystone species.

To know whether the ecosystem is healthy, alternative indicators than keystone species can be monitored, such as biomass or the biodiversity and extent of key habitats. These will be first discussed in the following sections, before moving on to keystone species. Keystone species proposed belong to terrestrial plant and mammal groups. Other promising indicators may be found in for example the insect group, but further identification and analysis are needed of the data collected during the SCIONA project (e.g. De Cauwer and Becker 2018, SCIONA Field trip report: Biodiversity survey of mountain tops in the Kaokoveld Centre of Endemism 2021) or of data available in musea and herbaria. Despite the limited research done in remote

areas of Angola, the number of specimens (15187) collected in the Namibe province is relatively high compared to the rest of Angola; it is the second-highest of all Angolan provinces, most of it for birds and plants (Figueira and Lages 2019).

7.3.1 Sensitive habitats

Life in arid ecosystems is highly dependent on a few habitats where biodiversity is concentrated. In the west, these habitats are the dune hummocks found in a very narrow strip along the coastline, the rocky outcrops and hills, the riverbeds, and the Kunene River mouth with its associated wetlands. These habitats are also highlighted in the new management plan of the SCNP (MEFT, 2021). An additional sensitive and biodiverse habitat is the afromontane vegetation on the highest mountaintops of the Himba highlands that straddle the Angolan-Namibian border and the Kunene. All these habitats were described earlier (1.3, 2.1 - 2.3). The sensitive lichen fields of the southern SCNP, that support invertebrate communities (MEFT, 2021), were not part of the SCIONA study area.

Biodiversity in and the extent of these habitats form good indicators of ecosystem health in the Transfrontier Park and the Kaokoveld Centre of Endemism. Unfortunately, no systematic inventory or mapping has been done of all types of special habitats and sites (MEFT, 2021). A research project was started during the SCIONA project to create a habitat map of the study area (2.1.2).

7.3.2 Perennial grass biomass and proxy indicators

The most obvious indicator for the SCIONA study area is the biomass of grass species, as they provide food to a range of insects, which are at the bottom of the food chain, and mammals. They also prevent wind and water erosion. Especially perennial grass biomass is a good indicator of ecosystem health as they provide continuous soil protection and food, even during dry years. Much of the Namibian Kaokoveld was already overgrazed fifty years ago resulting in the extermination of perennial grasses and areas with bare soil for most of the year, except on the higher and more rugged slopes (Malan and Owen-Smith 1974).

However, key indicators are only relevant if enough monitoring data can be collected and analysed, hence they should be easy to monitor continuously and with the available resources (Timko and Innes 2009), preferably also by the communities. Monitoring perennial grasses is however problematic for several reasons:

- Grass biomass or productivity is difficult to monitor on satellite images because of the annual and seasonal variation in rainfall (Figure 3; Figure 26). Moreover, it is not possible to distinguish perennial from annual grasses on the images of most satellite sensors (except some hyperspectral).
- Grasses are barely present during drought periods so that they cannot be identified in the field as they are either not there or cropped very short by livestock and game (Figure 47). This was the case during the SCIONA project. During our vegetation surveys, there was not enough grass to allow identification, except on the mountaintops of Serra Cafema, Serra Tchamalinde and Middelberg in the Otjihipa range.



Figure 47. Bare soil was a common sight during our fieldwork in Iona National Park (Photo by Vera De Cauwer).

Hence, grass biomass does not make such a good indicator as it is difficult to monitor, an essential requirement for an ecosystem indicator. It makes more sense to use proxy indicators for grasses; species dependent on grass as their main food source whose movements are therefore influenced by the seasonal and spatial distribution of grass. Good proxy and easy to monitor species include large mammals such as springbok.

7.3.3 Diversity and biomass of palatable woody species

In the hyper-arid and arid areas of the study area, indicators other than grass biomass can be used because many animals do not rely on grass as their main food resource. For example, large mammals browse a range of woody species year-round, and particularly rely on them during the dry winter period. Fifty years ago, there was already evidence that domestic livestock and people were affecting the populations of the most palatable shrubs in the Namibian Kaokoveld (Malan and Owen-Smith 1974). Hence, the abundance of palatable shrubs and herbs form good key indicators of ecosystem functioning. The major species are listed here per habitat; many are endemic to the Kaokoveld.

One of the most essential food sources for animals and humans in the **Namib Desert** is the !Nara (*Acanthosicyos horridus*), from insects at the bottom of the food chain to ostrich and oryx. The ancient *Welwitschia mirabilis* appears especially browsed in the neighbourhood of Espinheira, INP (Figure 48). Browsing is not only by wildlife, but also by the Himba cattle (Huntley, 2017).



Figure 48. Browsed *Welwitschia mirabilis* near Espinheira, Iona National Park (Photo by Vera De Cauwer).

In the **Pro-Namib**, livestock and game, including giraffe (Fennessy et al. 2019), favour all *Boscia* and *Maerua* species for browsing. *Boscia foetida* is so heavily browsed that it is seldom more than a stunted shrub (Malan and Owen-Smith 1974). Fruits of most species are also eaten by people and birds. Almost all *B. tomentosa* trees encountered during the SCIONA vegetation surveys showed signs of debarking by donkeys and zebra. The stunted seedlings of *B. albitrunca* and *B. tomentosa* found in our vegetation plots showed clear signs of regular grazing. The carrot tree (*Steganotaenia araliacea*) was observed during the mountain survey and all plants showed signs of browsing and insect damage (Figure 49).



Figure 49. Young carrot tree (*Steganotaenia araliacea*) at Middelberg, Otjihipa range, Namibia (Photo by Vera De Cauwer).

Shrubs and plants of the genera *Monechma* and *Petalidium* are important dry season stock feed for game and livestock (Malan and Owen-Smith 1974). *Euphorbia damarana*, a succulent endemic to Namibia and poisonous to people, is browsed by kudu and rhino in areas where few other food sources are available and its fruit is consumed by a number of wildlife species.

As both wildlife and livestock congregate in the rivers during the dry months (Malan and Owen-Smith 1974), it is essential to indicate keystone species for the **riverine vegetation**. The Makalani palm (*Hyphaene petersiana*) is of considerable importance to the local communities as they use the leaves to make a range of products such as baskets, bowls, twine, and bows. Additionally, the sap is tapped to make an alcoholic beverage, but the crown has to be removed in doing so, which results in the death of the tree (Malan and Owen-Smith 1974). The pods of the Ana tree (*Faidherbia albida*) are very important forage for game and livestock (Malan and Owen-Smith 1974). Many trees along the Kunene River near the Hartmann's Valley were dying, possibly because the seasonal flooding no longer occurs since several dams were constructed upstream in Angola (see 1.3). The leaves of the Kaoko Combretum (*Combretum watti*), which also occurs along ephemeral rivers, are browsed year-round by several wildlife species (Mannheimer and Curtis 2009).

7.3.4 Hartmann's mountain zebra (*Equus zebra hartmannae*) and zonkeys

The type specimen of Hartmann's mountain zebra (HMZ) was collected in 1898 within the SCIONA study area (Gosling et al., 2019). It makes sense for this species to be a key indicator for the transboundary park as it is endemic to Namibia and southern Angola and a typical component of the escarpment and arid plains habitats, it has a limited distribution (Figure 50) and is classified as vulnerable on the IUCN Red List¹⁴. It is also a species of economic importance as a preferred trophy hunting species for its attractive hide and cape mounts (Figure 51).

Our surveys in the INP suggested that there were approximately 428 adult, 33 juveniles, and 17 foals in the Angolan part of the study area in Iona National Park. However, the population was dominated by females in all age classes, with a sex ratio of 1:3.5 (male:female). The adult-dominated age structure, representing 89.6% of the total population, is concerning as it makes the population vulnerable to increasing anthropogenic and environmental threats (Chicomo, 2021). The emerging population of zebra-donkey hybrids ("zonkeys") in Angola, with a population of 19 adult individuals in INP (Chicomo, 2021) is a good example of how human presence is threatening the survival of this sub-species here. Noninvasive genetic analysis of HMZ, donkey and zonkey dung samples is currently being conducted by the Centre for Integrative Biology (CIBIO) laboratories dedicated to the extraction and genomic analysis of low quality DNA. This will specifically look at the degree of hybridisation in the HMZ population. Further field monitoring of the zonkey population in INP is recommended to get a better insight into the degree and level of hybridisation and how it may affect the HMZ population.

¹⁴ The IUCN Red List of Threatened Species [WWW Document], n.d.. IUCN Red List Threat. Species. URL <https://www.iucnredlist.org/en> (accessed 1.5.19).



Figure 50. Distribution of Hartmann's mountain zebra in the SCIONA study area (Map: M. Hauptfleisch).



Figure 51. Zebra along the road between Opuwo and Orupembe (Photo by Wessel Swanepoel).

7.3.5 Spotted hyaena (*Crocuta crocuta*)

The species is known to be an important keystone predator in southern Africa (Paine, 1969). Although Trinkel (2009) suggests that protected areas will provide the most important growth area for the species, there has been a noted increase in the number, and an extension of range, of spotted hyaena in the eastern part of north-west Namibia (Figure 52). The increase in the incidence of human-wildlife conflicts in the area

is indicative of an imbalance between the availability of wildlife prey and carrion, and persistent cattle populations being kept alive through provision of artificial water and sometimes feed. Spotted hyaena is a species particularly susceptible to ecosystem flux, and once impacted, their numbers are known to recover slowly.

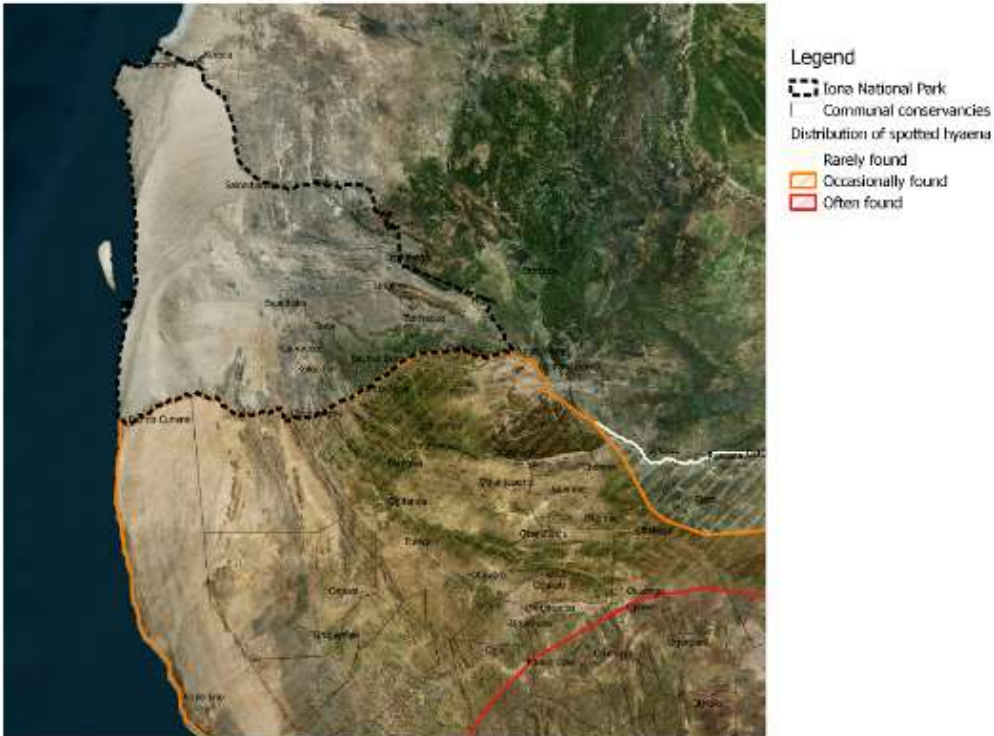


Figure 52. Spotted hyaena distribution and density in the SCIONA study area (Map: M. Hauptfleisch).

7.3.6 Cape fur seal *Arctocephalus pusillus*

The Cape Fur seal is proposed as a keystone species for the study area as it is a marine and terrestrial energy and nutrient link and an indicator of marine productivity, as well as sustainable commercial fisheries.

Distribution

The west coast of southern Africa is the most important habitat for this species. It provides the cold water and productive fish stocks of the Benguela current (Alava, 2017). The main colonies of the Namibian coastline are censused annually. Between 1976 and 2006 the Cape fur seal extended its range along the Namibian coast by ca. 680 km, from Cape Cross to Baia dos Tigres in Angola (Kirkman et al., 2012). Using the recently produced high-resolution images for Iona, a little over 15,000 seals were counted within Baia dos Tigres alone (Mendelsohn and Haraes, 2018). The reason for this dramatic range shift, which occurred in spite of overall stability in population numbers, is not clear but it could be related to the effects of climate change, or resource competition due to overfishing, or other forms of human-caused disturbance (Kirkman et al., 2012).

Ecology

Cape fur seals prefer rocky outcrops or islets which remain dry at high tide (Skinner and Chimimba, 2005). Within the SCIONA study area, False Cape Fria holds the largest colony. The seals are in direct competition with commercial fisheries as both target the same species. Much has been written about the effect of increasing seal numbers on fisheries and vice versa (Shannon *et al.*, 2004).

Within the context of SCIONA, Cape fur seals are an important nutrient and energy transfer link between the ocean and the land ecosystems. Feeding in the ocean, seal droppings fertilise the coastline, and predation by hyena, jackal and other predators spreads the nutrients inland to supplement terrestrial systems.

7.4 FLAGSHIP SPECIES

Flagship species have a particular allure to the general public and tourists, often promoted to garner public support for a conservation cause or tourism attraction (Home *et al.*, 2009; Walpole and Leader-Williams, 2002). This is particularly important in an area dependent on tourism as a key source of income, especially for communal conservancies. Suggested flagship species for the SCIONA TFCA are provided below.

7.4.1 Angolan giraffe (*Giraffa giraffa angolensis*)¹⁵

Distribution

Historically and naturally, Angolan giraffe occurred throughout Namibia, including most of the the SCIONA arid zone (Cunningham, 2014). In north-west Namibia, Shortridge (1934) referenced sightings of giraffe across much of what was then known as Kaokoland, and by the late 1950s giraffe were reported to be numerous and widespread, except for the extreme hyper-arid western desert (Cunningham, 2014). Occurrence along the Kunene River seems to have always been restricted to the eastern sections of the river in Namibia (Shortridge, 1934). Angolan giraffe frequently moved across north-central Namibian where Aawambo hunters mostly utilised them for meat and hides (Shortridge, 1934). Civil unrest likely caused the major decline of giraffe (and other large wildlife) in north-west Namibia from the 1970s to end of 1980s. Giraffe historically occurred in the Mopane and Acacia savannas of southern Angola (Shortridge, 1934). The Acacia and Mopani savanna immediately to the east of INP between the Curoca and Kunene Rivers historically was the heartland of the Angolan giraffe population in the west of the country (Marais *et al.*, 2020).

Presently giraffe occur in the Orupembe, Sanitatas and Okondjombo Conservancies¹⁶ and the eastern parts of riverbeds in the SCNP and have been recorded in recent times from other neighbouring conservancies (Figure 53). The furthest north that giraffe have been sighted in the SCIONA study area was in Hartmann's Valley, approximately 40 km south of the Serra Cafema Camp on the Kunene River. They are thought to be solely dependent on the riparian woodland of the ephemeral rivers of the area (Fennessy, 2004). The last overall estimate of giraffe numbers in the entire north-western part of Namibia's Kunene Region was 1,105

¹⁵ Previously *Giraffa camelopardalis angolensis*

¹⁶ <http://www.nacso.org.na/resources/game-count-poster>

individuals in 2004 (Fennessey, 2004). Annual counts of giraffe in the communal conservancies of the entire north-west (including areas well to the south of the SCIONA study area) fluctuated between 59 and 256 individuals over the past 16 years, with a steadily increasing population trend until 2012 and stable thereafter (NACSO, 2020). Current estimates for the area north of the Hoanib River is approximately 450 animals (Julian Fennessey, personal communication).

Ecology and conservation concerns

Studies of the ecology of giraffe in arid and hyper-arid areas are largely restricted to the west-flowing ephemeral rivers of Namibia's Kunene Region (Fennessey, 2004; Fennessey et al., 2003). In this area, giraffe are totally water independent and rely solely on riverine woodland vegetation (Hamutenya, 2021).

Recent genetic research has separated what was until then one species of giraffe globally into four distinct species (Fennessey et al., 2016; Winter et al. 2018; Coimbra et al. 2021) of which SCIONA's giraffe together with the South African giraffe form the southern giraffe species (*G. giraffa*) (Figure 54). This increases the vulnerability of giraffe globally, as each species has a far smaller population and distribution than one species with its greater global distribution. Southern giraffe are however the only species of giraffe which is not under immediate conservation threat (Fennessey et al., 2016).

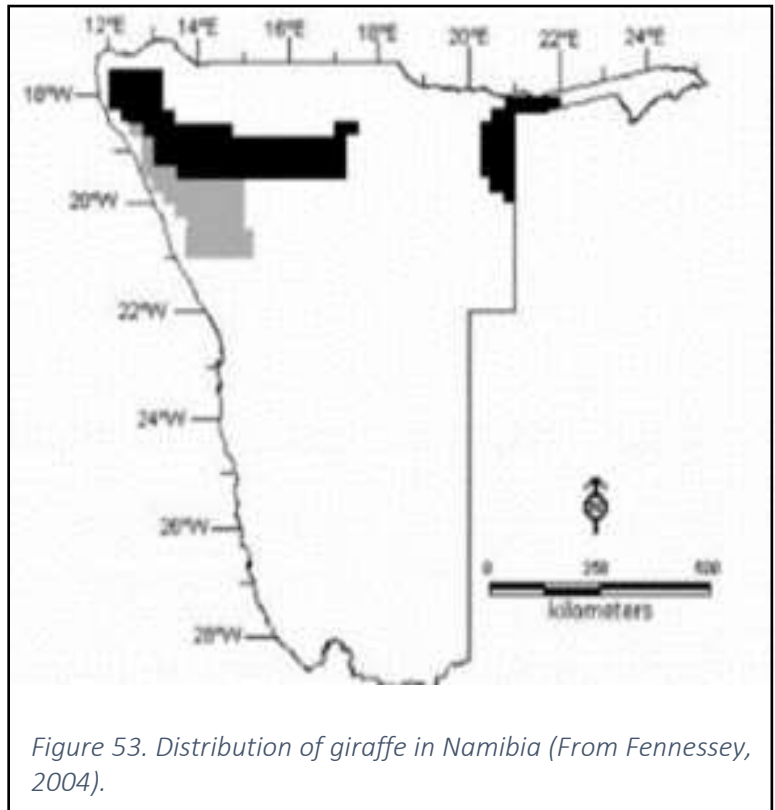


Figure 53. Distribution of giraffe in Namibia (From Fennessey, 2004).

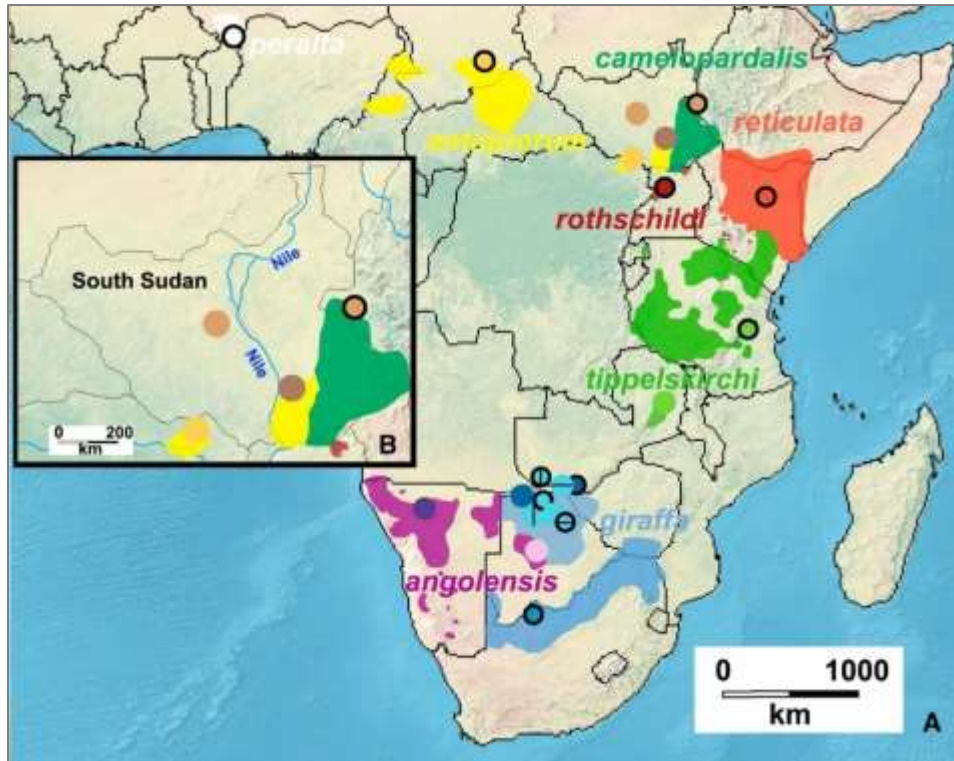


Figure 54. Distribution of giraffe species and subspecies in Africa (From Fennesey et al. 2016).

In 2015, the estimated overall Angolan giraffe population was approximately 13,000 individuals, with all of these occurring only in Namibia and Botswana. In the last decade (re-)introductions from Namibia into privately owned game reserves in Angola have occurred and the South African subspecies has been introduced into Quicama NP (Marais et al., 2020), which is far outside its natural range. Extra-limital introductions such as the latter could cause genetic pollution and hybridization.

Reintroduction of Angolan giraffe into the SCIONA study area is being considered, with an assessment of habitat and security currently underway. Were communities in Angola to show tolerance for the species and an interest in conserving wildlife in general, as is currently the case in Namibia, a reintroduction is likely to be successful.

7.4.2 Cheetah (*Acinonyx jubatus*)

Distribution

The Pro-Namib has historically been an important habitat for cheetah (Coetsee, 1971; Figure 55), and the SCIONA area of Angola and Namibia contains a significant portion of this habitat type. Cheetahs are, with brown hyenas, the most regularly observed large predators in the SCIONA study area. The SCIONA project found that cheetahs are relatively well distributed across both the Namibian and Angolan part of the study area (Figure 56) and across the whole Namib Desert with healthy and continuous populations (Portas et al., 2017). Both Orupembe and Marienfluss conservancies informally reported seeing them annually. In Iona National Park, cheetahs with young were observed on camera trap images taken during the SCIONA project.

This population is considered resident given the frequent report of sightings, including that of females with cubs (Bruce Bennett and Álvaro Batista, personal communication October 2021). Their persistence in Angola throughout the war is remarkable, and resident individuals on the Iona plains are now being studied more closely through camera traps and currently being targeted for telemetry studies (Pedro Monterroso, unpublished data).

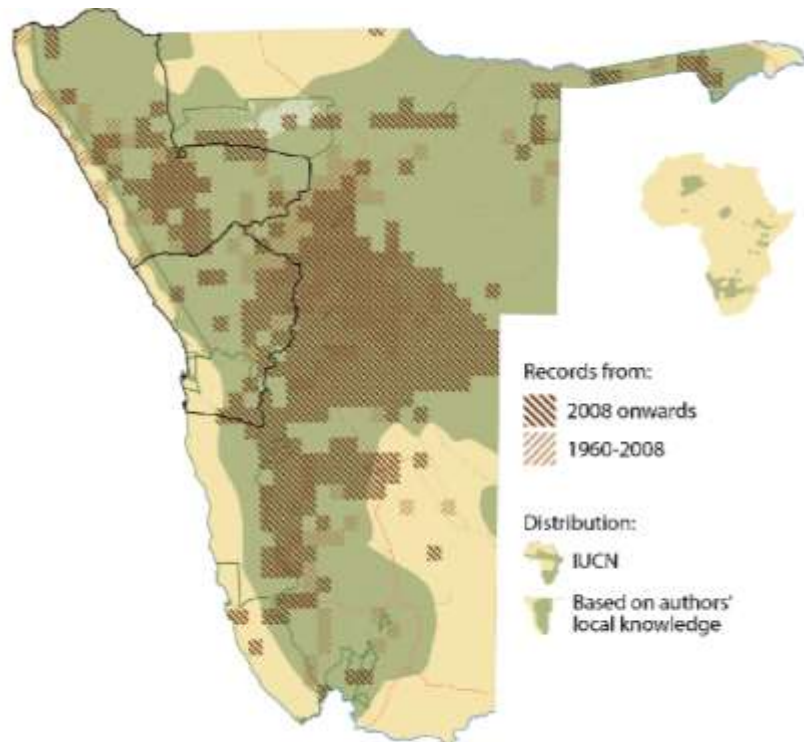


Figure 55. Distribution of cheetah across Namibia (Namibia Carnivore Atlas, In press).

Ecology and conservation concerns

As an apex predator, cheetah numbers reflect the prey base populations. Cheetahs are considered poor competitors and their numbers decline with increases in populations of lion and spotted hyena (Caro 1994). Cheetahs are particularly fond of springbok and ostrich in arid areas (Skinner and Chimimba, 2005). In the central Namib, a pilot study carried out in 2020 found oryx calf, ostrich, springbok and zebra foal to be the main prey of three male coalitions (Portas et al., In prep.) Cheetah also preys on livestock when it's left unattended because kraaling and herding are methods that have considerably reduced cheetah related livestock losses (Marker et al., 2018; Melzheimer et al., 2020). In the Iona NP, several scats containing goat hair were found at marking sites. Conflict with humans, overgrazing and livestock competition with wild ungulates seem to be the main cheetah threats within the SCIONA study area (Pedro Monterroso and Ruben Portas, personal communication October 2021). Killing a cheetah and eating its heart is believed to enhance bravery and prevent cowardice by the ovaHimba (Chesselet et al., 2004).

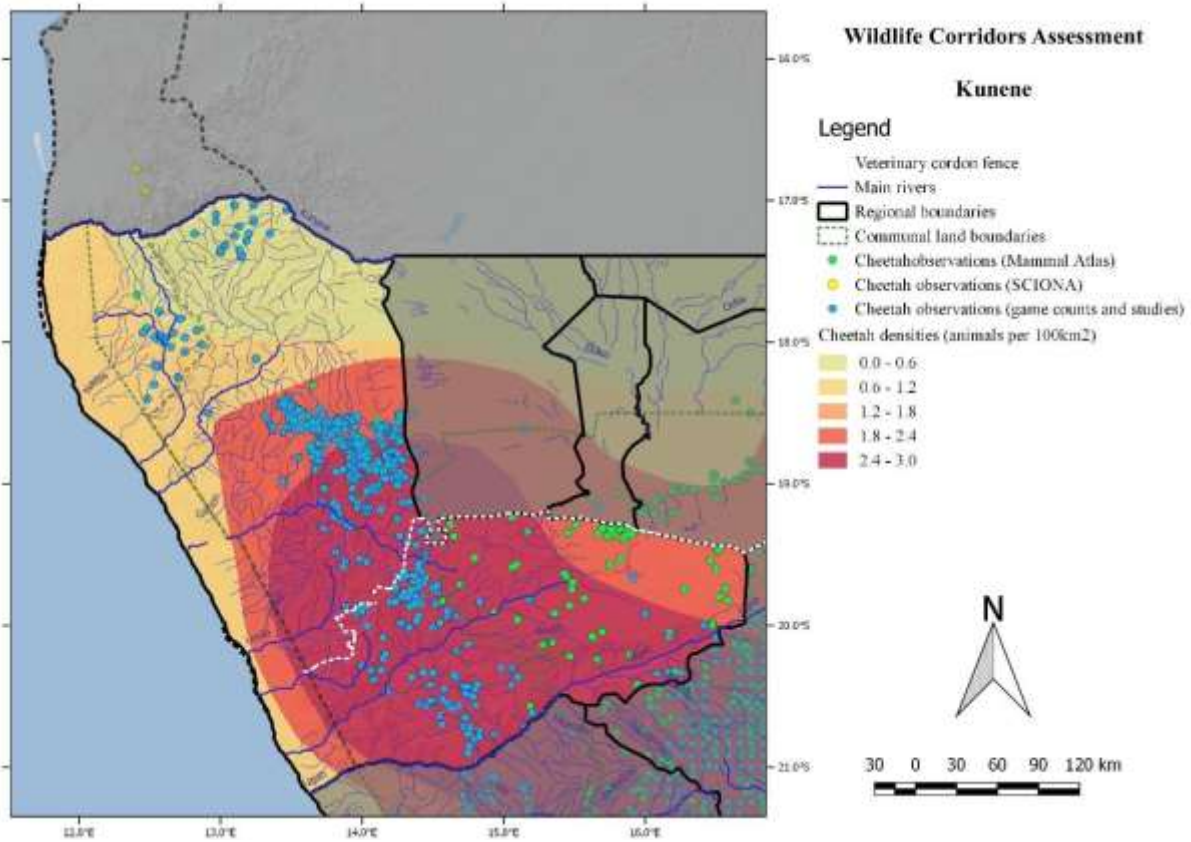


Figure 56. Reported sightings of cheetah in SCIONA study area and adjacent parts of Kunene region.

The Iona cheetah population appears to be genetically like the Namibian counterpart based on a limited scat sample size ($n = 22$) genotyped at 8 loci (Fabiano et al., unpublished data). This is reported to be an indicator of recovering herds of the species' prey base in southern Angola (Morais et al., 2018).

Data collected in the Skeleton Coast show that cheetahs are well adapted to the arid environments of the Namib Desert (Portas et al. 2017). Males and females without offspring barely visit waterholes and can go several months without drinking. Due to its wide-ranging requirements, cheetah presence is a clear indication of well-preserved continuous habitat with healthy prey populations. Cheetah also preys on livestock when it's left unattended because kraaling and herding are methods that have considerably reduced cheetah related livestock losses (Marker et al., 2018; Melzheimer et al., 2020).

Cheetah are globally listed as vulnerable on the IUCN red list, while a plethora of specialists have suggested the status should be upgraded to endangered (Durant et al., 2017). This is because of declines across most of its range, and that the Namibian stronghold for the species is largely on unprotected farmland where conflict with livestock owners is rife. Since most of the distribution of wild cheetah in southern Africa exist outside of formally protected areas (Durant et al., 2016), the Skeleton Coast–Iona Transfrontier Park could be an important conservation area for the species as general wildlife populations increase. The healthy population found in most of the Namib Desert (Portas et al., 2017) confirms that the combination of absence of conflict with humans and reduced competitors makes Namib a valuable refuge habitat for the species. Increases in the cheetah population of SCIONA will therefore have globally significant value.

Population density in the northern Namib using as methodology a combination of GPS telemetry and camera traps set at marking sites was estimated at 0.1 cheetahs/100 km² (Portas et al., 2017). We would expect similar densities to be found across the SCIONA study area. However, Fabiano et al. (unpublished data) estimated that cheetahs occur across approximately a third of Iona's plain habitat, at a density of 0.61 individuals/100 km² supporting the attributed value of SCIONA for the species.

7.4.3 Black faced impala (*Aepyceros melampus petersi*)

Very few, if any, black-faced impala still occur in the study area, but historically the Kunene riparian was the core of their distribution. Reintroducing breeding groups to the Kunene could be easily achieved, and would be an important conservation management action for the TFCA. It may also in the future lead to the potential of trophy hunting, since the sub-species is considered a rare trophy among hunters.

Distribution

Once the core distribution of the subspecies, the SCIONA area now offers infrequent sightings of black-faced impala. More than half of the total estimated population of 3 000 animals occurs in Etosha National Park after a translocation of 305 animals between 1968 and 1971 (Joubert, 1971) from the SCIONA area. With effective conservation and law enforcement, re-establishment of populations of the subspecies on both sides of the Kunene River could be considered.

In 1934, Shortridge (1934) referred to the subspecies as Angolan impala and observed the Kunene River riparian to be the species' core distribution area where they were plentiful. By 1971 their population in the area of the Kunene was limited to areas around Epupa, Otjipembe and Swartbooisdrift. Currently small populations exist in the southern communal conservancies of the Kunene region, but none are known to presently occur in the TFCA¹⁷ (Figure 57). Extended periods of drought, grazing pressure and overhunting have been thought to be the main cause of the local extinction of black-faced impala from the SCIONA core area in Namibia. Presently Etosha National Park has become the main sanctuary for the subspecies. This population grew steadily from a small group of around 60 at Otjovasandu to high numbers across all woody dominated areas of the park (Joubert, 1971). As the colloquial name Angolan impala of 1934 suggests, black-faced impalas were plentiful in the riparian woodland of the southern Angolan rivers but their current distribution is unknown.

Ecology

The impala is a mixed feeder (Bothma and Toit, 2010), and the black-faced impala subspecies is no different. It was observed to graze and browse in equal volumes in times of good rainfall when grazing is readily available. In dry periods however, they rely heavily on browse in riparian woodland. Leaves of *Acacia* and *Combretum* species are preferred, and especially the leaves and pods of *Faidherbia albida*.

¹⁷ EIS, 2020. Atlasing in Namibia | Biodiversity monitoring in Namibia [WWW Document]. URL <http://www.the-eis.com/atlas/> (accessed 4.3.18).

Conservation concerns

Impala's habit of occupying habitats with dense bush, e.g. the riparian forest of the Kunene River, makes them vulnerable to illegal hunting through hidden snares or walk-and-stalk practices. Plains species such as springbok and oryx are more likely to spot and flee from humans which are usually seen from a distance. The plains also provide less cover for illegal activities and camouflage of snares and traps.

Importation of common impala (*Aepyceros melampus melampus*) into the study area must be avoided. Hybridisation with black-faced impala would threaten the genetic integrity of the endemic, black-faced impala population.



Figure 57. Suspected distribution of black-faced impala in the SCIONA study area in the early 2000's (Mendelsohn et al. 2002).

7.4.4 Flagship plant species

There are many flagship species amongst plants of the Kaokoveld; iconic species with high aesthetic or scientific value, especially succulents. Many of those species have high horticultural potential but few were tested in cultivation trials. Flagship plant species are listed per habitat of the SCIONA study area.

7.4.4.1 The Namib Desert:

Lithops ruschiorum is an endemic succulent of Namibia and the only lithops known to occur in SCNP (Ministry of Environment, Forestry and Tourism, 2021) (Figure 58). This is also the northernmost occurrence of this genus.

Welwitschia mirabilis is a near-endemic gymnosperm of the Namib Desert, attracting many tourists in the central Namib (Figure 59). It is the only species within the family of the Welwitschiaceae and has occurred here for more than 100 million years. There are several geographically and genetically separated populations of the species (Jacobson and Lester 2003, Jacobson et al. 2014; Bombi et al., 2021; Jürgens et al., 2021) and there is some evidence that the Kunene population is threatened by climate change (Bombi et al., 2021). Their sensitivity to climate change is based on correlations between plant health and predicted changes in environmental conditions (unpublished data).



Figure 58. *Lithops ruschiorum* growing in the SCNP. (Photo by Malan Lindeque.)



Figure 59. A large *Welwitschia* plant, part of the central Kunene population, growing on a steep fragile sandstone slope in the Kaokoveld landscape near Orumborovimbari. (Photo by Theo Wassenaar)

7.4.4.2 Pro-Namib:

The succulent Elephants-foot (*Adenia pechuelii*), endemic to Namibia, and Kobas sp. (*Cyphostemma* spp.) form excellent flagship species. Three Kobas species occur in the study area (Annex 1). The large-leaved Sterculia (*Sterculia quinqueloba*) is also remarkable as a medium-sized tree with a beautiful and characteristic white stem. It does occur in other southern African countries, but only in areas with much higher rainfall. It is also found in the mopane shrubland.

7.4.4.3 Mopane shrubland:

Flagship plant species in the mopane shrublands include the Baobab (*Adansonia digitata*), which is used for a variety of purposes by local people, the Bushman poison (*Adenium boehmianum*), a poisonous succulent shrub with beautiful pink flowers, the Phantom tree (*Moringa ovalifolia*), a deciduous, succulent-stemmed tree of which the bark is eaten by game and the roots by herders during drought (Mannheimer and Curtis 2009), and the Bottletree (*Pachypodium lealii*), a deciduous, succulent-stemmed tree with beautiful white flowers in spring.

7.4.4.4 Afromontane vegetation:

The Kaoko tree euphorbia (*Euphorbia eduardoi*) is a magnificent single-stemmed, succulent tree endemic to the Kaokoveld and growing on rocky slopes (Figure 60).



Figure 60. The Kaoko tree euphorbia (*Euphorbia eduardoi*) at Middelberg, Otjihipa range, Namibia. The tree can easily reach a height of 6 metres (Photo by Vera De Cauwer).

7.5 INVASIVE ALIEN SPECIES

Alien plant species were recorded in abundance along the Kunene River, but also many of the ephemeral rivers such as the Hoanib. They compete with indigenous species and several of the most vigorous species have the potential to suppress local vegetation. As indicated in the new management plan of Skeleton Coast National Park, the rivers are “ideal transmission belts” for infecting both parks with alien species from upstream catchments.

The most invasive species that need control measures are:

- Wild Tobacco (*Nicotiana glauca*) (Figure 61): very abundant close to the Kunene riverbank, especially after the flood of February 2020. The plant has many seeds and is highly invasive. The best method to remove it is to take it out with the root, as the plant will resprout from the root if it is cut. Gloves are advised. If that is not possible or takes too much time, the flowers/seeds should be cut off the plant as soon as possible and burned (or dried out).
- Castor Oil plant (*Ricinus communis*): very abundant along the Kunene riverbank, especially after the flood of February 2020, but also along perennial rivers such as the Curoca. The best method to remove it is to take it out with the root, as the plant will resprout from the root if cut. Gloves are needed as the plant is fairly toxic. Although uprooting this plant is a difficult job because of its large, strong tubular taproot, it is the best way to get rid of it over the long term. If this removal spans a long period, the seeds can be removed in the meantime. The seeds are toxic and resistant to fire so should not be burned.
- Thorn Apple, Stinkblare (*Datura innoxia*): very abundant along the Kunene after the flood of February 2020, also further away from the riverbank. The plant is also found in ephemeral rivers such as the Hoanib and the Gomatum, a river that ends in the Hoarusib. The best method to remove it is to take it out with the root, as the plant will resprout from the root if cut. Uprooting is fairly easy for this plant. Gloves advised.

Manual removal is very labour intensive but there are not many other options in a national park, especially as applying poison may cause worse problems than the invasive species do. Therefore, it is advised to work together with communities upstream the river and work downstream. The new management plan of Skeleton Coast National Park advises working with the Sesfontein community for the Hoanib. Similar initiatives will be needed elsewhere to tackle the problem. For example, the Pediva community can assist with the clearing of the Curoca, the Purros community with the clearing of the Hoarusib, and the Epupa, Monte Negro and Otjiningwa communities with the Kunene. It should be possible to get external funding to train communities and perform the removal of alien species in cooperation with them.

Other alien species found in the Kunene River Valley included Mexican Prickly Poppy (*Argemone mexicana*), Indian Heliotrope (*Heliotropium indicum*), Phoenix sp. (*canariensis* or *dactylifera*), Giant Wattle (*Leucaena leucocephala*), and the climber *Cardiospermum* sp. (probably balloon vine, *C. halicacabum*). Mexican Prickly Poppy is highly invasive and should be removed.



Figure 61. Invasive alien vegetation near the Kunene Riverbank: Wild Tobacco is the tall plant on the left with Litogyne gariepina around it. A Castor Oil plant can be seen behind the donkey and a thorn-apple at the front right (Photo by Vera De Cauwer).

7.6 HUMAN-WILDLIFE CONFLICT

Human-wildlife conflicts (HWC) are a major problem in the SCIONA study area. On the Angolan site, the communities of Monte Negro and Otjinungua indicated that crocodiles were the biggest problem. Baboons, caracal, hyenas, snakes and leopards are a problem in Cambeno, Humbi, Colonjai, and Pediva, where they mainly attack goats and chicken (SCIONA: Iona field trip report. Internal Field trip report, 2019; Nacale, 2021). Cheetah and leopard prey mainly on cattle and donkeys. The communities of Humbi, Cambeno and Colonjai indicated that attacks on humans are rare, although crops and houses (sambos) are also invaded. Humans, in turn, invade the territory of the wild animals in search of water and food for their livestock (Nacale, 2021). Communities lack knowledge of managing and monitoring HWC, and do not receive assistance from the authorities when predators kill livestock. They receive little direct benefits from the park, but they expressed their willingness to conserve wildlife for the future generations.

HWC incidents are relatively well documented and monitored in Namibia. Figure 62 illustrates a steady increase in incidents over five years for the six main carnivore species in Namibia. In the SCIONA study area, most incidents are recorded in the most eastern of the Namibian target conservancies, Epupa and Okanguati, as illustrated in Figure 63. The increase in HWC's coincides with the increasingly debilitating drought conditions the communal conservancies have seen. This in turn led to an out-migration of wildlife and increased reliance of carnivores on domestic livestock as prey.

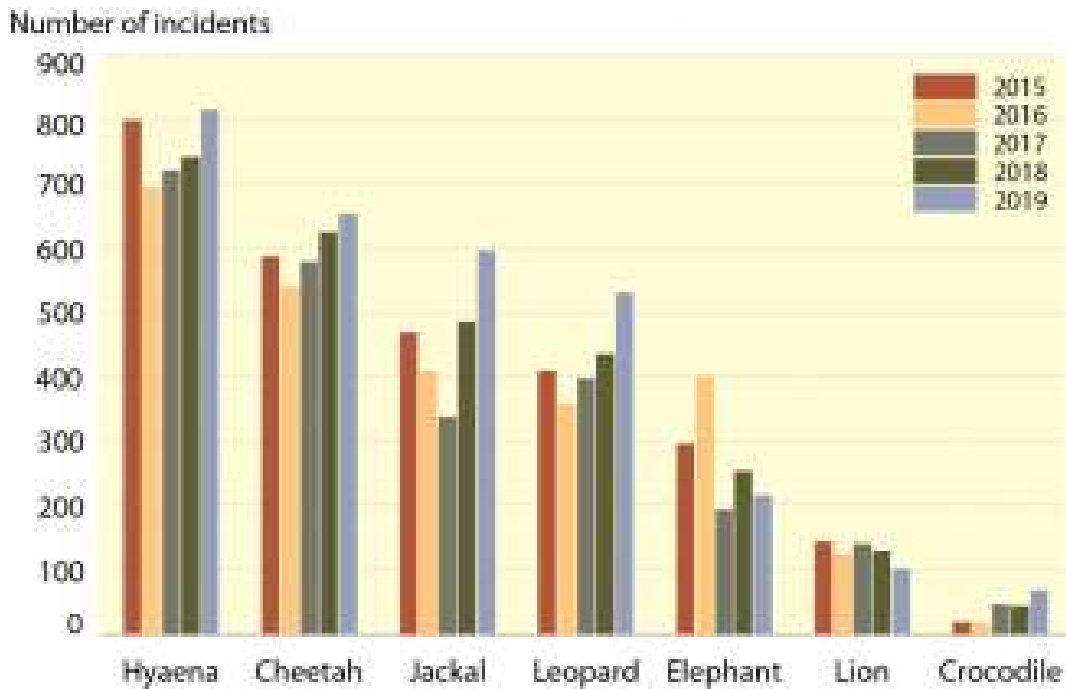


Figure 62. Human-wildlife conflict incidents in Kunene and Erongo regions of Namibia over the five year period 2015 to 2019.

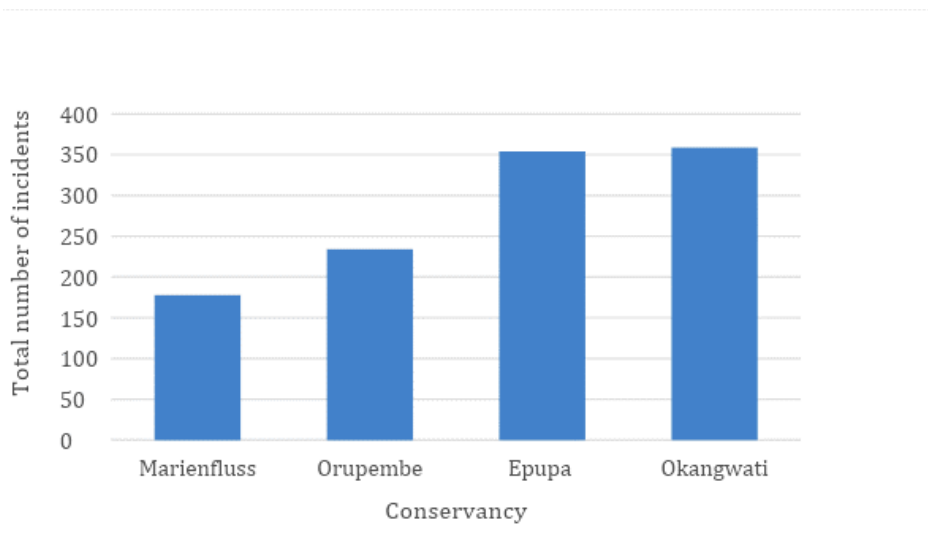


Figure 63. Total number of Human-wildlife conflicts within the 4 Namibian conservancies over 5 years (2012-2016). Source: Raw Data from Event Book 2017 Database, provided by NACSO.

Human-wildlife conflict in the Namibian SCIONA study area is high (per capita) in comparison to other parts of Namibia. This is partially because of human and livestock losses to crocodiles along the Kunene River in the Marienfluss and Epupa conservancies, and an increase in predation from spotted and brown hyaena during the protracted drought.

Further analysis of existing HWC data reveals that spotted hyaena, brown hyaena (*Hyaena brunnea*), leopard (*Panthera pardus*), cheetah, and black-backed jackal (*Canis mesomelas*) were the main species causing the conflicts (Figure 64). Cheetah caused most conflicts in Orupembe and Okanguati, hyaena in Marienfluss and caracal and leopard in Epupa. During the SCIONA project, a detailed analysis for the HWCs in the period 2014 - 2019 was done which confirmed cheetah causing most conflicts in Okanguati (32%) and caracal in Epupa (35%). Most of the conflicts occurred near permanent settlement areas (Iiyambula, 2021).

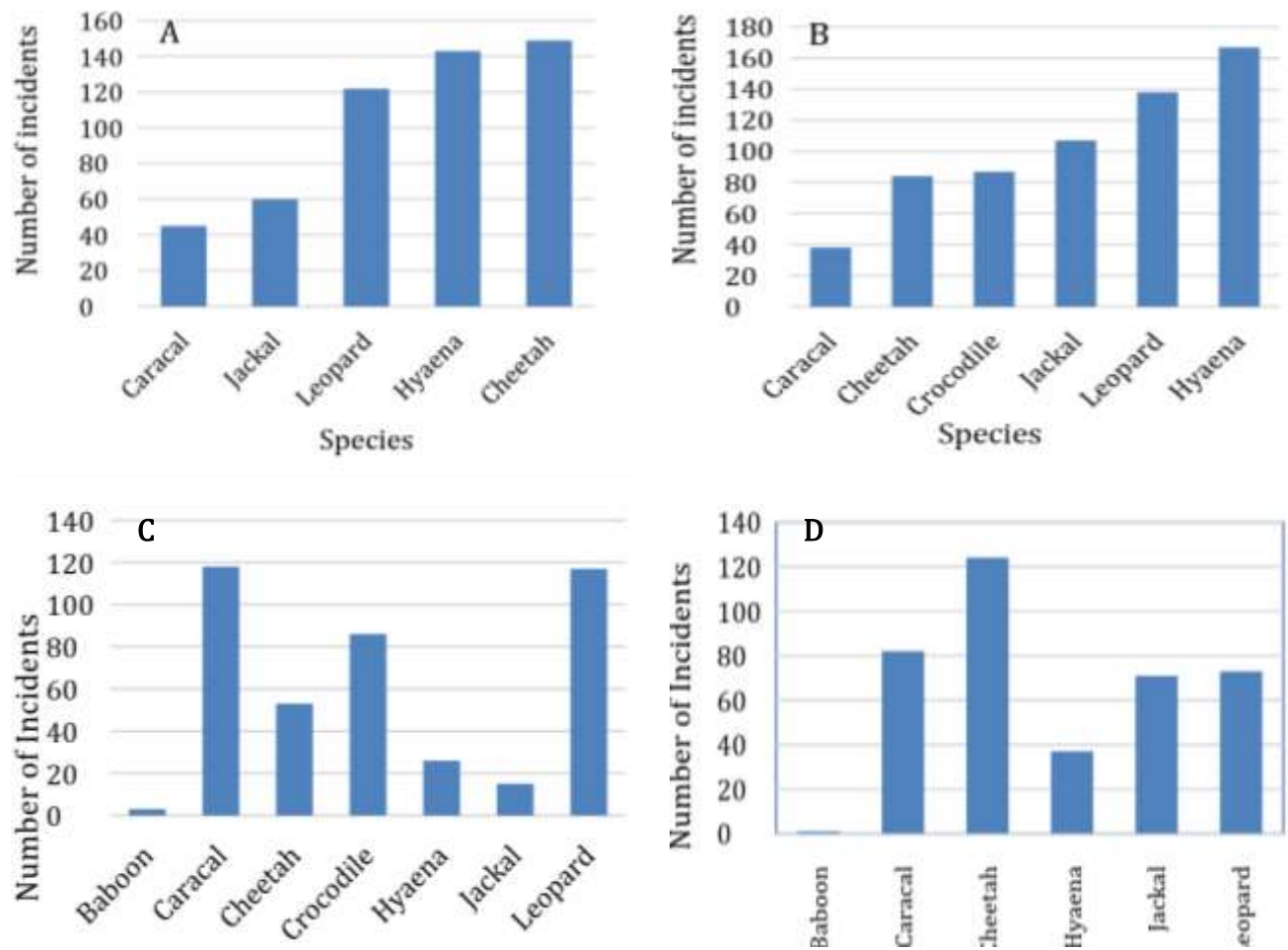


Figure 64. Predator species causing human wildlife conflict incidents from 2005 to 2016 for Orupembe conservancy (A) and Marienfluss conservancy (B) and from 2012 – 2017 for Epupa (C) and Okanguati (D). Source: Raw Data from Event Book 2017 Database, provided by NACSO.

About 84% households surveyed in the four target conservancies (Marienfluss, Orupembe, Okanguati and Epupa) reported having experienced livestock loss to predation. Orupembe and Epupa had the highest percentage of households experiencing livestock losses (about 94% in each conservancy). Apart from livestock predation, eight households in Epupa Conservancy and one household in Okanguati reported having had crops raided by baboons and monkeys. However, no property damages and loss of human life were reported.

Crocodile was ranked third in Epupa conservancy in terms of the number of incidents recorded in six years (2012 – 2017) (Figure 64 C and D). During SCIONA interviews, it appeared that crocodiles were perceived as the most problematic species in the Marienfluss and Epupa conservancies, even if the species did not cause most of the recorded HWC's. The Iona community also ranked crocodiles as the species causing most problems, due to the threat to human lives. This perception was shared by members of the Epupa community. Several cases of crocodile poisoning took place during the SCIONA project.

Hunting by the communities is a common activity in Iona and the Namibian conservancies. The communities mainly hunt for their own consumption, and they will not hunt carnivores ("no animals with claws"). In Iona, hunting is mainly done with traps. If hunting is far from home and there is no means of transportation, they cut the animal and dry the meat. Currently, the issue of hunting is not openly addressed because of the ban on hunting in the Park, however these communities hunt only for food. Most of the hunting for commercial purposes is done by people who do not inhabit the Park (Nacale, 2021).

7.7 RESPONDING TO CLIMATE CHANGE

7.7.1 Climate change mitigation

A key strategy to facilitate the adaptation of wildlife to climate change is the development of open and interconnected landscapes. This facilitates the movement of wildlife in response to increasing spatially and temporally unpredictable and erratic rainfall associated with climate change for the region (Turpie et al., 2010). SCIONA's objective of supporting a large open landscape co-managed across boundaries and between parks and neighbours adds well to this adaptation strategy. Another key strategy recommended to manage climate change impacts is effective monitoring programmes for protected areas, another objective of the SCIONA project. Furthermore, grazing by livestock should be strictly limited on the highest mountains of the Kaokoveld Centre of Endemism, as its diversity rich fauna and flora is very sensitive to climate change.

7.7.2 Plant species providing early warning signs of climate change

The steep rainfall and temperature gradient near the escarpment and on the highest mountains can cause an accelerated effect of climate change on range-restricted species. Hence good indicator plant species for early warning of climate change impacts in the Kaokoveld include escarpment species with limited range, such as:

- Kaoko Ceraria (*Portulacaria longipendunculata*): a small tree endemic to the Kaokoveld of which quite a few dead individuals were observed in Iona National Park,
- Kaoko tree euphorbia (*Euphorbia eduardoi*): a magnificent single-stemmed, succulent tree endemic to the Kaokoveld and only growing on rocky slopes,

- Short stem candelabra tree (*Euphorbia otjingandu*): the only records of this Kaokoveld endemic are in Namibia; in the Otjihipa mountain range and the Kunene River valley downstream of the Ruacana Falls (Swanepoel, 2009). The tree showed signs of distress, mortality, and browsing by baboon at Middelberg, the mountain visited during the SCIONA project (SCIONA Field trip report: Biodiversity survey of mountain tops in the Kaokoveld Centre of Endemism 2021) (Figure 65),
- *Euphorbia berotica*: this is a little known succulent herb, looking very similar to *E. mauritanica* that officially only has been recorded in southwestern Angola (Leach 1975). It is probably the Euphorbia species we found at the top of Serra Cafema in Iona National Park. The species shows signs of distress in the Namibian part of the study area (Wessel Swanepoel, personal communication 2021),
- Large-leaved Sesame tree (*Sesamothamnus leistneri*): a small and iconic tree endemic to the Kaokoveld, first recorded in Angola during the SCIONA project, at Serra Tchamalinde. Many trees are dying because of the ongoing drought in the study area (Wessel Swanepoel, personal communication 2021),
- Namibian myrrh (*Commiphora wildii*): although this shrub is more abundant and has a much larger range than the previous species, it is also a relevant indicator species of the escarpment as the resin is harvested by the ovaHimba and overharvest is possible during drought periods. Moreover, models developed during the SCIONA project do indicate that range restriction is possible. Hence, sustainable use requires close monitoring.



Figure 65. Dead short stem candelabra tree or Otjingandu in Himba (*Euphorbia otjingandu*) at Middelberg, Otjihipa range, Namibia (Photo by Vera De Cauwer).

An additional indicator of climate change is the range of the mopane woodlands. The woodlands are characterised by the woody species *Colophospermum mopane*, which mainly occurs as a shrub in the study area but can become a large tree in the river valleys and areas with more rainfall. During SCIONA workshops, the local communities made it very clear that the mopane is considered the most important tree. It provides good quality firewood, construction material, medicines, fodder for game and domestic animals, and young bark for ropes and it is a food plant for mopane worms (Madzibane & Potgieter, 1999, Mannheimer & Curtis, 2009).

Informal reports (Wessel Swanepoel, personal communication 2018) and a study of Venter et al. (2018) indicate that the mopane shrub and woodlands of northwestern Namibia are thickening and expanding towards the east. On the other hand, drought-induced mortality of the mopane tree was observed in South Africa (Macgregor and O'Connor 2002). Further monitoring and research are needed to establish a potential range shift of the mopane woodlands. The habitat map that is currently being modelled (Figure 21) will provide an essential tool in this regard.

8 MONITORING

The main goal of a monitoring programme in protected areas is to assess the implementation of the area's management plan and provide early detection of ecological changes or new threats. It relates to the ecosystem and natural resources, as well as to management effectiveness. Monitoring, therefore, needs to be integrated into adaptive management and indicators should be scientifically robust. Moreover, training of park staff is needed to ensure that data are correctly recorded (MEFT, 2021). This chapter aims to focus on the research background for monitoring relevant indicators in SCIONA, even though no management plan exists yet. Certain goals, such as to maintain biodiversity, are part of each protected area's management plan.

Long term monitoring within the SCIONA study area is currently limited, although a biodiversity and climate observatory was established at Espinheira, in Iona National Park, by ISCED in cooperation with the University of Hamburg.

8.1 INDICATORS OF ECOSYSTEM STRUCTURE AND FUNCTIONING

The previous section described a range of indicators for ecosystem structure and functioning. Perennial grasses were described as an ideal indicator for primary productivity, however, they are very difficult to monitor (7.3.2). Using satellite images to monitor temporal and spatial variation in grass production is complicated by the high temporal and spatial variability of the rainfall in arid regions, including the SCIONA study area. Moreover, it is only possible to distinguish perennial from annual grasses on hyperspectral satellite images. This makes the assessment of overgrazing and land degradation based on satellite images difficult unless hyperspectral images or a long time series can be used. An example of a relevant long time series are the 1 km resolution NDVI data of 40 years, a dataset developed by Thompson (2021) for Namibia and currently under development for other SASSCAL countries.

A major requirement for key indicators is that they are measurable within the constraints of available management capacity and information. If long satellite time-series and the resources to analyse them as part of a continuous monitoring system are not available, it is better to focus on monitoring the other key species described in Chapter 8, especially those that may provide early warning for overharvesting, overgrazing/browsing, or shifts in species ranges and biodiversity.

8.1.1 Baseline data for plant indicator species

During the SCIONA project, occurrence data were collected for several indicator species described in chapter 7. Occurrence data were collected for amongst others the following plant species through observations and with apps that were developed for the project:

- *Acanthosicyos horridus*
- *Boscia microphylla*
- *Boscia tomentosa*
- *Commiphora kuneneana*
- *Commiphora mossamedensis*
- *Commiphora virgata*

- *Commiphora wildii*
- *Euphorbia damarana*
- *Euphorbia ohiva*
- *Maerua kaokoensis*
- *Moringa ovalifolia*
- *Pachypodium lealii*
- *Sesamothamnus benguellensis*
- *Welwitschia mirabilis*.

The baseline data allowed the creation of habitat maps for each of the plant species, such as illustrated in Figure 66 and Figure 67. More information can be found in the Masters' thesis of Phillipus (2021). Developing species distribution models will also contribute to determine the exact extent of the Kaokoveld Centre of Endemism, something that is currently unknown (Craven & Vorster, 2006). The centre's boundaries can be defined with a systematic approach that determines the area of congruence between endemic species distributions (Craven & Vorster, 2006).

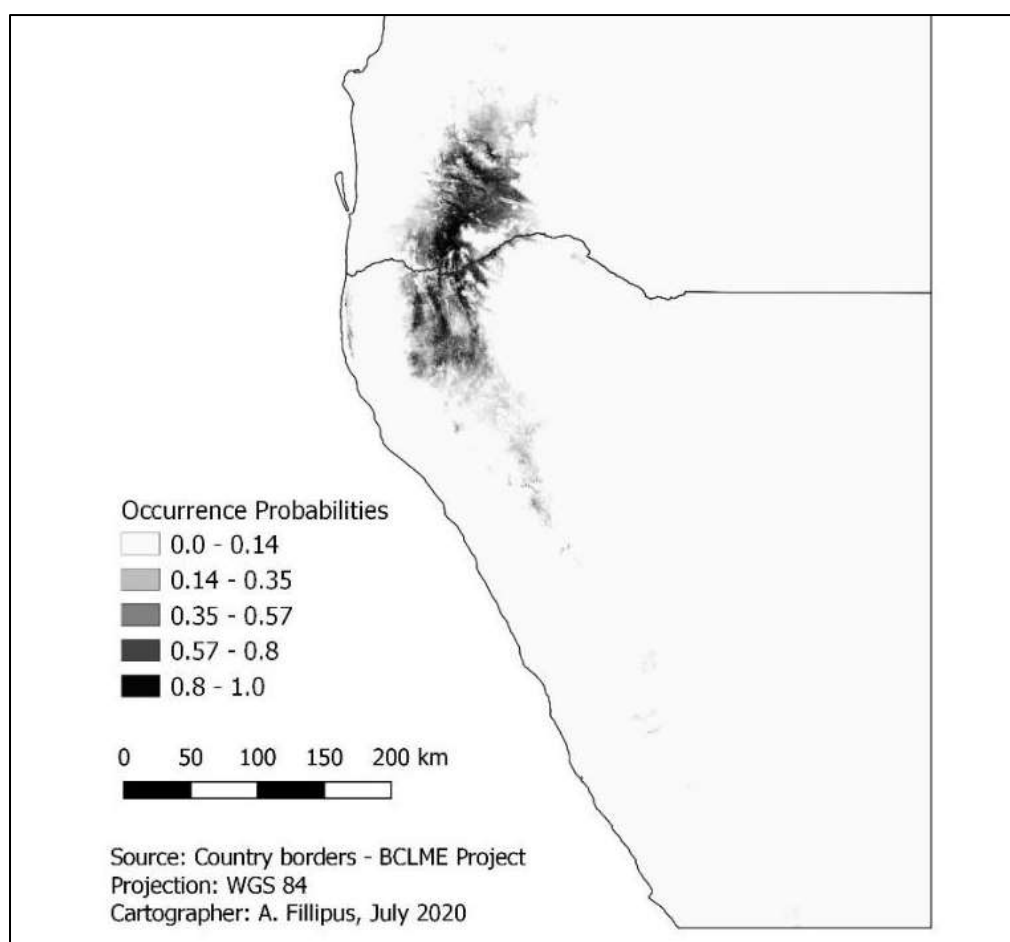


Figure 66. Habitat and potential distribution of *Boscia tomentosa*. The distribution is represented as an occurrence probability. A threshold of 10 percentile training presence, equaling 0.14, was applied (Modelling: A. Phillipus).

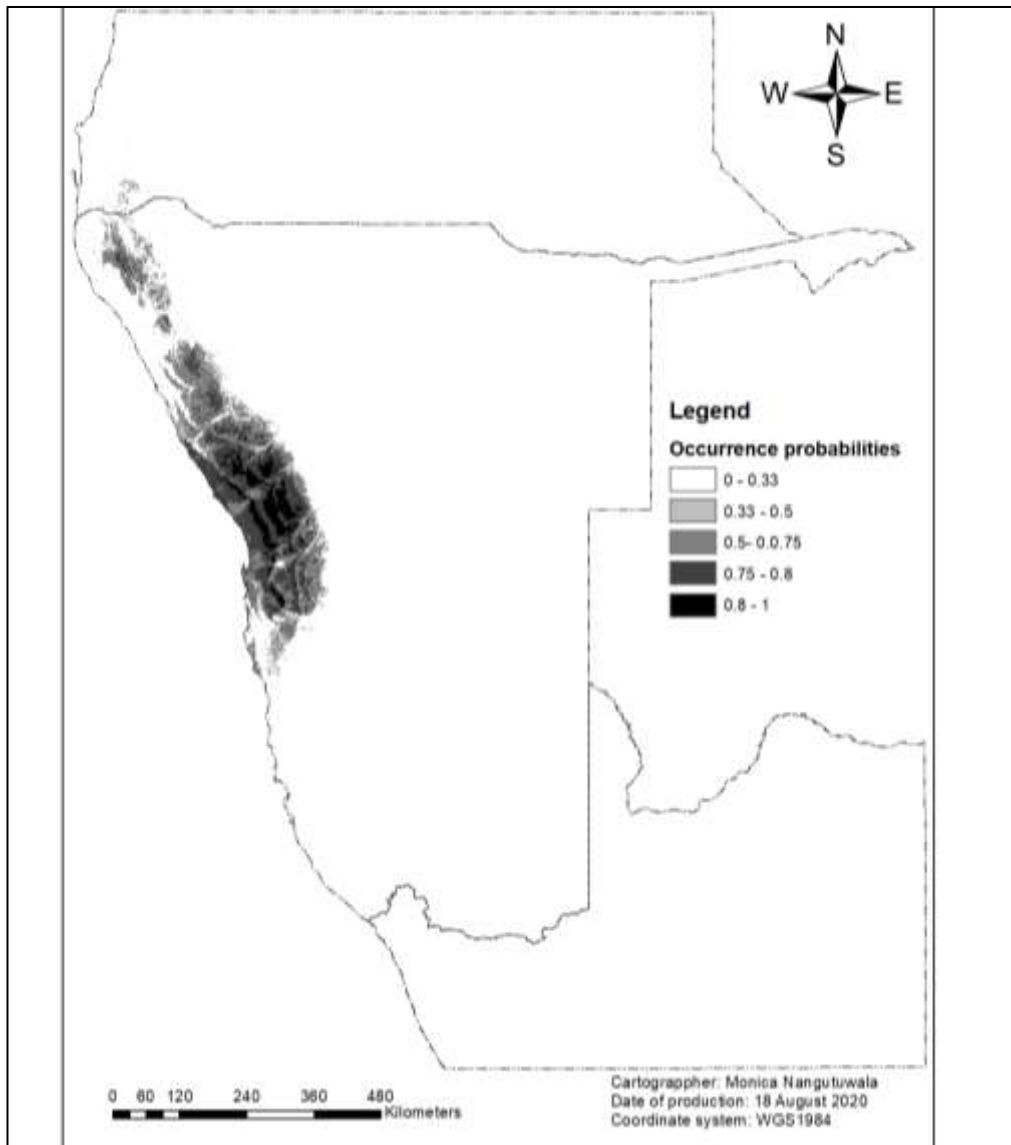


Figure 67. Habitat and potential distribution of *Euphorbia damarana*. The distribution is represented as an occurrence probability. A threshold of 10 percentile training presence, equaling 0.33, was applied (Modelling: M. Nangutuwala 2021).

8.1.2 Baseline data for animal indicator species

The data on the occurrence of wildlife species were collected with a range of methods during the SCIONA project: species observations collected with the EpiCollect and WAR Apps, camera traps, telemetry, and detection on high-resolution aerial photographs. While the aerial photographs provided a snapshot in time and can be a valuable monitoring tool, the camera traps and telemetry data enabled a better detection of their activity patterns. Specifically, camera traps were installed near the Kunene River on the western side of the Otjinhungwa corridor (Figure 28) during the project to detect potential movements.

The aerial count that was done for the project was conducted using the same methods as the previously done survey of INP. Results showed that wildlife densities were much higher in Iona for the most common species such as oryx, ostrich, zebra and springbok. On the Namibian side, wildlife is mainly concentrated in the Orupembe area, where two intermediate ephemeral rivers provide habitat while water is available in several drinking troughs and the springs at Ougams and Sanitatas. The ephemeral rivers also allow wildlife to range into the SCNP. Livestock densities were slightly higher on the Namibian side, especially in the Epupa and Okanguati conservancies. The aerial count's findings are described in more detail in Appendix 4. We recommend that an aerial count, covering the same flight paths as before, should be repeated once every five years.

Large mammals can relatively easily be equipped with telemetry trackers to monitor individuals and/or observations recorded by game guards in the field whilst on patrol. Most telemetry trackers are expensive, their batteries have only a limited lifetime once deployed, and depending on the species can be time intensive to trap/catch, as was illustrated during the SCIONA project. Livestock such as cattle, sheep and goats can also be used as proxy species and equipped with telemetry trackers. A potential solution could be Ceres Tags, a revolutionary and low-cost GPS satellite system of monitoring cattle (and wildlife) that is used in Australia and being piloted by Giraffe Conservation Foundation in Southern Africa (Julian Fennessy, personal communication).

8.1.3 Permanent monitoring plots

Monitoring of sensitive habitats in the Namib and Pro-Namib is ideally done with permanent sampling plots. Regular assessments of biodiversity and vegetation structure in these plots provide trends of data on natural resources and provide an early warning system for changes in ecosystem health. A permanent sample plot has been established in the pro-Namib zone of Iona, Espinheira, for vegetation sampling purposes. No permanent sample plots exist in the riverbeds, dune hummocks, or rocky outcrops.

During the SCIONA project, vegetation sample plots were established in the central zone of Iona National Park and along the riverbeds in northern Kunene. The plots in Iona include the sensitive Afromontane habitat of three mountaintops of the Himba mountains: Middelberg in the Otjihipa range of Namibia, Serra Cafema and Serra Tchamalindi in Iona National Park. The plots could form the basis of a monitoring network of sensitive habitats. Next to vegetation, monitoring of invertebrate diversity in the permanent sample plots would be advised. Several small plots were already established in the dune hummocks of SCNP for these purposes.

8.1.4 Monitoring of invasive aliens

The removal of invasive alien species (Section 8.4), should be combined with regular monitoring of plant occurrence along the major riverbeds. As the area is vast, it is advised to start with removal and monitoring upstream, as plants will otherwise continue seeding the areas downstream.

8.2 COMMUNITY-BASED MONITORING

Communal conservancies in Namibia are already involved in biodiversity monitoring. More information on the current system of ecosystem monitoring is described in the Community Assessment Report. While the event book has proven to be a resilient and very useful monitoring system used by the Namibian communities, the system has a few shortcomings. For example, location accuracy, plant species, climate and soil data, etc. are often insufficient or missing. These shortcomings could be addressed by complementing it with the use of tools (GPS's and apps), as piloted by the SCIONA project. However, another, and potentially more efficient method, would be for these missing data to be collected by researchers and students working in close cooperation with park management and communities.

Local communities have a good knowledge of indicator species for local land use units. A study of Verlinden & Davot (2005) used key informants in north-central Namibia to understand the local indigenous environmental knowledge (IEK). The key informants had a good environmental knowledge and were appointed by the headman of the villages. All key informants could identify woody species while the majority identified the main common grass and herb species. A minority of informants identified almost all grass and herb species. Similar observations were made in the target communities during the SCIONA project and a plant app was developed in cooperation with some of the key informants. Another app was developed in cooperation with game rangers to record wildlife observations or human-wildlife conflicts (WAR app). The data feed into the SCIONA data portal that is currently under development.

8.3 PARA-ECOLOGISTS AS AN APPROACH TO BENEFIT COMMUNITIES IN THE SCIONA STUDY AREA

Para-ecologists are members of local communities with no academic background in ecology who are trained on the job to support research and project activities related to the environment (Schmiedel et al., 2016). Community members from each of the four target conservancies in Namibia and some community members from Iona National Park were trained to become para-ecologists. The training in conservancies particularly targeted community game guards. The training was done by different project team members on various aspects of natural resource management and monitoring. These trainings included: use of GPS devices, human wildlife conflict data collection, co-design of wildlife monitoring technologies, guidance of ethnobotanical tours, and vegetation monitoring. The para-ecologists have been getting incentives for their activities. Therefore, communities are benefitting from the para-ecologist approach through job creation and skills development. It is also anticipated that the trained community members may have competitive advantage and get recruited by other researchers in the future due to the experience they gained during the SCIONA project. In total, 21 para-ecologists have been trained in Namibia and Angola. The details on community members trained and the training received are shown in

Table 3. More information on the para-ecologists is given on the SCIONA website and in the SCIONA videos (sciona.nust.na).

Table 3. A summary of the training received by para-ecologists in the SCIONA study area.

| Training received | Name | Conservancy |
|----------------------------|------------------------|--------------------|
| GPS | Jatemberaike Mutambo | Epupa |
| | Ketupuea Tjिताura | Epupa |
| | Kakondo Veriunga | Okanguati |
| | Karipangura Tjiposa | Okanguati |
| Ethnobotany | Fillipa Tjimbiru | Iona national park |
| Digital wildlife recording | Kautjikua Tjivinda | Orupembe |
| | Uakaevisa Tjisuta | Orupembe |
| | Epson Tjanjekua Tjinge | Orupembe |
| | Mavetoto Tjiningire | Orupembe |
| | Iriua Hepute | Marienfluss |
| | Vaandako Tjambiru | Marienfluss |
| | Kazorondu Hevita | Marienfluss |
| | Veturarara Hepute | Marienfluss |
| | Uamanehi Tjiundiro | Marienfluss |
| | Ngahitue Tjihange | Marienfluss |
| | Tjirunga Matias | Okanguati |
| | Veriunga Kakondo | Okanguati |
| | Tjiposa Karipangura | Okanguati |
| | Tjirambi Vaondjavi | Okanguati |
| | Katupewa tjिताura | Epupa |
| | Tjihaori Ngumbi | Epupa |
| | Kuejaike Mujekua | Epupa |
| | Kureja Kapika | Epupa |
| | Usengwa Hembinda | Epupa |
| | Kausanekwa Kavari | Epupa |
| | Tjिताura Ndjundja | Epupa |
| | Uokizombete Tjinge | Epupa |
| | Topias Kazondanga | Epupa |
| | Kauzeerwe Tjiposa | Epupa |
| | Urisavi Rutjindo | Epupa |
| | Kamuzembo Tjiposa | Epupa |
| Katjikotu Kapika | Epupa | |

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APPENDIX 1: THE CLIMATE OF THE KAOKOVELD

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There is a paucity of long-term climate data available for the SCIONA region. As a result of this, to gain an understanding of the long term trends within the region we have analysed the long term bioclimatic records derived from the WorldClim vs2 dataset (Fick & Hijmans, 2017). This dataset through regional spline interpolations provides 19 bioclimatic variables based on global data collected from between 9000-60000 weather stations (variable dependent) for the temporal range of 1970-2000 (*ibid.*). Two trends seem to be evident when analysing these long-term trends within the study area. The first is an increase in rainfall, excluding fog, from West to East with average annual rainfall ranging from near 0 mm in the West to 450 mm in the NE (Figure 68b). Most of this rain appears to fall within a single wet quarter (Figure 68a). Within this long-term rainfall regime there appears to be an increase in rainfall associated with the topography around the Hartmann mountain range.

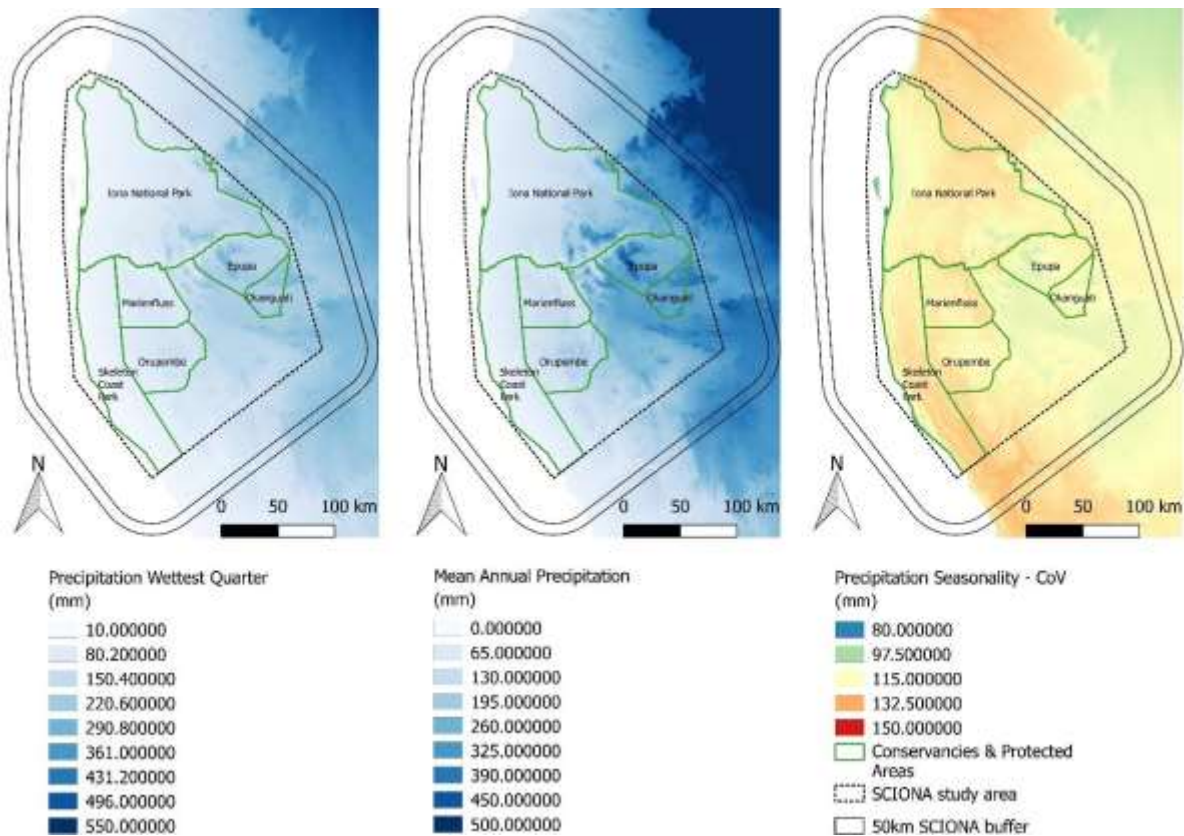


Figure 68. Rainfall climatic variables a) Precipitation during the wettest quarter, b) Average annual precipitation, c) Precipitation seasonality (coefficient of variation) derived from the Worldclim vs2 dataset (Fick & Hijmans, 2017) (Maps: N. Knox).

The second climatic trend appears when analysing the temperature variables (Fig 5 & 6). For the temperature variables the E-W trend is less defined, but there is an increase in the minimum and average temperature from South to North (Figure 69a & b), and a less clear similar trend with the maximum temperature (Figure 69c). The diurnal and annual temperature ranges (Figure 69a & b) show the impact of the coastal climate with small changes (8 & 10°C respectively) along the coastline along the entire study area, and inland temperature changes of ca. 16°C diurnally and ca. 20°C annually. Similar to the trends observed with the rainfall, the area around the Hartmann mountain range appears to differ to the trend of the entire study area, with cooler temperatures and less difference between the minimum and maximum temperatures (Figure 69; Figure 70).

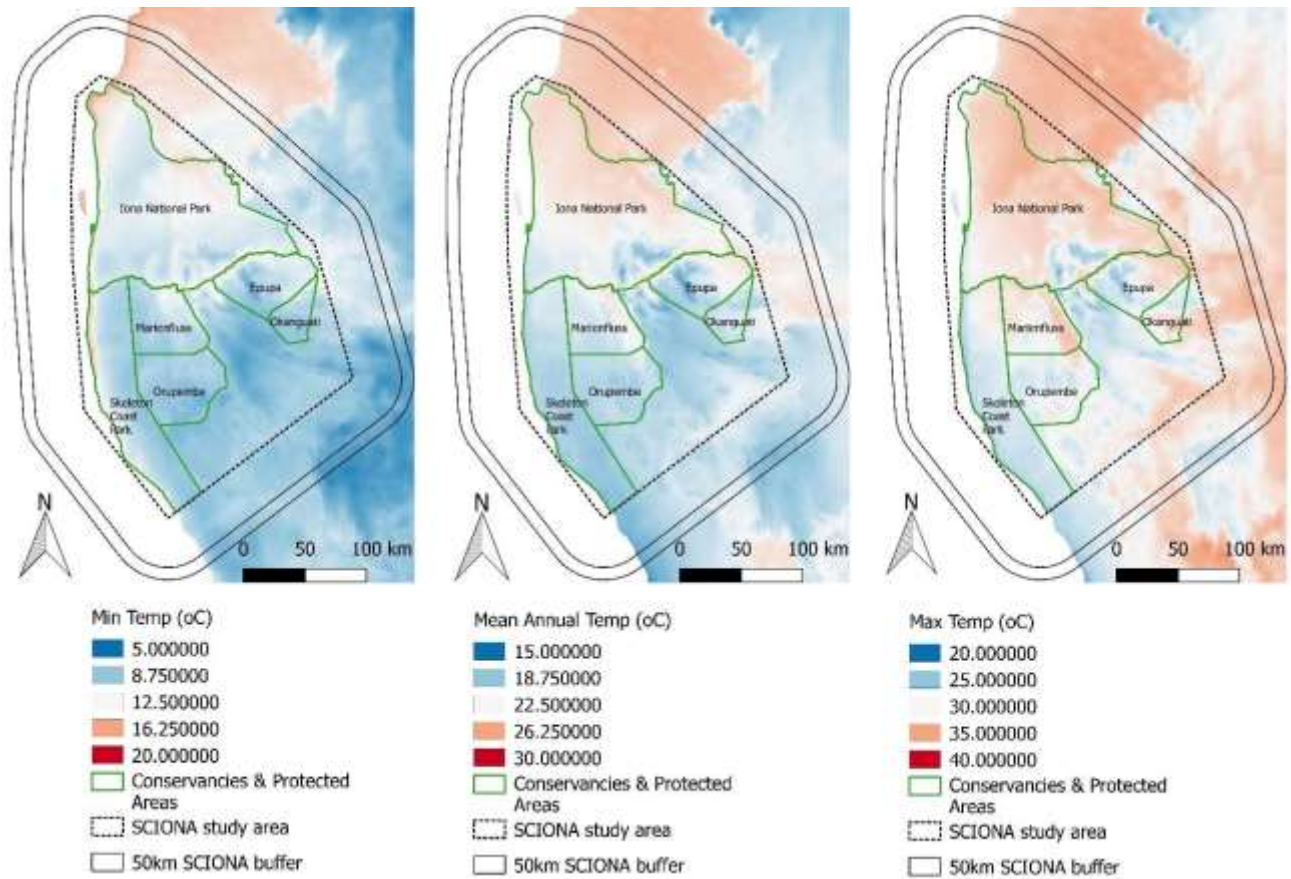


Figure 69. Temperature climatic variables a) Minimum temperature, b) Mean annual temperature, c) Maximum temperature derived from the Worldclim vs2 dataset (Fick & Hijmans, 2017) (Maps: N. Knox).

So-called ‘Benguela Niño’ events – when the South Atlantic is warmer than normal and the Inter-Tropical Convergence Zone progresses further south – bring higher than normal rainfalls to the Kaoko highlands which result in high-magnitude flash floods that last several days (Jacobson et al., 1995; Krapf et al., 2003; Stollhofen et al., 2014), for example in 1982 and 1995.

Since 2015 under the SASSCAL Weathernet program, four weather stations were instrumented within the core study area, and a further three falls within the 50km buffer area (Figure 71). Within the study area the Espinheira station has been operational since 2015, the Iona Coastal and Marienflusstal have both been decommissioned in 2017, thus currently in the core study area there are two operational stations (Espinheira and Okangwati) (Table 1). Analysis of the monthly recordings (derived from the daily observations) for the seven Weathernet stations within the study area, shows a seasonal trend in the minimum temperature, but no clear seasonal trends in either the average or maximum temperature. The minimum temperatures falls within the months May-August. For all stations there is a dry season from May-September, the rainy season appears to be bi-modal, with a small peak in December and the main rains in February/March.

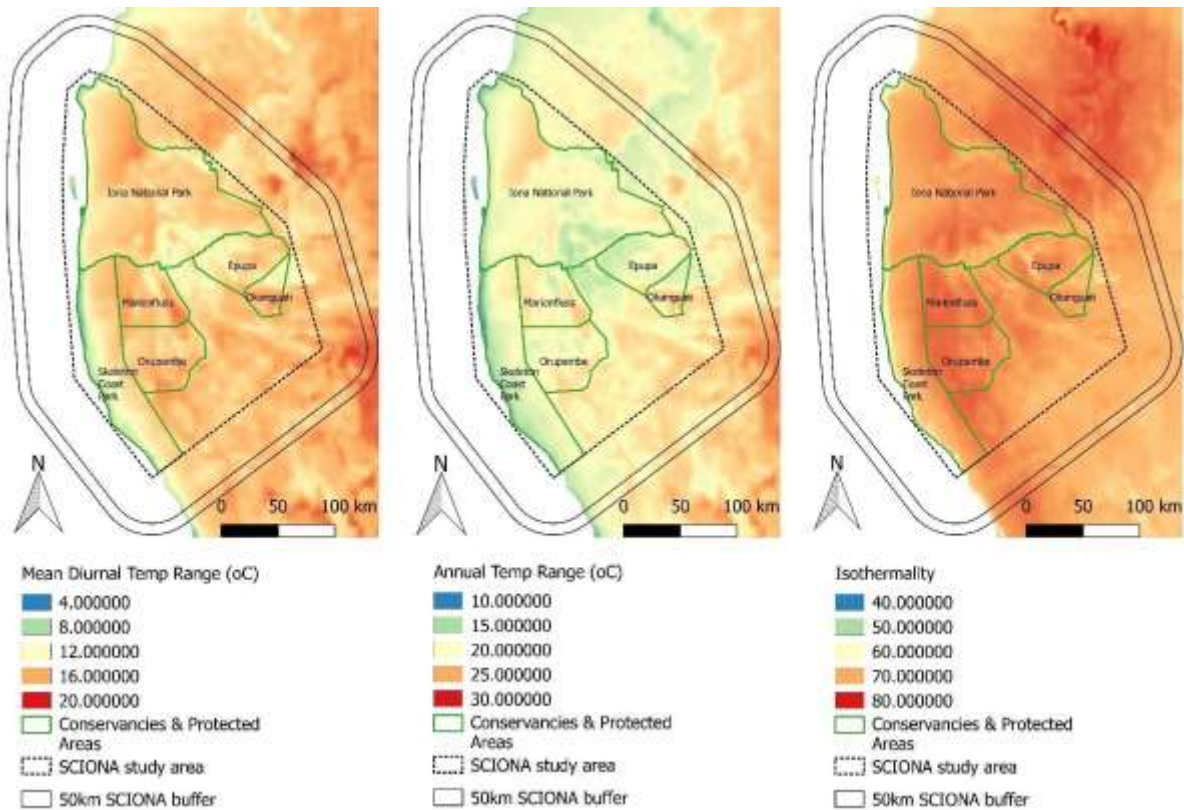


Figure 70. Temperature climatic variables a) Mean diurnal temperature range, b) Annual temperature range, c) Isothermality derived from the Worldclim vs2 dataset (Fick & Hijmans, 2017) (Maps: N. Knox).

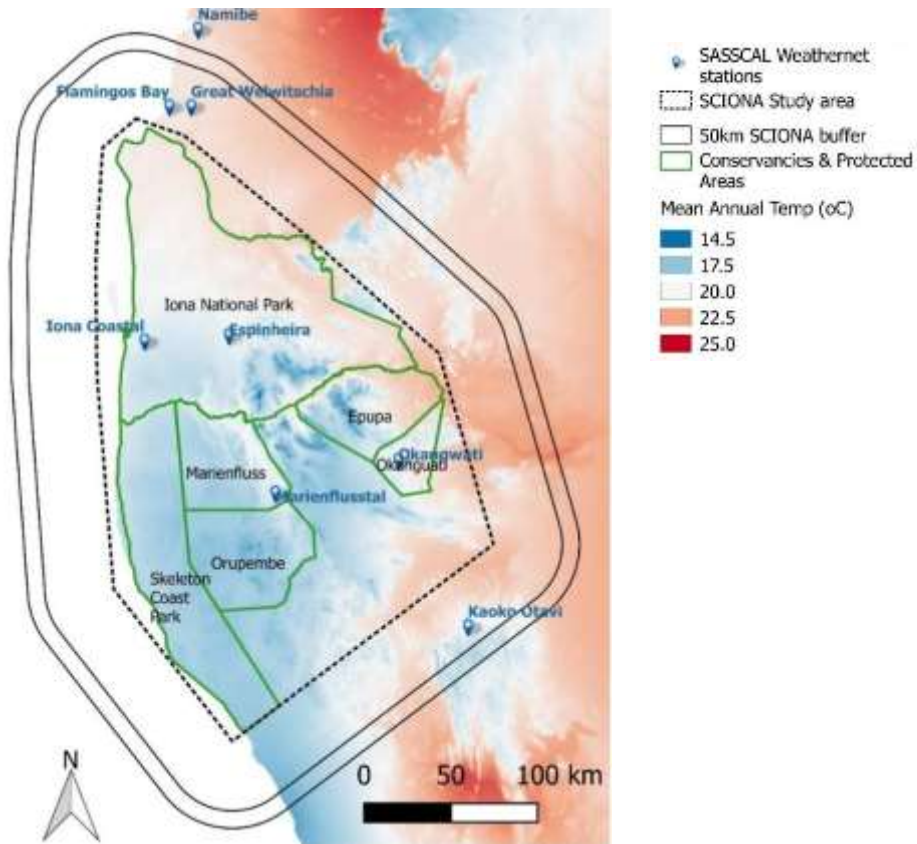


Figure 71. SASSCAL Weathernet stations within the study area (Map: N. Knox).

Table 4. SASSCAL Weathernet stations for the SCIONA study area, including the date of implementation and an end date if they have been decommissioned. The number of observations refers to the number of days of recorded data used to derive the current

| Station | Start Date (end if applicable) | # obs (days) |
|--------------------------------|--------------------------------|--------------|
| Espinheira ^b | 2015-10-20 | 1126 |
| Flamingos Bay ^b | 2017-10-13 | 398 |
| Great Welwitschia ^b | 2015-10-26 | 1120 |
| Iona Coastal ^c | 2017-01-15 (2017-02-04) | 21 |
| Kaoko Otavi ^a | 2016-04-17 | 901 |
| Marienflusstal | 2015-06-30 (2017-05-07) | 678 |
| Okangwati ^a | 2016-04-15 | 903 |

^aData range until 4 Oct 2018; ^bData range until 18 Nov 2018; ^cRemoved from analysis because of two few data records

APPENDIX 2: LIST OF ALL WOODY SPECIES WITHIN THE STUDY AREA

Source: Compilation of De Cauwer, Swanepoel & van Jaarsveld based on own observations, complemented with data of the Tree Atlas of Namibia (Curtis and Mannheimer 2005), the African plant database (Conservatoire et Jardin botaniques (CJB) & South African National Biodiversity Institute (SANBI)), the Global Biodiversity Information Facility (GBIF), and the Namibian biodiversity database.

| Species | Iona NP | Skeleton Coast NP | Marien-fluss | Oru-pembe | Epupa | Okanguati |
|--|---------|-------------------|--------------|-----------|-------|-----------|
| <i>Abrus kaokoensis</i> | | | | | X | |
| <i>Acacia arenaria</i> | | | | | X | X |
| <i>Acacia ataxacantha</i> | X | | | | X | X |
| <i>Acacia hebeclada subsp. tristis</i> | X | | | | | |
| <i>Acacia erioloba</i> | X | | | X | X | X |
| <i>Acacia erubescens</i> | | | | | X | X |
| <i>Acacia fleckii</i> | | | | | X | X |
| <i>Acacia hebeclada subsp. tristis</i> | | | | X | | |
| <i>Acacia kirkii</i> | | | | X | | |
| <i>Acacia mellifera subsp. detinens</i> | X | | X | X | X | |
| <i>Acacia mellifera subsp. mellifera</i> | | | X | | X | |
| <i>Senegalia montis-usti</i> | X | | X | | | |
| <i>Acacia nilotica</i> | X | | | | X | X |
| <i>Acacia reficiens</i> | X | | | X | X | X |
| <i>Acacia senegal</i> | | | | X | X | X |
| <i>Acacia tortilis</i> | X | | | | | |
| <i>Acanthosicyos horridus</i> | X | X | X | X | | |
| <i>Adansonia digitata</i> | X | | | X | X | |
| <i>Adenia pechuelii</i> | | | | | | |
| <i>Adenium boehmianum</i> | X | | X | X | X | X |
| <i>Adenolobus garipensis</i> | X | | X | X | X | |
| <i>Adenolobus pechuelii</i> | | | | | | |
| <i>Albizia anthelmintica</i> | | | | | X | X |
| <i>Albizia antunesiana</i> | X | | | | | |
| <i>Albizia brevifolia</i> | | | | | X | X |
| <i>Albizia tanganyicensis</i> | | | | | X | |
| <i>Allophylus africanus</i> | | | | | X | |
| <i>Aloe littoralis</i> | X | | | X | X | X |
| <i>Aloe mocamedensis</i> | X | | | | | |
| <i>Annona senegalensis</i> | X | | | | | |
| <i>Antiphonia fragrans</i> | X | | X | X | | |
| <i>Arthroerua leubnitziae</i> | | X | | | | |
| <i>Asparagus cf. virgatus</i> | | X | | | | |
| <i>Balanites angolensis subsp. welwitschii</i> | X | | X | X | X | |

| Species | Iona NP | Skeleton Coast NP | Marien-fluss | Oru-pembe | Epupa | Okanguati |
|--|---------|-------------------|--------------|-----------|-------|-----------|
| <i>Berchemia discolor</i> | X | | | | X | X |
| <i>Boscia albitrunca</i> | X | | | X | X | X |
| <i>Boscia foetida</i> | | | X | X | X | X |
| <i>Boscia microphylla</i> | X | X | X | X | X | X |
| <i>Boscia mossambicensis</i> | X | | X | X | X | |
| <i>Boscia tomentosa</i> | X | | X | X | X | |
| <i>Bridelia tenuifolia (or cathartica)</i> | X | | | X | X | X |
| <i>Cadaba schroepelii</i> | X | | | X | X | |
| <i>Caesalpinia rubra</i> | | | | X | | |
| <i>Calicorema capitata</i> | X | | X | X | | |
| <i>Catophractes alexandri</i> | X | | | X | X | X |
| <i>Cissus nymphaeifolia</i> | X | | | | X | |
| <i>Clerodendrum glabrum</i> | | | | | X | |
| <i>Colophospermum mopane</i> | X | X | X | X | X | X |
| <i>Combretum apiculatum</i> | X | | X | X | X | X |
| <i>Combretum hereroense</i> | | | | | X | |
| <i>Combretum imberbe</i> | X | | X | X | X | X |
| <i>Combretum molle</i> | X | | | | | |
| <i>Combretum mossambicense</i> | | | | | X | |
| <i>Combretum oxystachyum</i> | | | | | X | |
| <i>Combretum wattii</i> | X | | | | X | |
| <i>Combretum zeyheri</i> | X | | | | | |
| <i>Commiphora africana</i> | | | | | X | |
| <i>Commiphora anacardiifolia</i> | X | | X | X | X | |
| <i>Commiphora angolensis</i> | | | | | X | |
| <i>Commiphora crenato-serrata</i> | X | | | | X | X |
| <i>Commiphora dinteri</i> | | X | X | X | | |
| <i>Commiphora discolor</i> | X | | | | X | |
| <i>Commiphora giessii</i> | X | | X | X | X | |
| <i>Commiphora glandulosa</i> | X | | | X | X | X |
| <i>Commiphora glaucescens</i> | X | | | | X | X |
| <i>Commiphora kuneneana</i> | X | | X | X | X | |
| <i>Commiphora mollis</i> | X | | | | X | X |
| <i>Commiphora mossamedensis</i> | X | | | | | |
| <i>Commiphora multijuga</i> | X | | X | X | X | X |
| <i>Commiphora oblanceolata</i> | X | | | X | X | |
| <i>Commiphora otjhipana</i> | X | | | | | |
| <i>Commiphora pyracanthoides</i> | | | | X | X | |
| <i>Commiphora schimperi</i> | X | | | | | |
| <i>Commiphora steynii</i> | X | X | | X | | |
| <i>Commiphora tenuipetiolata</i> | X | | | X | X | X |
| <i>Commiphora virgata</i> | X | | X | X | X | |
| <i>Commiphora wildii</i> | X | X | X | X | | |

| Species | Iona NP | Skeleton Coast NP | Marien-fluss | Oru-pembe | Epupa | Okanguati |
|--|---------|-------------------|--------------|-----------|-------|-----------|
| <i>Cordia ovalis</i> | X | | | | | |
| <i>Cordia sinensis</i> | X | X | X | X | X | |
| <i>Croton gratissimus</i> | X | | | X | X | X |
| <i>Croton megalobotrys</i> | X | | | | | |
| <i>Croton menyharthii</i> | X | | | | X | X |
| <i>Cryptolepis decidua</i> | | | | | | |
| <i>Cyphostemma currorii</i> | X | | | | X | |
| <i>Cyphostemma juttae</i> | | | | X | | |
| <i>Cyphostemma uter</i> | X | | | X | X | |
| <i>Dalbergia nitidula</i> | X | | | | | |
| <i>Dichrostachys cinerea</i> | X | | | X | X | X |
| <i>Dinteracanthus kaokoanus</i> | X | | X | X | | |
| <i>Diospyros lycioides</i> | | | | | X | |
| <i>Diospyros mespiliformis</i> | | | | | X | X |
| <i>Diplorhynchus condylocarpon</i> | X | | | | X | |
| <i>Dombeya kirkii</i> | X | | | | | |
| <i>Dombeya rotundifolia</i> | X | | | | X | |
| <i>Ehretia sp.</i> | X | | | | X | |
| <i>Elaeodendron transvaalense/buchananii</i> | X | | | | X | X |
| <i>Elephantorrhiza suffruticosa</i> | X | | | | X | |
| <i>Entandophragma spicatum</i> | X | | | | X | |
| <i>Erythrina decora</i> | X | | | | X | |
| <i>Erythrocca kaokoensis</i> | X | | | | X | |
| <i>Euclea divinorum</i> | X | | | | X | X |
| <i>Euclea pseudebenus</i> | X | | X | X | X | X |
| <i>Euclea undulata</i> | X | | | | X | |
| <i>Euphorbia curocana</i> | X | | | | | |
| <i>Euphorbia damarana</i> | | | | X | | |
| <i>Euphorbia eduardoi</i> | X | | | X | X | X |
| <i>Euphorbia guerichiana</i> | X | | | X | X | X |
| <i>Euphorbia leistneri</i> | X | | | | X | |
| <i>Euphorbia monteiroi subsp. brandbergensis</i> | X | | | | | |
| <i>Euphorbia monteiroi subsp. monteiri</i> | X | | | | | |
| <i>Euphorbia ohiva</i> | X | | X | X | X | |
| <i>Euphorbia otjingandu</i> | | | X | | | |
| <i>Euphorbia virosa</i> | X | | X | X | X | |
| <i>Faidherbia albida</i> | X | X | X | X | X | X |
| <i>Ficus bubu</i> | X | | | | | |
| <i>Ficus capreifolia</i> | X | X | X | | X | |
| <i>Ficus cordata</i> | X | X | | | X | |
| <i>Ficus glumosa</i> | X | | | | X | |
| <i>Ficus ilicina</i> | X | | | X | X | |

| Species | Iona NP | Skeleton Coast NP | Marien-fluss | Oru-pembe | Epupa | Okanguati |
|---|---------|-------------------|--------------|-----------|-------|-----------|
| <i>Ficus natalensis</i> subsp. <i>graniticola</i> | X | | | | | |
| <i>Ficus sycomorus</i> | X | | X | X | X | |
| <i>Ficus thonningii</i> (previously <i>burkei</i>) | | | | | X | |
| <i>Fluggea virosa</i> | | | | | X | |
| <i>Fockea multiflora</i> | | | | | X | X |
| <i>Gossypium anomalum</i> | X | | | | X | |
| <i>Grewia bicolor</i> | X | | | | X | X |
| <i>Grewia flava</i> | | | | | X | |
| <i>Grewia flavescens</i> | X | | | | X | |
| <i>Grewia schinzii</i> | | | | | X | |
| <i>Grewia subspathulata</i> | | | | | X | |
| <i>Grewia tenax</i> | X | | | X | X | X |
| <i>Grewia villosa</i> | X | | | | X | X |
| <i>Gymnosporia senegalensis</i> | X | X | X | X | X | X |
| <i>Gyrocarpus americanus</i> | | | | | X | |
| <i>Hermannia gariepina</i> | | X | | | | |
| <i>Heteromorpha arborescens</i> | X | | | | | |
| <i>Hexalobus monopetalus</i> | X | | | | X | |
| <i>Hibiscus praeteritus</i> | X | | | | | |
| <i>Hymenodictyon floribundum</i> | | | | | X | |
| <i>Hymenodictyon kaokoensis</i> | | | | | X | |
| <i>Hyphaene petersiana</i> | X | X | X | X | X | X |
| <i>Jamesbrittenia heucherifolia</i> | X | | X | X | X | |
| <i>Kirkia acuminata</i> | X | | | | X | X |
| <i>Leucaena leucocephala</i> | | | X | | | |
| <i>Lonchocarpus nelsii</i> | X | | | | | |
| <i>Lycium bosciifolium</i> | | | | X | | |
| <i>Lycium decumbens</i> | | X | | | | |
| <i>Maerua kaokoensis</i> | X | | | | X | |
| <i>Maerua parvifolia</i> | | | X | X | X | |
| <i>Maerua schinzii</i> | X | | X | X | X | X |
| <i>Manuleopsis dinteri</i> | X | | | | X | |
| <i>Maytenus cf. undata</i> | X | | | | | |
| <i>Mimosa pigra</i> | X | X | | | X | |
| <i>Montinia caryophyllacea</i> | X | | | | X | X |
| <i>Moringa ovalifolia</i> | X | | X | X | X | X |
| <i>Mundulea sericea</i> | X | | | | X | X |
| <i>Myrothamnus flabellifolius</i> | X | | | | X | |
| <i>Mystroxydon aethiopicum</i> | X | | | | X | |
| <i>Nicotiana glauca</i> | X | X | X | | | |
| <i>Nuxia oppositifolia</i> | X | | | | | X |
| <i>Obetia carruthersiana</i> | X | | | | X | |
| <i>Olea europaea</i> subsp. <i>africana</i> | X | | | | | |

| Species | Iona NP | Skeleton Coast NP | Marien-fluss | Oru-pembe | Epupa | Okanguati |
|--|---------|-------------------|--------------|-----------|-------|-----------|
| <i>Ormocarpum kirkii</i> | X | | | X | X | |
| <i>Othonna lasiocarpa</i> | | X | | | | |
| <i>Othonna sp. (huillensis?)</i> | X | | | | | |
| <i>Ozoroa crassinervia</i> | X | | X | | | |
| <i>Pachypodium lealii</i> | X | | | X | X | X |
| <i>Pappea capensis</i> | X | | | | | |
| <i>Parkinsonia africana</i> | X | | X | X | X | |
| <i>Pavetta schumanniana</i> | | | | | X | |
| <i>Pavetta zeyheri</i> | | | | | X | X |
| <i>Pechuel-Loeschea leubnitziae</i> | | | | X | X | X |
| <i>Peltophorum africanum</i> | X | | | X | X | X |
| <i>Petalidium coccineum</i> | X | | | X | X | |
| <i>Petalidium halimoides</i> | X | | X | X | | |
| <i>Petalidium kaokoense</i> | | | X | X | | |
| <i>Petalidium welwitschii</i> | X | X | X | | | |
| <i>Phaeoptilum spinosum</i> | X | | X | X | X | |
| <i>Philenoptera nelsii</i> | | | | | X | X |
| <i>Phoenix sp. (canariensis/dactylifera)</i> | X | X | | | | |
| <i>Phyllanthus reticulatus</i> | | X | X | | | |
| <i>Pleurostyliia capensis</i> | X | | | | | |
| <i>Pluchea bojeri</i> | | X | X | | | |
| <i>Plumbago zeylanica</i> | X | | | | | |
| <i>Portulacaria carrissoana</i> | X | | | | X | |
| <i>Portulacaria kaokoensis</i> | X | X | X | X | | |
| <i>Portulacaria kuneneana</i> | X | | X | | | |
| <i>Portulacaria longipedunculata</i> | X | | X | X | X | |
| <i>Pseudolachnostylis maprouneifolia</i> | | | | | X | |
| <i>Ptaeroxylon obliquum</i> | | | | | X | X |
| <i>Pterocarpus lucens</i> | X | | | | X | |
| <i>Rhigozum brevispinosum</i> | X | | | X | X | X |
| <i>Rhigozum virgatum</i> | X | | | | X | |
| <i>Ricinus communis</i> | X | | | | X | |
| <i>Roepera orbiculata</i> | X | X | | | | |
| <i>Salix mucronata subsp. mucronata</i> | | | | | X | |
| <i>Salsola nollothensis</i> | | X | | | | |
| <i>Salsola spp.</i> | | X | | | | |
| <i>Salvadora persica</i> | X | X | X | X | X | X |
| <i>Sarcocaulon mossamedense</i> | X | X | | | | |
| <i>Saueda sp.</i> | | X | X | | | |
| <i>Schrebera alata</i> | X | | | | | |
| <i>Sclerocarya birrea</i> | X | | | X | X | X |
| <i>Searsia leptodictya</i> | X | | | | X | |
| <i>Searsia pyroides</i> | | | | | X | |

| Species | Iona NP | Skeleton Coast NP | Marien-fluss | Oru-pembe | Epupa | Okanguati |
|--|------------|-------------------|--------------|-----------|------------|-----------|
| <i>Searsia quartiniana</i> | | X | X | | X | |
| <i>Senna italica</i> | X | | | | | |
| <i>Senna singuena</i> | X | | | | | |
| <i>Sesamothamnus benguellensis</i> | X | | X | X | | |
| <i>Sesamothamnus guerichii</i> | | | | X | | |
| <i>Sesamothamnus leistneri</i> | X | | X | X | X | X |
| <i>Sesbania sesban</i> | | X | | | X | |
| <i>Spirostachys africana</i> | | | | | X | X |
| <i>Steganotaenia araliacea var araliacea</i> | X | | | | X | X |
| <i>Sterculia africana</i> | | | X | X | X | X |
| <i>Sterculia quinqueloba</i> | | | X | X | X | |
| <i>Strophantus amboensis</i> | X | | | | X | |
| <i>Syzygium kuneneense</i> | X | X | X | | | |
| <i>Tamarix usneoides</i> | X | X | X | | X | X |
| <i>Tarchonanthus camphoratus</i> | X | | | | | X |
| <i>Terminalia prunioides</i> | X | | | X | X | X |
| <i>Terminalia sericea</i> | | | | | X | |
| <i>Tetraena clavata</i> | | X | | | | |
| <i>Tetraena stapfii</i> | | X | | X | | |
| <i>Tetragonia reduplicata</i> | X | X | | | | |
| <i>Tinnea rhodesiana</i> | | | | | | X |
| <i>Turnera oculata var. oculata</i> | X | | | | | |
| <i>Trema orientalis</i> | | | | | X | |
| <i>Vangueria infausta</i> | X | | | | X | X |
| <i>Welwitschia mirabilis</i> | X | X | | X | | |
| <i>Ximenia americana</i> | X | | | X | X | X |
| <i>Ximenia caffra</i> | X | | | | X | |
| <i>Zanthoxylum ovatifoliolatum</i> | X | | | | | |
| <i>Ziziphus mucronata</i> | | | | X | X | X |
| TOTAL | 161 | 38 | 60 | 85 | 152 | 69 |

APPENDIX 3: LIST OF ALL MAMMAL SPECIES WITHIN THE STUDY AREA

Source: ?

| Species | Scientific name | Estimated abundance |
|-----------------------------------|------------------------------------|---------------------|
| Terrestrial | | |
| Aardvark | <i>Orycteropus afer</i> | High |
| Aardwolf | <i>Proteles cristatus</i> | Medium |
| Baboon, Chacma | <i>Chacma Papio ursinus</i> | High |
| Bat, Angolan epauletted fruit | <i>Epomophorus angolensis</i> | Unknown |
| Bat, straw-coloured | <i>Eidolon helvum</i> | Unknown |
| Bat, Mauritian tomb | <i>Taphozous mauritanus</i> | Unknown |
| Bat, Angolan free-tailed | <i>Mops condylurus</i> | Unknown |
| Bat, Chapin's free-tailed | <i>Chaerophon chapini</i> | Unknown |
| Bat, little free-tailed | <i>Chaerophon pumila</i> | Unknown |
| Bat, Egyptian free-tailed | <i>Tadarida aegyptica</i> | Unknown |
| Bat, Schreiber's long-fingered | <i>Miniopterus schreibersii</i> | Unknown |
| Bat, Cape serotine | <i>Neoromicia capensis</i> | Unknown |
| Bat, banana | <i>Neoromicia nanus</i> | Unknown |
| Bat, aloe serotine | <i>Neoromicia zuluensis</i> | Unknown |
| Bat, Angolan hairy | <i>Cistugo seabrai</i> | Unknown |
| Bat, butterfly | <i>Glauconycteris variegata</i> | Unknown |
| Bat, Schlieffen's | <i>Nycticeinops schlieffenii</i> | Unknown |
| Bat, Damara wooly | <i>Kerivoula argentata</i> | Unknown |
| Bat, hairy slit-faced | <i>Nycteris hispida</i> | Unknown |
| Bat, Egyptian slit-faced | <i>Nycteris thebaica</i> | Unknown |
| Bat, Rupell's horseshoe | <i>Rhinolophus fumigatus</i> | Unknown |
| Bat, Geoffrey's horseshoe | <i>Rhinolophus clivosus</i> | Unknown |
| Bat, Dent's horseshoe | <i>Rhinolophus denti</i> | Unknown |
| Bat, Commerson's roundleaf | <i>Hipposideros commersoni</i> | Unknown |
| Bat, Sundevall's roundleaf | <i>Hipposideros caffer</i> | Unknown |
| Bushbaby, lesser | <i>Galago moholi</i> | Low |
| Bushbaby, thick-tailed | <i>Otolemur crassicaudatus</i> | Unknown |
| Caracal | <i>Felis caracal</i> | Low |
| Cat, African wild | <i>Felis lybica</i> | Low-medium |
| Cat, black-footed / small spotted | <i>Felis nigripes</i> | Rare |
| Cheetah | <i>Acinonyx jubatus</i> | Low |
| Civet, African | <i>African Civettictis civetta</i> | Rare |
| Dassierat | <i>Petromus typicus</i> | Low |
| Dik dik, Damara | <i>Madoqua damarensis</i> | Low |
| Duiker, common | <i>Sylvicapra grimmia</i> | Medium |
| Eland | <i>Taurotragus oryx</i> | Locally extinct |
| Elephant | <i>Loxodonta africana</i> | Locally extinct |
| Elephant shrew, round-eared | <i>Macroscelides proboscideus</i> | Low |

| | | |
|--------------------------------------|--|--------------------------|
| Elephant shrew, Western rock | <i>Elephantulus rupestris</i> | Medium |
| Elephant shrew, bushveld | <i>Elephantulus intufi</i> | Medium |
| Elephant shrew, Etendeka round-eared | <i>Macroscelides micus</i> | Rare |
| Fox, bat-eared | <i>Otocyon megalotis</i> | Low |
| Fox, Cape | <i>Vulpes chama</i> | Medium |
| Gemsbok | <i>Oryx gazella</i> | High |
| Genet, small-spotted | <i>Genetta genetta</i> | Medium |
| Gerbil, short-tailed | <i>Desmodillus auricularis</i> | Unknown |
| Gerbil, hairy-footed | <i>Gerbillurus paeba</i> | Unknown |
| Gerbil, Setzer's hairy-footed | <i>Gerbillurus setzeri</i> | Unknown |
| Gerbil, bushveld | <i>Gerbilliscus leucogaster</i> | Medium |
| Gerbil, highveld | <i>Gerbilliscus brantsii</i> | Unknown |
| Giraffe, Angolan | <i>Giraffa camelopardalis</i> <i>Angolensis</i> | Low to medium |
| Groundsquirrel, Cape | <i>Xerus inaurus</i> | High |
| Groundsquirrel, Damara | <i>Xerus princeps</i> | Low |
| Hare, Cape | <i>Lepus capensis</i> | Medium |
| Hare, scrub | <i>Lepus saxatilis</i> | Medium |
| Hare, spring | <i>Pedetes capensis</i> | Medium |
| Hartebeest, red | <i>Alcelaphus buselaphus</i> | Locally extinct |
| Hedgehog | <i>Atelerix frontalis</i> | Rare |
| Hippopotamus | <i>Hippopotamus amphibius</i> | Locally extinct |
| Honey Badger | <i>Mellivora capensis</i> | Medium |
| Hyena, brown | <i>Hyaena brunnea</i> | Medium |
| Hyena, spotted | <i>Crocuta crocuta</i> | Low |
| Hyrax (Dassie), rock | <i>Procavia capensis</i> | High |
| Hyrax (Dassie), yellow-spotted | <i>Heterohyrax brucei</i> | Medium |
| Impala, black-faced | <i>Aepyceros melampus</i> | Locally extinct |
| Jackal, black-backed | <i>Canis mesomelas</i> | High |
| Klipspringer | <i>Oreotragus oreotragus</i> | Low |
| Kudu, greater | <i>Tragelaphus strepsiceros</i> | Medium |
| Leopard | <i>Panthera pardus</i> | Medium |
| Lion | <i>Panthera leo</i> | Locally extinct |
| Mole-rat, Bocage's | <i>Cryptomys bocagae</i> | Unknown |
| Mole-rat, Damaraland | <i>Cryptomys damarensis</i> | Unknown |
| Mongoose, banded | <i>Mungos mungo</i> | Low |
| Mongoose, dwarf | <i>Helogale parvula</i> | Low |
| Mongoose, Selous | <i>Paracynictis selousi</i> | Rare (unlikely to occur) |
| Mongoose, slender | <i>Galerella sanguinea</i> | Low-medium |
| Mongoose, water | <i>Atilax paludinosus</i> | Rare |
| Mongoose, yellow | <i>Cynictis penicillata</i> | Medium |
| Monkey, vervet | <i>Cercopithecus aethiops</i> | Low |
| Mouse, single-striped grass | <i>Lemniscomys rosalia</i> | Low |
| Mouse, four-striped grass | <i>Rhabdomys pumilio</i> | Low |
| Mouse, desert pygmy | <i>Mus indutus</i> | Low-medium |

| | | |
|------------------------------|-----------------------------------|--------------------------|
| Mouse, pouched | <i>Saccostomys campestris</i> | Medium |
| Mouse, Southern multimammate | <i>Mastomys coucha</i> | Medium |
| Mouse, Shortridge's | <i>Mastomys shortridgei</i> | Rare (unlikely to occur) |
| Mouse, grey climbing | <i>Dendromus melanotis</i> | Low |
| Mouse, fat | <i>Staetomys pratensis</i> | Low |
| Mouse, tiny fat | <i>Staetomys parvus</i> | Low |
| Mouse, shortridge's rock | <i>Petromyscus shortridgei</i> | Rare |
| Mouse, large-eared | <i>Malacothix typica</i> | Low |
| Otter, Cape clawless | <i>Aonyx capensis</i> | Low |
| Otter, spotted necked | <i>Lutra maculicollis</i> | Low |
| Pangolin, Temminck's ground | <i>Manis temminckii</i> | Rare |
| Porcupine | <i>Hystrix africaeaustralis</i> | High |
| Rat, Acacia | <i>Thallomys paedulus</i> | Low-medium |
| Rat, black-tailed tree | <i>Thallomys nigricauda</i> | Low |
| Rat, red veld | <i>Aethomys chrysophilus</i> | Low |
| Rat, Namaqua rock | <i>Aethomys namaquensis</i> | Medium-high |
| Rat, Gambian giant | <i>Cricetomys gambianus</i> | Rare |
| Rhino | <i>Diceros bicornis</i> | Locally extinct |
| Serval | <i>Felis serval</i> | Rare (unlikely to occur) |
| Shrew, reddish-grey | <i>Crocidura cyanea</i> | Rare |
| Shrew, lesser red | <i>Crocidura hirta</i> | Rare |
| Springbok | <i>Antidorcas marsupialis</i> | Medium-high |
| Squirrel, striped tree | <i>Funisciurus congicus</i> | Medium |
| Squirrel, tree | <i>Paraxerus cepapi</i> | Low |
| Steenbok | <i>Raphicerus campestris</i> | Medium |
| Suricate | <i>Suricata suricatta</i> | Low |
| Warthog | <i>Phacochoerus aethiopicus</i> | Rare |
| Wildebeest, blue | <i>Blue Connochaetes taurinus</i> | Rare |
| Zebra | <i>Equus burchellii</i> | Low |
| Zebra, Hartmann's mountain | <i>Equus zebra hartmannii</i> | Medium |
| Marine | | |
| Dolphin, bottlenosed | <i>Tursiops truncatus</i> | Medium |
| Dolphin, Heaviside's | <i>Cephalorhynchus heavisidii</i> | Medium |
| Dolphin, dusky | <i>Lagenorhynchus obscurus</i> | Low-medium |
| Dolphin, humpbacked | <i>Sousa teuszii</i> | Rare |
| Dolphin, rough-toothed | <i>Steno bredanensis</i> | Rare |
| Dolphin, Atlantic spotted | <i>Stenella frontalis</i> | Rare |
| Seal, Cape fur | <i>Artcocephalus pusillus</i> | High |
| Whale, humpback | <i>Megaptera novaengliae</i> | Medium |
| Whale, Southern right | <i>Eubalaena australis</i> | Medium |
| Whale, Bryde's | <i>Balaenoptera brydei</i> | Rare |
| Whale, blue | <i>Balaenoptera musculus</i> | Rare |

| | | |
|---------------------------|----------------------------|------|
| Whale, fin | Balaenoptera physalus | Rare |
| Whale, sperm | Physeter macrocephalus | Rare |
| Whale, killer | Orca orcinus | Low |
| Whale, short-finned pilot | Globicephala macrorhynchus | Low |
| Whale, false killer | Pseudorca electra | Rare |

APPENDIX 4: AERIAL PHOTOGRAPHIC WILDLIFE SURVEY

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An aerial photographic wildlife survey was performed in Iona National Park in 2017 (Bushskies, 2017). The same methodology was used to monitor wildlife in the Namibian part of the SCIONA study area. The photographic survey was performed with a light aircraft from 19 July 2018 and 31 July 2018. Flights were conducted at a flight height of about 1130 m to 1507 m using parallel flight lines. Two standard cameras tilted at an angle of 20° took colour photos, with a lateral and forward overlap of approximately 10%. The resulting strip surveyed by both cameras was circa 695 m in width. The distance between strips varied according to a stratification of the study area, based on the expected wildlife density in each stratum. This resulted in image coverages ranging from 20% in the northern Skeleton Coast National Park to 100% along rivers (Figure 72).

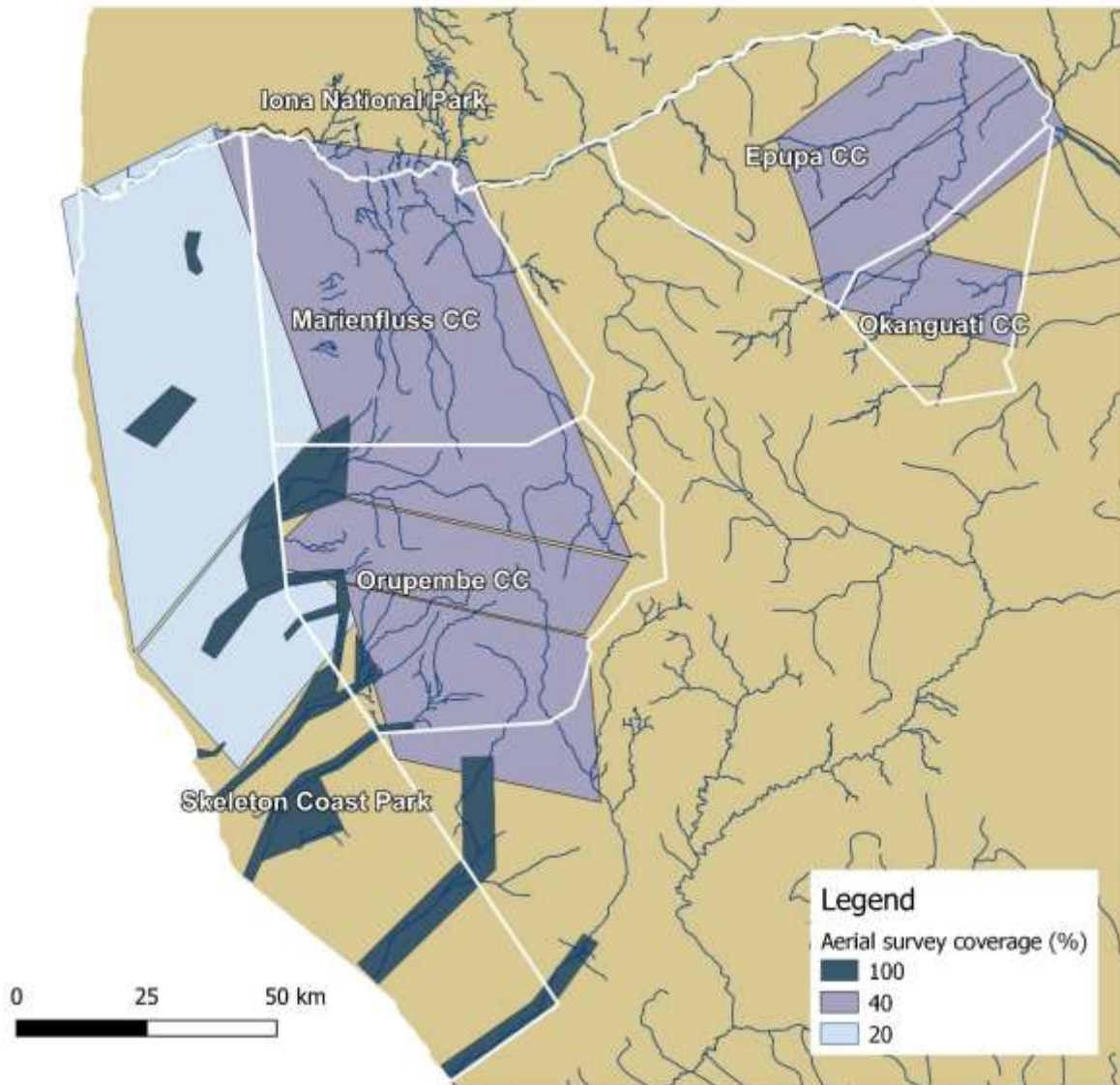


Figure 72. – Aerial photographic survey performed in 2018 in northern Kunene for the SCIONA project (Map: V. De Cauwer).

The photos were imported in a GIS and displayed on a high definition monitor to search the images individually. Wildlife and other features of interest were manually and systematically counted on all images. Resolution of the images is approximately 4 cm allowing detecting large mammals, including livestock, up to the size of a springbok or goat. Goats and sheep could not be differentiated on the photos and were grouped under 'shoats'. Shadows were an important feature in detecting and identifying wildlife. An excel sheet was designed to record the photo number, type and number of wildlife, and other features of interest observed on each image.

The wildlife count numbers per landscape unit were extrapolated to represent 100% of each respective landscape unit area. Image coverage was determined by multiplying mean strip width with total strip length. The survey areas were determined with GIS software for the .kml files used in the flight planning (Figure 72).

RESULTS OF WILDLIFE SURVEY

The results are represented in Table 5. For Skeleton Coast National Park, they only represent the part north of and including the Khumib River. Overall photo coverage was 5,954 km², almost identical to the area covered in Iona in 2017 (6,000 km²), representing approximately 33 % of the study area.

The results show very low wildlife densities. The most common animals were oryx and springbok, which were concentrated in Orupembe conservancy and Skeleton Coast National Park. Most of the animals observed in Skeleton Coast were along the Ondusengo, Nadas and Sechomib ephemeral rivers. Giraffe were concentrated in the Orupembe area, where the SCIONA/GCF giraffes are being tracked with telemetry. No wildlife was recorded in Okanguati conservancy, which confirms the information received from the communities. On the other hand, only 15% of the area was covered, which makes the estimate less reliable than for the other conservancies.

Our method resulted in total counts of the population, real numbers without estimates of variance and thus precision. To obtain an estimate of the variability in population estimates (confidence intervals), it is necessary to replicate the sample counts over part of the study area (Ferreira and Van Aarde 2009) or to compare with results from a ground survey performed over part of the area at the same time as the aerial survey. However, wildlife densities in the study area are so low - 297 animals over a photographed area of almost 6000 km² - that a very large area would need to be resampled or surveyed on the ground to obtain reliable estimates of the accuracy of the counts. As the area itself is already extremely large, this is hardly a feasible option. Moreover, data derived from high-resolution images are often more accurate than traditional ground-based data collection methods (Hodgson et al. 2018). Manual counts on photos are extremely labour and time-intensive to apply successfully over areas of several square kilometres (Hollings et al. 2018). Hence, automatic animal detection algorithms for aerial photos are advised to obtain estimates of population estimates, which can then be double-checked by manual counts in sample areas to derive confidence intervals. An animal detection tool for high-resolution aerial photos was developed at the end of the SCIONA project.

Table 5. Results of wildlife survey.

| | | Epupa Conservancy | Marienfluss Conservancy | Okanguati Conservancy | Orupembe Conservancy | Northern Skeleton Coast NP | TOTAL |
|---|-----------|------------------------------|------------------------------------|----------------------------------|---------------------------------|---|---------------|
| Total area (km ²) | | 2,912 | 3,034 | 1,159 | 3,565 | 6,487 | 17,157 |
| Flight area (km ²) | | 762 | 1,569 | 177 | 1,404 | 2042 | 5,954 |
| Survey area (km ²) | | 1,770 | 3,774 | 428 | 2,739 | 5199 | 13,909 |
| Mean coverage survey area (%) | | 43 | 42 | 41 | 51 | 39 | 43 |
| Mean coverage total area (%) | | 26 | 52 | 15 | 39 | 31 | 33 |
| Actual individuals counted | Giraffe | 1 | 0 | 0 | 7 | 3 | 11 |
| | Zebra | 0 | 0 | 0 | 34 | 0 | 34 |
| | Oryx | 6 | 0 | 0 | 78 | 45 | 129 |
| | Ostrich | 0 | 5 | 0 | 15 | 1 | 21 |
| | Springbok | 0 | 0 | 0 | 54 | 18 | 72 |
| | Eland | 0 | 0 | 0 | 2 | 1 | 3 |
| | Kudu | 0 | 0 | 0 | 27 | 0 | 27 |
| Estimated population total area | Giraffe | 3.8 | 0.0 | 0.0 | 17.8 | 9.5 | 31.1 |
| | Zebra | 0.0 | 0.0 | 0.0 | 86.4 | 0.0 | 86.4 |
| | Oryx | 22.9 | 0.0 | 0.0 | 198.1 | 143.0 | 364.0 |
| | Ostrich | 0.0 | 9.7 | 0.0 | 38.1 | 3.2 | 50.9 |
| | Springbok | 0.0 | 0.0 | 0.0 | 137.2 | 57.2 | 194.3 |
| | Eland | 0.0 | 0.0 | 0.0 | 5.1 | 3.2 | 8.3 |
| | Kudu | 0.0 | 0.0 | 0.0 | 68.6 | 0.0 | 68.6 |
| Wildlife density (animals per 1000 km²) | Giraffe | 1.31 | 0.00 | 0.00 | 4.99 | 1.47 | 1.85 |
| | Zebra | 0.00 | 0.00 | 0.00 | 24.22 | 0.00 | 5.71 |
| | Oryx | 7.87 | 0.00 | 0.00 | 55.57 | 22.04 | 21.66 |
| | Ostrich | 0.00 | 3.19 | 0.00 | 10.69 | 0.49 | 3.53 |
| | Springbok | 0.00 | 0.00 | 0.00 | 38.47 | 8.82 | 12.09 |
| | Eland | 0.00 | 0.00 | 0.00 | 1.42 | 0.49 | 0.50 |
| | Kudu | 0.00 | 0.00 | 0.00 | 19.24 | 0.00 | 4.53 |

RESULTS FOR LIVESTOCK AND HUMAN INFRASTRUCTURE

In contrast with the low wildlife numbers, the number of livestock were high (Table 6). The highest livestock and human settlement densities were observed in Epupa and Okanguati conservancies. This indicates that the higher shrub canopy in the conservancy was not a major obstacle to count large mammals and not an explanation for the lack of wildlife observations in Okanguati. Rather, the high livestock and settlement densities will be the major reasons for the low wildlife counts. The number of huts and kraals were close to ten-fold those of the conservancies further west.

Table 6. Results for livestock and human infrastructure.

| | | Epupa Conservancy | Marienfluss Conservancy | Okanguati Conservancy | Orupembe Conservancy | Northern Skeleton Coast NP | TOTAL |
|---------------------------------|---------|------------------------------|------------------------------------|----------------------------------|---------------------------------|---|-----------------|
| Total area (km ²) | | 2,912 | 3,034 | 1,159 | 3,565 | 6,487 | 17,157 |
| Flight area (km ²) | | 762 | 1,569 | 177 | 1,404 | 2042 | 5,954 |
| Survey area (km ²) | | 1,770 | 3,774 | 428 | 2,739 | 5199 | 13,909 |
| Mean coverage survey area (%) | | 43 | 42 | 41 | 51 | 39 | 43 |
| Mean coverage total area (%) | | 26 | 52 | 15 | 39 | 31 | 33 |
| Actual count | Kraals | 877 | 175 | 261 | 389 | 4 | 1,706 |
| | Huts | 455 | 52 | 165 | 68 | 0 | 740 |
| | Cattle | 372 | 22 | 194 | 62 | 0 | 650 |
| | Shoats | 2,563 | 36 | 870 | 66 | 0 | 3,535 |
| | Donkeys | 10 | 7 | 9 | 71 | 0 | 97 |
| Estimated for total area | Kraals | 3,349.5 | 338.4 | 1,707.1 | 988.0 | 12.7 | 6,395.8 |
| | Huts | 1,737.8 | 100.5 | 1,079.2 | 172.7 | 0.0 | 3,090.3 |
| | Cattle | 1,420.8 | 42.5 | 1,268.9 | 157.5 | 0.0 | 2,889.7 |
| | Shoats | 9,788.9 | 69.6 | 5,690.4 | 167.6 | 0.0 | 15,716.6 |
| | Donkeys | 38.2 | 13.5 | 58.9 | 180.3 | 0.0 | 290.9 |
| Density (per 1000 km2) | Kraals | 1,150.3 | 111.5 | 1,472.9 | 277.1 | 2.0 | 286.5 |
| | Huts | 596.8 | 33.1 | 931.2 | 48.4 | 0.0 | 124.3 |
| | Cattle | 487.9 | 14.0 | 1,094.8 | 44.2 | 0.0 | 109.2 |
| | Shoats | 3,361.6 | 22.9 | 4,909.8 | 47.0 | 0.0 | 593.7 |
| | Donkeys | 13.1 | 4.5 | 50.8 | 50.6 | 0.0 | 16.3 |

COMPARISON WITH IONA NATIONAL PARK

When comparing the results of the 2018 survey with the survey done in Iona in 2017 (Table 7), it is very surprising to see that wildlife densities in Iona are much higher than on the Namibian side of the SCIONA study area, especially for the most common species, oryx, springbok, zebra and ostrich. It is not clear to what extent the season of the survey has an effect on the results. The survey in Iona was during the warmest period of the year (November 2016 – February 2017), while the Namibian survey was during the coldest period.

The Iona survey was done after a drought in 2014 had decimated wildlife and livestock (Huntley, 2017). A comparison with the first aerial photographic survey of Iona (Kolberg and Kilian, 2003) showed a decline of about 22% for wildlife and 91% for livestock (Bushskies, 2017). It is possible that the effects of the drought had become even more severe by 2018 (Chris Brown, personal communication October 2021) and that animals in Namibia had moved more southwards.

On the other hand, livestock densities were very similar in Iona, although slightly lower than in Namibia, while more human infrastructure was observed on the Namibian side.

Table 7. Comparison with Iona National Park.

| | Actual counted in SCIONA study area | | Density per 1000 km ² | |
|-----------------------------|-------------------------------------|---------|----------------------------------|---------|
| | Iona | Namibia | Iona | Namibia |
| Large wildlife | | | | |
| Oryx | 358 | 129 | 59.7 | 21.7 |
| Springbok | 627 | 72 | 104.5 | 12.1 |
| Hartmann's zebra | 147 | 34 | 24.5 | 5.7 |
| Ostrich | 137 | 21 | 22.8 | 3.5 |
| Crocodile | 3 | 3 | 0.5 | 0.5 |
| Giraffe | 0 | 11 | 0.0 | 1.8 |
| Eland | 0 | 3 | 0.0 | 0.5 |
| Kudu | 0 | 27 | 0.0 | 4.5 |
| Domestic Livestock | | | | |
| Cattle | 502 | 650 | 83.7 | 109.2 |
| Sheep / goats | 3,386 | 3,535 | 564.3 | 593.7 |
| Donkey | 59 | 97 | 9.8 | 16.3 |
| Human infrastructure | | | | |
| Kraals | 1114 | 1706 | 185.7 | 286.5 |
| Homesteads | 440 | 740 | 73.3 | 124.3 |