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Research Notes

Determining risk of a regime shift in a coupled arid Social-Ecological System

Theo Wassenaar[1,2], Cornelis van der Waal[2], Wilka Ndapulamo[1,2], Kakunamuua Tjiningire[1,2], Dylan Dentlinger[2], Venomukua Tjiseua[2], Francois Engelbrecht[3]
[1] Namibia University of Science and Technology, 13 Jackson Kaujeua Street, Windhoek
[2] Gobabeb Namib Research Institute, Namib-Naukluft National Park; PO Box 953, Walvis Bay
[3] University of the Witwatersrand, 1 Jan Smuts Avenue, Johannesburg, South Africa

Abstract

Southern Africa has been identified as a climate change hot-spot, warming at about twice the global rate. The projected warming and drying of this arid and semi-arid region will limit the options for adaptation to climate change, especially in marginalized communities. A particular risk is that climate change may cause an abrupt, irreversible 'regime shift' in ecological processes and functions with cascade effects on coupled social-ecological systems and profound consequences for the capacity of those systems to support livelihoods.

Together with southern African and German partners, the Gobabeb Namib Research Institute and Namibia University of Science and Technology recently launched a SASSCAL-funded project called TIPping Points Explained by Climate Change (abbreviated TIPPECC) to 1) to assess the risk of climate change induced regime shifts or tipping points in southern Africa, 2) to provide a range of climate services, and 3) to co-produce with affected communities, policymakers, and natural resource managers adaptation options to safeguard against the effects of such tipping points should they occur.

The Namibian contribution to TIPPECC (TIPPECC-Kunene) focuses on the arid zone pastoralist rangeland system of the Ovahimba of northern Kunene. Ovahimba have inhabited the region for over 200 years, surviving several intense droughts. The pastoralist lifestyle is finely attuned to its environment, adapting to seasonal and longer-term fluctuations in their resources. However, several factors, including population growth and increased sedentarisation have put pressure on the whole social-ecological system (SES), making it vulnerable to climate change and subsequent regime shifts in their resource base. TIPPECC-Kunene aims to use both traditional ecological knowledge and scientific data to determine 1) the probability of climate tipping points leading to regime shifts in the SES, and 2) those factors that will cause changes and/or shifts, with an emphasis on the role that climate tipping points will play in this. We further aim 3) to co-develop, with affected communities, feasible adaptation strategies to ongoing global change, ensuring alignment with inherent coping strategies. TIPPECC-Kunene is organised around eight thematic groups, including studies on vegetation change and degradation, livestock foraging ecology, changes in resource access rules, adaptation, and livelihoods, and the role of boreholes in driving social and environmental change.

Background

Southern Africa has been identified as a climate change hot-spot (Hoegh-Guldberg et al., 2018). Its interior regions are warming at about twice the global rate of temperature increase (Engelbrecht et al., 2015) and further drastic warming is projected under low mitigation climate change futures (Lee et al., 2021). Moreover, the region is likely to become generally drier in a warmer world (Ranasinghe et al., 2021). The projected further warming and drying of this already arid and semi-arid region will limit the options for adaptation to climate change, especially in marginalized communities. A particular risk is that climate change may cause abrupt, irreversible shifts in ecological processes and functions (Lenton et al., 2008), with cascade effects on social systems. Such sudden, high-impact changes in natural systems (Rietkerk et al., 2004; Guttal & Jayaprakash, 2008; Zeng et al., 2012; Berdugo et al., 2020) are called 'tipping points' or 'regime shifts'. A crucial feature in dryland coupled systems is that a negative change in a driving factor – such as decreasing rainfall and more frequent heat waves – can lead to a regime shift in the associated hydrological, ecological, agricultural, and social systems, with profound consequences for the capacity of those systems to support livelihoods.

Together with southern African and German partners, we recently launched a project to study the risks that such regime shifts may significantly affect various important water, food, and biodiversity systems of southern Africa. This project, called **TIP**ping **P**oints **E**xplained by **C**limate **C**hange (abbreviated TIPPECC), is a collaboration under a SASSCAL[1]-funded Grand Challenge consortium led by the Global Change Institute (GCI) at the University of the Witwatersrand (Wits) in South Africa. The overall goals of TIPPECC are 1) to assess the risk of climate change induced tipping points in southern Africa, 2) to provide a comprehensive range of climate services, closely informed by and co-developed with various actors (e.g. policymakers, water managers, organized agriculture, rural communities, and conservation practitioners), and 3) co-produced adaptation options to safeguard against the effects of such tipping points should they occur.

TIPPECC is generating a core set of downscaled (increased local detail) climate projections and a climate services gateway offering free access to informative indicators of change in important water, food, and biodiversity systems of southern Africa. These outputs are the responsibility of the GCI, the University of Zambia (UZ), and our German partners at the Friedrich Schiller University Jena (FSU) and the Helmholtz-Zentrum Geesthacht Climate Service Center Germany in Hamburg (HZG-GERICS). In addition, five regional case studies will be investigating the potential occurrence of regime shifts or tipping points in urban and industrial water availability (South Africa: Wits), in intensively farmed beef and maize production (Botswana: University of Botswana [UB], and South Africa: GCI), in large-scale wildlife movements (Botswana: UB), in rural water supply (The Zambezi basin, Zambia: UZ) and in the arid zone pastoralist rangeland system of the northern Kunene, the home of the Ovahimba. It is the last-mentioned component of the project, led by the Gobabeb Namib Research Institute in collaboration with the Namibia University of Science and Technology (NUST), which we will refer to as **TIPPECC-Kunene**, which is the topic of this paper.

[1] Southern African Science Service Centre for Climate Change and Adaptive Land Management

A focus on the Ovahimba pastoralist[2] livelihood

The dominant form of agriculture in the arid northwest of Namibia[3] is pastoralism (Eisold et al., 2006). 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 which still is practised in more than 100 countries, involving nearly a billion animals and supporting about 200 million households (FAO, 2001). Globally, pastoralists produce about 10% of the world's meat production (FAO, 2001).

It is essentially a system of management of common pool resources that developed in response to the typically high variability of resources in drylands. In its "pure" form, given no restrictions on mobility and relatively small human population density, it is an energetically conservative and sustainable form of resource consumption, with minimal long-term impacts on vegetation composition and productivity (Coughenour et al., 1985; Ward et al., 1998; Sullivan 1999).

Transhumant and nomadic pastoralism are principally practised in arid and semi-arid rangelands (Weber & Horst, 2011). 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 spatially variable quality forage. In the case of nomadism, no permanent home base is established, and movement is not planned but closely adapted to current conditions (Weber & Horst, 2011). Historically, the Ovahimba (and other Namibian pastoralist groups) practise a mixed form of these two types. Although the distinction and shifts between transhuman and nomadic forms may show an interesting and potentially important relationship with long term climate changes, this will not be further explored here, and the term pastoralism will be used to refer to both forms.

Ovahimba pastoralists, an offshoot of a larger Ovaherero group that moved into the region from the north, have inhabited much of northern Kunene for more than 200 years (Bollig & Schulte, 2014). A rich culture has developed around key features of their livelihood such as livestock ownership, free movement, family ties, livestock value, and kinship ties (Bollig & Schulte, 1999). During German colonial times and before, when human and livestock densities were lower, the management of the common pool resource

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[2] For more on the pastoralist social-ecological system and its changes over the last seven decades, see Wassenaar et al. (2021), from which much of the description here has been taken.

[3] The arid northwest of Namibia is often referred to as the Kaokoveld, but that strictly refers to the World Wildlife Fund-defined Terrestrial Ecoregion encompassing the most arid western part, including the Skeleton Coast (Dinerstein et al., 2017). The term Kaokoland refers to the old Apartheid-era Native Reserve, a designation which is no longer acceptable, although it may still be encountered in the popular media, referring to northern Kunene.

of rangeland was a simple function of the availability of forage and surface water at different times of the year (Bollig & Schulte, 1999; Bollig & Gewald, 2000).

Until the 1960s most permanent and semi-permanent settlements were restricted to the higher-lying semi-arid plateau with its higher precipitation and sandy soils associated with the Kalahari system, and to larger ephemeral river courses where groundwater was readily available (Owen-Smith, 1972; Malan & Owen-Smith, 1974). Unrestricted seasonal movements occurred around these permanent settlements as livestock owners made use of ephemeral surface water to access grazing in distant pastures during the rainy season (Bollig, 2013).

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), the absence of permanent water over most of the area meant that large tracts of land were not used at all or were used very seldom (perhaps the most crucial feature from an ecological perspective). This pattern of rangeland uses effectively meant that grazing areas were effectively rested, allowing especially perennial forage species to recover. The period between 1960 and Namibian Independence saw a marked decline in the mobility of Ovahimba pastoralists (Bollig, 2006), caused by several factors including an active political goal to control the indigenous population (Bollig, 1998; 2020). After the rise of Apartheid in South Africa in 1948, the official policy shifted towards "modernizing" agriculture in the so-called Native Reserves to enhance food production. The Odendaal Commission of 1963 aimed to grant semi-independence to Kaokoland (as the area was known at the time) and recommended borehole drilling as the key to agricultural modernization and economic development. Opening up "under-exploited pastures" in the vast arid savannas of the Kaokoveld was a core tenet of that plan (Bollig, 2013). Starting from just a few waterholes created through blasting in the 1930s, the number of boreholes and the area they covered increased rapidly and cumulatively: 136 holes were drilled in the 1960s, 128 added in the 1970s, 57 in the 1980s, and 40 in the 1990s (Bollig, 2013). This significant expansion of water infrastructure was replicated in Native Reserves across Namibia, often with minimal concern for its ecological consequences.

Perhaps the most important feature of the post-1960 drilling programme was that most of the holes were drilled in the arid zone, where the aridity index[4] ranges between 0.03 and 0.2 (Figure 1). These indices indicate a large water deficit and high plant water stress,

[4] The long-term mean of the ratio of mean annual precipitation to mean annual evapotranspiration (i.e. MAP/MAE, called the Aridity Index or AI) provides a handy index of dryness that summarises the net soil water balance (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 ≤ 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 four types—dry subhumid, semiarid, arid, and hyper-arid—reflecting an increasing moisture deficit. Conventionally, the four subtypes are divided as ranges of the AI.

pointing to an ecosystem that is highly vulnerable to the combined effect of disturbance (overgrazing) and droughts.

Coming on the back of a decade of above average rainfall in the 1950s, the increased surface water availability since the early 1960s also saw an increase in cattle numbers from ~65,000 in 1960 to ~218,000 in 2006 (Bollig, 2006). This dramatic increase happened despite a significant dip in the 1980s when a particularly intense drought led to the loss of a large part of the herd (Bollig, 2006). The higher herd size also led to a fundamental change in rangeland management rules when the traditional migration to under-utilised pastures changed from the rainy season to the dry season with apparently intensely negative effects on pasture health (Behnke, 1998a, 1998b; Bollig, 1997; Bollig & Schulte, 1999; Bollig, 2013; Werner, 2015; Bollig 2020; Coppock et al., 2022).

The apparently continuous growth in herd size coincided with an increase in human populations and, perhaps more significantly, a higher settlement density linked to boreholes. When combined with what seem to be more frequent and severe droughts, this situation becomes particularly conducive to ecological degradation. Unsurprisingly, multiple studies, along with a wealth of anecdotal evidence and oral history among pastoralist farmers, allude to a widespread loss of ecological integrity and vegetation productivity (Bollig & Schulte, 1999; Bollig, 2013; Inman et al., 2019; 2020; Coppock et al., 2022).

Despite the obvious signs of degradation, such as massive loss of topsoil in some places (Figure 2), much of the common knowledge is based on speculation or remains anecdotal, with little evidence available in the peer-reviewed literature over the last two to three decades (but see Brunotte & Sander,

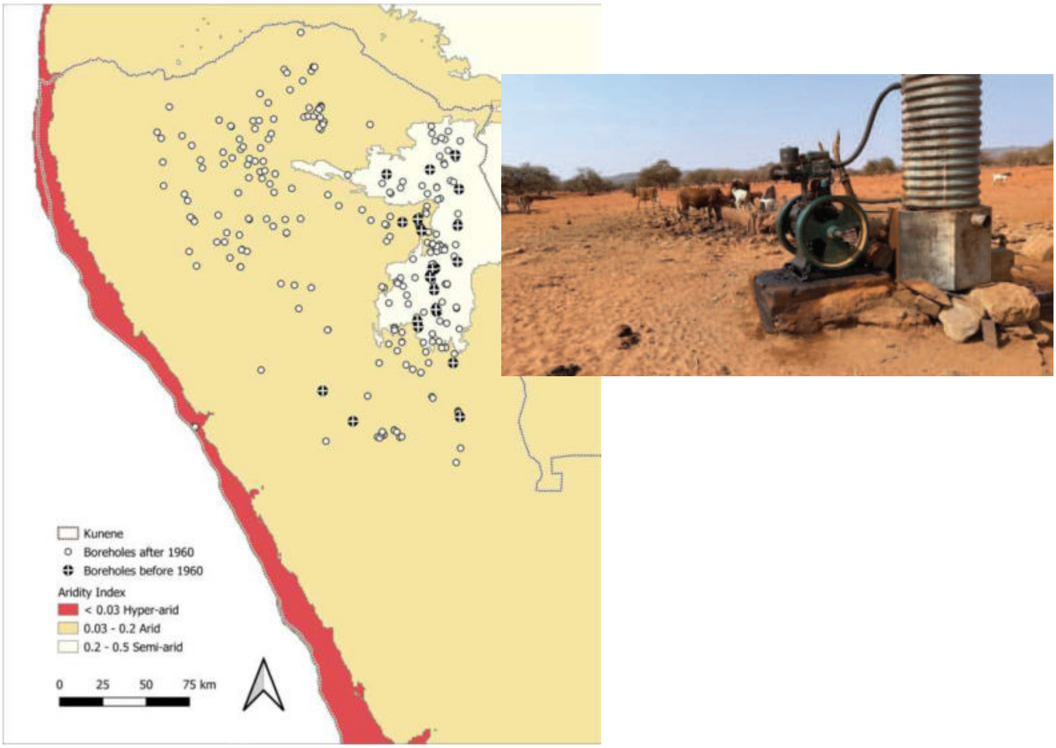


Figure 1: The location of boreholes drilled before and after 1960, on the spatial pattern of the aridity index. The aridity index is a ratio of precipitation to potential evapotranspiration. Source of point data of borehole locations and their completion dates: National Groundwater database (GROWAS) (IGRAC, 2013).

2000; Brunotte et al., 2002; Inman et al., 2019; Inman et al., 2020; Pringle, 2021; Coppock et al., 2022).

Yet the pressures on the social-ecological system (SES) have to all accounts increased dramatically as both human and livestock populations have grown, and mean precipitation has evidently declined (Ranasinghe et al., 2021). A central question facing an SES today is how to maintain system resilience and build capacity to adapt to multiple interacting forces that operate across scales and that increase at varying rates (Galvin et al., 2016). It has thus now become critical to fill several looming knowledge gaps and uncertainties to be able to provide a better assessment of the risks that the region's natural resource base – and by inference its human population – faces going into a future that is likely to be significantly warmer and drier than is current (Engelbrecht et al., 2015; Engelbrecht 2018; Ranasinghe et al., 2021). This type of information is of course crucial for developing climate change adaptation options, but more directly it is vitally important for understanding the likelihood of tipping-point kind of behaviour. A sudden and significant change in critical climate parameters, such as drought duration and intensity and frequency of heatwaves (which may reach physiological limits for people, livestock, and plants), could catalyse a regime shift towards hyper-aridity and a death knell for pastoralism over large parts of the region.

Figure 2: Loss of topsoil in the Omungunda valley.

However, there are several uncertainties around the dynamics of the ecosystem that underpins the natural resource base, as these may be influenced not only by more frequent and intense droughts but also by different grazing rules, different herd-compositions, and potentially alternative livelihood options. In addition, there is uncertainty about the most efficient climate change adaptation strategies that build on existing social and environmental coping and risk management strategies. Interventions to date have almost all focused exclusively on improving rangeland management approaches, improving livestock quality and marketing, and rangeland restoration (Behnke, 1998a, 1998b; Coppock, 2022).

These uncertainties define the main motivation for TIPPECC-Kunene. Our project, which will be the first to integrate the critical environmental and social forcing factors into a predictive suite of models, will aim to fill in some of the more important knowledge gaps, hopefully forming the basis for the co-development of feasible adaptation strategies with communities.

Objectives and approach

The project has three main objectives. We want to use both traditional ecological and cultural knowledge and scientific data to understand 1) the probability of climate change and especially climate tipping points leading to regime shifts in the ecological and social systems (Guttal & Jayaprakash, 2008; Dakos et al., 2023) given current and likely future climate and socio-economic-political conditions, 2) the identity and nature of those factors that will cause changes or shifts, with an emphasis on the role that climate tipping points will play in this, and 3), based on results and ensuring alignment with inherent coping strategies and social mechanisms, we aim to co-develop, with affected communities, feasible adaptation strategies to ongoing global change.

Research activities will be divided into several thematic groups that will contribute to a complex of SES model(s) and related outputs (Figure 1).

Themes 1 to 5 form the core of the science activities. **Livestock foraging ecology (theme 1)** will investigate basic aspects of livestock foraging, inter alia aspects like dietary preferences of cattle, sheep, and goats, and the impacts of foraging intensity on vegetation composition, structure and function and on keystone forage species (those species without which droughts will not be survivable). In **theme 2 (resource access rules and coping practices)** we will rely on the collective memories of the elders of the two focal communities to characterise the evolution of resource access rules, including grazing and water point access rules. Similarly, we will document inherent coping strategies and analyse their potential role in overcoming the effects of climate tipping points. The bulk of these first two themes will be made up of two Masters projects.

The **3rd theme, soil and vegetation**, focuses on the dynamics of rangeland vegetation condition across the whole northern Kunene, and will use various remote sensing products and historical photographs to analyse and map changes over the last four to five decades. As part of this theme we will additionally map the degradation trajectory, aiming to understand the possible role that climate and human population density played in this.

Anecdotal evidence that the expansion of the borehole network has had a major influence on settlement patterns, on grazing rules, and on the rise in resource access conflicts suggests that some key properties of the spatial and temporal dimensions of surface water will be strong correlates of rangeland condition, changes in resource access rules, and in sustainability of pastoralist agriculture.

For that reason, we will focus **theme 4 on surface water points**. This will entail (a) documenting and analysing the development of the borehole network, (b) the extent of the piosphere effect, and (c) the role that borehole density relative to spatial and seasonal rangeland patterns will play in determining the 'giving-up density' (the density of water points, livestock and people at which it becomes unfeasible to continue farming). Theme 4 will be addressed in a PhD study.

Climate is arguably the principal driver of resource status and condition. **Theme 5, climate**, is therefore central to the project's main thesis, namely that a shift in the climate regime – the "tipping point" – could lead to a concomitant regime shift in the ecosystem and thus in the resource base. Several climate and climate-associated variables are potentially key players in the coupling of climate change with the SES model, through various paths. Tipping points can appear in aspects such as mean and maximum temperature (Lee et al., 2021), and the frequency and intensity of heatwaves (Hoegh-Guldberg et al., 2018; Engelbrecht and Monteiro, 2021). These variables are thus likely to be important determinants for where and when livestock and humans can persist in the region.

Theme 6, the SES risk of regime shift, represents the set of outputs that will together define the likelihood of a regime shift in the resource base of the pastoralist livelihood or in other global change factors, signalling a significant threat to people's livelihoods. Depending on outcomes from the different themes, this might be in the form of a systems model that will integrate and summarise the effects of the various factors on pastoral livelihoods (see Filatova et al. [2016] for a comprehensive description of this approach), or a simpler critical analysis of the complex of results. Together, these results will describe the likelihood that climate change would lead to a drastic change in the pastoralist ecosystem and provide opportunities to identify likely approaches to adaptation. It should also allow an assessment of the risk that these changes may be beyond the existing suite of adaptation strategies and coping range (Ash et al., 2012).

In theme 7, adaptation and livelihoods, we aim to use the results of all the studies to co-develop, with the affected communities and authorities, potential adaptation options based on inherent coping strategies. Additionally, in a parallel research effort to those in themes 1 to 5, we will investigate the extent to which the restoration of grazing resources might improve rangeland condition enough to ensure sustainability of the pastoralist livelihood and/or to become a net carbon sink. We will also investigate, through a Masters study, the potential for the restoration of a productive grass layer through thinning of encroaching mopane trees, as well as the potential for defining alternative income streams using the encroaching mopane trees for wood and other biomass products. This will be the first major effort to understand the phenomenon of encroachment in the arid zone, where the interactions between woody density and grass layer productivity are both poorly known and arguably even more sensitive to droughts than in the traditional bush encroachment zones.

Finally, all our **outreach and visibility** activities are captured in **theme 8**. Here we aim to co-develop training topics, focusing on those issues that the affected communities identify themselves, and to produce various media through which we will communicate the objectives and achievements of the project and the people that implement it, including the focal communities.

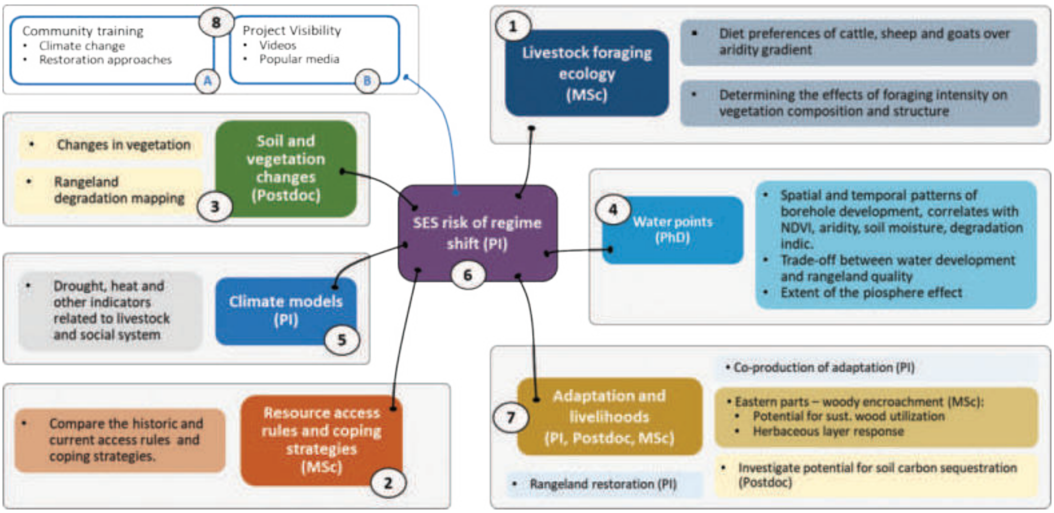


Figure 3: Diagram of the main topics and concepts addressed by TIPPECC, organised into nine thematic groups.

Study area

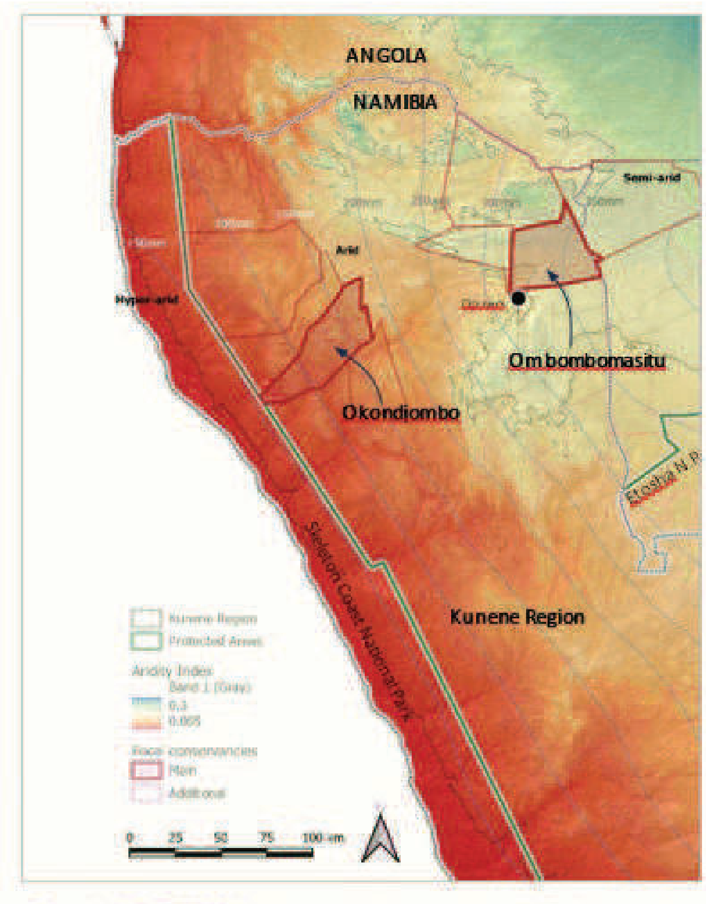
The study area for the TIPPECC project is in the northern part of the Kunene region in Namibia, excluding the Skeleton Coast and Etosha National Parks (Figure 4). Two sites that are embedded in this area will receive more focused research effort, namely the Okondjombo communal conservancy in the arid west and the Ombombomasitu conservancy in the semi-arid east (Figure 4).

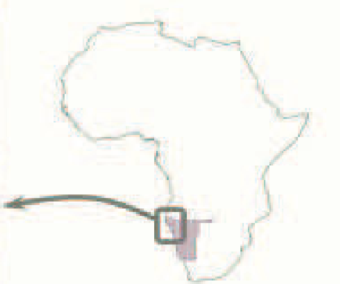
The northern Kunene is characterized by low annual rainfall ranging from below 100 in the west to less than 350 millimetres per year in the east (Atlas of Namibia Team, 2022). The rainfall mostly falls during the summer with large variation from year to year. The variation in annual rainfall increases from east to west (Atlas of Namibia Team, 2022). Most of the study area is arid (Figure 4), where the potential evapotranspiration far exceeds the rainfall received in a year.

The topography is marked by rugged terrain, with rocky plateaus and mountainous regions covering most of the central and eastern parts. The landscape features extensive erosional features, such as canyons and inselbergs, with the prominent highlands of the escarpment transitioning into low-lying coastal plains with occasional rocky outcrops that together define several physiographic units and support several vegetation types (Viljoen, 1980; Atlas of Namibia Team, 2022).

Soils in the study area are predominantly Leptosols, interspersed with locally dominant Calcisols, Arenosols, Cambisols, and Regosols (Coetzee, 2021; Atlas of Namibia Team, 2022).

The vegetation in this region is characterized by plant species adapted to arid conditions with several species endemic to Namibia. The Kaokoveld and escarpment is one of the 19 southern African Centres of Endemism in for plants and is uniquely diverse in terms of invertebrates, mammals, birds, and reptiles (Simmons et al., 1998). Plant productivity tends to decline from east to west (Atlas of Namibia Team, 2022). The central and eastern parts are covered by the Tree-and-shrub savanna biome, transitioning to Nama Karoo and eventually Namib Desert along the coastline (Atlas of Namibia Team, 2022). Tree and shrub cover is highest in the east, with evidence of recent encroachment in places (Venter et al., 2018). Vertebrate and invertebrate diversity is relatively intact with high endemism observed in vertebrates, reptiles, birds, and mammals (Atlas of Namibia Team, 2022). Nevertheless, land degradation, linked to unsustainable agricultural practices, is currently a key risk, threatening both the biodiversity and the pastoralist system in this region (Wassenaar et al., 2021). The irreversible loss of productive vegetation in large parts of northwest Namibia seems imminent (Wassenaar et al., 2021), particularly considering the projected climate regime shifts (Engelbrecht et al., 2015; Hoegh-Guldberg et al., 2018; Engelbrecht and Monteiro, 2021; Lee et al., 2021; Ranasinghe et al., 2021).





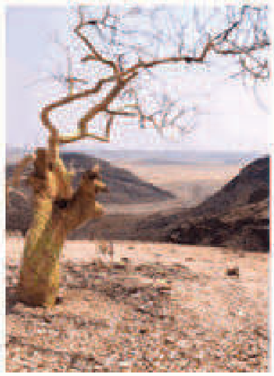


Figure 4: The TIPPECC study area is in the northwest of Namibia. It includes the northern Kunene Region and parts of Omusati Region but is principally focused on two communal conservancies: Ombombomasitu in the eastern part, located in the semi-arid zone, and Okondjombo in the west in the arid zone (thick red outlines). Some adjacent conservancies (thin red outlines) might be included in our study should the co-design process require an expanded footprint.

What do we mean by co-design

A core feature of the TIPPECC project is the focus on co-design and co-production of each aspect of the project. Co-design (also referred to as collaborative design, participatory design, co-development, or co-creation) has emerged over the last two decades as a transdisciplinary approach to collaborative problem solving across a range of disciplines, including rangeland management (Galvin et al., 2022). The core principle is that individuals who are affected by a problem should be actively engaged in shaping solutions (Galvin et al., 2016; Turnhout et al., 2020). It recognizes that expertise is distributed among diverse stakeholders, including users, designers, policymakers, and community members (Turnhout et al., 2020). In effect, co-design attempts to leverage this collective intelligence by creating spaces for collaboration and shared decision-making.

It has the potential to address complex challenges because it is transdisciplinary, involving not only experts from various fields but also diverse stakeholders in the creative process of designing research, applications, and solutions to complex problems.

As an approach, it represents a fundamental departure from traditional, expert-driven problem-solving methods. It places an emphasis on inclusivity, active participation, and the integration of varied perspectives. In addition, it is not a one-step solution, rather emphasising an iterative approach with cycles of ideation, prototyping, testing, and refinement (Zamenopoulos & Alexiou, 2018).

In the TIPPECC project we are aiming to include the communities that we are targeting with the study, local and national authorities, and other stakeholders in the design not only of the research itself, but also of any applications that may arise from our results. Our goal is to create a working space that will foster co-creation of the investigative approach, the fieldwork and data collection, and the interpretation of results (see e.g. Bestelmeyer et al., 2019). By allowing the voices of communities (including their traditional authorities) and other stakeholders to be heard, we hope to arrive at adaptation solutions that are more sustainable and enjoy broader acceptance from the affected people.

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