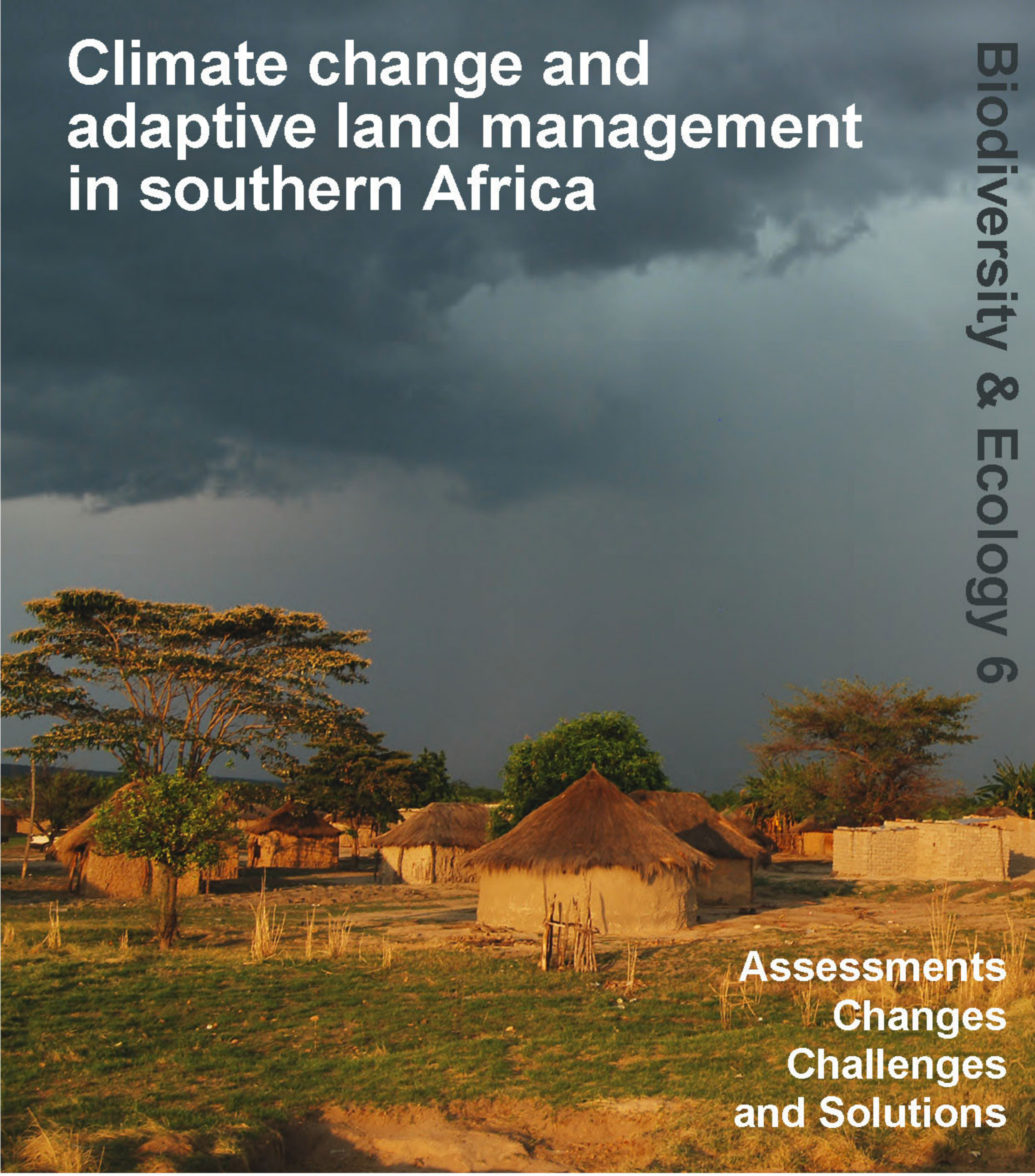
Climate change and adaptive land management in southern Africa

Biodiversity & Ecology 6



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Changes
Challenges
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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

Edited by

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Biodiversity

Biodiversity observation – an overview of the current state and first results of biodiversity monitoring studies

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Abstract: The SASSCAL region is home to a very rich biodiversity, which provides significant economic and intrinsic value to human society. This biodiversity, however, is subject to multiple stresses emerging from human land use and climate change, which leads to biodiversity loss at substantial scale. To assess the current state and changes in biodiversity in the SASSCAL region, a standardised biodiversity observation network has been established. The network comprises 47 biodiversity observatories and 10 auxiliary observatories, where biodiversity change is monitored according to a standardised approach. The network currently covers the countries of Angola, Namibia, Zambia, and South Africa.

The newly established observatories in Angola and Zambia provided urgently needed baseline inventory data on flora and faunal species for the study areas. The observatories in Namibia and South Africa already extend up to 17 or even 30 years and provide important insights into the complexity of the biodiverse systems and their drivers.

We provide an overview of the outcomes of the biodiversity assessment and monitoring work at the observatories. We discuss the contribution of these findings for the understanding of the systems and their changes over time. We also outline new approaches (e.g. experiments, monitoring of key ecological processes like the water pathways in the vegetation, as well as automatised monitoring) to be applied in the ongoing monitoring activities.

Resumo: A região do SASSCAL é o lar de uma biodiversidade muito rica, a qual fornece um valor económico e intrínseco significativo à sociedade humana. No entanto, esta biodiversidade está sujeita a múltiplas pressões emergentes do uso da terra pelo Homem e das alterações climáticas, o que leva à perda da biodiversidade a uma escala substancial. Para avaliar o estado actual e as alterações da biodiversidade na região do SASSCAL, foi implementada uma rede de observação de biodiversidade padronizada. A rede é composta por 47 observatórios de biodiversidade e 10 observatórios auxiliares, onde as mudanças da biodiversidade são monitorizadas no contexto de uma abordagem padronizada. A rede cobre actualmente Angola, Namíbia, Zâmbia e África do Sul.

Os observatórios recém-estabelecidos em Angola e na Zâmbia forneceram dados de referência urgentemente necessários sobre os inventários das espécies de flora e fauna para as áreas de estudo. Os observatórios na Namíbia e África do Sul já existem há 17 ou até mesmo 30 anos, e fornecem informações importantes sobre a complexidade dos sistemas biodiversos e os seus catalizadores.

Fornecemos uma visão geral dos resultados da avaliação da biodiversidade e do trabalho de monitorização nos observatórios. Discutimos o contributo destas descobertas para a compreensão dos sistemas e suas alterações ao longo do tempo. Descrevemos também novas abordagens (e.x.: experiências, monitorização de processos ecológicos chave, tais como percursos da água na vegetação, bem como monitorização automatizada) para serem aplicadas nas actividades de monitorização em curso.

Preface

This article deals primarily with the biodiversity monitoring activities in the geographical space encompassing Angola, Zambia, and Namibia. For South Africa, only activities in the Succulent Karoo Biome of Namaqualand are described; it would be too ambitious to review the wealth of monitoring projects and publications produced by the South African scientific community for the Republic as a whole.

Introduction – the many needs and demands for biodiversity monitoring

The SASSCAL region houses a rich biodiversity and the value of biodiversity is acknowledged in many ways. The species richness of charismatic mammals and birds is the foundation of a large and still growing ecotourism industry. The diversity of plants and insects drives many ecosystem functions and services that support a diversity of agricultural land uses. There is also a diversity of bacteria, fungi, and algae that contribute to soil fertility and nutrient cycling. A wide range of plant and animal species are used commercially. The traditional market products like meat and timber are further complemented by a growing number of new and specialised medicinal, cosmetic, artisanal, and other products.

From a species conservation perspective, the SASSCAL region is home to many important and/or threatened wildlife species like African bush elephant, African forest elephant, southern giraffe, Masai giraffe, cheetah, wild dog, lion, and the largest remaining population of black rhino and other rare species (Western & Vigne, 1985; Emslie & Brooks, 1999; Fennessy et al., 2016). Evolutionary history has created plants and animals with many extraordinary adaptations such as the highly succulent plants commonly known as “living stones” or *Psammotermes* sand termites that create “fairy circles”. Furthermore, “living fossils” such as *Welwitschia mirabilis* have survived until today.

In awareness of the importance of the various ecosystem services which depend on biodiversity, all SASSCAL countries are signatories to the Convention on Biological Diversity (CBD). The Ministries of Environment of these countries lead action to protect their country’s biodiversity. There are also a large number of international institutions and NGOs that contribute to the conservation and management of biodiversity in the region.

The above-mentioned economic and intrinsic values of biodiversity underline the need to keep stock of these values and to monitor changes in their quantity and quality. Due to their very different purposes and uses, different approaches are needed to monitor the state of biodiversity. It makes a difference whether a farmer community assesses the number of valuable timber trees within their conversancy in order to define the number of trees that can be harvested in a sustainable land use system. It also matters that a country fulfils its reporting duties to the Convention on Biodiversity. However, in order to carry out these different activities, whether at local or national scale, it is required that a number of different variables need to be recorded accurately.

In addition to all the above-mentioned aspects of biodiversity and its changes, we now also have to consider the role that rapid anthropogenic climate change plays as an important driver of changes to ecosystem properties as well as biodiversity.

Therefore, it is important to establish standardised methods for long-term monitoring of biodiversity and ecosystems. Together with existing meteorological recording, this monitoring will allow for the impact of climate change to be assessed against other drivers, especially those related to land use.

With regard to the SASSCAL region and its domination by arid ecosystems, the need for long-term monitoring is of even greater importance. This is because of the high spatio-temporal variability of arid systems, the impact of stochastic processes and rare events, as well as the slow response of many of the organisms and ecosystems to environmental change. The development of monitoring methods that are appropriate for different purposes is itself a subject of research.

Unpacking monitoring: the first step towards monitoring is the assessment of baseline knowledge

When dealing with biodiversity and its long-term changes, it is important first of all to have an overview of what exists, in what quantity and quality, and where it occurs. Although southern Africa has been subject to early scientific explorations (e.g. Baum 1903; Dinter, 1927; Pole Evans, 1948) followed by modern checklists and taxonomic studies, we are still a long way from having a holistic picture of the region and how it has changed over time. While South Africa plays a special role and has been explored relatively systematically (e.g. Acocks, 1988; Mucina & Rutherford, 2006), other parts of the region are still under-researched, some of them very much so.

Basic information on biodiversity is provided by simple checklists based on thorough assessments. They are essential tools in biodiversity research. A checklist provides an inventory of a particular taxonomic group for a given area. Taking the example of plants, the first checklist for Angola was published only in 2008: Plants of Angola – Plantas de Angola by Figueiredo & Smith. For other taxonomic groups and regions, such checklists are still unavailable or are currently in the process of being compiled or amended, for example on herpetofauna (Baptista et al., 2018, this volume) and Checklist Zambia Baltodea (Mbata, 2018, this volume).

Similarly, a full understanding of the spatial extension of vegetation units also provides a baseline assessment that can be used later to identify spatial changes. In this volume the state of the art with regard to vegetation mapping and classification is presented for the Huíla Province, Angola (Chissingui et al, 2018, this volume) and for south-west Botswana (Thireletso, 2018, this volume). In Namibia, vegetation surveying is well advanced with over 12,000 surveyed plots. Also, several regional descriptions have been published in this country over the past few years, or are in the process of being published (e.g. Strohbach, 2013, 2014, 2017d). Here, the work is advancing from making pure

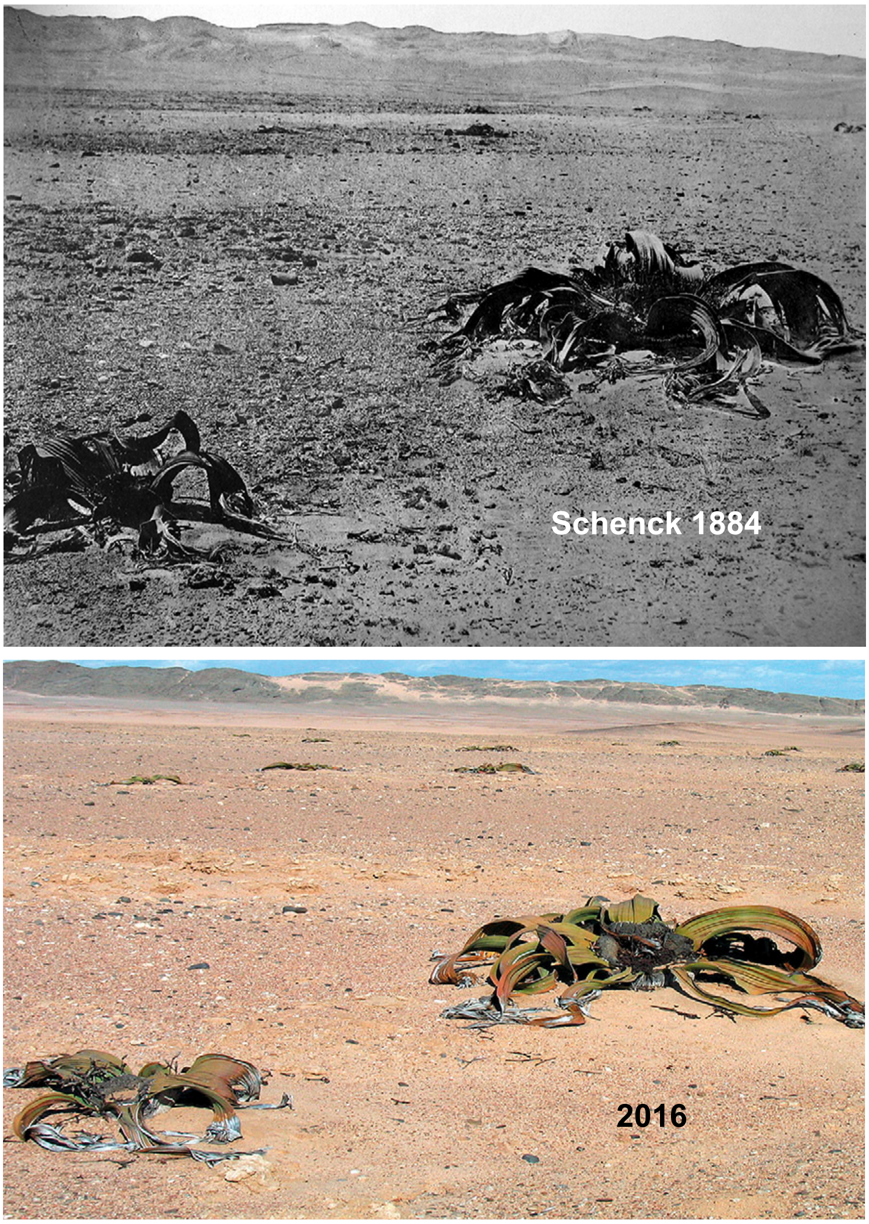


Figure 1: Repeat photography allows comparison over long periods of time. Welwitschia population near the Swakop River (1884 and 2016) (Observatory Welwitschia Vlakte (A09).

baseline descriptions to developing a tool for land use planning (Strohbach, 2017c).

Different approaches to monitoring

In principle, monitoring always aims at detecting, measuring, and understanding change in time. Most current approaches to managing biodiversity are based on interpreting temporal changes in biodiversity, although they often differ in format and content.

Some approaches to studying temporal changes aim at a historical understanding of the origin of the current biodiversity. A vast body of literature describes the presence of wildlife during pre-colonial times. The formerly much wider ranges of large mammals makes us aware of the extent to which their populations have shrunk as a result of human appropriation of productive ecosystems. Taking photographs as replicates of those in historical archives allows us to look backwards in time (Fig. 1), and understand slow changes driven by land use or climate change.

However, the majority of monitoring approaches do not use a retrospective view but instead record biodiversity data in the present time. In this article we explore the latter type of scientific monitoring with a focus on activities in this millennium. We use the current approaches to Essential Biodiversity Variables (EBV, Pereira et al., 2013) and biodiversity indicators (Geijzendorffer et al., 2015). We follow Proença et al. (2016) by classifying sources of primary observations into four types: extensive monitoring schemes, intensive ones, ecological field studies, and satellite and drone remote sensing.

Extensive ground-based monitoring

Extensive monitoring maximises input towards a clear focused goal, while limiting sampling effort on additional site parameters (see also Couvet et al., 2011, for a more detailed discussion). Such an approach is necessary when the management of farming systems or conservation areas is the immediate goal of the monitoring activities. In these cases, focused data that describe the quantity or quality of the managed subject or system are needed. Rapid interpretation of the data allows immediate responses in terms of management decisions. For example, regular game counts from the ground or the air are an important indicator of the effectiveness of previous management decisions. Modern apps allow the growing dimension of civil society-based monitoring. In response to the intensified poaching for animals such as rhino, elephant, and pangolin, targeted monitoring with drones and planes has been undertaken in those regions most threatened by poachers. Threatened species are also monitored with modern tools like GPS collars, camera traps for game, and time lapse cameras. Some examples for game count access can be found at the following websites: http://www.landscapesnamibia.org/sossusvlei-namib/game-counts; http://www.nacso.org.na/resources/game-count-data.

The above activities are typically focused on: (a) threatened or iconic larger animals that are important for conservation and ecotourism, including long distance migratory species; (b) the size and number of populations; and often (c) within geographically or politically defined management units, for example

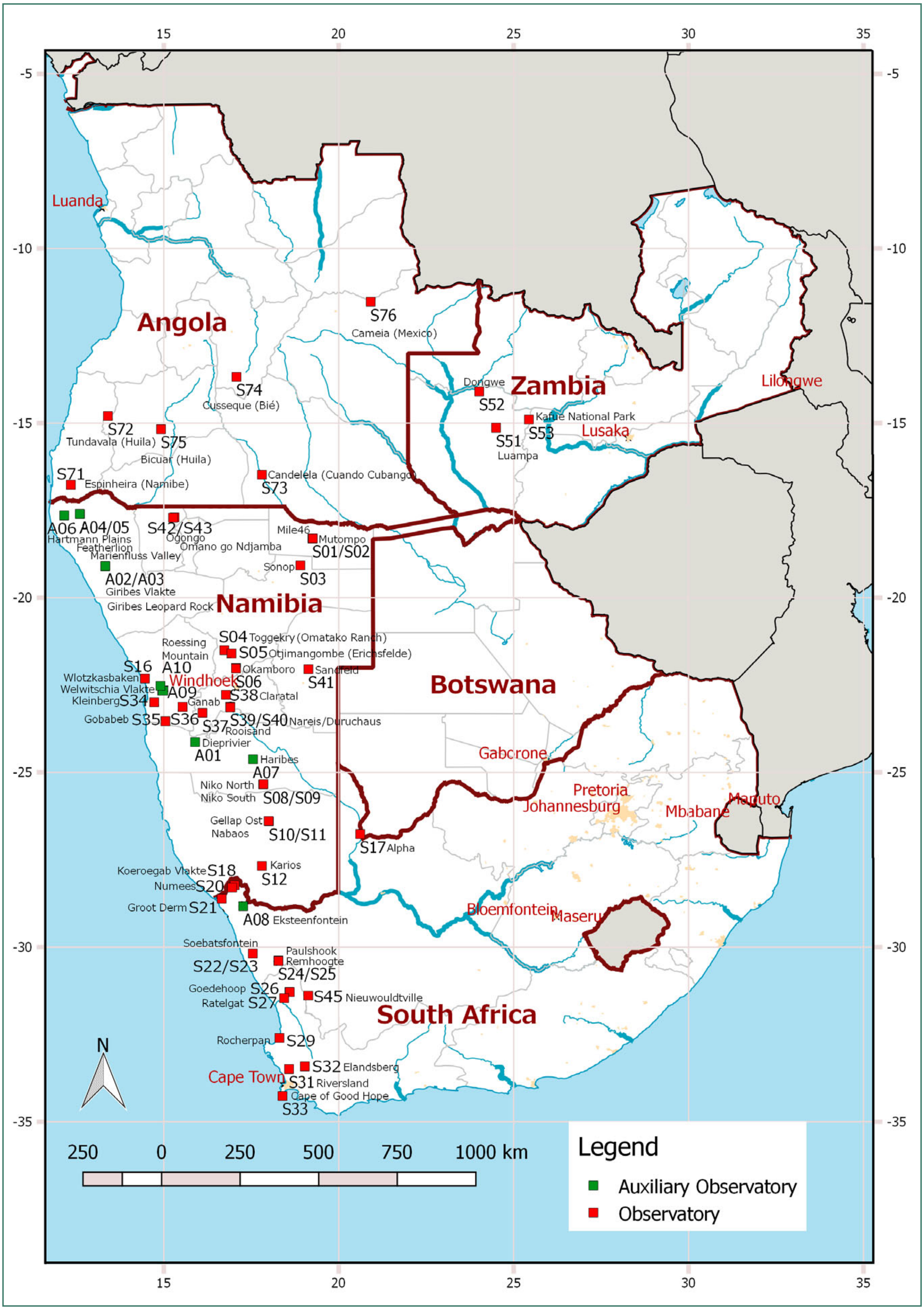


Figure 2: Location of the 57 current Biodiversity Observatories.

Table 1: Biodiversity Observatories within the SASSCAL Observation Net. Rainfall regime: S = summer rainfall, W = winter rainfall, MAP = mean annual precipitation (mm)

Country	Name	No.	Year of Impl.	Ecoregion	Altitude a.s.l. [m]	Land use type	Rainfall regime	MAP
Angola	Espinheira (Namibe)	S71	2015	Kaokoveld Desert	442	Conservation	S	~100
Angola	Tundavala (Huíla)	S72	2014	Angolan montane forest-grassland mosaic	2250	Pasture, wood cutting, charcoal	S	~1400
Angola	Candelela (Cuando Cubango)	S73	2013	Zambezian Baikiaea woodland	1133	Grazing, slash and burn agriculture	S	~730
Angola	Cusseque (Bié)	S74	2013	Angolan Miombo woodlands	1572	Slash and burn agriculture, woodcutting, charcoal	S	~1000
Angola	Bicuar (Huíla)	S75	2015	Angolan Miombo woodlands	1220	Conservation	S	~650
Angola	Cameia (Moxico)	S76	2016	Western Zambezian Grasslands	1132	Conservation, grazing	S	~900
Namibia	Mile 46	S01	2001	Zambezian Baikiaea woodland	1180	Research faming for cattle breeding	S	527
Namibia	Mutompo	S02	2001	Zambezian Baikiaea woodland	1180	Cropping and cattle grazing	S	527
Namibia	Sonop	S03	2001	Kalahari Acacia-Baikiaea woodlands	1236	Experimental farming with cattle, game	S	498
Namibia	Toggekry (Omatako Ranch)	S04	2001	Kalahari xeric savanna	1519	Farming for game hunting	S	346
Namibia	Otjimangombe (Erichsfelde)	S05	2001	Kalahari xeric savanna	1495	Farming with cattle, game for hunting	S	346
Namibia	Okamboro	S06	2001	Kalahari xeric savanna	1490	Farming with cattle, goats and sheep	S	~400
Namibia	Niko North	S08	2001	Namibian savanna woodlands	1070	Farming with goats	S	~200
Namibia	Niko South	S09	2001	Namibian savanna woodlands	1076	Farming with goats	S	~200
Namibia	Gellap Ost	S10	2001	Namibian savanna woodlands	1099	Farming with sheep, cattle, horses	S	183
Namibia	Nabaos	S11	2001	Namibian savanna woodlands	1045	Farming with sheep, goats, donkeys	S	183
Namibia	Karios	S12	2001	Nama Karoo	909	Conservation	S	103
Namibia	Wlotzkasbaken	S16	2001	Namib desert	73	Conservation area	S	~10
Namibia	Kleinberg	S34	2004	Namib desert	188	Conservation area	S	~10
Namibia	Gobabeb	S35	2004	Namib desert	419	Conservation area	S	~50
Namibia	Ganab	S36	2004	Namibian savanna woodlands	995	Conservation area	S	~80
Namibia	Rooisand	S37	2004	Namibian savanna woodlands	1160	Cattle farming and tourism	S	~200
Namibia	Claratal	S38	2004	Kalahari xeric savanna	1865	Farming with cattle and game	S	~300
Namibia	Narais	S39	2004	Kalahari xeric savanna	1624	Farming with cattle	S	289
Namibia	Duruchaus	S40	2004	Kalahari xeric savanna	1614	Farming with cattle and goats	S	289
Namibia	Ogongo	S42	2007	Angolan Mopane woodlands	1103	Demonstration farming with cattle	S	~500
Namibia	Omano go Ndjamba	S43	2007	Angolan Mopane woodlands	1100	Cropping and cattle and small livestock	S	~500
Namibia	Sandveld	S41	2004	Kalahari xeric savanna	1523	Experimental farming with cattle	S	404
Namibia	Dieprivier	A01	2006	Namib Desert	1049	Tourism	S	100
Namibia	Giribes Vlakte	A02	2006	Namib Desert	621	Semi-nomadic farming	S	100
Namibia	Giribes Leopard Rock	A03	2006	Namib Desert	633	Semi-nomadic farming	S	100
Namibia	Featherlion	A04	2006	Namib Desert	583	Semi-nomadic farming	S	200
Namibia	Marienfluss Valley	A05	2006	Namib Desert	566	Semi-nomadic farming	S	200
Namibia	Hartmann Plains	A06	2006	Namib Desert	554	Semi-nomadic farming	S	100
Namibia	Haribes	A07	2010	Nama Karoo	1194	Commercial farm	S	200
Namibia	Welwitschia Plain	A09	2009 (1884)	Namib Desert	437	National Park	S	20
Namibia	Roessing Mountain	A10	2009 (1917)	Namib Desert	467	National Park	S	20
South Africa	Alpha	S17	2001	Kalahari xeric savanna	896	Game farming, conservation	S	192
South Africa	Koeroegab Vlakte	S18	2001	Succulent Karoo, Richtersveld	635	Semi-nomadic farming	W	138
South Africa	Numees	S20	2001	Succulent Karoo, Richtersveld	362	Semi-nomadic farming with goats, sheep, cattle	W	114
South Africa	Groot Derm	S21	2001	Succulent Karoo, Sandveld	193	Communal small-livestock farming	W	84
South Africa	Soebatsfontein	S22	2001	Succulent Karoo, Hardeveld	392	Communal small-livestock farming	W	131
South Africa	Soebatsfontein	S23	2004	Succulent Karoo, Hardeveld	392	Exclosure	W	131
South Africa	Paulshoek	S24	2001	Succulent Karoo, Kamiesberg	1048	Communal small-livestock farming	W	168
South Africa	Remhoogte	S25	2001	Succulent Karoo, Kamiesberg	1027	Commercial small-livestock farming	W	168
South Africa	Goedehoop	S26	2001	Succulent Karoo, Knersvlakte	245	Conservation	W	124
South Africa	Ratelgat	S27	2001	Succulent Karoo, Knersvlakte	239	Conservation	W	124
South Africa	Moedverloren	S28	2001	Succulent Karoo, Knersvlakte	140	Conservation	W	131
South Africa	Rocherpan	S29	2001	Lowland fynbos and renosterveld	35	Conservation area	W	251
South Africa	Riverlands	S31	2001	Lowland fynbos and renosterveld	140	Conservation area	W	453
South Africa	Elandsberg	S32	2001	Lowland fynbos and renosterveld	95	Conservation area	W	560
South Africa	Cape of Good Hope	S33	2001	Montane fynbos and renosterveld	83	Conservation area	W	689
South Africa	Nieuwoudtville	S45	2007	Conservation area	722	Conservation area	W	301
South Africa	Eksteenfontein	A08	2001	Succulent Karoo, Richtersveld	622	Communal small-livestock farming	W	~200
Zambia	Luampa	S51	2014	Central Zambezian Miombo Woodlands	1148	Forest reserve and crop farming	S	~1150
Zambia	Dongwe	S52	2014	Central Zambezian Miombo Woodlands	1066	Forest reserve and forestry	S	~1100
Zambia	Kafue National Park	S53	2014	Central Zambezian Miombo Woodlands	1210	National Park	S	~1150

conservancies. In summary, these monitoring schemes could be called ‘applied monitoring’ because data are generated for a concrete and direct management goal within a short timeframe.

Intensive ground-based monitoring

Less common than extensive monitoring schemes are monitoring schemes that observe changes in: (a) less visible animals such as insects; (b) higher plants; (c) mosses, lichens, fungi, algae or bacteria; (d) communities of particular taxonomic groups (or of all organisms); and (e) ecosystem functions and services. In many of the above cases, changes within populations and communities are interpreted as a response to environmental change. These approaches meet the definition of intensive monitoring schemes. Again, following Proença et al. (2016), the goal of these approaches is “to capture ecological responses to environmental change, by monitoring ecosystem functioning and species interactions”. The outcomes of these approaches will ultimately also allow application and utilisation for management, although in an indirect and more complex way. To some extent, they can also be regarded as pure research because they are driven by a curiosity in the fundamental rules and processes of living ecosystems.

One of the largest intensive monitoring schemes, and the only one that is regionally integrated, is the SASSCAL Observation Net. This presently comprises 47 biodiversity observatories and 10 auxiliary observatories ranging from central Angola and western Zambia to the northern and western Cape of South Africa (see Fig. 2). Here, standardised fixed-site observations are made within real landscapes at a size of one square kilometre, subdivided and permanently marked with metal poles and metal numbers into 100 hectare cells. For more detail on the layout of the observatories and sampling design, see Jürgens et al. (2012). In a number of landscapes, two of these square kilometre observatories are placed next to each other but are subject to different land-use practices or intensities, in order to compare their impact on biodiversity (Hanke et al., 2014).

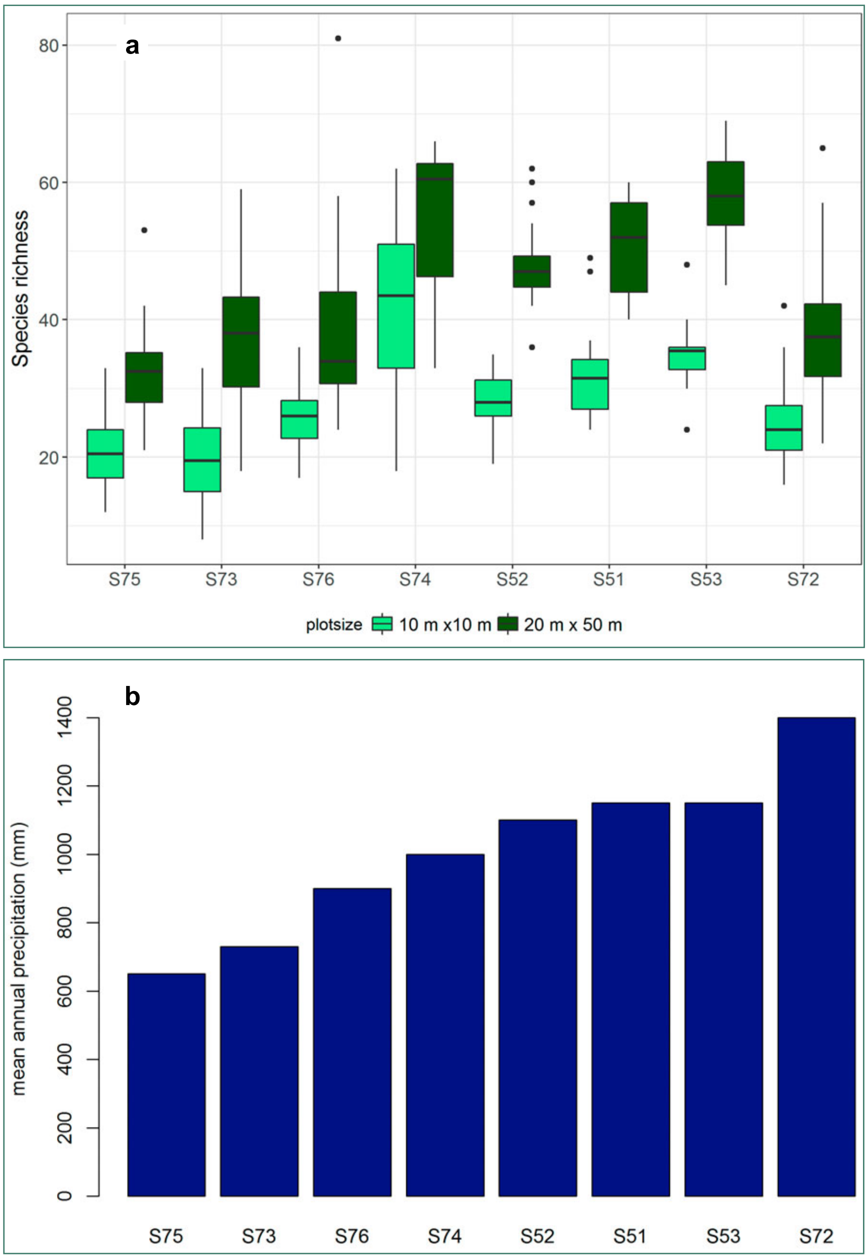


Figure 3: (a) Species richness at the newly established observatories in Angola and Zambia in the 100 m² plots and the 1000 m² plots. Note that the data were collected in different years. n = 20 plots per observatory, except for the 1000 m² plots at observatory S74 where only 6 plots were included. For location and detailed information on the observatories see Table 1 and Figure 2; (b) mean annual precipitation at the observatories.

Ground-based monitoring in Namibia

In Namibia, a total of 22 biodiversity observatories and 9 auxiliary observatories were established during the BIOTA project (2001–2010) (Jürgens et al., 2010). Of these, eleven are in the extremely arid Central Namib and show continuity over the decades due to the rarity of rainfall in combination with the longevity of species like *Welwitschia mirabilis* (see, for example, Jürgens, 2006; Jürgens et al., 2013) (Fig. 1). The two closest observatories to the west coast (Kleinberg and Wlotskas Baken) are of particular interest due to the dynamics of the lichen fields associated with the fogs created by the cold Benguela current around the western coast of southern Africa. The remaining 20 biodiversity and auxiliary observatories are arranged along a north–south transect, and two shorter east–west ones, following the predominant rainfall gradients.

Eleven of the 22 biodiversity observatories in Namibia have been ear-marked as high-priority observatories, with their vegetation having been re-surveyed every year since 2001. These are, from north to south, the observatory pair Mile 46 (S01) and Mutompo (S02), Sonop (S03), the pair Toggekry (Omatako Ranch – S04) and Otjimangombe (Erichsfelde – S05), Sandveld (S41), the pair Narais (S39) and Duruchaus (S40), the pair Gellap Ost (S10) and Nabaos (S11), and finally Karios (S12) (Tab. 1). The dynamics of the four observatories within the Kalahari basin (Mile 46, Mutompo, Sonop, and Sandveld) were compared making use of the full time series (Shidolo, 2017). The phanerophytic (i.e. woody) vegetation proved to be stable overall, but we were able to show considerable shifts in the composition of especially the grass layer, which appears closely related to annual rainfall fluctuations and fire events. Surprisingly, the more arid Sandveld proved to be far more stable than the moister northern observatories of Sonop, Mile 46, and Mutompo. Processing of the available long-term data, collected by five different observers over the past 17 years, showed a high degree of observer bias. The observer bias is evident especially in the identification of minor species, but also in the abundance ratings of the dominant species. Thus, the thorough documentation of all observed taxa underpinned by herbarium specimen is a necessary requirement for meaningful long term monitoring. The abundance rating of the dominant species is another parameter which seems prone to observer bias.

On the main observatories, we also managed to undertake a survey of tortoises as part of the ongoing effort to collect baseline data on additional taxonomic groups (Amutenya, 2016). In addition to these regular surveys, we resurveyed the Gobabeb observatory in 2017. This was done in collaboration with Gobabeb Research and Training Centre, in support of their FogNet initiative. As part of the drone surveying (see below), we identified at each FogNet weather station a square kilometre that can be used as a biodiversity observatory. Using drone imagery, we were able to demarcate habitats, subdivide the square kilometre into 100 one hectare plots, and rank these according to the regular ranking scheme. No physical on-the-ground demarcation has yet been undertaken, but we also collected aerial imagery for baseline data for the Aussaninas, Vogelfederberg, and Garnet Koppie observatories.

At the Karios observatory, in addition to the standard protocol, a more detailed, individual-based monitoring was carried out at the scales of 1000 m², 100 m², 10 m², and 1 m². At the auxiliary observatories of Dieprivier, Giribesvlakte, Leopard Rock, Hartmann Dunes, and Featherlion Hill/ Marienfluss Valley, annual vegetation records and automatic soil humidity measurement were recorded in combination with faunal records. In addition to the annual vegetation monitoring, on the Karios (S12) observatory we annually monitored the arrival, growth, and death of all individuals of perennial plant species.

Ground-based monitoring in Angola

The first biodiversity observatories in Angola, Candelela (S73) and Cusseque (S74), were installed in 2013. Thereafter, four others were added following the BIOTA south–north mega-transect and integrated with the regional network of biodiversity observatories (see Tab. 1). All are located in the southern part of the country (between -11.5° S and -16.8° S latitude and 20.9° E and 12.4° E longitude), and represent four different ecological regions (Burgess et al., 2014). The altitude varies from about 400 m to more than 2200 m above sea level, and mean annual rainfall is in the range 60–100 mm (S71) to 1250–1500 mm (S72).

Annual visits to the observatories have been made in the dry and rainy seasons to record the vascular plant species occurring in the selected plots including their estimated cover, following the BIOTA protocols. Vegetation surveys were carried out, with all vascular plants being recorded, respective checklists prepared, and data stored in BIOTAbase. Specimens are deposited in the herbaria of Lubango (LUB) and Hamburg (HBG), in some cases still awaiting identification. We are currently building a photographic database of all vascular plants occurring at Tundavala Biodiversity Observatory (S72), with the aim of producing a guide to the plants from the Huíla escarpment area. To date, more than 300 different species have been recorded in this observatory, at least 12 of which are endemic to Angola. Figure 3 shows the species richness of vascular plants of the newly-established observatories in Angola and Zambia (for a comparable figure for the other observatories, see Schmiedel et al., 2010). The highest number of species was recorded in the more mesic miombo woodlands (S51–53, S74).

Animal monitoring

In July 2017, a monitoring system for terrestrial mammals using photo-trapping was implemented in a central part of the Bicuar National Park and in the neighbouring observatory (S75). The aim of this approach is to evaluate the patterns and processes determining the structure and functioning of mammalian communities, and the relative importance of resource availability and predation on herbivore behaviour and habitat use. This monitoring system also investigates whether seasonal variation in resource availability regulates herbivore population parameters (CIBIO-UP partnership). In the central area of the park, 49 cameras were arranged in a regular grid of 7 by 7 cameras with a distance between camera locations of ca. 2 km. This allows for a wide spatial coverage in the different types of habitats and ensures the spatial independence of sampling points. This regular design is directly adjacent to an opportunistic sampling scheme of 7 camera sites for the 1 km² observatory. During the dry season in 2017, 33 mammal species were identified with this combined approach. This monitoring scheme continued during the rainy season of 2017/2018.

The Tundavala observatory (S72) is located in a key region of the Angolan escarpment where high animal and plant endemism is recognised (Hall, 1960; Huntley & Matos, 1994). The herpetofauna has been monitored since April 2016 using traplines with pitfalls and funneltraps, as well as visual encounter surveys. Several scientifically interesting species have been registered, some being new records for Angola and species not sighted for decades. The specimens are being deposited in ISCED's new herpetological collection. In Bicuar (S75) and Cusseque (S74), the survey so far comprises a number of non-standardised sampling seasons and opportunistic records. In the Cameia (S76) and Candelela (S73) observatories, the records of herpetofauna are based on opportunistic sampling. Information on the herpetofauna of the Angolan biodiversity observatories is accessible vía the website of the SASSCAL Observation Net (www.sasscalobservationnet.org; see infobox by Hillmann et al., 2018).

Ground-based monitoring in Zambia

To extend the existing network of standardised biodiversity observatories in southern Africa, three biodiversity observatories were established in western Zambia in 2014, following the spatial design and methodology of the BIOTA protocol (Jürgens et al., 2010). All the sites fall within the Miombo Woodland sensu White (1983) and extend over latitudes S 14°–16° and longitudes E 24°–26° at an elevation ranging from 1068 to 1210 metres above sea level (Tab. 1; Fig. 2). The three observatories differ in their land-use type and intensity.

These observatories were installed and assessed during the growing season of 2014 with the intention of providing benchmark data on vascular plant diversity from each site. For each of the plots, the presence of vascular plant species, their cover, and their abundances were recorded. Additionally, of tree height and diameter at breast height (DBH) biometric data were collected for all tree species with DBH >5 cm, with the aim of estimating the above-ground tree biomass. When the species identification is completed, voucher specimens will be lodged at the Herbarium Hamburgense (HBG) and at the Herbarium of the University of Zambia (UZL).

Ground-based vegetation monitoring in South Africa

The 16 biodiversity observatories and one auxiliary observatory in South Africa are located along a north–south transect from the Cape of Good Hope to the Richtersveld in the north-west of South Africa. The transect describes a gradient of decreasing annual rainfall, which in this western part of South Africa mainly falls during the cool winter season between May and August. The mean annual rainfall along the transect ranges from 700 mm at the Cape Peninsula to <100 mm in the Richtersveld (Jürgens et al., 2010). Only one of the South African observatories is located in the summer rainfall region of South Africa, namely at the southern fringe of the Kalahari. For the SASSCAL research activities, special attention has been paid to the ten observatories in the semi-arid and arid part of the winter rainfall gradient of the country, and on the observatory in the southern Kalahari. The winter rainfall observatories represent five bioregions (Tab. 1).

The observatories in the semi-arid to arid winter rainfall region of South Africa fall within the Succulent Karoo biome, which is a renowned biodiversity hotspot (Mucina et al., 2006). It is therefore not surprising that the number of species per 100 m² plot of our Succulent Karoo observatories can reach 50 to 60, and that the cumulative species number per observatory over a period of 17 years lies well above 350 species for most of the observatories (e.g. 398 spp. for observatory Remhoogte (S25)). Many of the species are cryptic in nature, being tiny, well-camouflaged (like the popular “living stones”), found growing inside other plants, and/or strongly resembling each other morphologically. The monitoring of the observatories was hence done on the ground and involved annual visits to each plot to record the cover and (for the 100 m² plots) abundance of individuals of all vascular plant species present in the plot. Two local citizens, who have been trained over several years as para-ecologists (Schmiedel et al., 2016), supported the time-consuming annual field work by counting and recording the abundance of individuals per species.

We analysed the monitoring data of the observatories for patterns of vegetation dynamics in response to inter-annual variation in weather conditions and land use. The current state of the analysis already highlights the complexity of the vegetation dynamics and its drivers in these diverse systems. At the Soebatsfontein observatory (S22) in the Namaqualand Hardeveld bioregion, the vegetation response to the release from high land-use pressure at the beginning of the monitoring activity varied with habitat type, the particular environmental conditions of the plot, and the species that dominated the vegetation (Schmiedel & Oldeland, 2018). Further investigations into the species-specific response to the inter-annual variation in seasonal and total annual rainfall revealed that the total annual rainfall did not affect the abundance of individuals per species for a given year. Instead, the abundance of individuals per species depended on the rainfall amount received during certain seasons. Rainfall during the late summer (between January and March) turned out to be critical in determining the abundance of many of the perennial species. It is assumed that the amount of rainfall received towards the end of the dry period in the winter-rainfall region is critical for the survival, in particular, of the newly established individuals of many of the species (Schmiedel, unpublished data). The analysis of the vegetation monitoring data of the South African Kalahari observatory at the game farm Alpha (S17) showed the joint effect of annual rainfall and game density on total vegetation cover, grass and shrub/ tree cover, and species richness (Jacke, 2016).

Complete vegetation surveys were also carried for the northern-most observatories within the Succulent Karoo biome in South Africa, Numees (S20) and Koeroegab Vlakte (S18) and Groot Derm (S21). However, in this region the annual monitoring scheme deviates from the standardised design and focuses on 45 permanent plots of 10 m x 10 m (100 m²) as well as experimental exclosures (protected from grazing) that have been established here and have been monitored intermittently since 1980. These are regarded as being of high value because of their age, warranting the different design. These plots showed recovery after a drought in 1979/1980 and high continuity during the subsequent 30+ years. Since 2016, however, there has been a drastic decline in the composition and cover of vegetation in the plots due to a major drought. In 2017, the winter rainfall was completely absent from the Richtersveld and many of the permanent observation plots lost all their vegetation. This is the

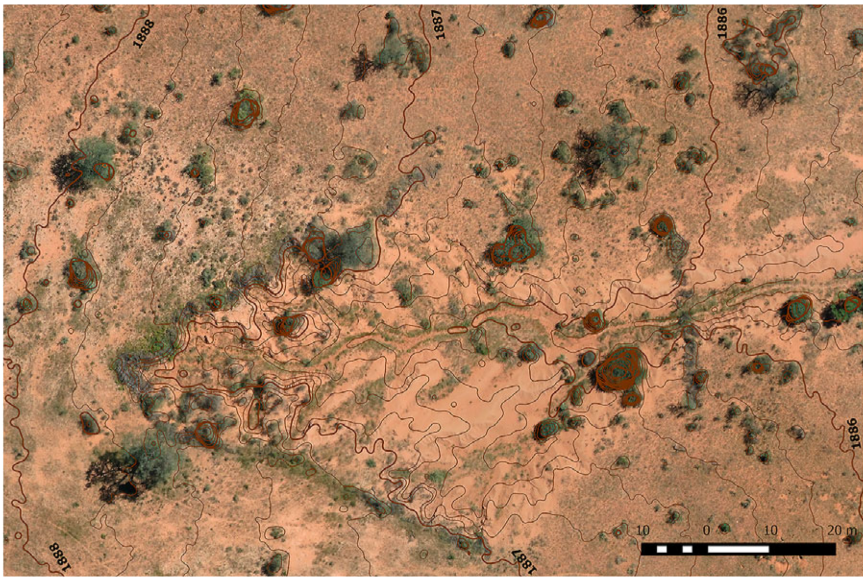
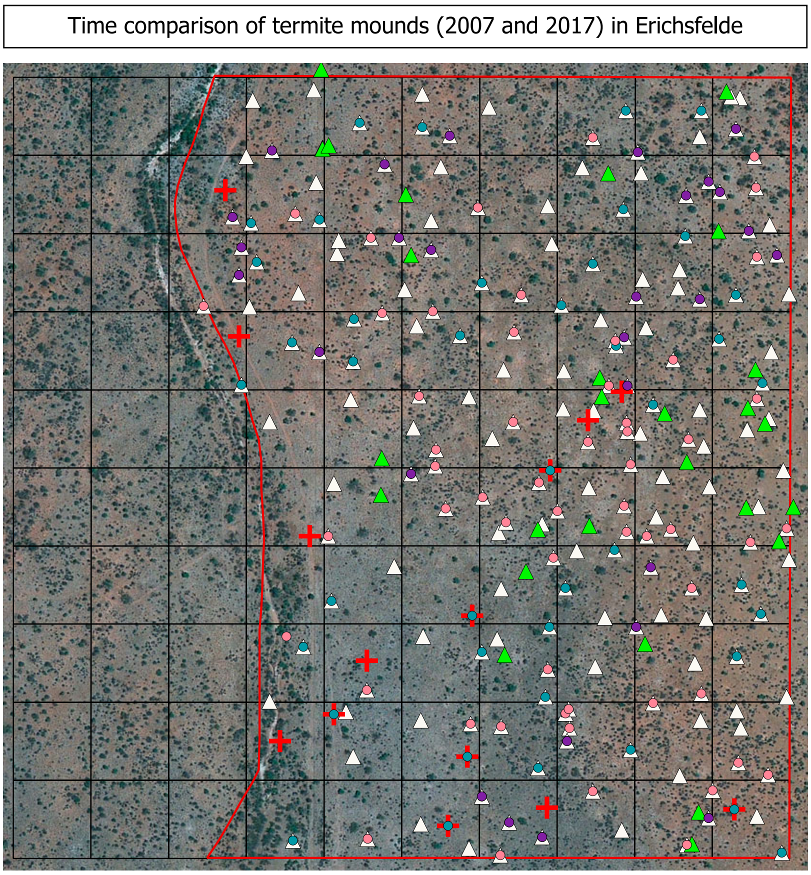


Figure 4: An erosion feature on the Farm Krumhuk outside Windhoek, with a brush filter as counter measure along its head (April 2016). With the calculated DSM we are able to illustrate sub-metre height differences.



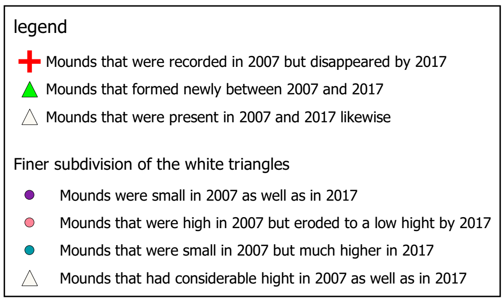


Figure 5: Turnover of mounds of *Macrotermes michaelsii* on the Farm Erichsfelde north of Okahandja in Namibia between 2007 and 2017 (Lisa-Marie Hahn, unpublished). What does it mean that during this decade new termitaria (green triangles) only formed on the non-calcareous soil in the north-east but not on the calcrete in the south centre nor along the river bed in the west? Do the termites respond to bush encroachment? What will the consequence be for future fire dynamics in the area with fewer termite mounds?

harshest drought of the last half century and it is scientifically very interesting to record the longest surviving plant species and the response of the animals and the stock farmers.

In addition to the annual vegetation monitoring, on four observatories in Namaqualand we selected five 100 m² plots where we annually monitored the arrival, growth, and death of all individuals of perennial plant species. This was also performed at all of the 100 m² sites in the Richtersveld. For this purpose, each individual has an identification number and its coordinates locate the plant on the plot map. The individual-based monitoring provides critical information on the year of arrival of the newly-established individuals, their growth rates, year of death, and thus life span. In this way, we get a better understanding of the population dynamics, and can deduce which climatic or other events facilitate the establishment and cause the die-back of individuals of different species. Such detailed data on population dynamics are extremely scarce even though they are also extremely valuable for the interpretation of species turnover and vegetation change under climate change conditions. Previous analyses of long-term individual-based monitoring

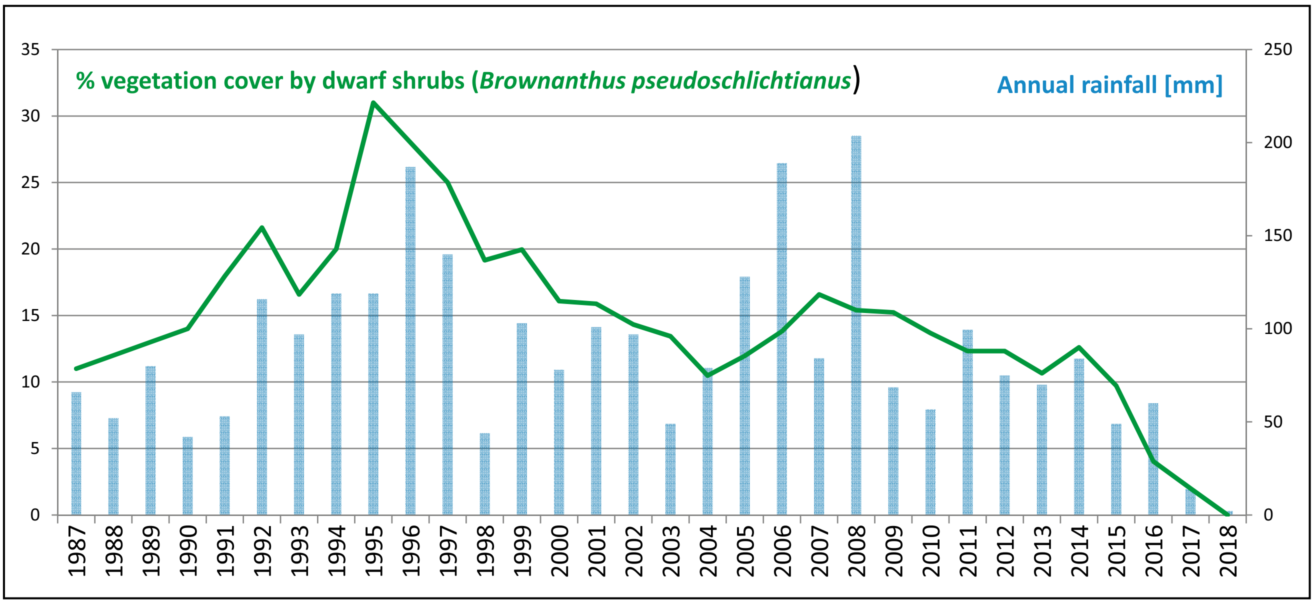


Figure 6: One of several hundred time series that show the impact of the present extreme drought in the northern and western Cape on vegetation. The green line shows the measured cover of vegetation, while the columns represent the annual rainfall. The variability observed in both rainfall and vegetation cover during the last three decades has recently been replaced by a strong decline in both, and agriculture utilisation has come to an end. (Example from the valley of Numees, Richtersveld National Park).

from the Succulent Karoo (Jürgens et al., 1999; Schmiedel et al., 2012), have already provided valuable insight into the drivers of the population dynamics of the endemic flora in the Succulent Karoo.

Drone-based remote sensing observation

Because of the obvious difficulties in resurveying all observatories, we decided to at least obtain a regular (annual) photographic record of the observatories. For this reason, a pair of eBee drones (SenseFly) were purchased, equipped with Canon G9X colour cameras (taking photos which can be separated into the three basic bands of red, green, and blue – RGB). Near-infrared (NIR) capability was originally provided by a Canon S110 camera modified with a NIR filter, but we found that these cameras are highly dust sensitive and were destroyed by regular landings in the Namib and the Kalahari. The NIR capability is planned to be replaced with more robust Sequoia cameras. A large amount of practical experience has been compiled in a short practical guide on the use of such drones for biodiversity surveying (Strohbach, 2017 a,b).

Aerial survey data are available for 2016 for 17 observatories as well as the seven additional FogNet stations, and for 2017 for all observatories and FogNet stations with the exception of Okamboro (S06). A basic data processing routine has been worked out as follows. From the RGB images, a digital surface model (DSM) is calculated (i.e. providing heights of individual features such as trees and termite mounds), as well as regular orthophotos (rectified aerial photographs), in GeoTiff and even Google Earth tiles. From both the RGB and the NIR images, a variety of indices can be calculated, which in turn can be used to identify specific features on the ground (see, for example, Oldeland et al., 2017; Strohbach, 2018). The vegetation indices being calculated as standard are the excessive green, normalised excessive green, and excessive red indices derived from RGB images (Meyer & Neto, 2008; Rasmussen et al., 2016), whilst a NDVI and Modified SAVI are also calculated (Huete, 1988; Huete et al., 1992) from the NIR images if available.

First attempts to map tree species to species level are promising (Oldeland et al., 2017), but require more ground-truth data. The aerial images were also successfully used to determine the degree of forest degradation and deforestation in the Mopane savanna in Namibia (Strohbach, 2018), as well as the woodland structure of the Kavango woodlands (Knox et al. 2018). We are also busy determining the compatibility of current high-resolution colour images with old low-resolution, panchromatic aerial photographs, to monitor bush encroachment trends since the 1950s (Walters, 2016).

Monitoring with drone-based aerial imagery is not limited to tree and shrub species. We are able to monitor the density and vigour of the grass sward, an important requirement for grazing monitoring, using remote sensing data. This, in turn, feeds into the ongoing programme to restore Namibian Rangelands (see http://www.nrmps.org, http://www.agra.com.na/news/rangeland-monitoring-project.php and http://www.namibiarangelands.com/). Furthermore, erosion features are both clearly visible and measurable in drone imagery (Fig. 4). Even the response of vegetation and soils to restoration measures can be made visible on NIR imagery.

We are also measuring the success of rehabilitation measures at the B2Gold Oshikoto mine (Strohbach & Hauptfleisch, in prep.), mapping the endemic *Neoluederitzia sericeocarpa* populations in the lower Fish River (Hakalume, 2018), determining location, height and health of termite mounds in savanna ecosystems (Fig. 5), as well as determining regrowth of alien invasive *Prosopis* species at Gibeon. Trials are also undertaken

Figure 7: Experimental fire plot ("Purgatory") at observatory S75 Bicuar National Park on the 12 September 2017. The experimental design comprises thirty-six 15 m x 15 m plots and a 5 m firebreak around the outer border of the experimental site. Early and late fire treatments are recognisable by green vs. dark brown patches. Controls (fire exclosure) are perfectly visible due to the bright orange colour of the mature grass sward.

to determine the number and density of burrows of ground-dwelling mammals, and their effects on grass dynamics (Hauptfleisch et al., 2017; Rodgers et al., 2017), as well as using the drone-based aerial imagery to undertake less-intrusive, automated game counts.

Current key messages from the observatory network

Over the past several years, a substantial effort has been invested in the establishment of the observation network. So far, some of the older time series already cover two or even three decades (e.g. from some observatories in the arid ecosystems of South Africa), which is sufficient for meaningful analyses (see references mentioned above and contributions in this book). Continuous monitoring of the newer observatories in Angola and Zambia will produce similarly valuable data in the future.

With the funding provided through the BIOTA, TFO, and SASSCAL initiatives, it was possible to establish and maintain the Observation Network as an important science infrastructure. Meanwhile, numerous important results have been achieved and presented at international conferences like the GEOSS GEO BON Open Science Conference in 2016. Below, some key messages are briefly outlined, without pre-empting careful data analyses in more extensive publications:

- In none of the observatories has a drastic invasion of exotic organisms been observed to date.
- In the observatories located in Kalahari sands, there is a continuous gradient from rich woodland to much less productive sparse arid vegetation types with fewer perennial grasses, and this may reflect a slow degradation process in time.
- During the observation period the majority of observatories have showed only minor changes. However, the droughts in parts of Namibia in 2015 and 2016 and in the Richtersveld and Namaqualand in 2017 and 2018 have caused a most dramatic – in many places complete – die-back of the vegetation, which has turned previously vegetated landscapes into desert (Fig. 6).
- In addition to a general increase or decrease of rainfall, seasonal changes in rainfall amounts have a major impact on species composition, especially in Namaqualand.
- Frost seems to be a neglected but relevant factor controlling the spatial array of the forest and grassland mosaic on the Central Angolan Plateau. Topoclimatic effects need much stronger attention in order to understand past transitions between savanna and forest states, to support conservation planning efforts, and to optimise agricultural land-use decisions.
- As well as the dominant control by climatic oscillations and land use, biotic interactions also play a major role and may cause cascading effects over many years.
- Termites, and especially the genus *Macrotermes,* are very important ecosystem engineers in savanna ecosystems. The role of their foraging of dead wood should be studied with regard to the management of bush encroachment/clearing and fire.
- Fire plays an important role for the vegetation dynamics of the observatories in the Miombo belt. So far, at least in the Angolan observatories, all observed fires have been of human origin and for land management purposes. Grassland management for hunting or grazing, and slash-and-burn of woodland and forest ecosystems, are among the most frequent causes of fires. Thus, the seasonality and intensity of fires in the observatories are controlled by human land use and not by natural causes.
- The newly developed remote sensing tools to detect ignition points and map spatio-temporal footprints of individual fires (see Röder et al, 2018) should be coupled to the SASSCAL Observation

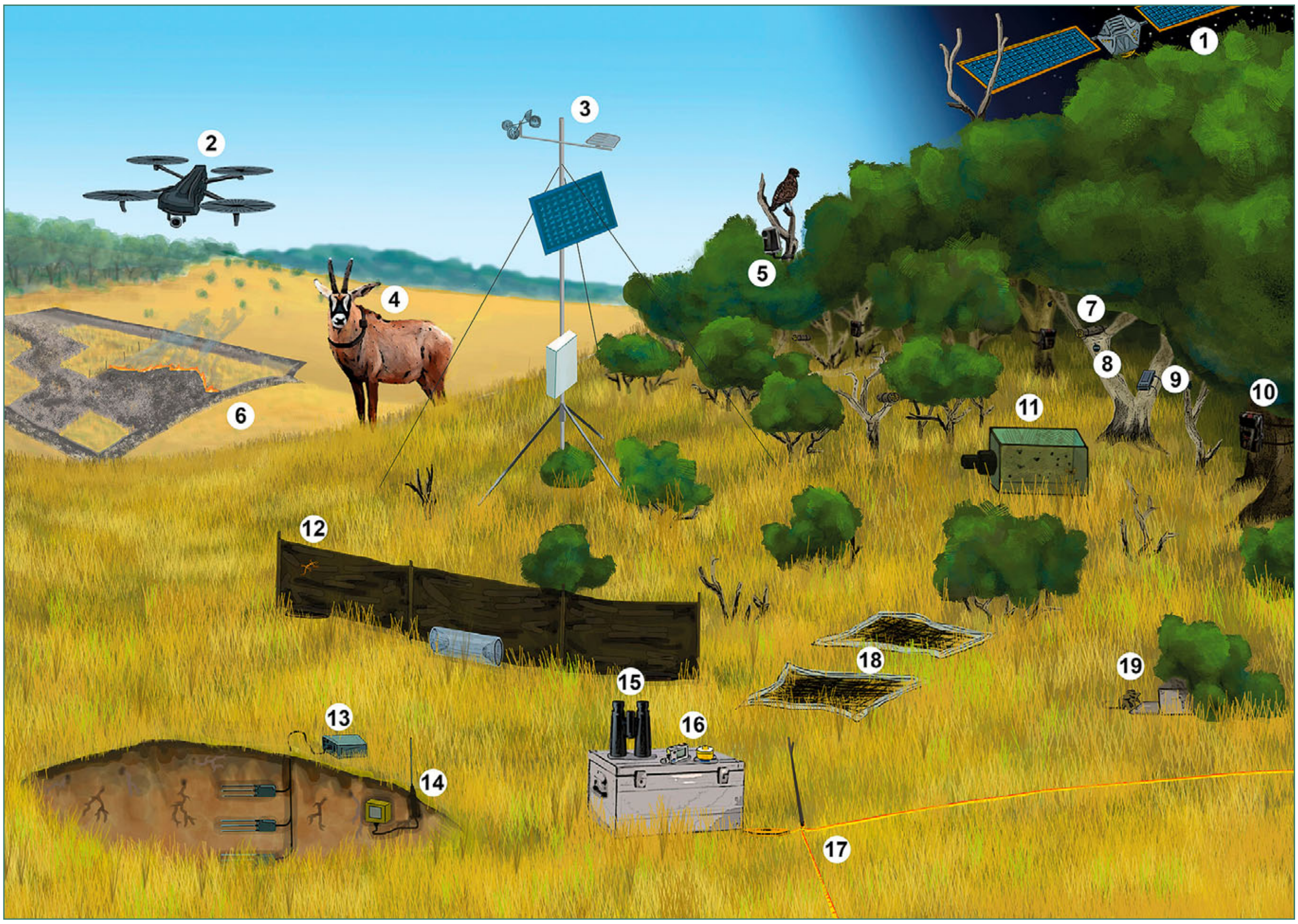


Figure 8: Smart monitoring devices and new experimental approaches for intensive and automatic biodiversity monitoring already in use or planned for SASSCAL Biodiversity Observatories. 1: Imagery/data transfer via satellite; 2: Arial imagery via drones; 3: Climate station; 4: GPS collars; 5: Phenocam; 6: "Purgatory"; 7: Insect trap nests; 8: Tree tagging/permanent marking; 9: Sound recording/bird calls; 10: Camera traps; 11: Photo sensor insect counter; 12: Herpetofauna trapping; 13: Soil water measurements; 14: Temperature loggers; 15: Binoculars/observations; 16: Tree height measurements; 17: Vegetation surveys; 18: Decay monitoring/litter bags; 19: Small mammal monitoring.

Net. They offer new potential for near real-time analyses of fire dynamics and fire impacts on forest and savanna ecosystems.

- Several of the newly established Angolan observatories have lost most of their larger fauna over the last few decades. The extent of faunal depletion and its consequences for vegetation dynamics, fire behaviour and fuel loads, nutrient cycles and spatial nutrient translocation, and ecosystem services for local communities, need urgently scientific attention.

The road ahead

For the future we will need a more functional understanding of the processes of change in order to propose adequate responses. Therefore, we regard it as necessary to integrate more monitoring of (a) key ecological processes and (b) organismic interactions, and to (c) integrate a stronger experimental component. To do the monitoring work more efficiently, we also aim for (d) a stronger use of automatic measuring systems that are made available by technological innovation.

(a) Key ecological process monitoring

In addition to the already established monitoring of variables that describe the quantity and quality of biological organisms, in future we should enhance and integrate the monitoring of environmental variables and processes. Ecohydrological monitoring, which includes the monitoring of water in the topsoil and how it is used by vegetation, could quite easily be established at many of the arid and semi-arid observatories.

(b) Organismic interactions

The decline of insects in Europe has recently increased awareness of how important insects and birds are for ecosystem functions and services. The key services of insects and birds are not only related to plant pollination and seed dispersal, but also the ecosystem engineering functions of termites and ants, which drive soil fertility and productivity and, in so doing, influence the fire regimes of African savannas.

(c) Experiments

Apart from the original grazing exclosures and range management experiments, which were included at the start of our activities in the region, additional experimental approaches have already been integrated in the Observation System to a certain extent. Dantas et al. (2016) pointed to the role of fire as a key mechanism in maintaining the balance between alternate biome states in tropical ecosystems of West Africa. If fire is indeed a tipping mechanism between savannas and woodlands, we need a sound understanding of the differences between man-made and natural fire regimes in terms of seasonal timing, return period, fire intensity, and fire patterns. We also need to understand what the respective consequences of human-dominated fire regimes might be for the resilience of Africa's forest and woodland ecosystems. At present, well documented long term fire experiments from Afrotropical grasslands are rather scarce, the long term fire plots in South Africas Kruger National Park being the most prominent example (van Wilgen et al. 2007).

So far, we have established systematic fire experiments in the geoxylic grasslands of the Angolan observatories Cusseque (S74) and Bicuar National Park (S75), which are located in direct proximity to woodland habitats. The experiments follow a randomised block design with three different treatments – early dry season fire ("cold fire"), late dry season fire ("hot fire"), fire exclosure ("control") – and 12 repetitions for each treatment. The experiment is carried out in a 1 ha plot with 36 permanently marked subplots of 15 m x 15 m each and a 5 m firebreak around the outer edge (Fig. 7).

The experimental design allows for analyses of selected functional traits of perennial plants, as well as of performance indicators and species dynamics. Temperature loggers are installed to measure microclimatic patterns and fire heat. Changes in vegetation pattern will be documented at regular intervals with drone photography. In the future, we plan to extend this experimental approach to additional observatories in the Miombo Biome.

(d) Automatic monitoring systems

It is a global trend in biodiversity observation projects to make use of advances in technology to complement existing monitoring activities. Automated data recording and photography, robotic systems, genomic sampling, and sound sensors, are available and have recently become more robust. Such electronically recorded data can be integrated more easily into the existing data framework than in the past, and can even link up with remotely sensed data (Fig. 8).

The following country-specific perspectives can be formulated for the biodiversity monitoring activities in Angola, Namibia, and South Africa:

a) Angola: The first few years of implementation of the standardised biodiversity observatories have enabled us to establish a monitoring network and to build a baseline to carry out essential analyses to understand the current status of biodiversity in the country. The way ahead consists of the analysis of already-accumulated monitoring data in order to provide a better understanding of the dynamics of plant and animal communities, the environmental factors affecting species composition and habitat conditions, and to create comparable data layers on biodiversity status and trends within the region.

We must highlight that Angola faces a number of challenges in making a national biodiversity monitoring system operational. The monitoring system needs to secure the long-term sustainability of the observatory network that is already in place. The effective institutionalisation of the system is needed, as is a comprehensive program to maintain, strengthen, and expand Angola's system of observatories. As local capacity to conduct monitoring and the processing and analysing of data is still our Achilles' heel, we remain committed to continue the empowerment of a new generation of researchers able to address the scientific and technical needs for long-term biodiversity monitoring in the country.

b) Namibia: Although drone surveying proved to be a fast and cost-effective method to obtain baseline data, at best it yields information about the dynamics of individual woody plants and not the composition of the herbaceous and graminoid layers of the vegetation. The effective interpretation of such drone data also requires detailed ground-truth data. Whereas in the past we concentrated on detailed data related to the composition of all vegetation layers, we will in future need to collect additional data on grass sward density and the specific location of individual tree species in order to make the most of drone imagery. However, the potential of this imagery as part of an integrated long-term monitoring system is excellent. Of particular interest will be an extended use of Near Infrared (NIR) and Red Edge imagery available from the Sequoia sensors, once these are available. Here we hope to greatly improve the monitoring of erosion rehabilitation and of lichen field dynamics after highly destructive disturbance events such as off-road driving and the impact of film sets.

c) South Africa: The analyses of monitoring data from the dry regions of South Africa have so far revealed the complexity of the interaction between changes in plant species composition of the vegetation, the population dynamics of individual species, and the environmental drivers such as climate, herbivory, and habitat conditions. Current analyses of time-series data from the Succulent Karoo has revealed that the commonly used classification of plants into so-called life-form types sensu Raunkiaer as plant strategy types is not sufficient to explain the species' responses to the rainfall patterns. We will therefore further refine the classification of life form types for the Succulent Karoo by taking into account traits that are related to the life span of the species and to the strategies of resource allocation. For example, a quick response to high rainfall events versus protection of the water-storing organs against evaporation or herbivory are two extremes along the continuum of traits. With regard to the environmental drivers, we will place greater emphasis on understanding the seasonality of rainfall and the number of rainfall events that have an effect on plant growth (> 6 mm per rainfall event, Hanke et al., 2011) as well as the duration of periods with no efficient rainfall.

The long-term data on vegetation dynamics will further be made available for global analyses on changes in diversity, species, or life form composition. The study has already attracted great interest from researchers all over the world and has contributed, for example, to a global analysis on the influence of mean annual precipitation on the proportion of annual and perennial species in the regional flora (Torma et al., in subm.). Findings from our analyses have also been included in the global PREDICTS database (Projecting Responses of Ecological Diversity in Changing Terrestrial Systems (Hudson et al., 2017), and have contributed to the project “Drivers of communities’ temporal stability” of the Czech Academy of Science.

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