OPTIMASS

Options for sustainable geo-biosphere feedback management in savanna systems under regional and global change

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A joint Namibian-German research project

UNAM University of Namibia
Universität Potsdam
Namibia University of Science and Technology
Freie Universität Berlin
Eberhard Karls Universität Tübingen
Institute for Social-Ecological Research

The OPTIMASS team at the first annual meeting in Windhoek, 2015

Dear members of the Namibian rangeland community,

Namibian savanna rangelands are a hot spot of climate, land-use and socio-economic change. Management of these rangelands has to face complex links between climate, atmospheric carbon-dioxide, water, vegetation dynamics and livestock-production (Figure 1).

Between August 2014 and January 2018, the joint Namibian-German research project OPTIMASS explored these different links along a rainfall gradient across Namibia from north to south (Figure 2). Funded by the German Federal Ministry of Education and Research (BMBF), OPTIMASS aimed at providing science-based information that will assist land users and decision makers towards a sustainable management of these important and beautiful ecosystems. The project was jointly coordinated by the University of Potsdam, Germany and the University of Namibia, with further partners from the Namibia University of Science and Technology, Freie Universität Berlin, Universities of Tübingen and Hohernheim, and the Institute for Social-Ecological Research in Frankfurt/Main.

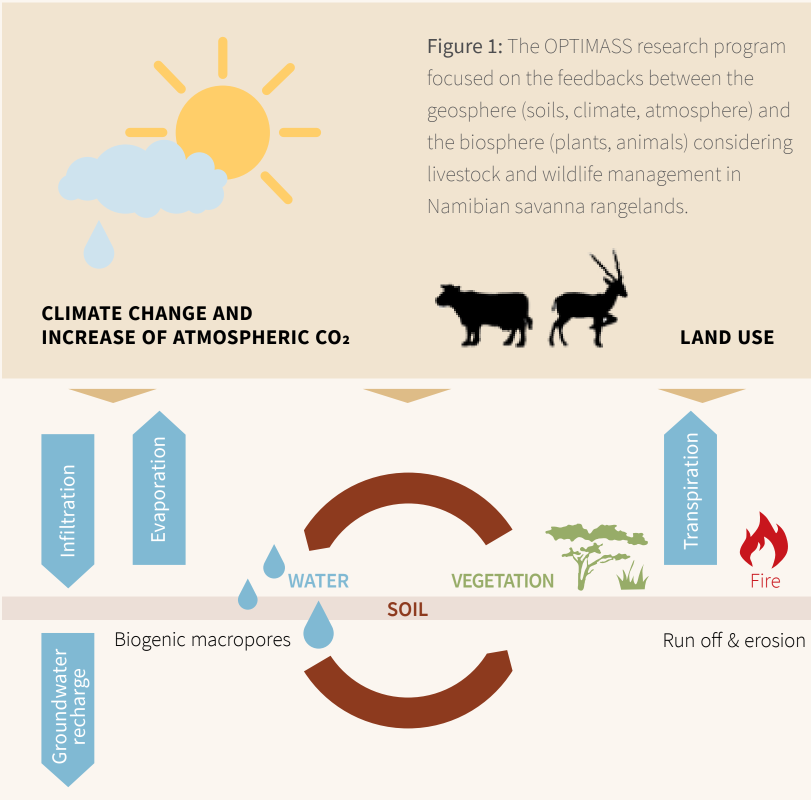


Figure 1: The OPTIMASS research program focused on the feedbacks between the geosphere (soils, climate, atmosphere) and the biosphere (plants, animals) considering livestock and wildlife management in Namibian savanna rangelands.

OPTIMASS IN NUMBERS

Project time
August 2014 – January 2018

German-Namibian project lead
Prof. Dr. Florian Jeltsch,
PD Dr. Niels Blaum,
University of Potsdam, Germany

Dr. Heike Wanke,
University of Namibia

Dr. Morgan Hauptfleisch,
Namibia University of Science and Technology

Partner Institutions
Institute of Social-Ecological Research, Germany
Freie Universität Berlin, Germany
University of Tübingen, Germany
University of Hohenheim, Germany

Advisory board
Harald Marggraf,
Namibia Agricultural Union

Bertus Kruger,
Agra Ltd. Namibia

Viviane Kinyaga,
Ministry of Agriculture, Water and Forestry, Namibia

Publications
48 awarded Honours, Bachelor and Master theses

6 PhD projects (three theses of Namibian and German students each)

24 publications in scientific journals (to date)

87 conference contributions

OPTIMASS was funded by the German Federal Ministry of Education and Research (BMBF-FKZ: 01LL1302A) with additional grants from the German Academic Exchange Service DAAD

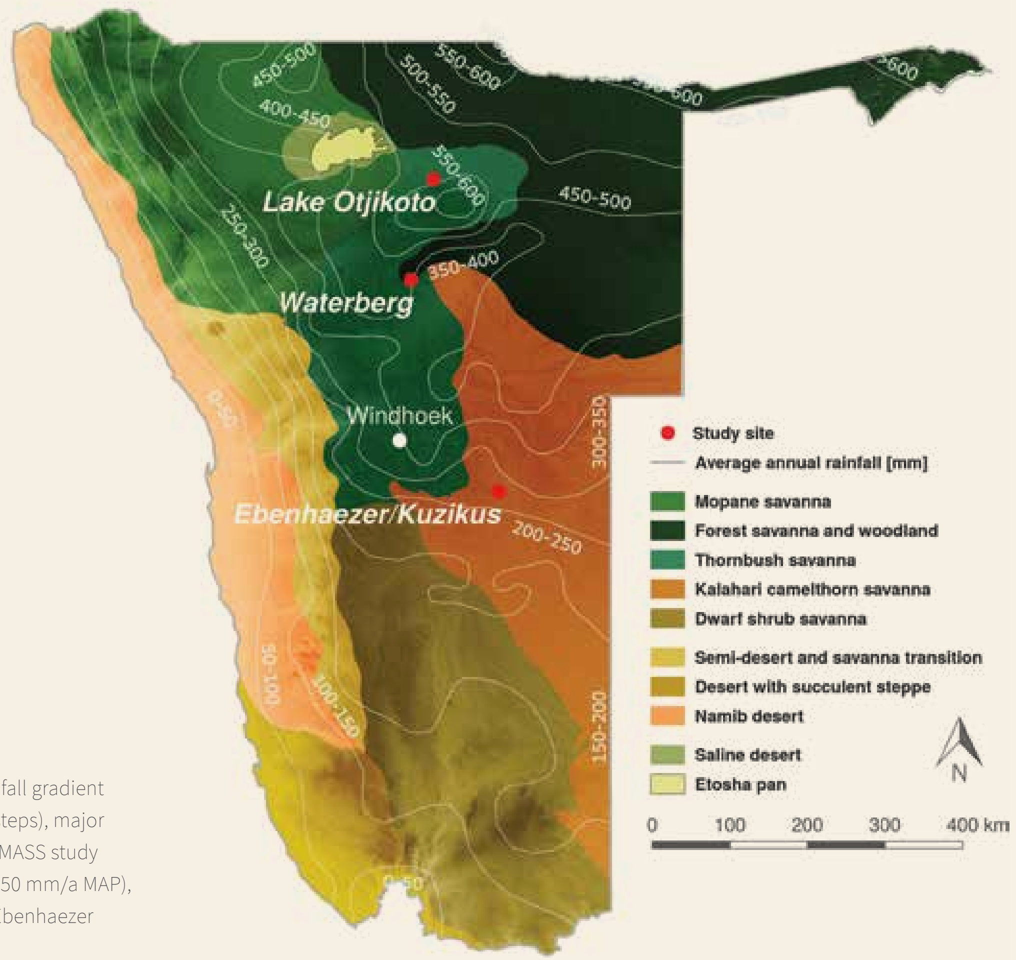


Figure 2: Map of Namibia with rainfall gradient (white lines depict 50 mm rainfall steps), major vegetation types (colors) and OPTIMASS study sites (red circles): Lake Otjikoto (±550 mm/a MAP), Waterberg (±410 mm/a MAP) and Ebenhaezer (±220 mm/a MAP).

Focusing on the interplay between the abiotic and the biotic world, OPTIMASS combined farmer interviews, field research, experiments and the development of novel computer simulation models. OPTIMASS scientists recorded current land use practices and analysed feedbacks between soil, water, vegetation and biodiversity explicitly considering the role of plant physiology and soil digging animals. This knowledge can be used to inform policy makers and to develop guidelines for sustainable management of water and rangeland under predicted changes in climate.

The booklet at hand summarizes the key findings of OPTIMASS and presents exemplary studies in more detail. The project came along with a strong educational component and enabled joint PhD-, Master-, Honours- and Bachelor-projects of Namibian and German students. In annual summer schools alternately held in Namibia and Germany, researchers of all involved institutions shared their knowledge about state-of-the art methodology, savanna rangeland ecology and hydrology with many students.

A direct involvement of stakeholders in the process of identification of suitable water management and rangeland restoration measures assured that the direction of research suited the demand of the involved businesses, communities and institutions. During the continuous dialogue with farmers and other experts, farmers repeatedly expressed the need for better knowledge and information sharing.

With this booklet we want to express our sincere gratitude to the Ministry of Environment and Tourism for granting research permission and hosting our summer school at

Participants of the first OPTIMASS Summer School focusing on experimental design and statistical data analyses at the Okatjikona Environmental Education Centre, Waterberg National Park, Namibia in 2015. Students developed small experiments as a group work, collected own data in the field and analyzed their data with the open source statistic software *R*.

Participants of the 21st National Rangeland Forum, hosted by OPTIMASS in Otjiwarongo, Namibia 17th-19th July 2017. More than 140 experts from the two largest farmer unions, the Namibia Agricultural Union and the Namibia National Farmers' Union, two Namibian ministries, the Ministry of Environment and Tourism and the Ministry of Agriculture, Water and Forestry, Namibian, South African and German Universities, and several NGOs used this platform to exchange knowledge and to discuss current challenges in savanna rangeland management and research.

Okatjikona Environmental Education Centre, and to the Ministry of Agriculture, Water and Forestry for access to their research farms. Our thankfully appreciations go to Pieter Hugo for hosting and maintaining the OPTIMASS research camp at Ebenhaezer, Mr. Shivute for his manifold help at Okumubonde, the divers Johan Le Roux and Chris Steenkamp for their help to collect the sediment cores at Lake Otjikoto, Ms. Andowa and Ms. Januarie for their repeated support, the members of our advisory board Harald Marggraff, Bertus Kruger and Viviane Kinyaga for their continuous advices, and all the farmers and other experts that helped us making OPTIMASS a success!

Please enjoy reading this booklet and share with us experiences made during various research activities.

On behalf of the OPTIMASS team

Dr. Heike Wanke | Prof. Dr. Florian Jeltsch | PD Dr. Niels Blaum | Dr. Morgan Hauptfleisch

Starting a drone at the third annual summer school on remote sensing and spatial analysis in Namibia, 2017

OPTIMASS Education and Exchange Program

Knowledge exchange between Namibia and Germany and educating future generations of scientists and rangeland experts were major aims of OPTIMASS. The three cornerstones of our Education and Exchange Program were (1) annual summer schools in Namibia and Germany, (2) OPTIMASS exchange travel grants to promote interdisciplinary exchange of more than 25 students and scientists between partner institutions in both countries, and (3) supervision of students from Namibia and Germany.

We are very proud of 48 degrees awarded to our OPTIMASS students at the level of Bachelor, Honours and Masters. Many theses were jointly supervised by a German-Namibian team. It is our great pleasure that one Doctoral degree has already been awarded by the University of Potsdam to a Namibian student and two more candidates from Namibia and three from Germany are currently finishing their dissertations. One reason for this success were the many new multicultural friendships bonded between students and scientist that created so much fun during the hard work in the field and in the labs.

Cecilia Ndunge at her Masters graduation

Classwork (left) and field work (rigth and bottom) at the first OPTIMASS Summer School focusing on experimental design and statistical data analyses at the Okatjikona Environmental Education Centre, Waterberg National Park, Namibia in 2015

SUMMER SCHOOLS

OPTIMASS researchers organized two summer schools in Namibia and one in Germany for students and researchers from universities of both countries, employees of the Ministry of Environment and Tourism and the Ministry of Agriculture, Water and Forestry, and SASSCAL students.

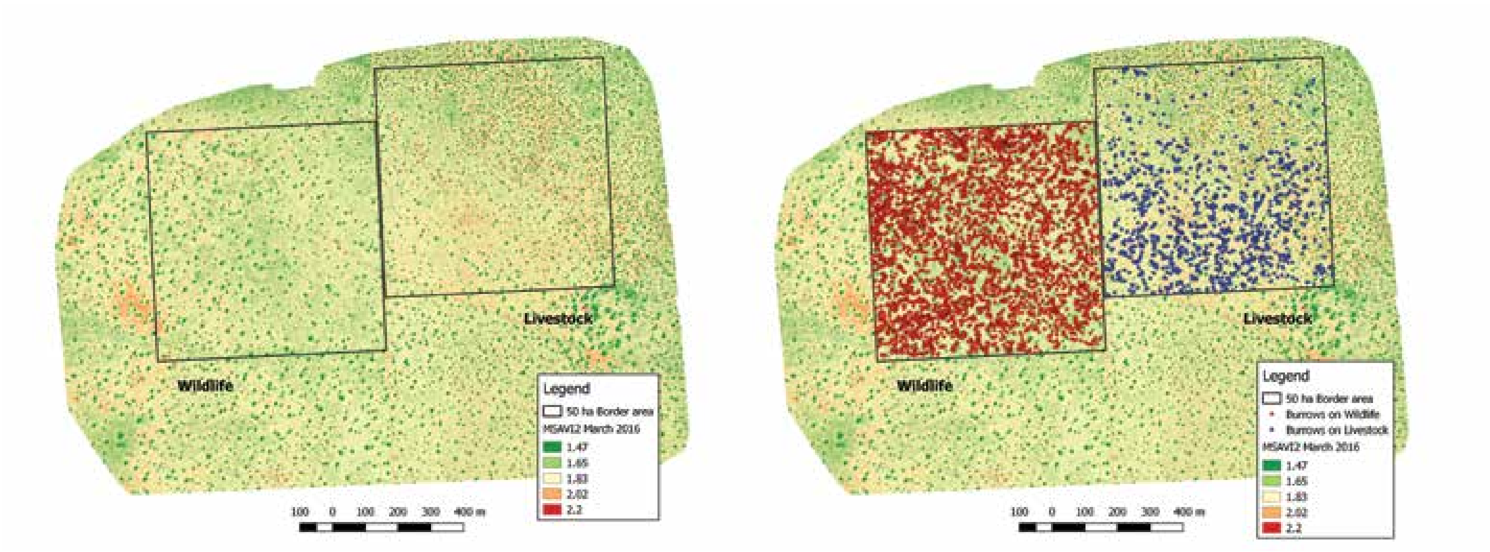
The first summer school in Namibia focused on experimental design and data analyses with the open source statistics software 'R'. The development of a well-designed studies and the selection of the appropriate statistical tests for data analyses is a key qualification for independent researchers.

The focus of the second summer school in Germany was on ecological modelling with the open source software 'NetLogo'. With this state of the art tool, students were able to develop their first simple computer simulation models to analyze, e.g. Elephant population dynamics. Understanding how simulation models are developed and how these function is a prerequisite of future scientists.

The last summer school in Namibia skilled students in analyzing remote sensing and other spatial data in the open source software Quantum GIS. Practical work of the students included the collection of aerial fotos with high spatial resolution using the SASSCAL eBee-drone and subsequent data analyses. In addition to the fun of flying a drone, this is one of the future key qualifications of rangeland experts for assessing veld condition and even animal counting.

The effect of burrowing mammals as bioturbators on Namibian rangelands

Michelle Rodgers, Morgan Hauptfleisch and Mark Bilton



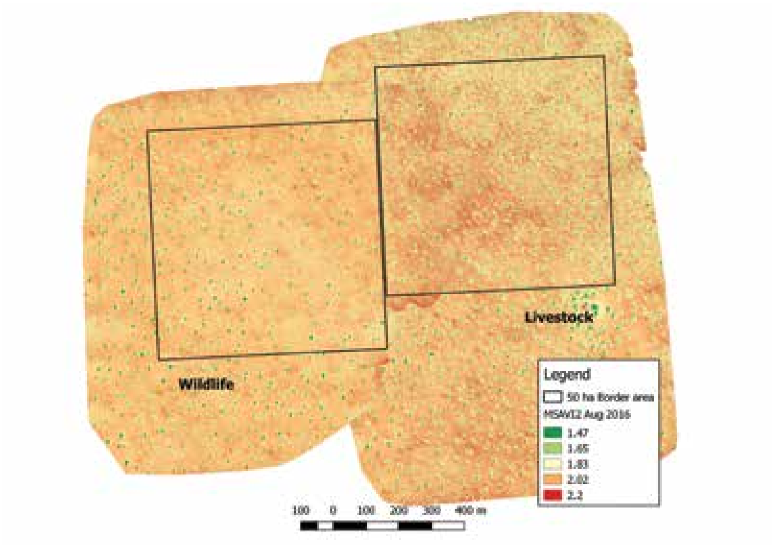


Figure 1: Multispectral imagery to show site productivity per season (top left and left), and burrow abundance per site (top right). The productivity index MSAV12 grades the image from green to red. Lower values (green) signify greater productivity, and higher values (red) indicate poor productivity.

KEY MESSAGE

Burrowing mammals have an important function in the geo-biosphere feedback system, providing ecosystem services for vegetation and land-use productivity.

At the OPTIMASS Kalahari site we compared the abundance and diversity of burrowing medium-sized nocturnal mammals between neighbouring livestock and wildlife land use types. We postulated that bioturbation by nocturnal mammals is an important feedback mechanism leading to improved soil conditions and therefore improved vegetation productivity.

We used nocturnal road strip counts and high resolution multispectral unmanned aerial vehicle (drone) imagery to quantify differences in medium-sized mammal population dynamics, burrow densities and dimensions, and vegetation productivity (Figure 1) between the land uses.

The study found a higher diversity of nocturnal medium-sized mammals on the wildlife reserve (Figure 2). Furthermore, clear seasonal patterns were observed (Figure 2). Whereas total sighting number was similar in the growing season and winter on the wildlife reserve; on the livestock farm, there were significantly more mammals spotted in summer, and far fewer in winter. Results showed that shrub encroachment had a negative relationship with burrow number on both sites, with the livestock farm particularly susceptible. Importantly, some benefits were indicated by areas around larger burrows showing higher vegetative productivity.

Important ecosystem services were also highlighted during the study. Aardvark and springhare were the most prolific bioturbators, turning over an estimated 3.6 tons of soil per hectare per year. This not only plays an important role in nutrient cycling, but also provides shelter for other wildlife, and traps seeds and moisture to enhance plant regeneration. The temperature respite provided by burrows were found to be of great value to wildlife using the burrows. In summer, surface temperatures averaged 39 °C while internal temperatures averaged a comfortable 22 °C in small burrows, 20.5 °C in medium burrows and 20.9 °C in large burrows. These are ideal temperatures, not only for mammals and reptiles, but also for seeds to germinate. Springhare were found to be a keystone species in the Kalahari. Their burrows (medium size class) were by far the most abundant and had the largest difference between surface and internal temperature, and are the dominant prey species for carnivores in the area.

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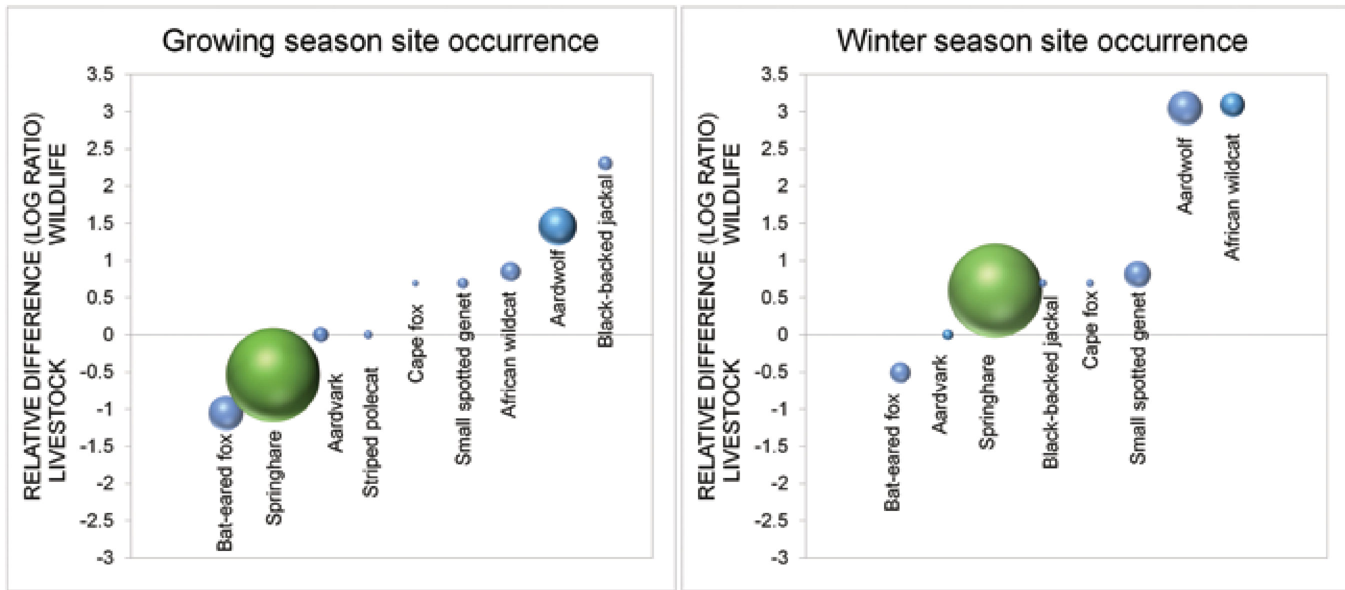

Figure 2: Relative frequency of single species sightings during night-time drives. Y-axis gives the log ratio of mammal sightings during the growing season (left) or winter (right) at the two sites. Spheres above the zero line indicate greater frequency of sightings during a season on the wildlife reserve, while spheres below the zero line indicate greater frequency of sightings during a season on the livestock farm. Sphere sizes indicate overall frequency of sightings of a given species. Springhare showed possible site preference based on season (indicated by green spheres).

Responses of beetle communities along a bush cover gradient

Robert Hering and Niels Blaum

Robert Hering planning his first beetle trapping session

One of the 2882 beetles we determined: *Graphipterus amabilis*

Some of the 600 pitfall traps we used to catch the beetles

KEY MESSAGE

The contribution of ground-dwelling beetles to the ecosystems welfare depends on diversified savanna systems comprising small and large bushes.

Ground-dwelling beetles play a vital role in the provision of ecosystem services such as nutrient cycling. They are one of the most important indicators of environmental health. In this project, we investigated the consequences of increasing bush cover for the beetle community. We recorded beetles on sites with different bush cover on two farms in the western Kalahari.

In total we collected 2882 beetles belonging to 107 species. These numbers demonstrate the remarkable diversity of this animal group in these savanna systems. Numbers and diversity were highest at sites with small bushes and few patches of large bushes.

Dung beetles (Scarabaeidae) distribute patchy dung more evenly and make its nutrients available for plants (Figure 1). We recorded 25 species, which were most present at medium bush cover (3 to 10%). Dung beetles indirectly depended on large, solitary bushes because they attract dung producing livestock. The beetles process the dung during the rainy season. Their larvae fulfil their life cycle below the surface during dry season, if soil is undisturbed, and emerge in the next rainy season. For this to be successful, the timing of grazing is a key management tool.

Darkling beetles (Tenebrionidae) feed on dead plant material and play an important role for the recycling of elementary nutrients (Figure 1). They were the most diverse beetle family with 31 species. The community was healthiest at medium bush cover ranging from 3 to 10%. Darkling beetles need bushes for shading, so that they do not overheat, and as shelter from predators. Small bushes below 1.5m height and at a density of 20 to 100 individuals per hectare provided good habitats if the forb and grass layer was well developed.

Ground beetles (Carabidae) are predators of small animals, making them good indicators for the welfare of other ground-dwelling organisms (Figure 1). Most of the 15 species occurred below 10% bush cover, demonstrating the environmental health there. However, some large Carabids, e.g. the Saber-toothed ground beetle, were mostly present under higher bush cover. Such areas with bare soil and many ants are good hunting grounds for these beetles.

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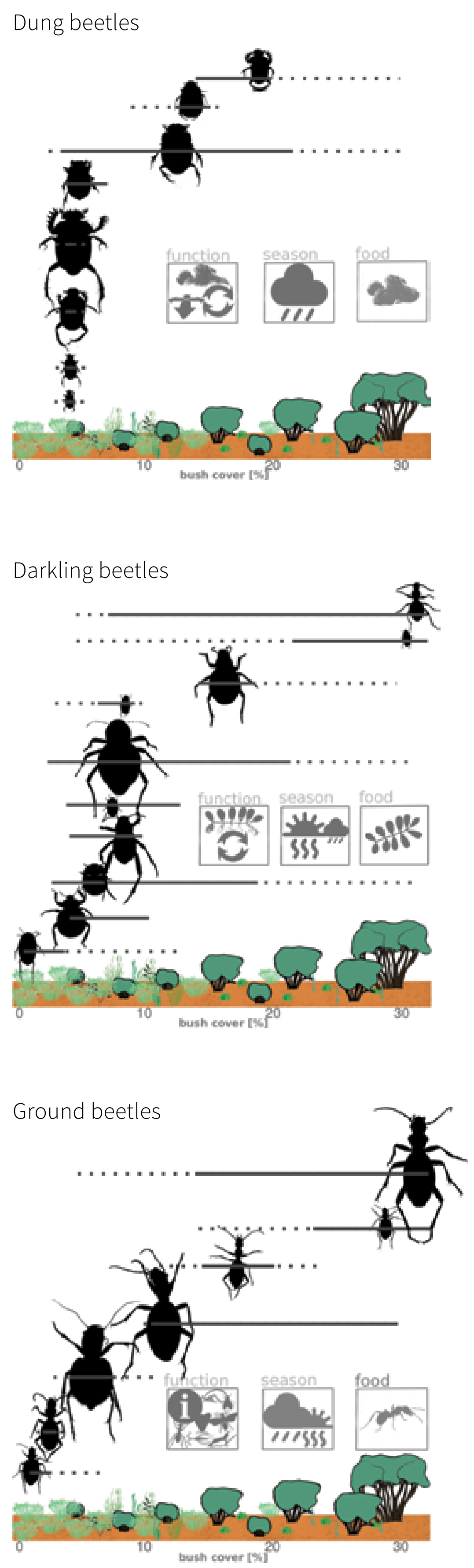

Figure 1: Common beetles and their optimum position along the bush cover gradient. Solid lines indicate the main and dotted lines the subordinate range of occurrence. The boxes show the preferred food, the main seasons of activity and the ecosystem function.

Effect of large and small scale vegetation patterns on biological macropores

Arnim Marquart, Katja Geißler, Maren Lönz and Niels Blaum

KEY MESSAGE

The occurrence of biological macropores, which can be a driver of water infiltration is positively influenced by shrub presence in a grass dominated savanna.

Macropores are underground tunnels which often have been shown to increase water infiltration (see also the following two projects), which in turn can affect vegetation patterns. Many soil-burrowing arthropods (e.g. termites and ants) depend on certain vegetation structures, as food source or shelter, meaning a shift in vegetation patterns, for example by shrub encroachment might affect arthropod diversity and abundance. It is also likely that rangeland management approaches such as shrub clearing can have severe impacts on the soil burrowing arthropod fauna thereby indirectly affecting soil water dynamics. This project focuses on the question, in how far the occurrence and abundance of macropores are influenced by large scale vegetation cover and small-scale vegetation structures such as grass tussocks and shrub canopies at different times of the rain season.

To study these effects, we conducted macropore surveys on seven 50m x 50m plots along a shrub cover gradient (0 – 22% aerial shrub cover) at the Ebenhaezer Farm 160 km south-east of Windhoek. On each plot, all macropores were counted and measured on 40 randomly choosen subplots (50cm x 50cm). This was done three times at the beginning, middle and end of the rain season 2016-2017. Furthermore, macropores were recorded on specific subplots neighboring either grass tussocks, shrubs or open soil to test how small-scale vegetation structures influence their occurrence.

This study revealed three main results: 1) The mean macropore area was about twice the size at the beginning of the rain season, compared to the two later surveys. 2) The number of macropores was much higher under shrub canopies, compared to grasses and open soil, and 3) about twice as high on grass dominated plots, compared to shrub dominated plots (Figure 1). Our results indicate, that arthropod burrowing activity often is triggered by the first rain events, which might increase water infiltration at later points throughout the rain season. The spatial preference of arthropods to build macropores suggests, that a high grass density with occasionally occurring shrubs is the best suited vegetation pattern in maintaining healthy soil dynamics. Therefore, this study suggests, that complete shrub clearance might negatively affect soil water dynamics and should be avoided.

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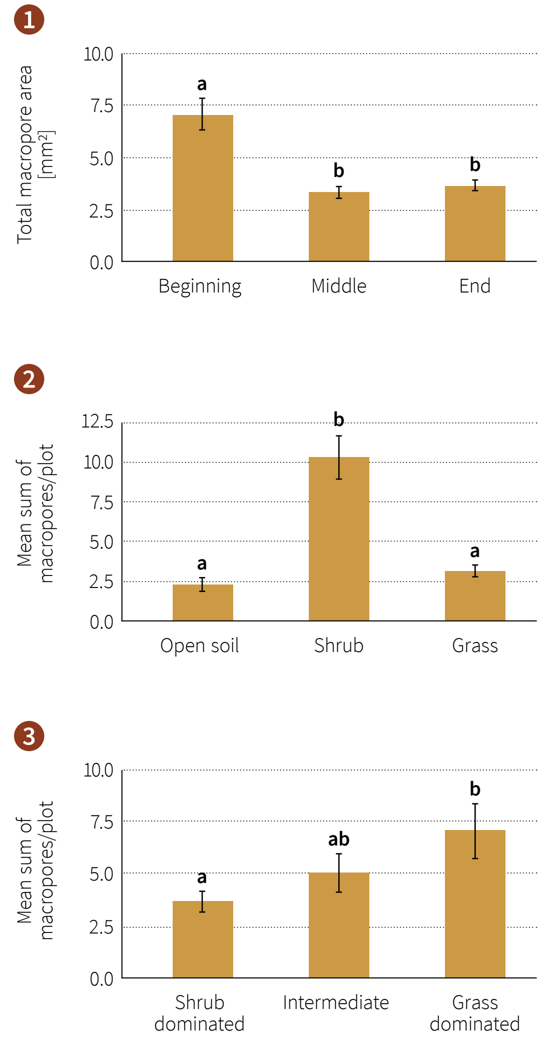


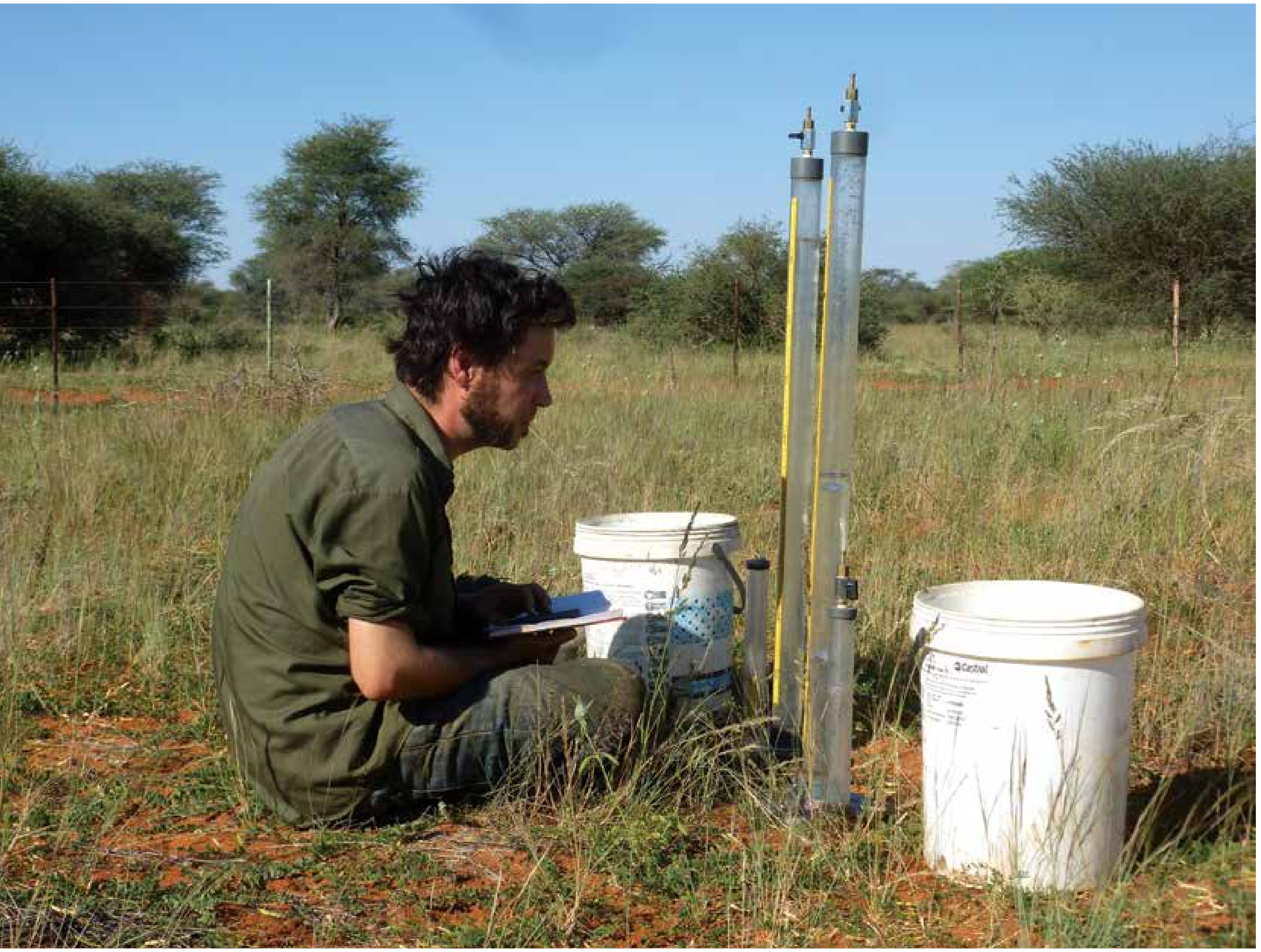
Figure 1: Figure 1: Bar plots showing the means and standard errors of (1) macropore area at the three different sampling periods, (2) macropore numbers on three plots with different aerial shrub cover and (3) number of macropores neighboring small scale vegetation structures and open soil.

WHAT ARE BIOLOGICAL MACROPORES?

Macropores are little inconspicuous holes in the ground. Only a few millimeters in size at soil surface macropores can branch out to complex belowground tunnel systems. They are built by termites, ants but also beetle larvae, wasps and many other animals. Larger macropores built by rodents, porcupine and aardvark can be quite annoying on farm raods.

Influence of biological macropores, bush size and soil type on infiltration rate

Arnim Marquart and Niels Blaum



KEY MESSAGE

Macropores play an important role in water infiltration, especially on soils with loam content.

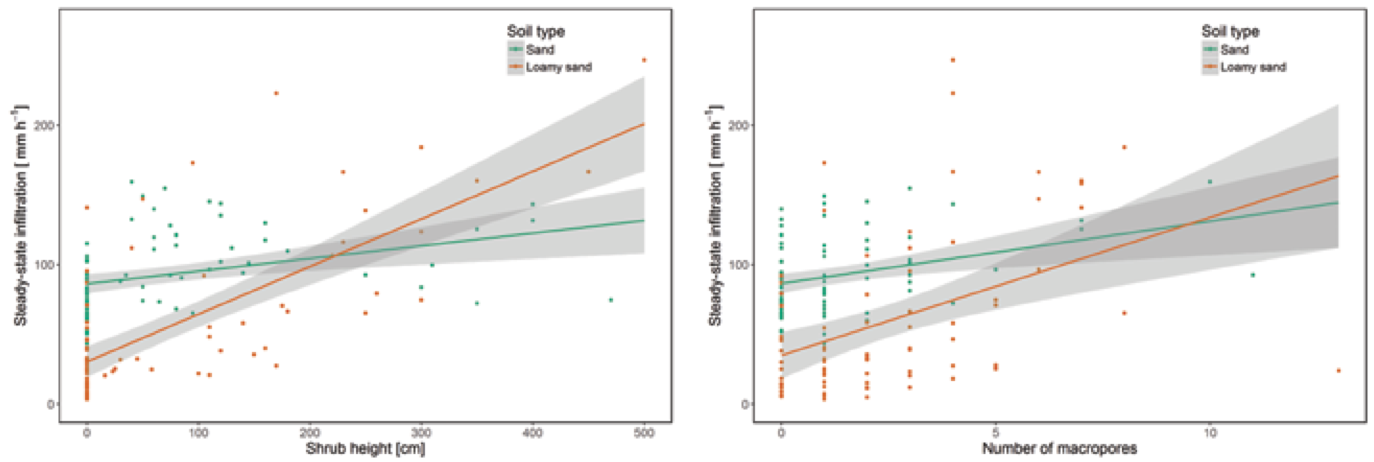


Figure 1: Effect of bush height (left) and number of macropores (right) on steady-state infiltration. Colors represent the soil types on the two farms. Macropores only had an effect at the Okomumbonde farm where the loam content of the soil was higher.

Namibian semi-arid rangelands are characterized by low annual rainfall, making water the limiting resource for plant growth and survival. Due to that fact, macropores, created by soil burrowing arthropods (insects, scorpions, millipedes etc.) may play a crucial role for soil water infiltration and hence vegetation dynamics, by differently affecting water availability for grasses and bushes. On the other hand, the soil beneath bush canopies might also have a higher water infiltration rate than in the open, since the soil surface is less compacted and dead roots can create channels enhancing water flow. Furthermore, it is very likely that the mentioned effects are also dependent of soil texture, i.e. a higher loam content would lead to a higher fraction of water flow through soil pores.

We performed paired infiltration experiments to measure steady-state infiltration (in saturated soils) using disc-permeameters. Each pair consisted of one plot randomly set up the canopy of a blackthorn bush (Senegalia mellifera) combined with a second plot in the open veld. Subsequently, all macropores were counted and the bush heights were measured. 40 paired experiments were carried out at the Ebenhazer Farm on sandy Kalahari soil and the Okomumbode Farm, beneath the Great Waterberg on loamy sand, respectively.

The infiltration measurements showed a significant increase in steady-state infiltration with bush size and with number of macropores at the Okomumbonde Farm where the soil had a higher loam content (Figure 1). This indicates, that arthropod created macropores can be of great importance on loamy sand soils at strong rain events, as they might lead to water infiltration into deeper soil layers and reduce water run-off. Healthy soils with a high faunal soil activity will thereby have the ability to uptake and store higher amounts of rain water, essentially for plant establishment, growth and survival. A healthy soil community should therefore be considered important, especially in management practices on loamy sand rangelands. Furthermore, scattered bush patches with bigger bushes should be kept, when considering bush removal practices.

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Arnim Marquart setting up the disc-permeameters to measure soil water infiltration

Effects of termite induced macropores on soil water infiltration

Lars Goldbach, Arnim Marquart and Niels Blaum

KEY MESSAGE

Termite induced macropores can have positive effects on soil infiltration processes during heavy precipitation events but it depends on the soil type and the season. It might be ecologically worthwhile to consider an appropriate use of termites in the renaturation of degraded savannas.

Figure 1: Example of an adjusted 50 x 50 cm infiltration profile picture on loamy soil with macropores (left) and its control plot without macropores (right). The blue colour showing the infiltration depth in the sandy soil profile is a common food colourant. The black and white parts show the inner 20 cm of the pictures used for the analysis.

Termites are considered important ecosystem engineers in savanna ecosystems. Rain experiments with a rain simulator were conducted to find out about the influence of termite induced macropores on soil infiltration. Macropores are tunnels and cavities in the soil larger than 75 µm in diameter that are usually generated by plant roots, soil cracks, rodents or invertebrates (e.g. ants, earthworms or termites). They can be found all over the savanna soils.

48 plots of size 50 x 50 cm2 were used to conduct one-hour-long rainfall experiments on two farms in Namibia. Six paired (many and no macropores) heavy precipitation events (40mm/h) were simulated for two soil types (loamy sand and sand) and two vegetation types (grass and bush dominated) respectively. A non-toxic food colouring was added to the water to be able to trace the infiltration depth. After 24 hours, three vertical infiltration profiles for each experiment were excavated and photographed.

On sandy and more loamy soils, termite macropores had a positive influence on infiltration depth. These results agree with other studies indicating the importance of termite macropores for soil infiltration. Surprisingly, no effect of termite macropores was found in bush dominated microhabitats, macropores even decreased the maximum infiltration depth in grass dominated microhabitats. Interestingly, these results from the vegetation treatments in the beginning of the rainy season stand in contrast to results from a previous study that was performed later in the rainy season. These seasonal differences might be explained by a different initial saturation of the soils.

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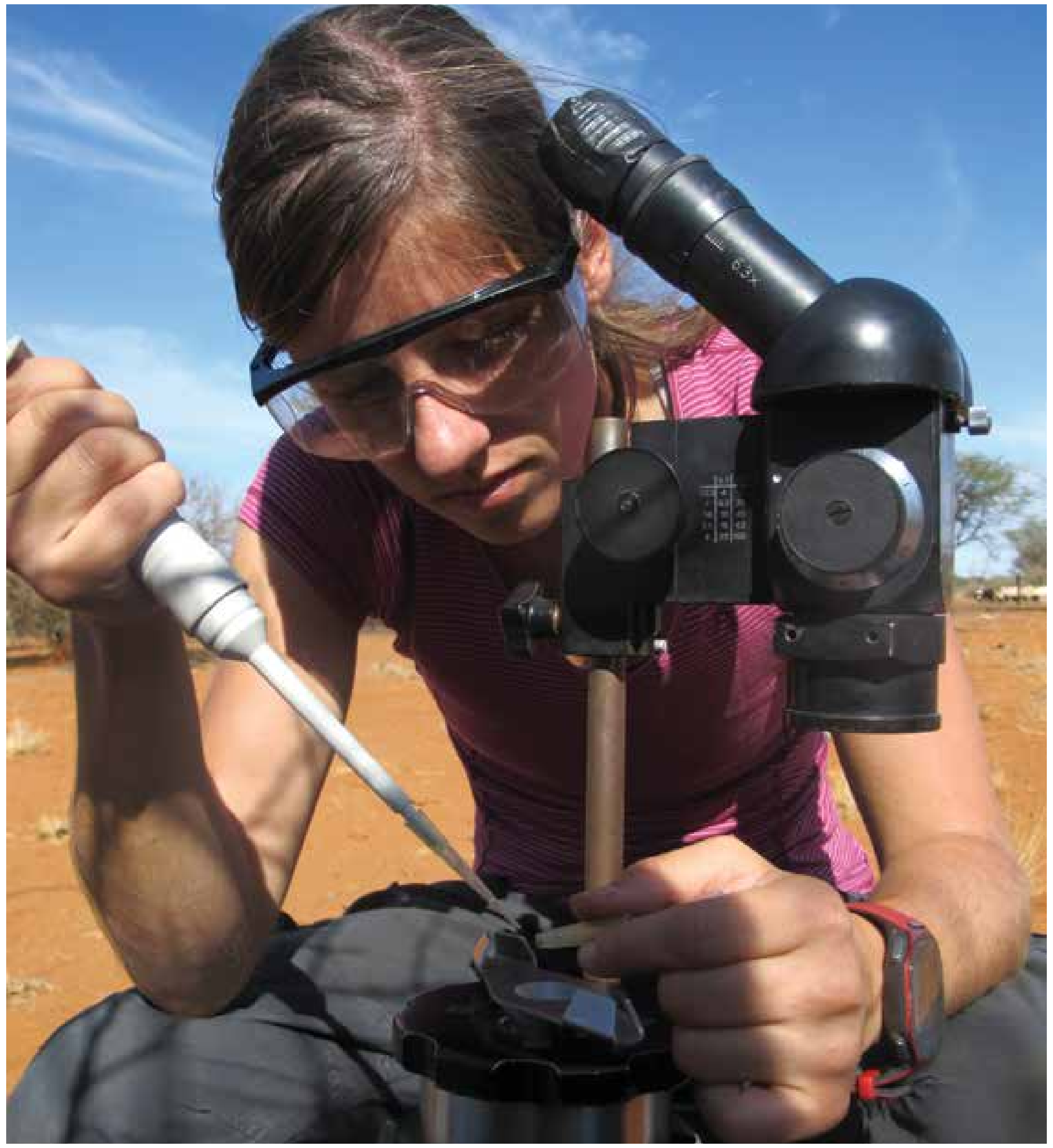
Lars Goldbach (right) with co-workers at the MAWF breeding farm Okumumbonde, Waterberg Plateau Park

Water sources of bigger bushes: A risk for groundwater recharge?

Katja Geißler, Heike Wanke, Shoopala Uugulu and Jessica Heblack



KEY MESSAGE

Size doesn't matter. Our results allow no recommendation, which bushes to clear first in terms of competing with potential groundwater recharge and perennial grasses water use. Anyway, blackthorn seems not much of a threat for groundwater recharge in this semiarid savanna system.

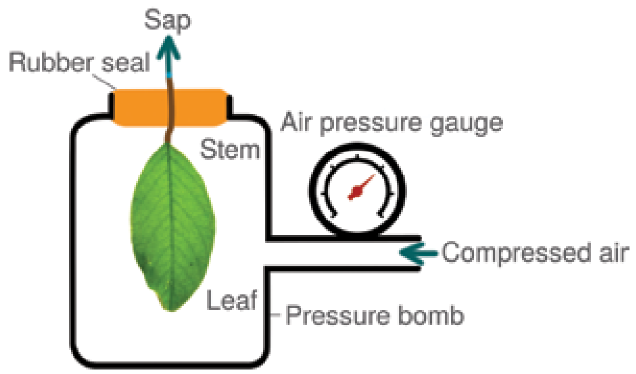


Figure 1: Sampling of plant water

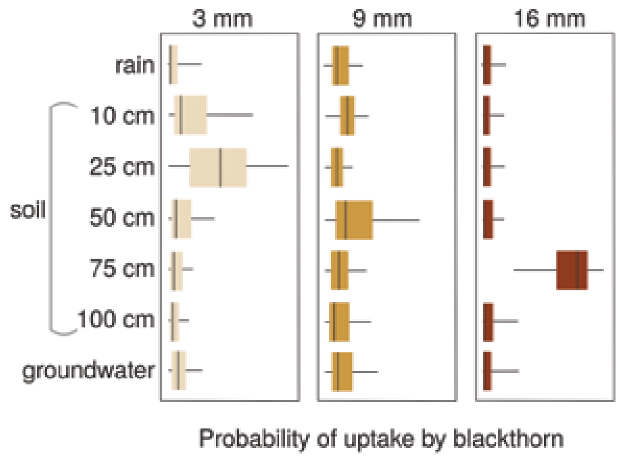


Figure 2: Water source pattern

Groundwater recharge is the most difficult component of the hydrologic cycle to measure in semiarid regions. In this study, we investigated how individuals of an important encroaching woody plant in southern African savannas might affect this process. We wanted to know whether differently sized bushes of blackthorn (Acacia mellifera) use water from different sources (rain, soil water, groundwater) and how this use changes during the growing season. A special focus was set on the effects of heavy rain events.

Study site was a commercial cattle farm in the semiarid Kalahari (MAP 250 mm). The measurements took place from the end of the dry season 2016 to the middle of the rainy season 2017 and comprised 8 rain events. We selected 15 differently sized blackthorn individuals and sampled water from their internal long distance transport system with a so-called pressure bomb (Figure 1). We used stable isotopes as markers, because rain, soil water in different depths, groundwater and plant water differ in their natural pattern of isotopes.

Our results show that big blackthorn bushes use the same water sources as small bushes. During a rain event, little rainwater is used directly. Instead, main water sources of blackthorn reside in deeper soil layers, with stronger rain events causing higher depths of use (Figure 2). Bushes prefer deep layers, even after a heavy rain event when soil water is also high in shallow depths. Our results suggest a short phase of intense competition with shallower rooting grasses only if rain amounts are low, in particular lower than 4mm. Groundwater is also rarely used by blackthorn as a direct water source. However, and independent of size, some bushes do compete with groundwater recharge. They use water that would normally go into the groundwater over time.

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Groundwater recharge for savanna aquifers along a rainfall gradient

Shoopala Uugulu and Heike Wanke

Shoopala Uugulu measuring of groundwater parameters in the field

KEY MESSAGE

Isotopic studies revealed that there is a significant evaporation of rainwater during infiltration in the Southern Omaheke; Waterberg has higher groundwater recharge rates due to a fast infiltration process.

Shoopala Uugulu analyzing chloride content in groundwater at UNAM laboratory in Windhoek

Quantification of groundwater resources is essential especially in water scarce countries like Namibia. One of the main objectives of the study was to identify groundwater recharge processes and quantify such in Namibian savanna aquifers along a rainfall gradient. Isotopic composition and the chloride mass balance (CMB) methods were used in determining groundwater recharge across a rainfall gradient at three OPTIMASS sites, namely: Tsumeb which lies within the south-eastern part of Cuvelai-Etosha Basin with 600 mm/a precipitation; Waterberg which is found in the south-western part of Omatako Basin with 450 mm/a precipitation and Kuzikus/ Ebenhaezer area which is part of the Stampriet Basin with 240 mm/a precipitation. Groundwater and rainwater were collected from year 2015 to 2017. Rainwater was collected monthly while groundwater was collected before, during and after rainy seasons. Rainwater collected in January, February and March are depleted in heavy isotopes while those in November, December, April and May are enriched. Variations in rainwater isotopic values could be attributed to a seasonal effect. Waterberg groundwater indicates absence of evaporation. Similarly, Tsumeb groundwater shows absence of evaporation with an exception of Lake Otjikotosamples that are showing evaporation. However, groundwater from Kuzikus/Ebenhaezer shows an evaporation effect with slopes around 5; probably evaporation occurs during infiltration since it is observed in all three sampling seasons. All groundwater from three sites plot in the same area with rainwater depleted values, an indication that recharge only take place mainly during January, February and March. CMB method revealed that Waterberg has the highest recharge rate. Such high recharge rates can be related to fast infiltration and absence of evaporation as indicated by the isotopic values. Hence, differences in recharge rates can not only be attributed to the rainfall gradient but also to the evaporation rates and the geology of each study site. Recharge rates estimated for these three sites can be useful in groundwater governance to ensure a sustainable groundwater abstraction in such areas. Groundwater users in Southern Omaheke (Kuzikus/Ebenhaezer) where recharge values a very low due to evaporation during infiltration of rainwater can explore options such as rainwater harvesting.

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Groundwater quality in Namibia and its relation to land use and management

Thomas Bergmann, Oliver Schulz, Heike Wanke and Stefan Liehr

Water basin with a wind-driven pump for drinking animals on a cattle farm in East Namibia

KEY MESSAGE

High nitrate concentrations of natural and anthropogenic origin are part of the problem of regionally low groundwater quality in Namibia.

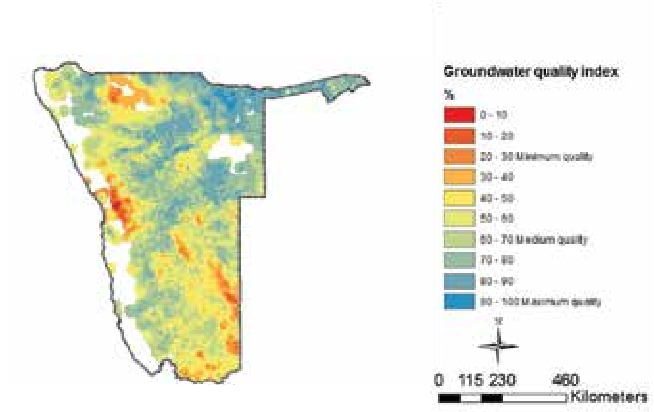

Figure 1: Groundwater quality index map (GQI-map) of Namibia based on the parameters nitrate, sodium and calcium (National data base GROWAS 2011)

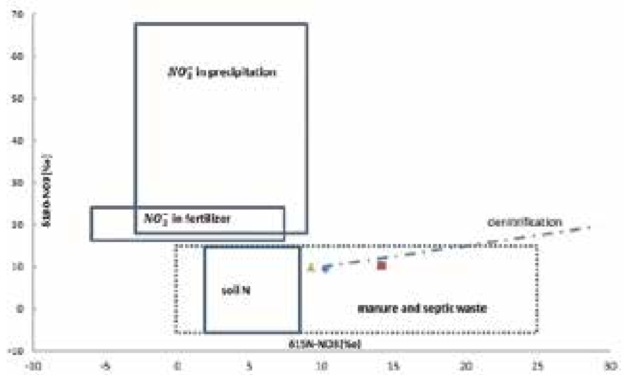

Figure 2: Isotope ratios of nitrate in three water samples at one site in East Namibia (coloured symbols) in relation to the characteristics of typical nitrate sources

Nitrate in groundwater is problematic and leads to health risks. In many cases, groundwater enriched with nitrate can be attributed to anthropogenic sources such as the application of fertilizers from agriculture. However, within semiarid environments, natural processes can lead to very high nitrate concentrations within the groundwater as well. The purpose of this study was to analyse the quality of groundwater in Namibia and to identify potential sources of pollution, with a focus on nitrate.

Data from the national GROWAS (Groundwater Information System) database were analysed to identify regions with low groundwater quality, using statistical and GIS (Geographical Information System) supported methods. The regions were studied in detail using secondary literature and own water samples that were analysed in the field and laboratory. In one of the regions, isotopic ratios of 15N-NO3 and 18O-NO3 in water samples were determined to identify anthropogenic contamination. A groundwater quality index map (GQI-map) was produced, based on a Kriging interpolation on data from point measurements.

Three rather large regions within Namibia showing low groundwater quality were identified (Figure 1). The correlations with potential sources of nitrate contamination such as geology and livestock density showed no clear results. This was possibly due to the high local variability of observed nitrate concentrations that was even found in cases of neighbouring wells. Reasons may also be different hydrogeological conditions and processes and missing information on boreholes (i.e. the type of aquifer). Groundwater that is naturally enriched with nitrate salt seems to be a major cause for low groundwater quality. However, in one of the regions, manure or septic waste are potential sources of nitrate contamination within groundwater (Figure 2).

In order to achieve a better attribution of the water quality at boreholes to sources of contamination, more information and measurements are needed. Monitoring of the local practices of land and water management and the environmental status are decisive for identifying areas with critical impacts of management.

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Thomas Bergmann (right) and farmers taking water sample at well on cattle farm in East Namibia

An ecohydrological impact assessment in urban areas: Urban water erosion in Windhoek

Rosemary Shikangalah, Florian Jeltsch, Eva Paton and Niels Blaum

Figure 1: Example of erosion damages to the road and house in Windhoek

This study aimed at assessing water erosion and the associated socio-environmental determinants in a typical dryland urban area and used the city of Windhoek, Namibia, as a case study. Accelerated soil water erosion is a serious environmental problem in cities as it gives rise to the contamination of aquatic bodies, reduction of ground water recharge and increase in land degradation, and also results in damages to urban infrastructures, including drainage systems, houses and roads (Figure 1).

The study used a multidisciplinary approach to assess the problem of water erosion. This included an in-depth literature review on current research approaches and challenges of urban erosion, a field survey method for the quantification of the spatial extent of urban erosion in the dryland city of Windhoek, and face to face interviews by using semi-structured questionnaires to analyse the perceptions of stakeholders on urban erosion.

KEY MESSAGE

Realising the diversity of the problems leading to urban water erosion compels urban centres to recognise the magnitude of aspects that need to be reflected on at different scales, therefore it is important to commence approaches for managing urban water erosion by carrying out urban-specific investigations.

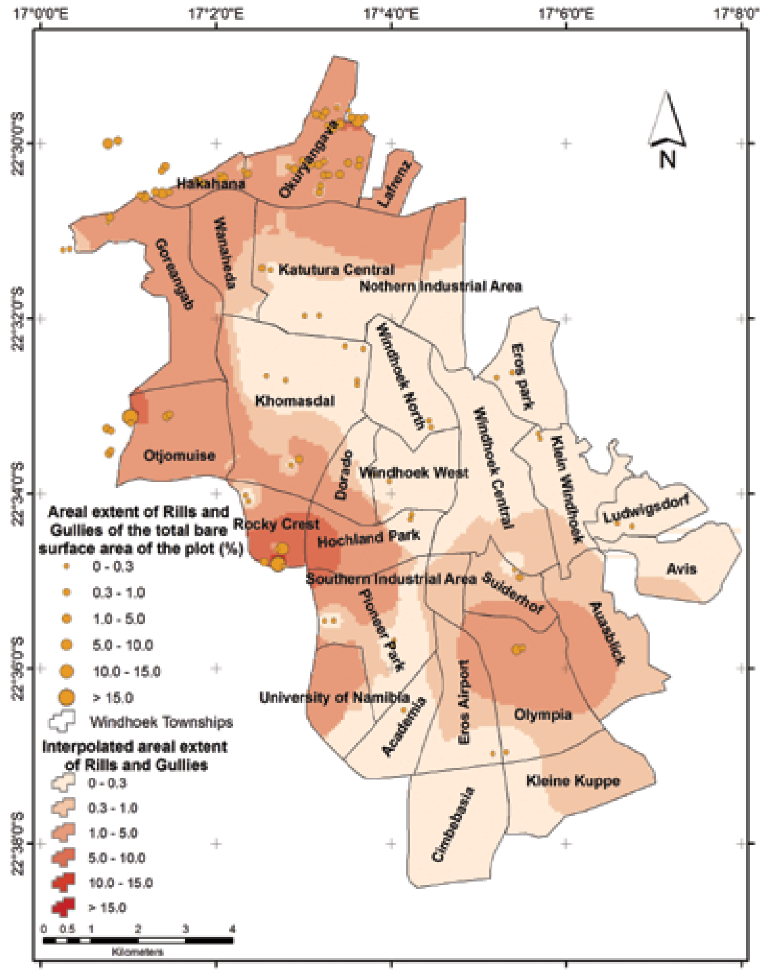

Figure 2: Spatial distribution of erosion in Windhoek

The field study, the spatial extent and severity of erosion in Windhoek was quantified. The results show that nearly 56% of the city may be affected by water erosion (Figure 2), mostly at areas of low income groups (Figure 3). About 69% of the stakeholders considered erosion damages to be ranging from moderate to very serious. There were however notable disparities between the private householders and public authority groups in terms of responsibilities.

We conclude that in order to combat urban erosion, it is crucial to understand diverse dynamics aggravating the process of urbanisation from different scales. Accordingly, we suggest that there is an urgent need for the development of urban-specific approaches that aim at: (a) incorporating the diverse socio-economic-environmental aspects influencing erosion, (b) scientifically improving natural cycles that influence water storages and nutrients for plants in urbanised dryland areas in order to increase the amount of vegetation cover, (c) making use of high resolution satellite images to improve the adopted methods for assessing urban erosion, (d) developing water erosion policies, and (e) continuously monitoring the impact of erosion and the influencing processes from local, national and international levels.

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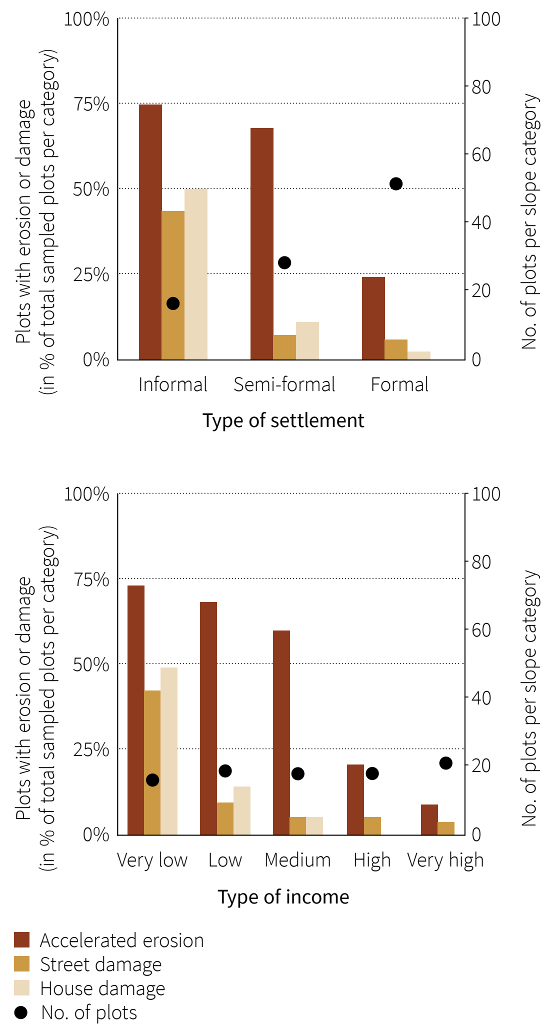

Figure 3: Occurrence of accelerated erosion in relation to damages and income groups

Modelling of erosion risk in savanna ecosystems

Selina Baldauf and Britta Tietjen

KEY MESSAGE

Landscapes with steep slopes, low vegetation cover and fine grain soil are under high risk of erosion in savanna ecosystems.

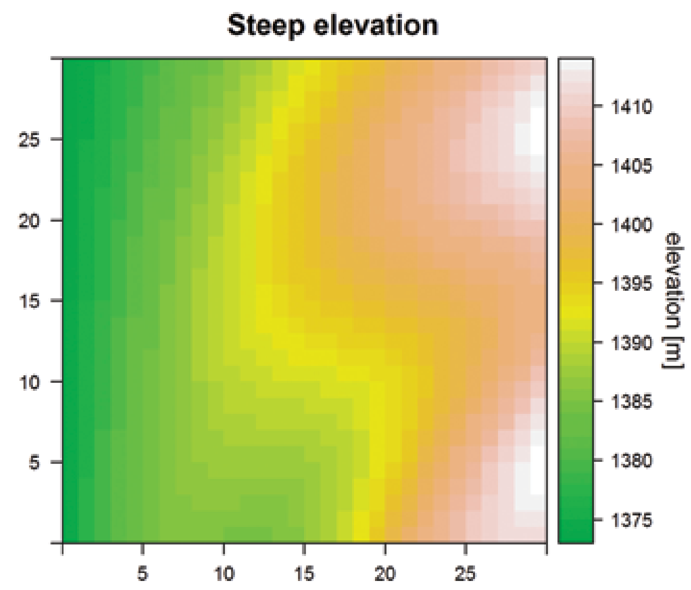

Figure 1: Topography of the landscape which was used for the simulation.

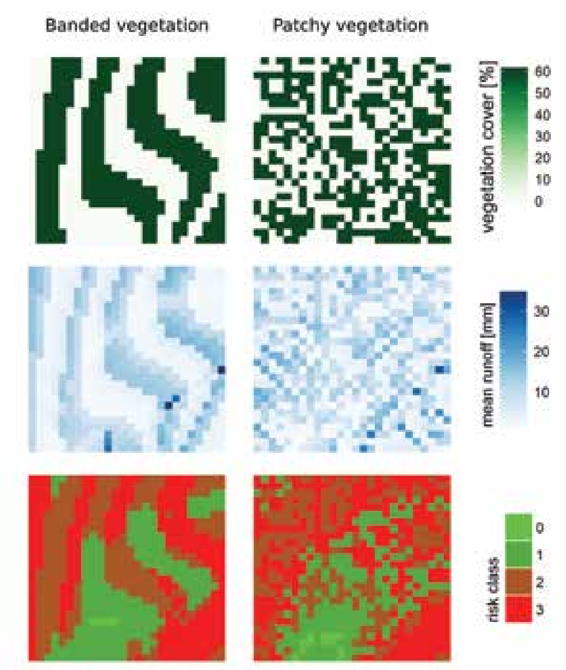

Figure 2: Simulated runoff (middle) on a steep hillslope (Figure 1) for a sandy soil, two different vegetation structures and a mean annual precipitation of 550 mm. The corresponding runoff shows that the vegetation units reduce runoff and therefore decrease critical overland flow that might lead to soil erosion (middle). A resulting lower erosion risk can be expected within the vegetated parts of the hillslope (bottom). Higher risks a found on bare soil patches, particularly on steep parts of the hillslope.

Soil erosion is a major cause for soil degradation in drylands. It is associated with a loss of water and resources, which negatively affects ecosystem productivity and biodiversity. To identify the major causes of soil erosion we developed a computer simulation model. In particular, we focused on the effects of soil texture, vegetation structure, and hill slope on surface runoff, which is a major driver of soil erosion (Figure 1). Figure 2 shows the simulation results for one particular hillslope. The general effects of soil, vegetation, and slope on erosion risk can be summarized as follows:

Soil texture: At a higher sand content of the soil, more rainfall water infiltrates at the expense of surface runoff production. Hence, the erosion risk is generally lower when the soils are sandy due to smaller overland flow rates.

Vegetation: Vegetation structures can obstruct surface runoff and therefore reduce soil erosion (Figure 2). This depends on the cover density and on the spatial distribution. Higher vegetation densities lead to reduced soil erosion because plants enhance the surface roughness and the infiltration into the soil. Therefore, less runoff is produced in vegetated patches. Additionally, the soil is stabilized by an extensive root system.

Slope: On steep slopes, the risk for soil erosion is significantly higher due to larger runoff velocities.

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Water shortage during bush seedling establishment: Not always detrimental

Katja Geißler, Melanie Schindler and Niels Blaum

KEY MESSAGE

Competition with perennial grasses is often weaker than facilitation. Consequently, the recovery of the grass matrix in degraded rangelands might not be sufficient for preventing further bush encroachment. Our results recommend measures that are more rigorous, such as controlled veld-fires.

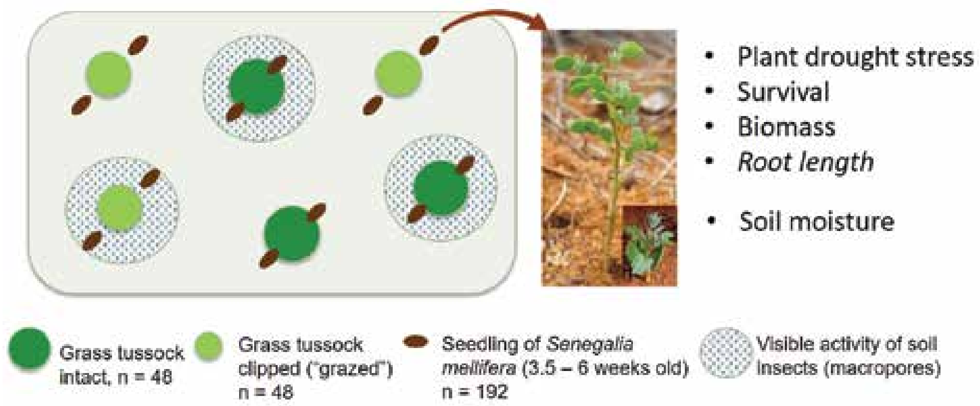

Figure 1: Experimental design

In this experimental study, we tested the influence of neighboring perennial grass tussocks, grazing, biological macropores (small holes in the soil digged by bugs) and root length on the level of physiological drought stress in young blackthorn (Acacia mellifera) sap-lings. Our main goal was to investigate water shortage during the establishment phase of an important encroaching woody plant in southern African savannas. We wanted to better understand the so-called demographic bottleneck of this species. By looking deeper into the co-existence between grasses and bushes, we aimed to explain general causes of bush encroachment.

The experiment was established on a commercial cattle farm in the semiarid Kalahari in the rainy season 2016. 1-week-old bush seedlings were planted next to Silky bushmen grass or Long-awned three-awn tussocks at different times (Figure 1). By doing so, we assured different root lengths at the time of final measurements. We selected tussocks that had either lots of macropores around or only smooth soil. Half of the tussocks were clipped to simulate grazing.

Our results show that drought was a clear reason for bush seedling mortality, since microsites of dead seedlings had lower soil moisture than microsites of seedlings alive. Bush seedlings suffered water shortage from grassy neighbors. Their physiological drought stress level increased when growing next to a tussock. Indeed, the soil was drier around intact grass tussocks. What is surprising is that bush seedlings grew much bigger next to an intact grass compared to a grazed one, even under the mentioned high internal strain due to competition for water. Reasons – although speculative – might be that perennial grasses protect the bush seedlings from pathogens or maybe facilitate root infection with N-fixing Rhizobium bacteria. Biological macropores had no effect on drought stress level and size of bush seedlings. Root length had no effect on the competition intensity for water between blackthorn saplings and perennial grasses.

Melanie Schindler marking the experimental plots at the farm Ebenhaezer

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Longterm physiological adaptations of bush encroachers to drought

Katja Geißler, Tina Klemme, Kaarina Shilula and Niels Blaum

KEY MESSAGE

If the climate changes in Namibia to more aridity and local populations become maladapted, ecotypes from other regions could replace the respective local ecotype. It will only depend on a successful migration. Thus, the dispersal ability of bush encroacher plants is one of the most important trait to investigate for the future.

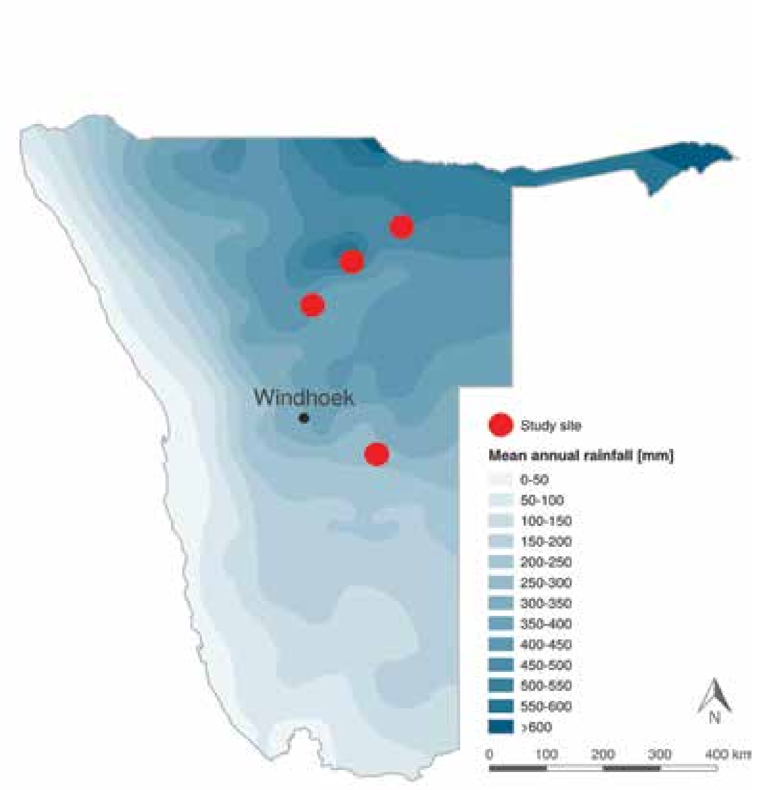

Figure 1: Study sites along Namibian rainfall gradient

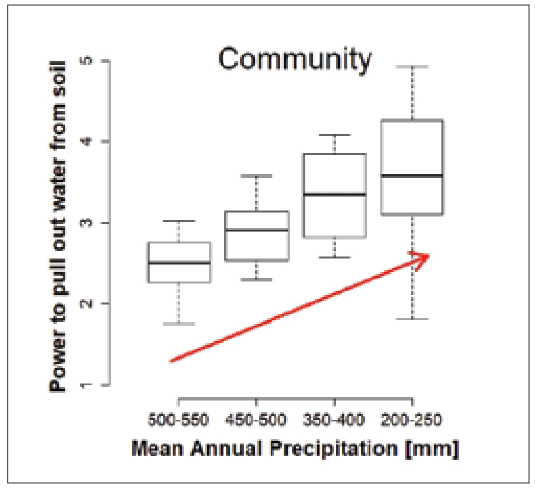

Figure 2: Inherit drought tolerance

There is good evidence that plants in stressful environments are selected by evolution to have inherently higher stress tolerance. In this field study, we evaluated such long-term effects of drought stress on savanna plants. Our main goal was to understand the genetic potential of savanna vegetation to shift distribution borders under predicted climate change. A special focus was set on bush encroacher plants.

The study was done at four sites along the north-south precipitation gradient in Namibia (Figure 1). To separate long-term evolutionary effects from short-term physiological effects, investigations took place between the end of the dry season and beginning of rainy season 2015/2016. Plant species included were raisin bush *(Grewia flava)*, sickle bush *(Dichrostachys cinerea)*, blackthorn *(Acacia mellifera)* as important encroacher bushes and silky bushmen grass *(Stipagrostis uniplumis)*. We measured various water related plant traits, which indicate drought response and drought tolerance.

Our results show that savanna communities comprise of ecotypes that are primarily adapted to their local climate. The inherent ability to pull out water from a drying soil is increasing with aridity across the Namibian aridity gradient (Figure 2). Across all species, blackthorn and raisin bush showed the best genetically determined drought adaptation.

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Kaarina Shilula (left) and Tina Klemme (right) worked in one of the successful Namibian-German tandem projects. Tina went to Namibia to work with Kaarina in the field, and Kaarina came to Potsdam for joint data analysis.

Plant diversity and strategies of drought tolerance in grasses

Katja Geißler and Ramona Heim

Ramona Heim measuring wilting points

KEY MESSAGE

There is no convincing evidence that perennial grasses suffer much under the changed water conditions of bush encroached habitats. The widely observed lower perennial grass cover must be limited by something else, presumably dispersal.

Long-awned three-awn

Silky bushmen grass

Kalahari sour grass

In this study, we quantified plant species diversity along a bush cover gradient in a semiarid African savanna rangeland and physiological drought stress traits of three co-occurring perennial and annual grass species. Our main goal was to evaluate ecohydrological consequences of bush encroachment and the degree of short-term drought tolerance differentiation between the three most conspicuous grass species Long-awned three-awn *(Aristida stipitata)*, Silky bushmen grass *(Stipagrostis uniplumis)* and Kalahari sour grass *(Schmidtia kalahariensis)*. We aimed to explain general survival strategies of desirable savanna grasses and their often-observed changes in abundance due to bush encroachment.

Our results show that high bush cover affected plant species number positively, which is – according to theory – a plausible argument for increased resource stress. Indeed, bush encroachment had a strong influence on ecohydrological conditions (Figure 1). Interestingly, drought stress for the herbaceous vegetation was lowest on intermediate bush encroached savanna sites and not as expected on grass dominated sites. That drought stress increased again above intermediate shrub cover was, however, not surprising given that woody plants are known to transpire much more water than grasses. What is surprising is that perennial grasses showed a much higher constancy in fitness than the annual grass, their individual tussock size even increased across our bush cover gradient with conditions becoming drier. One reason might be that perennial grasses have convincing physiological strategies of high drought tolerance, which gives them an adaptive advantage over annuals in dry habitats. Their strategies to survive under drought were in particular related to:

- their amazing ability to maintain a constantly high water content within the cells during drought, a rare ability within plant species worldwide
- their higher power to pull out water of a drying soil compared to annual grasses
- their thicker leaves that protect from water loss
- their ability to quickly lower their wilting point (although annual grasses can do so too)

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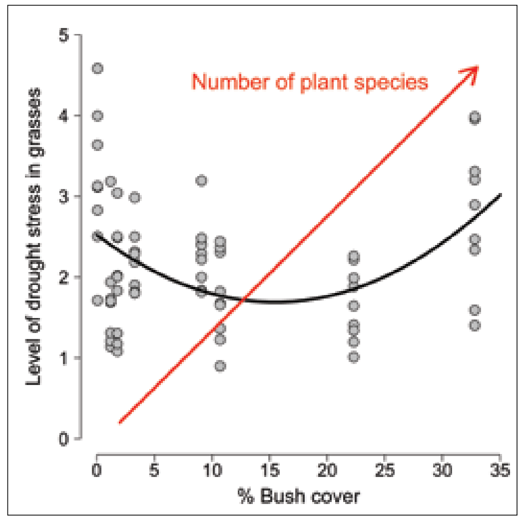

Figure 1: Lowest drought stress of grasses at intermediate bush cover, but most species and highest stress at highest bush cover

Water use partitioning between grasses and encroacher bushes

Katja Geißler, Maria Schoenen, Eva Ostertag, Ramona Heim and Kaarina Shilula

Eva Ostertag and Ramona Heim measuring wilting points

Ramona Heim at species determination

Kaarina Shilula measuring wilting points

KEY MESSAGE

Coexistence of bushes and grasses in semiarid savanna rangelands relies on both, equal drought tolerance traits and water use partitioning. There is convincing evidence that desired perennial grasses are not diminished due to competitive losing.

Maria Schoenen measuring grasses

Maria Schoenen marking a plot

Eva Ostertag sampling plants

The coexistence of woody plants and grasses is central to savanna systems. In this study, we quantified the water use partitioning between differently sized bushes and grasses and their root activity under field conditions. We were in particular interested in temporal and spatial patterns. Our main goal was to evaluate ecohydrological causes of the aforementioned coexistence and its consequences for other ecosystem functions.

Study site was a commercial cattle farm in the semiarid Kalahari (MAP 250 mm). The measurements took place from the end of the dry season 2014 to the middle of the rainy season 2015. We measured traits and the isotopic signature of plant water of two dominant perennial grass species, one annual grass species and differently sized blackthorn individuals.

Our results show that perennial grasses can be seen as strong competitors of establishing shrub seedlings. They have lower wilting points, or in other words a higher power to pull out water of a drying soil. They are, however, not different in this trait from adult bushes, neither in the beginning nor in the mid of season. Perennial grasses react more plastic than adult bushes, they can lower their wilting point quicker. This is probably not surprising, since adult bushes use deeper water than grasses, in particular late in the season. Interestingly, all functional markers indicated that smaller adult bushes are less adapted to drought than bigger bushes.

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Modeling and monitoring woody vegetation changes of savanna systems in response to water stress

Gregor Ratzmann and Britta Tietjen

KEY MESSAGE

Relatively dry ecosystems will experience increasing levels of shrub encroachment of drought tolerant species such as blackthorn.

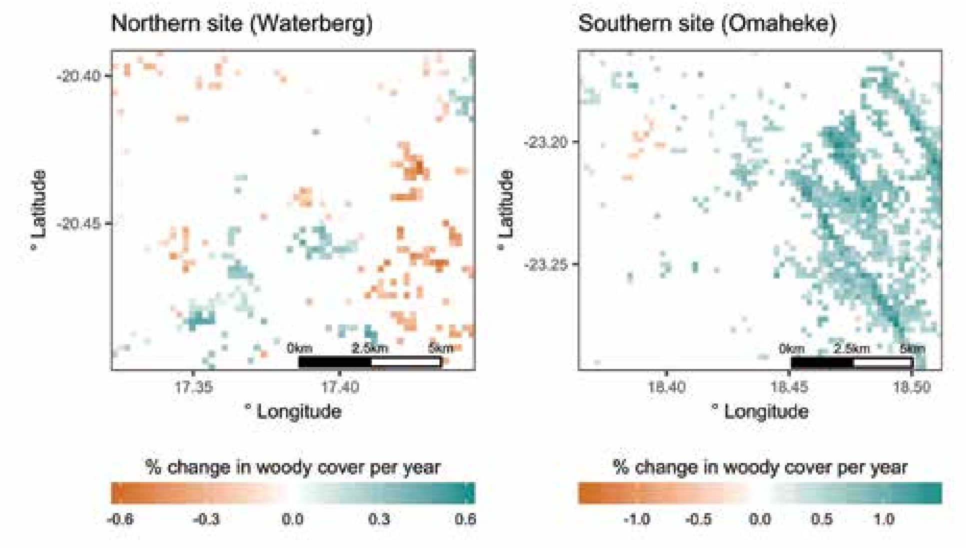

Figure 1: Relative change in woody cover on two pilot study sites, one close to the Waterberg plateau, northern site, and one in the southern Omaheke region, southern site . The coloring refers to significant changes in percent per year.

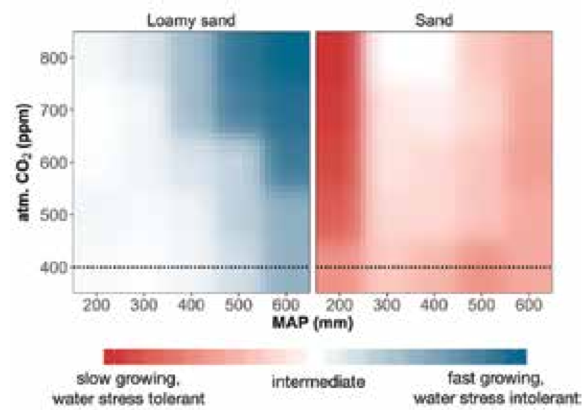

Figure 2: Best performing response type (fast growing but drought intolerant vs. slow growing but drought tolerant) to water availability dependent on mean annual rainfall (MAP) and atmospheric CO_2 concentration. Tolerant and drought enduring species (e.g. the encroacher shrub blackthorn) accept a high risk of desiccation in favor of water availability over a wide range of conditions. Drought intolerant species (e.g. the encroacher shrub sickle bush) accept water availability only over a limited range of conditions in favor of a lower risk of desiccation. The vertical dashed line indicates current day atmospheric CO_2 levels.

The savanna ecosystems of Namibia have experienced a rapid expansion of woody vegetation at the expense of herbaceous plants, which serve as forage for livestock. At the same time, climate models project that these dry landscapes are at risk of becoming even drier. In this project, we used computer simulation models and satellite imagery to quantify recent changes in Namibian woody vegetation and to project the fate of typical encroacher species.

Changes in woody cover were analysed for two sites in Namibia based on remote sensing data. The first site is close to the Waterberg plateau (northern site) and the second site comprises two farms in the southern Omaheke region (southern site). Results indicate that changes in woody cover over the last 15 years are rather small on the northern site, while the southern site is characterized by strong and widespread increases in woody cover (Figure 1). A possible reason for this is that on the northern site, tree and shrub cover has already been relatively high due to prior encroachment dynamics, while woody cover is still relatively sparse on the southern site. Extrapolating those trends into the future indicates that particularly in drier regions in southern Namibia an increase in woody cover in the next decades can be expected. The two studies will be extended to larger areas of Namibian rangelands in the future.

In order to determine which particular woody species may perform best under future environmental conditions we used a computer simulation model, which describes vegetation dynamics based on different environmental variables (rainfall, soil type, atmospheric conditions). The simulated species were grouped according to their drought tolerance ranging from fast growing, but non-drought tolerant to drought tolerant but slow growing. Generally, more drought tolerant species (such as the encroacher shrub blackthorn) succeed under decreasing rainfall and on coarser-grain soils. Less drought tolerant species (such as the encroacher shrub sickle bush) are more successful under increasing rainfall and on finer textured soils. Moreover, all plants perform better under rising atmospheric CO_2 levels.

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Pollen-based reconstruction of savanna vegetation history

Ximena Tabares and Ulrike Herzschuh

KEY MESSAGE

Pollen is suitable to reconstruct vegetation composition and disturbance along precipitation and grazing gradients in savanna environments.

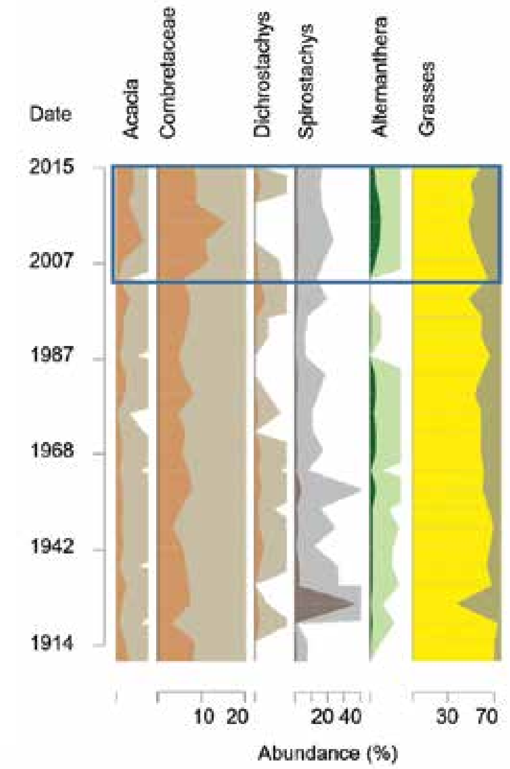

Figure 1: Fossil pollen diagram of selected taxa. The results reflect an increase in the pollen signal of encroacher taxa during the last 10 years (blue frame). Shadow curves correspond to 10x exaggeration to improve readability of major trends. Dates were obtained from 210Pb/137Cs analysis.

A deeper understanding of past vegetation dynamics is essential to better understand future vegetation responses to global change in African savanna systems. The specific aims of this project were (1) to track past vegetation changes on a long-term scale of at least 100 years using palaeoecological analysis of fossil pollen and (2) to determine how recent land use practices and climate may interact to drive vegetation dynamics.

In order to reconstruct past vegetation dynamics we collected several sediment cores from lake Otjikoto (photo 1). Sediment samples were dated and subjected to chemical, palynological (pollen identification) and genetic analyses. Interpreting past vegetation through fossil pollen analysis was validated through the comparison of modern pollen with current vegetation. Therefore, we extracted modern pollen from soil surface samples, which were collected at Otjikoto, Grootfontein, Waterberg and the southern Omaheke along local grazing gradients. At each site we defined a grazing intensity gradient beginning at a watering point. The local vegetation was concomitantly surveyed.

Our study results show that fossil pollen and chemical sediment analysis are suitable to reconstruct vegetation history and environmental conditions of Namibian savannas. Our results reflected changes in vegetation composition of the last 100 years following fluctuations in the precipitation. Not surprisingly, we observed an increase in the pollen signal of encroacher taxa for the last 10 years (Figure 1). Alongside with historical pollen analyses from the sediment core, analyses of modern pollen from soil surface samples is suitable to reconstruct vegetation composition and disturbance along precipitation and grazing gradients (Figure 2). This in turn, increases our confidence in the interpretation of fossil pollen records. Our results show the potential of palaeoecological analysis to track vegetation history in savannas and to understand the interplay of climate and land use as drivers of vegetation change. Since shrub encroachment is a major concern for land managers and policy makers, our results can contribute to validate and to improve the long- term projections of shrub encroachment under different future scenarios of climate/global change.

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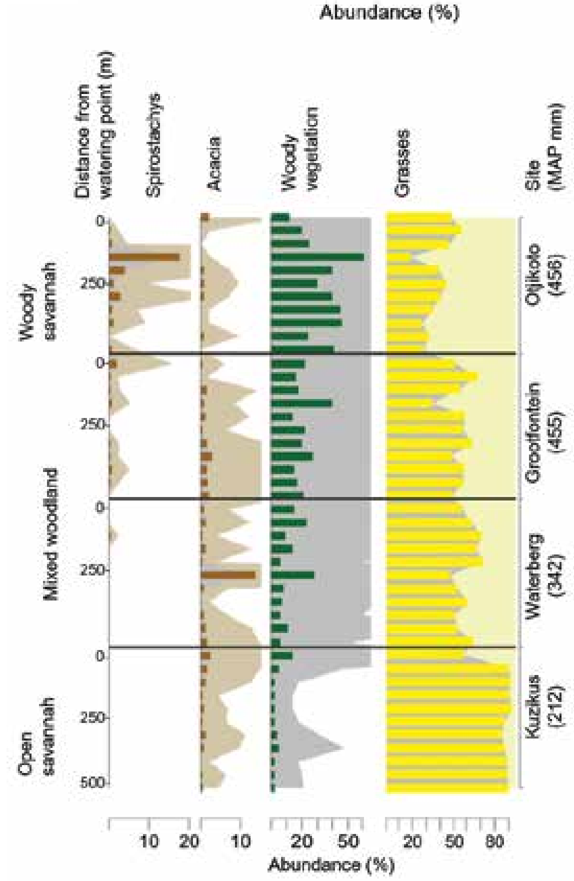

Figure 2: Modern pollen diagram of selected taxa. Modern pollen reflect change in vegetation composition according to mean annual precipitation (MAP) and grazing intensity. Each bar represents one plot, with eleven plots along each of the four grazing gradients, where highest grazing intensity is closest to the watering point (0 m) and least grazing farthest away (500 m). Shadow curves correspond to 10x exaggeration to improve readability of major trends.

Tree ring studies to understand environmental and climate change feedbacks

Benjamin Mapani, Isaac Mapaure, Ulrike Herzschuh, Ximena Tabares,
Rosemary Shikangalah and Aansbert Musimba

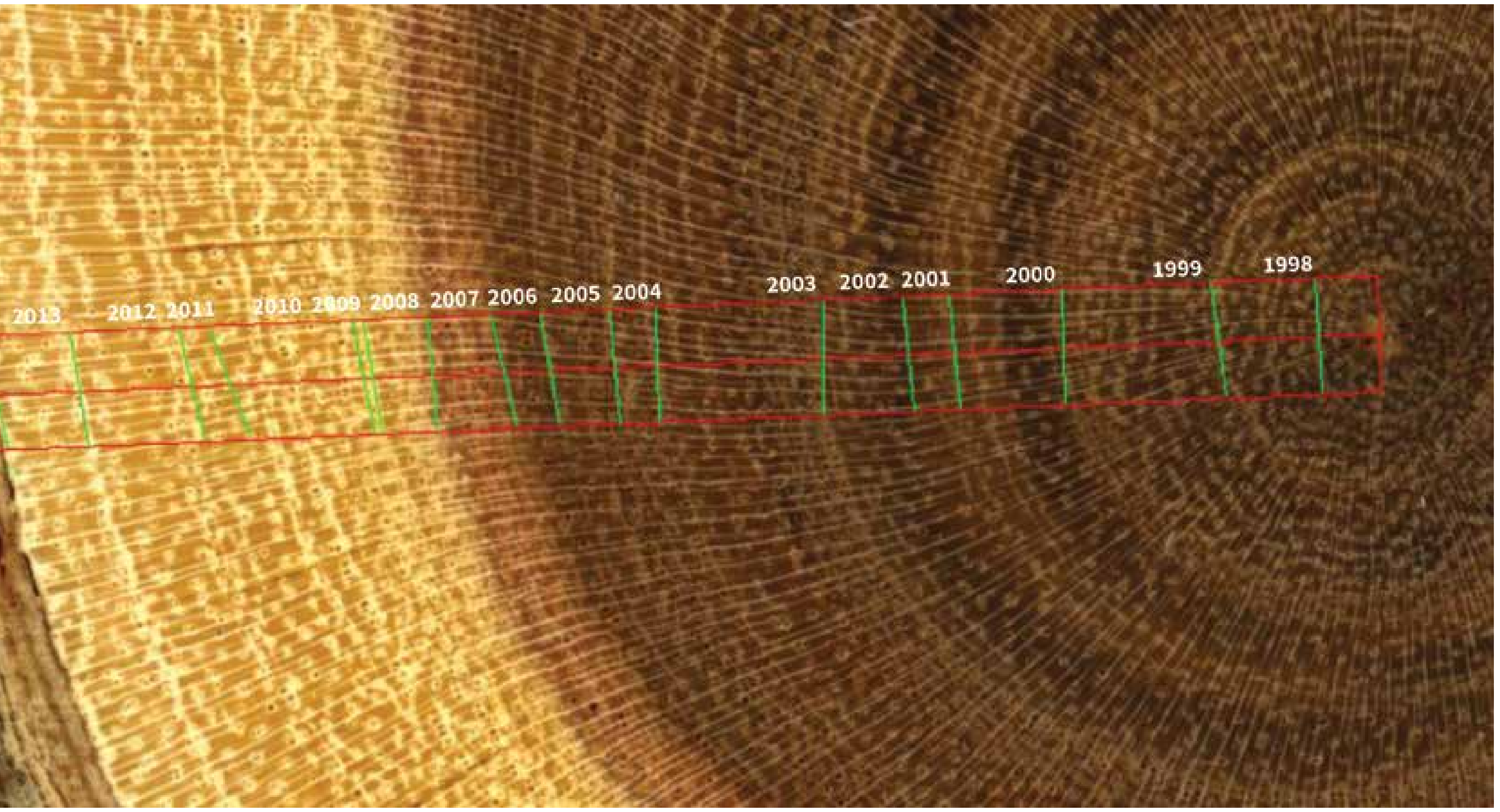

Figure 1: Example of a tree ring analysis with *Dichrostachys cinerea*. The width of the tree ring indicates soil moisture conditions and amount of rainfall in the respective year.

KEY MESSAGE

Tree rings can be used as a forecasting tool for climate change even in arid to semi-arid savannas, and be used in management strategies for farmers and local water managers.

Can tree rings be used as proxies for climate change? For this to work, a species chosen should be widespread and well distributed and resilient enough to live for a long period of time. Trees record site conditions, both biotic and abiotic. This information is largely recorded in tree rings. Suitable species for such tree ring studies in Namibia are *Acacia mellifera and Dichrostachys cinerea*, two widespread encroacher species. Tree discs of various diameters were collected from eight different sites long the OPTIMASS rainfall gradient in Tsumeb, Grootfontein, Waterberg, and Kuzikus.

Tree discs were, polished, scanned and analysed using the WinDendron software, for age determination and to relate single tree with the amount of annual rainfall. The specific tree ring width is characteristic for the moisture conditions at the site for a particular year of the ring growth. The features of the wood vessels also indicate the level and rhythm of the water uptake by the tree and whether or not the rain season was consistent or not.

Our results show a sympathetic correspondence between rainfall and tree ring growth and also between tree ring width within a particular rain season and the amount of rainfall received (Figure 1). It has been found that tree rings are reliable enough to reflect the true moisture and precipitation patterns of the past. Using this information, a time series analysis can be conducted and used as a predictive model for precipitation variation trends for the future. This information would be important in planning and management of water resources, forestry, animal husbandry and crop farming advice to local farmers.

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Tree ring analyses at AWI laboratory, Potsdam

Contrasting effect of aridity on grass-woody plants relationship

Wilhelmina N Hauwanga and Ben Strohbach

Wilhemina Hauwanga mapping vegetation at Ebenhaezer

KEY MESSAGE

With increasing mean annual rainfall, relative abundance of grazing biomass when compared to browse biomass decreases.

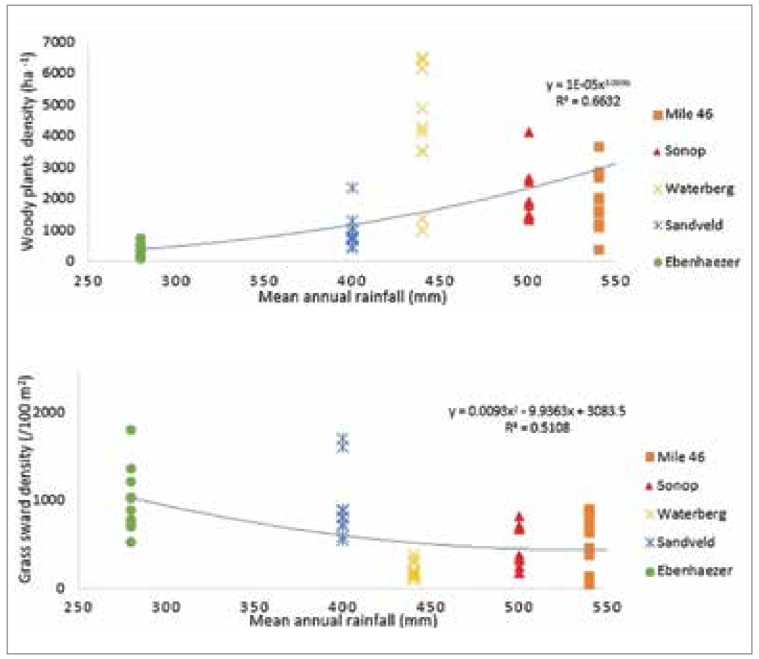

Figure 1: Change in woody plant density (top) and grass sward density (bottom) at the five study sites along the rainfall gradient.

In this study, we wanted to shed light on the relationship between woody plant density and grass sward density among the selected study sites along the aridity gradient in Namibia. Therefore, we collected woody plants and grass density data at Mile 46, Sonop, Waterberg, Sandveld and Ebenhaezer along the Kalahari aridity gradient in Namibia.

The observed decrease in grass density with an increase in rainfall was possibly caused by competition from increasing density of woody plants with increasing rainfall (Figure 1). This suggests that there is relatively more food for browsers in high rainfall areas and more food for grazers in low rainfall areas. Higher bush encroachment than expected from the given mean annual rainfall was recorded at Waterberg due to fire suppression. High woody plant cover significantly reduces grass density.

Information on grass-woody plants relationship can be used in stocking rate planning and overall conservation of savannas. Since bush encroachment leads to high water loss through evapotranspiration, further encroachment will worsen water shortages in Namibia if not addressed. Hence, fire suppression should be avoided or kept minimal.

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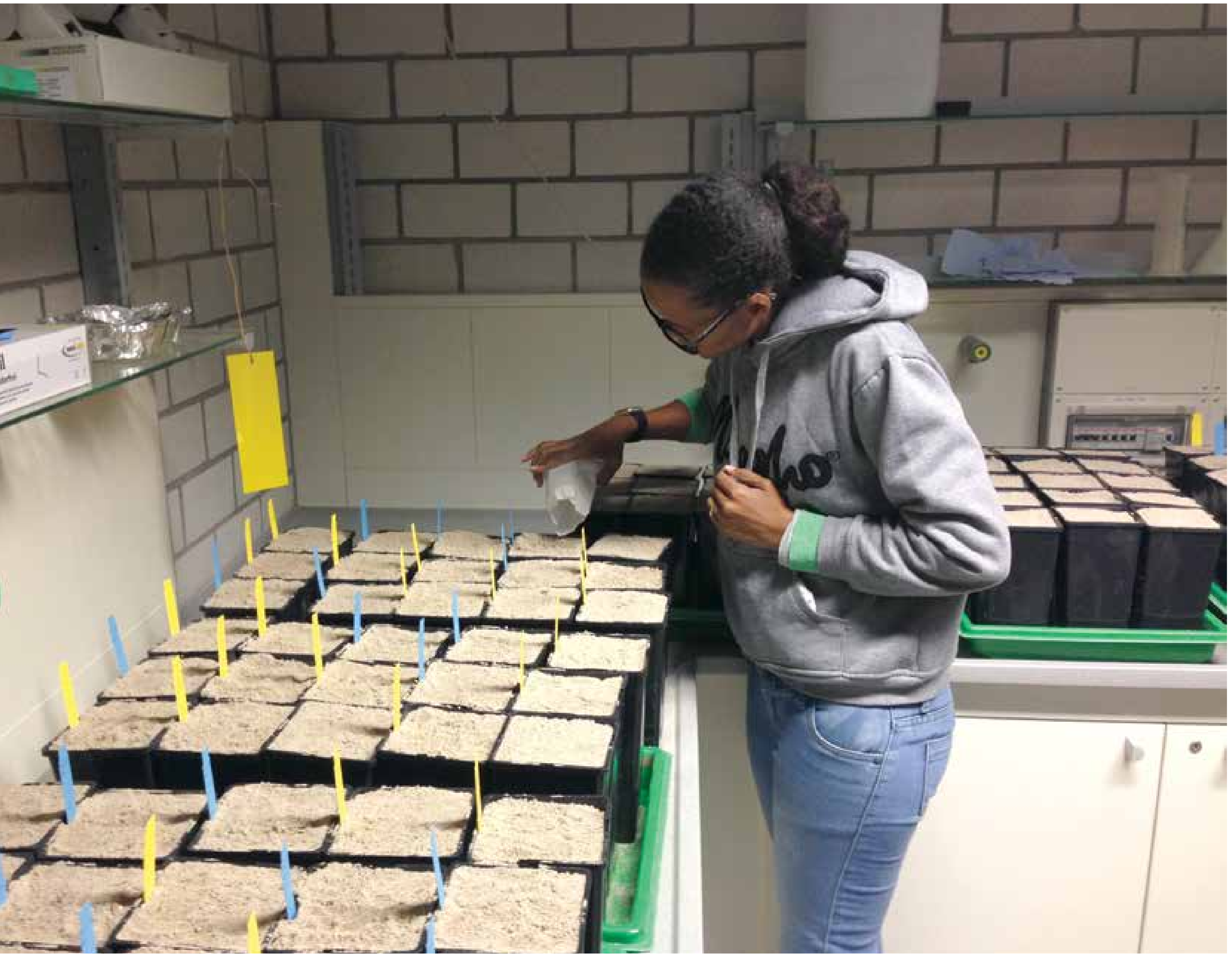
Climate change and elevated CO_2 effects on bush encroachment

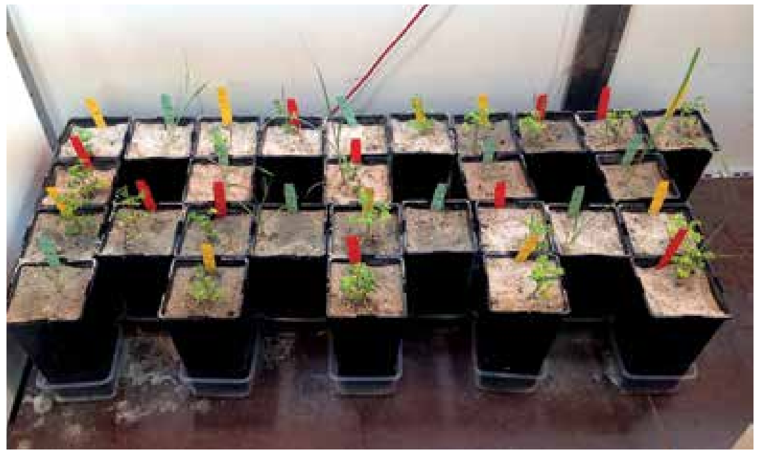
Wellencia Clara Nesongano, Andreas Fangmeier and Katja Tielbörger



Wellencia Clara Nesongano planting seeds for her competition experiment

KEY MESSAGE

The early seedling stage of Blackthorn may not suffer all that much from drought and competition from neighboring grass seedlings but may have higher biomass under elevated atmospheric CO_2 levels.



We performed experiments in climate chambers (growing chambers where temperature, moisture and CO_2 conditions are controlled) to determine the effects of drought, elevated CO_2 and possible competition, on seedling biomass of a palatable perennial grass, Wool-grass *(Anthephora pubescens)*, and a bush encroaching tree/shrub species, blackthorn, *(Acacia mellifera)*. Both the shrub and grass were sown alone (in monocultures) and with one another (mixed cultures). The seeds for the study were collected in Namibia, from around Farm Kuzikus (southern Omaheke) to areas closer to Kombat (especially for the grass). We expected that: 1) Blackthorn will have lower biomass under drought stress than Wool-grass, 2) Shrub biomass will increased more by elevated CO_2 than grass biomass and 3) Competition from Wool-grass will lower the biomass of Blackthorn more than the other way around.

Our results showed that the grass biomass was lowered by both drought and competition, while Blackthorn was not affected by the two treatments (Figure 1). On the other hand, as expected, the shrub did benefit more from elevated CO_2 (Figure 1). If shrub seedlings, like Blackthorn are less affected by drought and grass neighbours, while benefiting the most from elevated CO_2, we might have more bush encroachment in the future. We therefore recommend that rangeland managers should pay special attention to the recruitment stage of such species, to reduce the chances of further bush encroachment.

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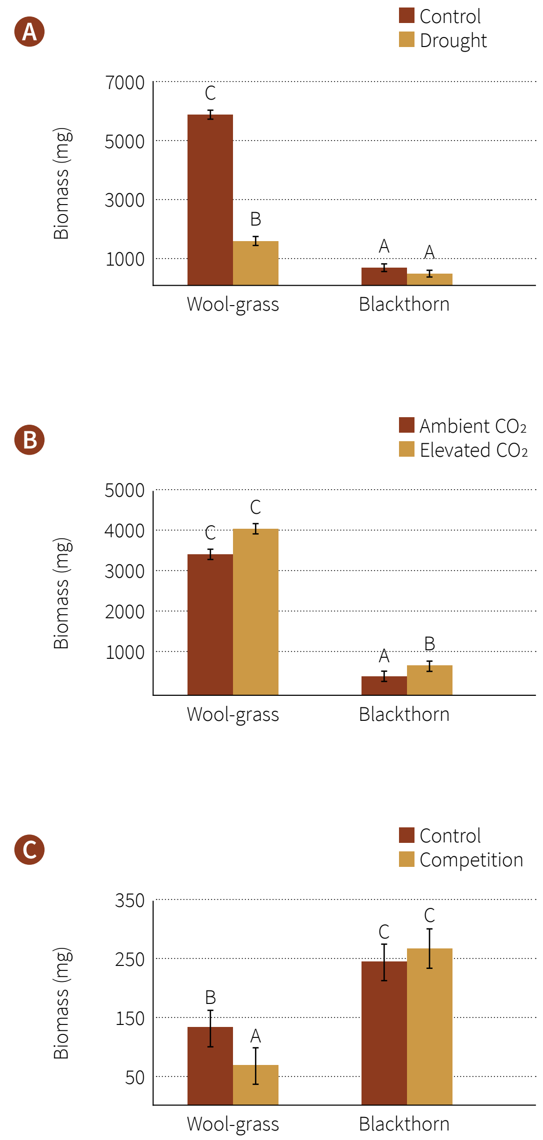

Figure 1: The effects of drought (A), elevated CO_2 (B) and competition (C) on seedling biomass (mean±SE) of Wool-grass and Blackthorn. Different letters indicate significant differences within treatment.

Effects of origin, drought and competition on woody plant and grass establishment

Cecilia Ndunge, Isaac Mapaure, Katja Tielbörger and Wellencia Clara Nesongano

KEY MESSAGE

Blackthorn survival was very high in both the local and drier site indicating the high flexibility of this bush encroacher species to drier conditions as predicted by climate change scenarios.

Acacia mellifera seedling at Ebenhaezer

Plant performance is expected to decrease when the rainfall decreases and when competing neighbours are present. In other studies it has been shown that seedling survival of both grasses and shrubs are very sensitive In this project, we wanted to find out how decreasing rainfall and the presence of neighbouring plants that compete for water and nutrients will affect seedling performance.

The study focused on three species, namely Blackthorn *(Acacia mellifera)*, Silky bushman grass *(Stipagrostis uniplumis)* and Wool grass *(Anthephora pubescens)*. Seeds were collected along the OPTIMASS rainfall gradient at three sites (Tsumeb, Waterberg area and Ebenhaezer). To test for possible effects of climate change, seeds were sown in the next drier site and germination, survival compared to seeds sown in the original site of seed collection. Neighbouring plants were clipped in half of the experiments to simulate absence of neighbours. Finally, germination, survival and plant height were measured.

This study revealed that the presence of neighbours did not have a significant effect on the germination, survival fractions and height of all the three species. Only Blackthorn survived in Tsumeb. The grass species (*S. uniplumis* and *A. pubescens*) did not survive, this can be due to the loamy soils found around Tsumeb and these limited the roots to penetrate deep into the soils to get water. This shows the sensitivity of young perennial grasses during their first weeks and months.

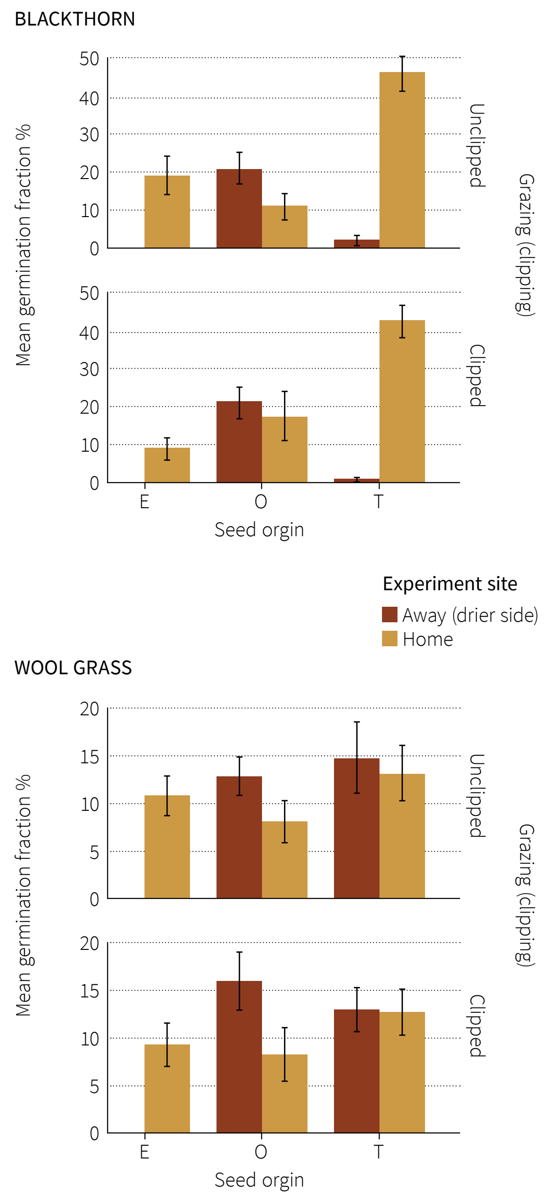

Figure 1: Germination fraction (% mean ±SE) of Blackthorn (*Acacia mellifera*, top panel) and Wool grass (*Anthephora pubescens*, bottom panel) seeds collected along the OPTIMASS rainfall gradient (E = Ebenhaezer farm, driest site; O = Okakarara, dry site; and T = Tsumeb, wet site). Seeds were sown at the home and the neighbouring drier site in clipped and unclipped sample plots.

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Reseeding Namibian savannas: Impact of nutrients and soil compaction on grasses

Allan Kandjai, Dave Joubert and Niels Blaum

KEY MESSAGE

Reseeding degraded rangelands with *A. pubescens* can be possible in a good rainy year and it could be improved by fertilizer application, neighbour removal and the removal of the outer covering of seeds to ensure better germination rates.

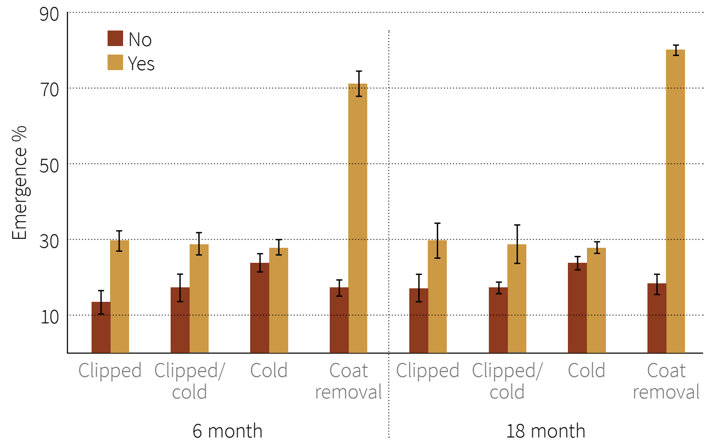

Figure 1: Seedling emergence of *Anthephora pubescens* from seeds of two different ages (6 & 18 months) after frost (cold: yes), with competition (clipped competitors: no) and with coat removal (coat removal: yes). Greenhouse experiment at B2 Gold.

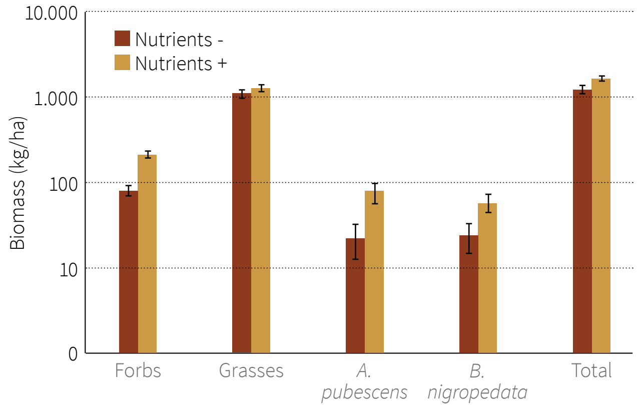

Figure 2: Effect of nutrient addition (NPK-fertilizer) on biomass production of forbs, grasses, and the two focal reseeding grasses *Anthephora pubescens* and *Brachiara nigropedata* in the herbivore exclosure at Waterberg National Park.

Since bush encroachment is one of the most pressing issues in Namibia, bush clearing has become a widespread practice. Nevertheless, how do we restore a healthy savanna rangeland after clearing? One important aspect could be the reseeding of native perennial grasses such as *Anthephora pubescens* and *Brachiaria nigropedata*. However, this is not an easy task and we have conducted a study to identify some fundamental requirements for a successful reseeding: First, we went to the greenhouse in order to figure out under which conditions collected seeds would be able to germinate. We tested frost, neighbour competition, seed age (6 vs. 18 months) dormancy effects on *Anthephora pubescens* seedling emergence. Second, we went into the field to test weather nutrient addition influences plant biomass after seeding under natural conditions.

Our greenhouse study indicates that seeds can mature and be sown after 6 months, hence farmers can sow seeds immediately during the offset of the rainy season after seed collection. To further boost or increase the chances of successful establishment, although its time consuming, removing the glumes from seeds will increase the seedling emergence by far since it supposedly breaks seed dormancy. Weed control further increases the seedlings survival chances and natural fires for example could burn away some of these competitors since *A. pubescens* is fire tolerant, although not tested in this study.

Our field study showed nutrient addition did not increase overall grass biomass but supported seedling establishment of the target species. Some soil types are more fertile that other, e.g those that contain clay and this can help farmers save money on fertilizing already fertile soils. However, the addition of nutrients did increase the plants vigour and possibly their quality for the grazing animal.

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Building of rhino and large herbivore fence to protect reseeding experiment at Waterberg National Park.

Impact of livestock grazing on savanna vegetation around water points

Katharina Ziegler, Gregor Ratzmann and Britta Tietjen

KEY MESSAGE

Land degradation through bush encroachment around water points in savanna rangelands can be avoided by adapting livestock stocking rates to the available precipitation.

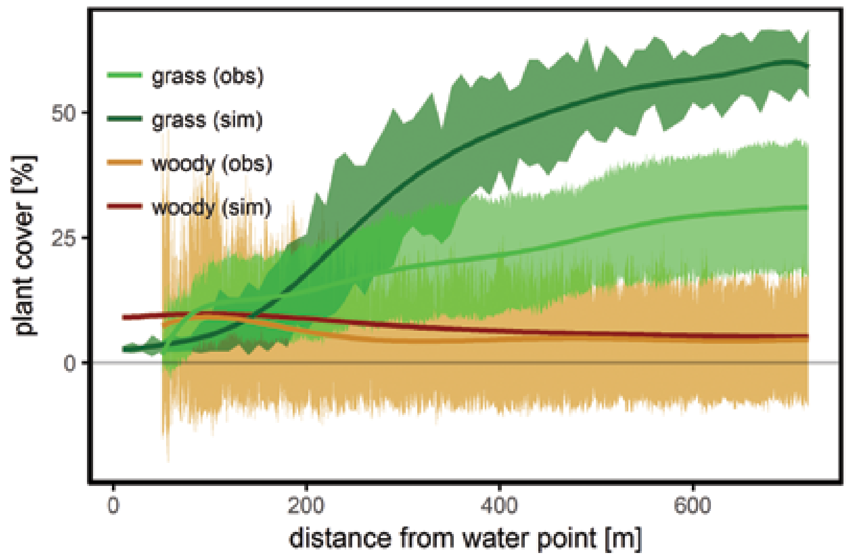

Figure 1: Simulated and observed plant cover around a water point after a long period of grazing. The simulated output shows the percentage of plant cover (mean and standard deviation after 10 simulations) of grasses and woody plants versus the distance from the water point after 80 years of livestock grazing. The stocking rate is 24 ha LSU-1 and mean annual precipitation is 250 ± 40 mm yr-1. Observed data are based on a satellite image of several water points on the Kuzikus game reserve.

Intensive livestock grazing is a major determinant of savanna vegetation composition and has fostered the establishment and growth of woody plants in savanna ecosystem worldwide. The increment of woody vegetation is caused by a reduction of herbaceous plants through grazing most strongly notable close to livestock water points. This loss of forage is associated with economic costs. Typically, woody cover is relatively high close to the water point and decreases with distance from it. Grasses, on the contrary, generally increase in cover with increasing distance from the water point. To quantify the effect of long-term grazing around water points on the woody-grass vegetation composition, a computer simulation model was developed. The results show a strong expansion of woody vegetation after long grazing periods, which is particularly the case close to water points. The degree of change in plant composition is strongly dependent on mean annual precipitation and livestock stocking rate. At sites that experience more annual rainfall woody thickening and losses in fodder production tend to be stronger close to the water point. At low rainfall sites, however, high stocking rates lead to a less strong but more widespread bush encroachment even further away from the water point. Consequently, given predictions of decreasing rainfall under climate change, maintaining high stocking rates increases the risk of rangeland degradation through woody thickening. Results thus suggest to adapt the livestock stocking rate to the available precipitation in order to avoid land degradation and high economic costs through overgrazing.

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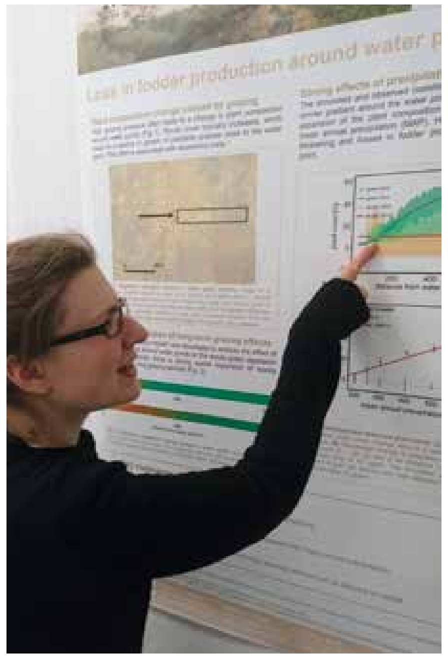

Katharina Ziegler presenting her study at the 21st National Rangeland Forum 2017

Simulated adaptive herd rotation for sustainable rangeland management

Elise Muench, Florian Jeltsch and Dirk Lohmann

KEY MESSAGE

Rotational grazing can help sustaining a healthy and productive rangeland if mode and timing of rotation are adapted to the availability of perennial grasses.

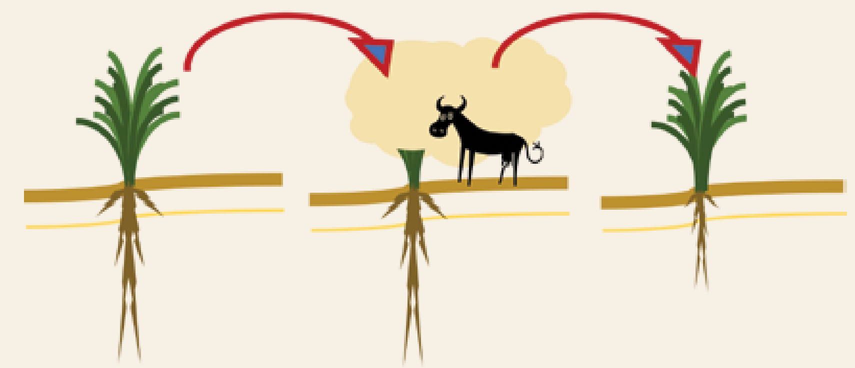

Figure 1: After grazing, grass tillers may re-grow quickly if root reserves are sufficient. Grass regeneration seems to be crucial to assess the effects of livestock grazing especially with regard to questions of when and how much biomass is removed and when the veld is rested.

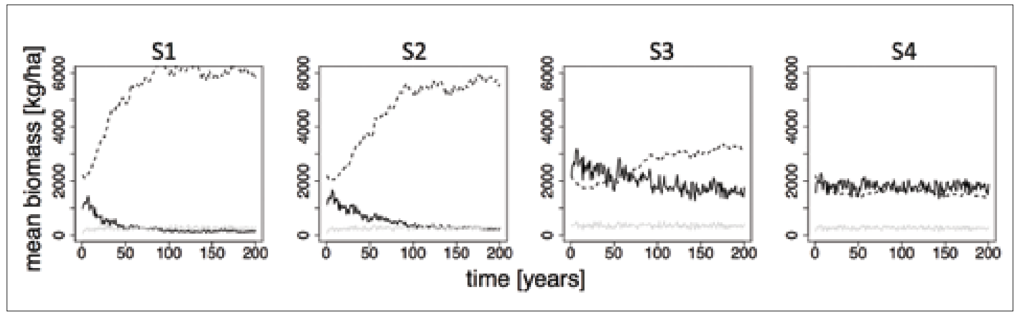

Figure 2: Biomass production of perennial grass (black line), shrubs (dashed line) and annuals (grey line) for 4 different management scenarios. Mean simulated livestock density was 12 ha / LSU and MAP 400 mm on loamy sand soils. S1: no rotation, S2: biweekly fixed rotation; S3 & S4: adaptive rotation. We simulated a farm with 5 camps.

It was one of OPTIMASS' main goals to provide information tackling the most pressing issues of Namibian rangeland management. After several discussions with stakeholders during workshops and interviews two issues kept coming up repeatedly, the rotational management of livestock herds and holistic management. In this project, we used the rangeland simulation model EcoHyD to simulate different modes of rotational herd management and to assess their long-term effects on livestock production and vegetation. The model simulates the dynamics of soil water and vegetation over time and explicitly distinguishes between above and below-ground grass biomass, calculates edible plant biomass and grazing effects (Figure 1).

The main focus was on keeping a healthy grass sward and preventing bush encroachment. Our simulations recommend such strategies where decisions on timing (Figure 2 S3) and direction of herd rotation (Figure 2 S4) are based on the composition of the vegetation. This relates to either the currently grazed or the next grazed camp respectively. A fixed temporal scheme of herd rotation (Figure 2 S2) did not improve veld condition. Continuous grazing leads to strong bush encroachment in all performed simulations (Figure 2 S1) and so did overgrazing.

Our results suggest that the timing and duration of rest periods for grasses are essential here. Further indicators point to an important role of vegetation – soil – water feedbacks. Healthy vegetation increases rainfall infiltration, which in turn leads to increased soil water availability for plant growth. Rotation can be one way to keep this positive feedback loop up.

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Learning in networks of practice: a case study with Namibian freehold farmers

Corinna Voll and Jenny Bischofsberger

KEY MESSAGE

Scientific results need to be translated to applicable management options for farmers. Furthermore farmers local knowledge can broaden scientific results.

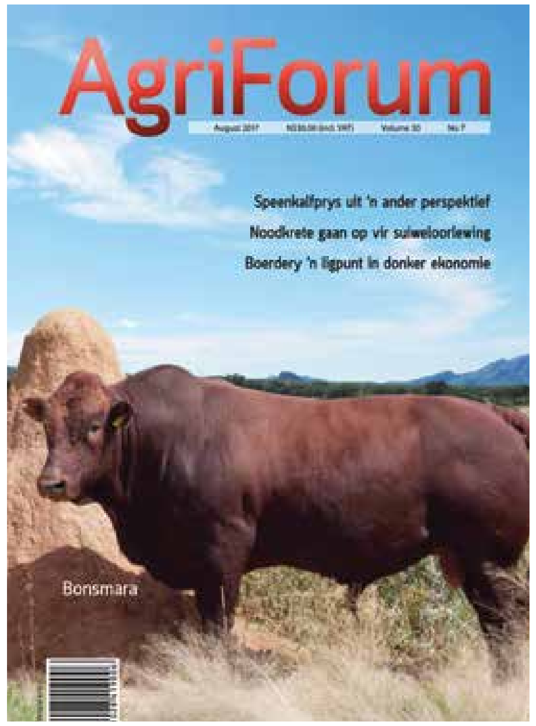
In order to facilitate knowledge exchange joint field experiments with farmers and scientists can be a useful tool.

In the Namibian freehold farming context, there is a demand to examine individual knowledge networks that enable learning about rangeland management. This project attempts to give a comprehensive picture of knowledge exchange and learning processes of Namibian freehold farmers including mechanisms and practical implications. An important part of learning would be its material aspect mediated in a certain context. Active, practical and participatory experiments are an example for people-centered learning. The key questions are:

- How do farmers learn about rangeland management in their personal networks?
- What are preferred practices of such learning, and why?
- How would farmers imagine knowledge exchange at its best?

The theoretical concept of 'networks of practice' was used to present everyday practices and their connections. Multiple influencers acting on different levels, such as scientists, politicians, other farmers or the media could therefore be taken into consideration. 'Practice approaches' further focused on everyday interventions and their interconnection (e.g. reading agricultural magazines and visiting other farms about which the farmers have read) and help to understand learning preferences. In depth interviews with three farmers in the Waterberg/Tsumeb Region were performed, and subsequently matched and confirmed with the results of 20 further interviews which were conducted as part of the extended survey of the overarching project.

While farmers already draw on a wealth of experience, most of them welcomed knowledge exchange about rangeland management. The farmers act as independent key facilitators in their network, based on various powerful influences including their own farming knowledge and experiences with governmental institutions and regulations, organized events and training (e.g. workshops, farmer's days), scientists (e.g. project OPTIMASS), other farmers, and the media (e.g. Agriforum, internet use). Despite that individual networks of the farmers are still quite fragmented, they exhibit pattern of interrelated learning practices. In the study we found out that the farmers rather prefer unstructured learning from experienced individuals in a local context. Knowledgeable, experienced farmers possess a certain authority and can act as role models or mentors. Applicable and tangible knowledge therefore plays a central role.



Does the media influence farmers? One of many possible sources of information: The Agriforum magazine

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Local knowledge for shaping adapted and flexible management strategies

Stefan Liehr, Jenny Bischofberger and Oliver Schulz

KEY MESSAGE

The heterogeneity of farming situations demands for adaptive and flexible management strategies; buffer mechanisms with the establishment of reserve biomass and the increase of soil moisture can strengthen a more vertical management perspective improving the sustainability of farming.

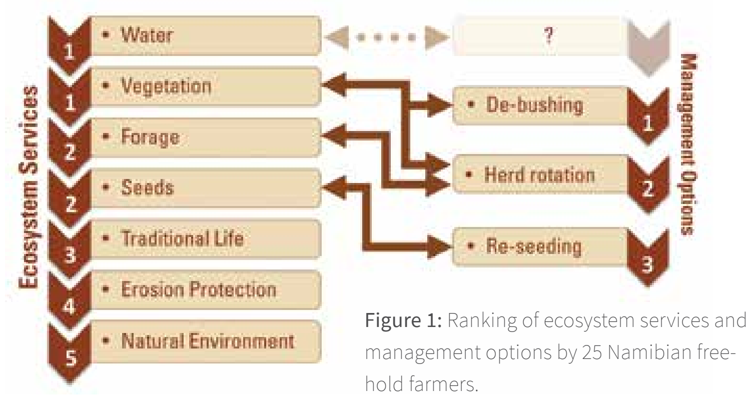

Figure 1: Ranking of ecosystem services and management options by 25 Namibian free-hold farmers.

In order to maintain the productivity of grazing areas in the face of bush encroachment, climate and land use change, adapted management strategies are needed. Local knowledge from land users constitutes an indispensable source of information for insights into processes, values and motivations of practitioners as the basis for their decisions and acting. Participatory methods led to a better understanding of the relations between actors and their natural environment, such as the farmers and the savanna ecosystems. At the same time, we developed adequate ways for knowledge exchange between science, society and policy.

Interviews with 25 livestock farmers and other experts were conducted. This survey showed that rangeland managers assess water, vegetation, forage and seeds as the key services of the savanna ecosystems from which they benefit most. On the other hand, de-bushing, herd rotation and reseeding are stated as the most important management options. The high priority of 'water' as an ecosystem service is not reflected on the side of management in correspondence to other services. In-depth discussions revealed that water management is understood rather implicitly as an integral part of other management options but needs to play a crucial and more explicit role in the development of future management strategies.

Further results derived from the survey and discussions with stakeholders are:

- Research and policies need to take the heterogeneity of farming situations with respect to the natural and socio-economic conditions into account. This demands for case dependent adaptive and flexible management strategies.
- Local knowledge provides valuable information for research and policies. It improves the development of applicable solutions when combined with scientific knowledge.
- Buffer mechanisms can serve as important components of management strategies to maintain the sustainable functioning of farming systems. The establishment of reserve biomass through adapted herd rotation or the increase of soil moisture through de-bushing is a typical example.

Taking the stakeholders' discussions at the 21st Namibian Rangeland Forum 2017 into account, a paradigm shift from a horizontal management of a wide area to vertical perspective which focusses on the generation of buffers in vegetation and soil emerged as being promising. This change in management thinking combined with new scientific insights opens the way for improved, forward-looking farming strategies.

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"On-site" discussions of Thomas Bergmann from ISOE with farmers in Namibia.

The challenges with managing rangelands for wildlife

Morgan Hauptfleisch

Wildlife farmers often provide expensive supplementary feed in poor rainfall years

KEY MESSAGE

Wildlife farming faces unique rangeland management challenges which can negatively affect the productivity of rangelands and associated ecological mechanisms if not managed effectively.

NUST lecturer and OPTIMASS PI Morgan Hauptfleisch with NUST students at a wildlife auction in Mariental in 2015 conducting rangeland management interviews. Students left to right: Mendes Vinte (OPTIMASS student), Jose Kaumba, Kenneth Kuingi, Toini Ekandjo, Leevi Nenyeni, Martin Handjaba, Allan Kandjai (OPTIMASS student) and Selma Kanandjembo

Rangelands provide a number of key natural resources and services, but their sustainable utilisation and productivity are under increasing threat. It is generally assumed that indigenous wildlife are better adapted than exotic livestock to Namibia's arid and variable climate and would therefore be more efficient in their use of rangeland resources. This has resulted in many livestock farmers converting to wildlife based land uses. There are however negative impacts of wildlife on grazing in African savannas, which are often not considered by farmers when converting from livestock to wildlife.

We surveyed 46 commercial wildlife farms in Namibia through physical inspection and farmer interviews. This represented over 11 000 km2 of farmland and a combined management experience with wildlife of 806 years. Our key question was whether wildlife farming presented unique rangeland management challenges, and how farmers overcome these challenges.

Our findings provide guidance for further research into the impacts of wildlife on rangelands. There are three key rangeland management issues that currently affect the sustainability of the fast-growing wildlife sector in Namibia. These are:

Drought reserve planning – Namibia's aridity exacerbated by climate change leads to frequent drought events. While livestock farmers using rotational grazing systems are able to use fencing to keep standing biomass for drought planning, wildlife farmers rely on extensive open systems, where grazing exclusion is difficult. Fencing is known to impact negatively on wildlife resulting in disturbance and negatively influencing herd territoriality in wild ungulates. The only option for wildlife farmers in drought periods is therefore to either destock (44% of interviewed farmers) or supplement feeding with purchased grass and Lucerne (52% of interviewed farmers). This is costly – with one interviewed farmer spending up to N$ 2 million per year on feed in low rainfall years. One farmer is currently experimenting with fencing his farm down the middle, applying a "two camp system" where wildlife are able to graze one half per year. This allows some form of grazing protection for drought years.

Difficulty to reduce grazing stock rates – In the face of poor rainfall years or when rangeland indicators point to overstocking, wildlife farmers find it harder to remove herbivores compared to livestock farmers. Domestic ungulates are easier to capture and transport, and a well established sale and slaughter industry allows for rapid removal of grazing mouths from rangelands. Wildlife capture is far more difficult, and sale or slaughter options are fewer. Hunting is a popular but slow destocking tool. Four of the interviewed farmers highlighted the importance of proactively managing stocking rates, relying on climatic predictions of low rainfall periods.

Types of wild herbivores – Wild herbivores use far more diverse grazing strategies compared to livestock. Cattle are bulk grazers, and most southern African livestock science is centred around this principle. Wildlife include bulk grazers (e.g. white rhinoceros, buffalo, zebra), selective grazers (e.g. oryx, red-hartebeest, wildebeest), mixed feeders (e.g. springbok, impala, eland), and browsers (e.g. giraffe, kudu, steenbok). The most commonly stocked wild herbivores among interviewed farmers were selective grazers (oryx & wildebeest), while zebra were the only bulk grazer on most farms, and generally in very low numbers. This results in species and area selective grazing, a challenge identified by 52% of interviewed farmers.

This OPTIMASS sub-project took place at an opportune time during the implementation phase of Namibia's Rangeland Management Policy. We were therefore able to engage the implementation team, and provide guidance on the consideration of wildlife specific rangeland management aspects. We further formed part of the formation of a wildlife taskteam to drive the implementation of the policy among wildlife farmers.

The majority of interviewed farmers thought that knowledge relating to wildlife rangeland management was not being shared among farmers and scientists, or shared in a limited way. All the farmers expressed the need for better knowledge and information sharing, and said that platforms such as wildlife auctions and farmers' association meetings were ideal platforms for information sharing sessions. This resulted in initial presentations of OPTIMASS learning related to rangeland management being presented at the Namibia Rangeland Forum (2017) and one farmers' association meeting.

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OPTIMASS
A joint Namibian-German research project
www.optimass.org

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Publisher
University of Potsdam
Plant Ecology & Nature Conservation
Am Mühlenberg 3
14476 Potsdam
Germany

Design
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Published 2018

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